Towards Fossil free India

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Towards Fossil-free India in near future

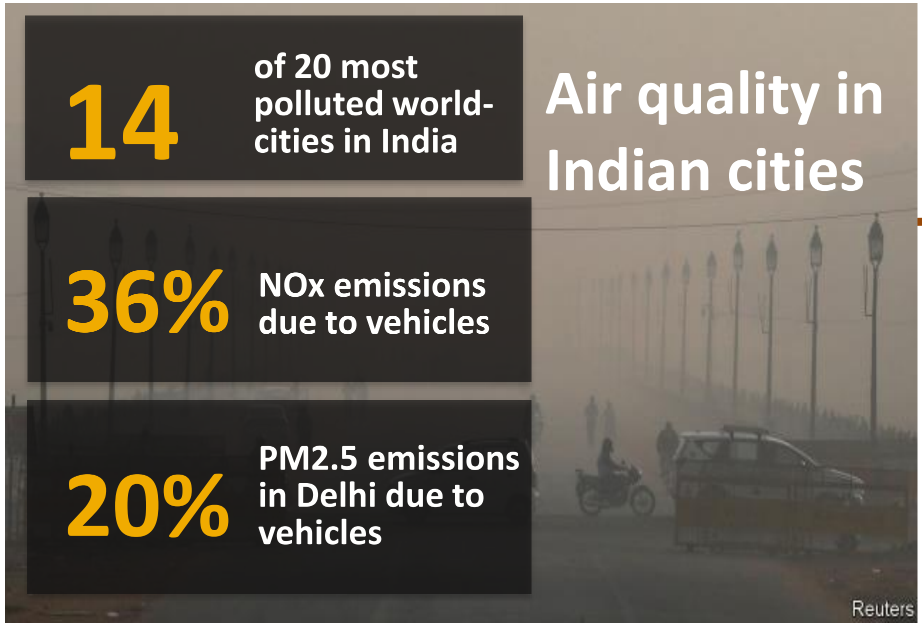
- Coal drives electricity (₹2.50 per kWh): highly polluting and adversely impacts climate
  - Plenty of sunlight / wind (₹2.50 per kWh): Not controllable
    - Would need energy-storage to make it 24x7

- Oil used for vehicular traffic and in diesel-generators
    - We import most oil and have huge impact on our environment
  - Electrically driven vehicles possible today: bottleneck is energy-storage

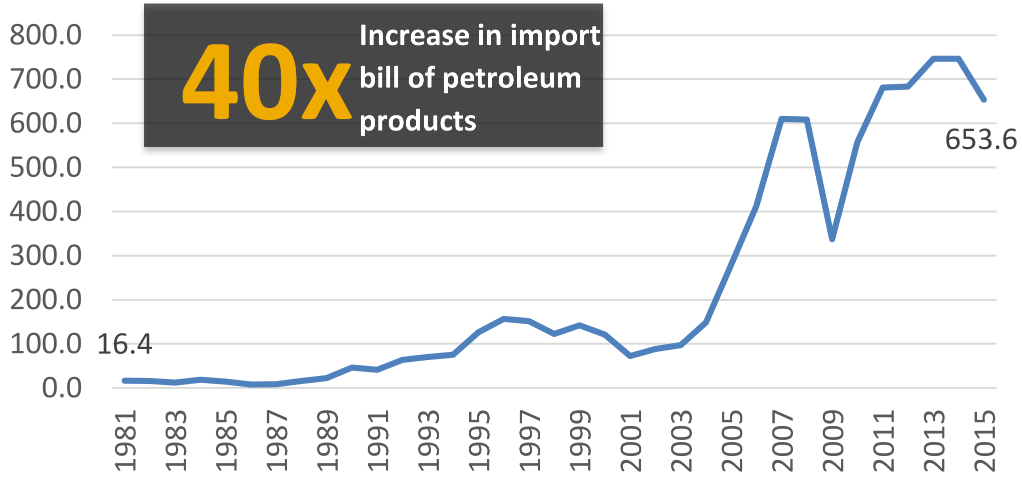
R&D, Start-ups and Industry-academia Collaboration

- To drive India to become leaders in energy Storage
  - And drive EVs and Grid-Storage today

Why so much interest in EVs?



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



Petroleum consumption up from 32.5 mill tons in 1981 to 184.7 mill tons in 2015

- 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%

Where is the problem to switch to EVs?

- Batteries: energy-storage
  - Energy-density of Li-Ion battery-cells is continuously increasing and is in between 250 to 300 Wh/kg today
    - But much less than that for petrol at 9000 Wh/kg
  - Even taking into account four times higher drive-efficiency
    - Battery weight per km is 8 to 9 times higher than that of petrol-tank per km
    - Same with the size

- And Cost of battery is inversely related to its energy density
  - Higher energy-density: lower use of materials like Lithium, Cobalt, Nickle
  - Higher energy density will have higher safety concerns

Increasing Energy Density → Affordable Batteries

- Energy density increasing rapidly: main driver for cost reduction
  - Li Ion Battery: up to 300 Wh/kg available
    - Towards 400 to 500 Wh/kg in coming years
    - NMC with Graphite-Silica anode
      - LFP is limited to 160 Wh/kg
  - Other variants of Li-battery may emerge to drive energy density higher
  - Higher energy-density: higher safety concerns

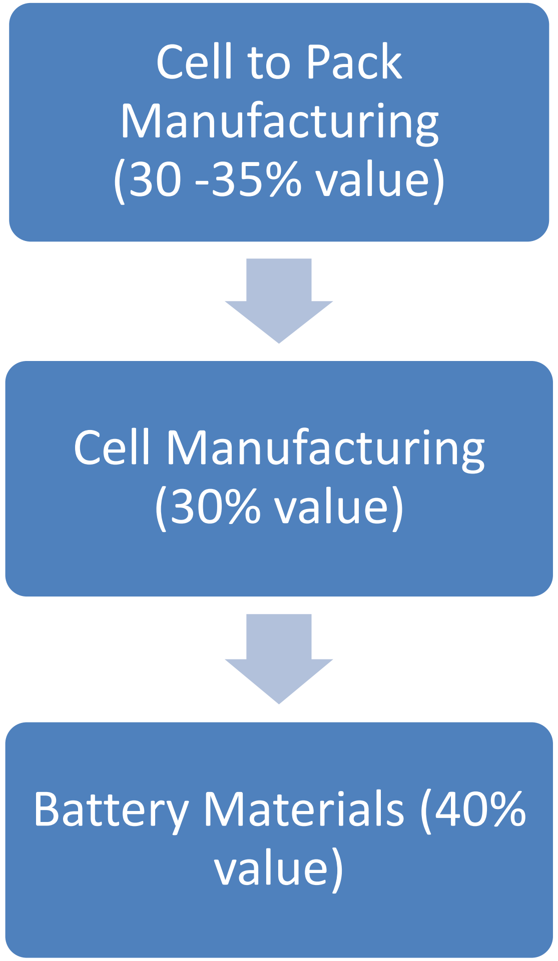
Year	Energy Density (Wh/kg)	Cell-price per kWh
2011:	80	\$800
2015:	140	\$275
2018:	220	\$140
2020:	310	\$110

- EV with large battery to overcome range anxiety (several hundred kms in a car) is still 1.7 to 2 times that of ICE car

Compute battery pack cost per km, taking into account its life-time, depreciation and interest

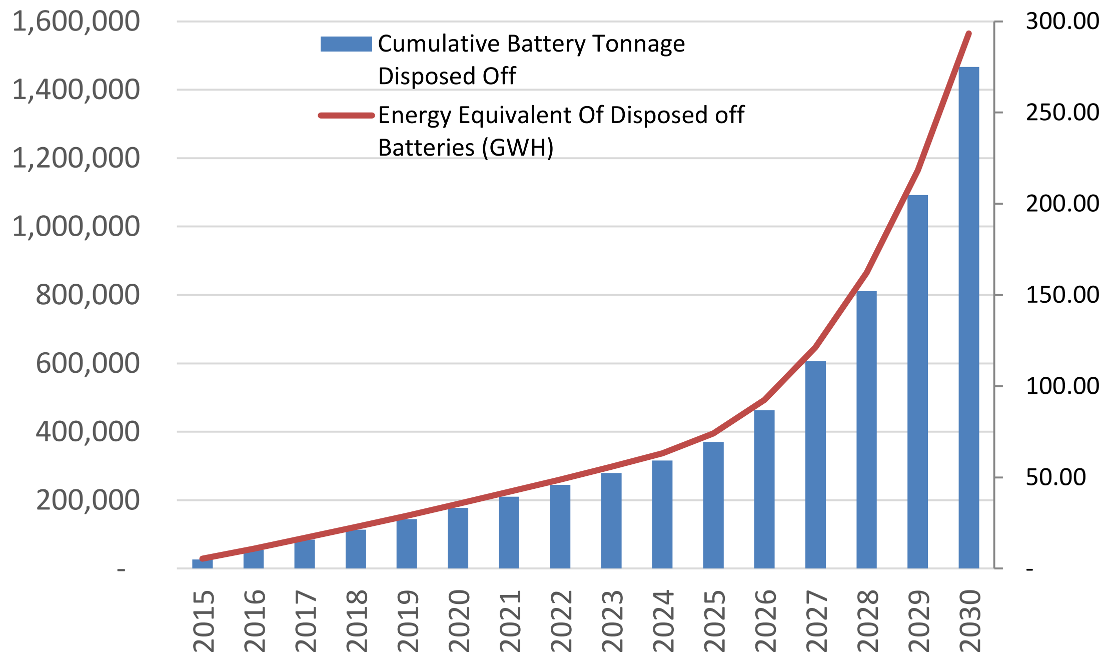
Li Ion Batteries for EV

- 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: handled by BMS
  - established and start-ups making waves in making BMS
- 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



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
  - Import bill could sky-rocket : 25 GWh per year by 2025
- Recycle used batteries (urban mining)
  - 90% of Li and Co, Ni, Mn and Graphite being recovered
  - Need 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



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

But are EVs affordable today?

- 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)
  - Economy Cars costing below ₹1 million: 12%
  - Premium Cars costing above ₹1 million: 2%
  - Buses and large goods vehicle (including trucks): 3%

  95% (2-wheelers, autos and economy cars)

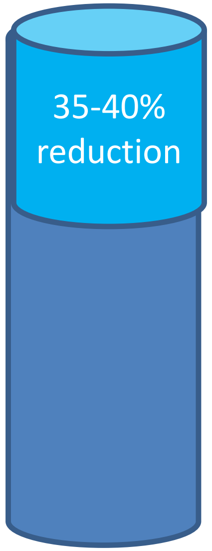
- 98% of public and affordable vehicles: not the focus of the rest of the world; India would attempt to get leadership here

- 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



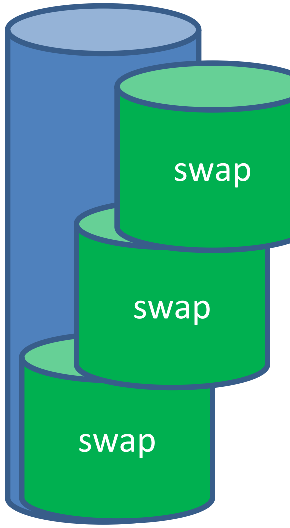
Battery size without range anxiety

- 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

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 vehicles
      - no further economic challenge or technical challenge
    - Engineering Challenges for battery-swapping need to be overcome

Battery size without range anxiety



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

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

- 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
    - 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)

- Suppose EVs have a small low-cost battery with limited range built-in: Affordable
  - Example: 100/ 50 km range for e-car / e-scooter: Enough 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 battery to completely overcome range anxiety
    - Swap-in a second (swappable) battery doubling the range at a petrol pump (3 to 5 minutes)
    - Swap the swappable battery again for still longer range (300 kms or 400 kms)
    - Swapping carried out by Energy Operators

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

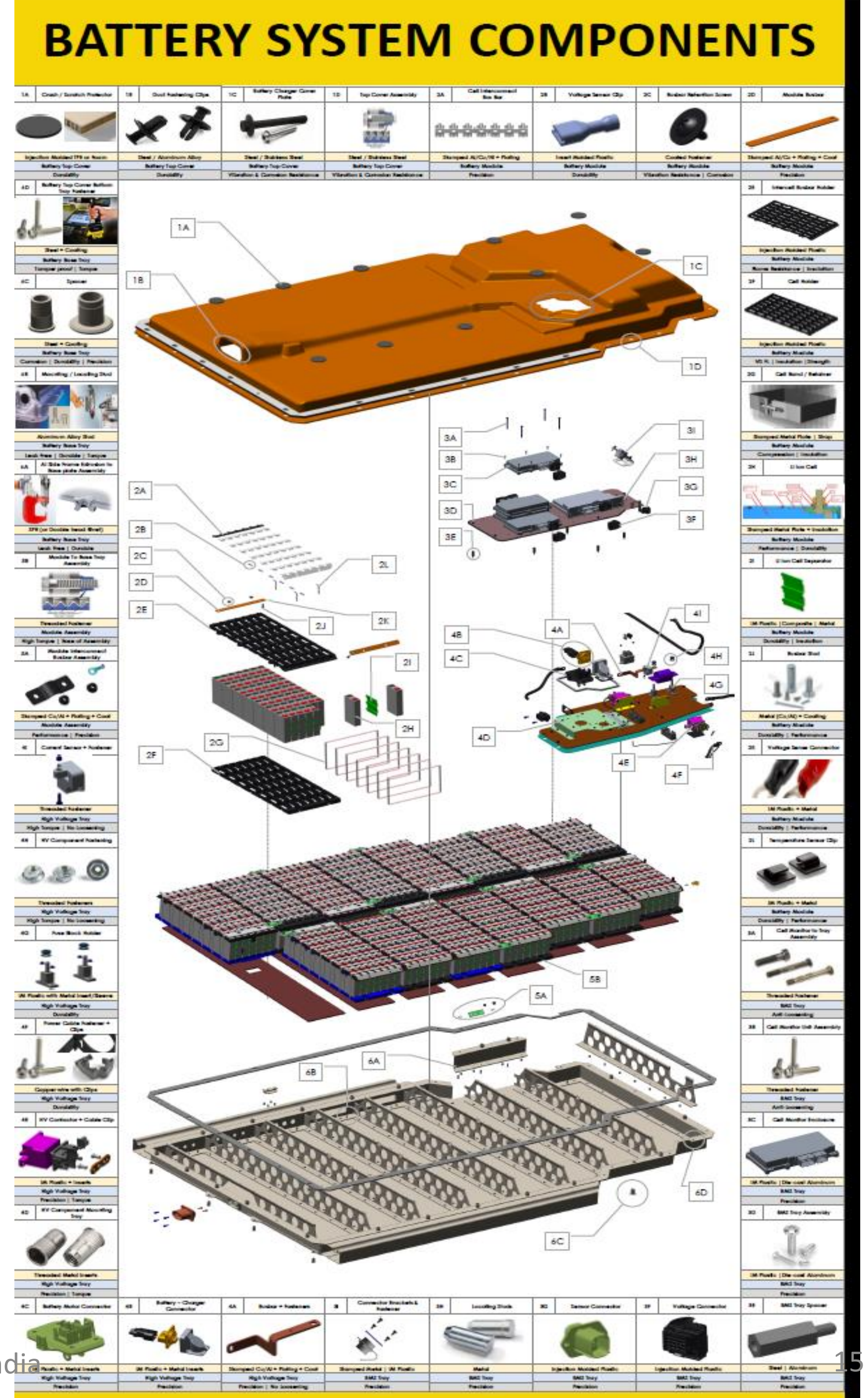
EV threatens India's GDP (auto-sector 7.1% + 5% transport fuel processing / distribution) and large number of jobs

Will we lose jobs and GDP?

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

- Battery-pack manufacturing involves large number of components
  - Large number of ancillary industry
  - Large number of jobs

- Battery-packs need to be designed for India’s environment conditions
  - Involves quality thermal design
  - Careful mechanical design
  - BMS to ensure cell life maximised and safe operations under all conditions



Cell-manufacturing: Requires Large plants for

- India needs over 100 GWh of cell manufacturing every year
    - Prismatic, Pouch and Cylindrical
- Battery cell manufacturing like a large process industry
    - High investments
    - Technology changes very rapidly
    - Cost falling rapidly
    - Will require lots of ancillary industries
        - Lots of jobs

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Will we have to import all Battery raw materials?

- Not if we recycle all used battery with ZERO effluent
  - Can recover over 90% of Lithium, Manganese, Cobalt, Nickle and Germanium
  - And reuse in new batteries
- Highly manual-intensive work: will create huge number of jobs
  - India could become Urban mining capital of the world
    - Import used battery and recover materials
- Battery Recycling market: $100M today, over $1B by 2030
  - 1 lakh ton battery waste available today: 23 GWh of batteries
  - Near Term Driver: Consumer Electronics and laptop battery
  - Long term Driver: Electric Vehicles & Stationary Storage Energy

- Need to recycle each battery
- Ensure that all spent Li Ion batteries are sent for recycling
  - Manufacture's obligation

Motors and Controllers

- Need motors and controllers for
  - Two-wheelers
  - Three-wheelers
  - Four-wheelers
  - Buses
  - Trucks
- Hundreds of components

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

Is it economically viable? What is the cost?

GRID STORAGE

to help renewable usage 24 x 7

Renewable Usage

- Assuming 70% of renewables is used directly when generated
  - Cost is ₹2.50 per kWh (unit)
- 30% of renewable energy passes through Storage
  - Let S be the cost to store 1 kWh in Storage and retrieving it later
  - Generation cost = (₹2.50 per kWh) + S
- Average cost per unit
  - 70% x ₹2.50 + 30% x (₹2.50 +S)
    = ₹2.50 + 0.3 * S per kWh

How much is S in India?

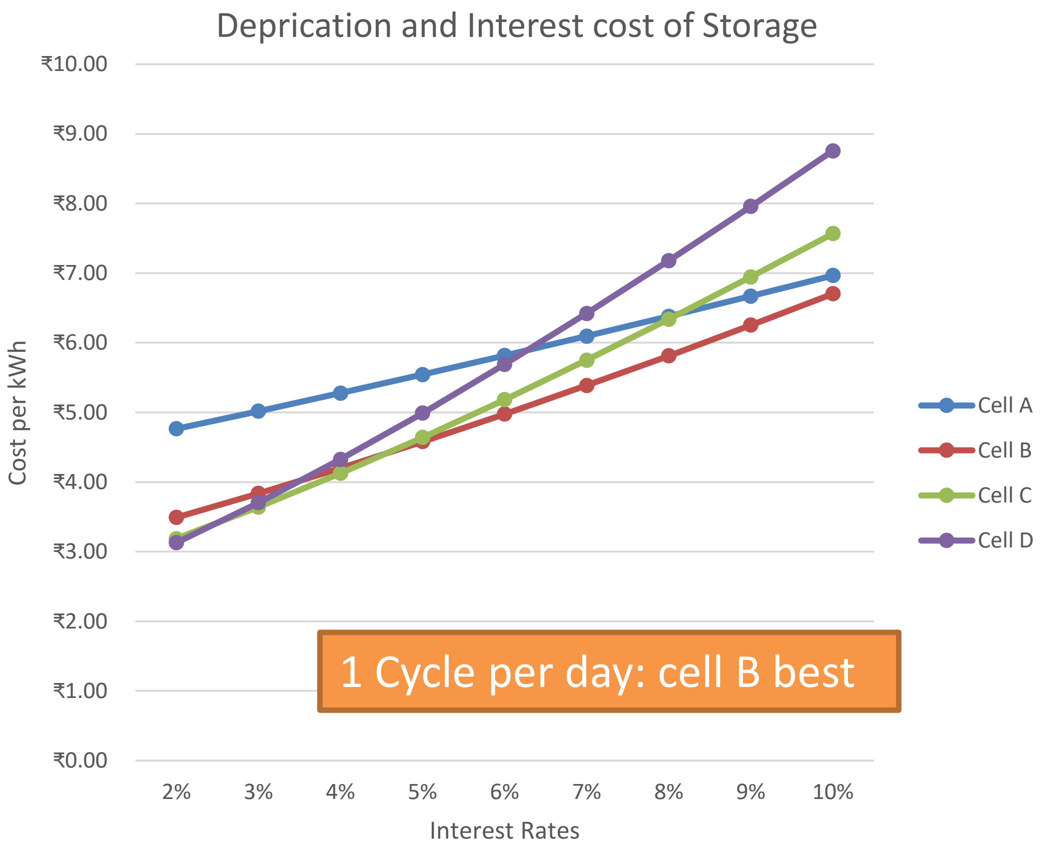
What is the cost of usage per kWh of Grid-Storage

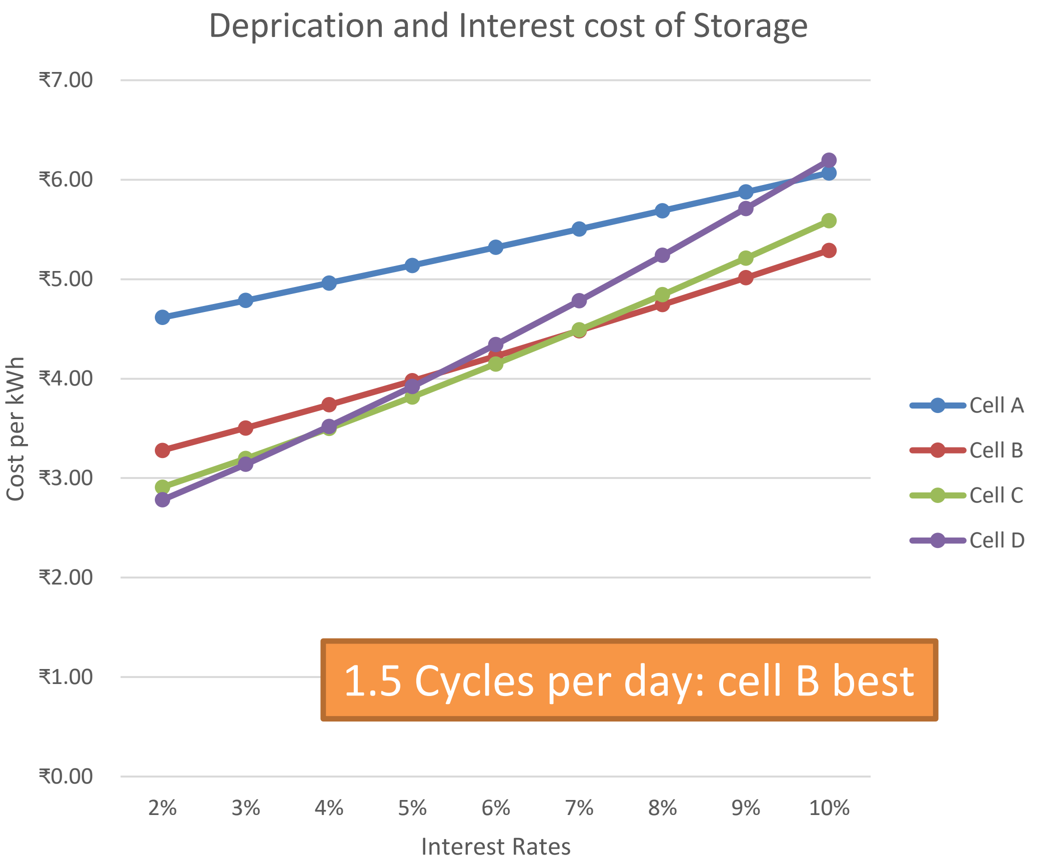
- Depends upon
  - Type of battery
    - Effective number of cycles
    - Capital cost
  - Number of cycles used per day
    - 1 to 3
  - End-to-end Energy efficiency
    - Assume 96%
  - Interest Rates: 2% to 10%

- Consider four type of batteries at today's cost

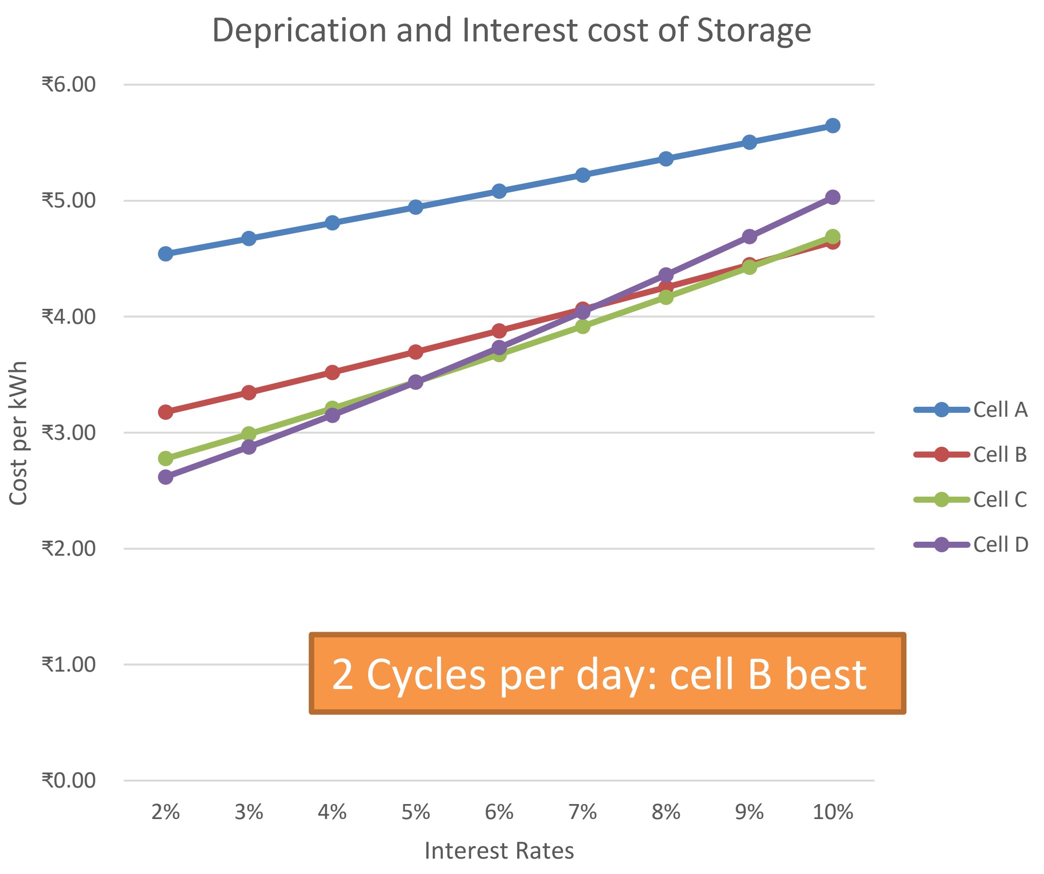
	Cell A	Cell B	Cell C	Cell D
Cost (₹) per kWh	15000	20000	25000	30000
Cycles	3650	7300	10950	14600
Chemistry	**NMC**	**Adv NMC**	**LTO**	**LTO**

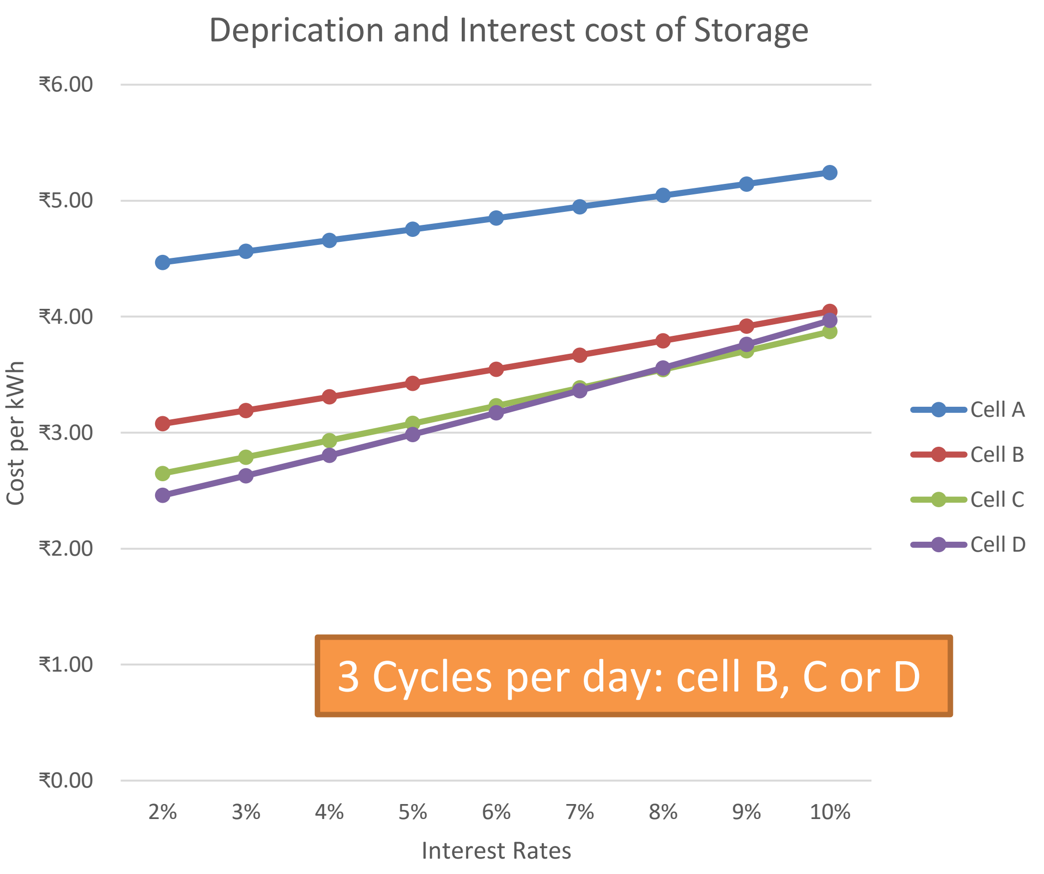
Cost of Storage per kWh





Cost of Storage per kWh





At 10% interest rate Cell B may be best

- 1 cycle per day: costs ₹6:50 per kWh
- 1.5 cycles per day: costs ₹5.25 per kWh
- 2 cycles per day: costs ₹4.50 per unit
- 3 cycles per day: cell B or C or D costs ₹4 per unit

- In West at 2% interest rate, Cells C and D (LTO) make sense

- With 70% renewable energy used directly and 30% through storage
- Cost per unit = ₹2.50 + 0.3*S
  - With S between ₹4 to ₹6.50
  - Cost per unit = ₹3.7 to ₹4.45
- Storage adds ₹1.2 to ₹1.95 per unit

- If renewable is 50% through storage
  - Addition of ₹2 to ₹3.25 per unit
  - Renewables with storage: ₹4.5 to ₹5.75 per unit
- 30% renewables through storage: OK today
  - Storage cost to drop by 50% in 5 to 7 years
  - Renewables through storage can then go to 50%

Decentralised Storage on Grid

- Decentralised roof-top solar used widely today in office-complexes
  - Makes business sense: provide power in day-time
- Can such office-complexes use Storage?
  - Yes, if Time of day metering is introduced
  - In fact, in addition to electric Battery-storage, one may also be able to use chilled-water storage
- First Objective: virtually Eliminate diesel generator
  - If ToD is available, one can considerably gain
  - Storage costs payable within a few years
  - Time has to come to act

To Conclude

- India can take lead towards Fossil-free future
- Transport can converted to EVs
- Electricity generation: move mostly to renewables
  - With the help of grid-storage

- R&D, Start-ups and Industry-academia joint development can take us there