India’s Renewable Energy Compulsion

Solar-DC and Electric Vehicles

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In first week of December 2015

- When whole of the Chennai city had no power for 75 hours
  - Even 1 MW solar plant at IITM failed to provide any power
  - There was one home at IITM which continued to have lights and fans and cell-phone / lap-top charger
    - 125W solar panel + 0.5 kWh of battery
    - Two tube-lights, a bulb and a fan + laptop and cell-phone charged some 15 times
    - Fails to add up
  - Solar DC Inverterless
    - Full DC wiring, all Loads DC, solar and battery connected on DC line, input grid power converted to DC

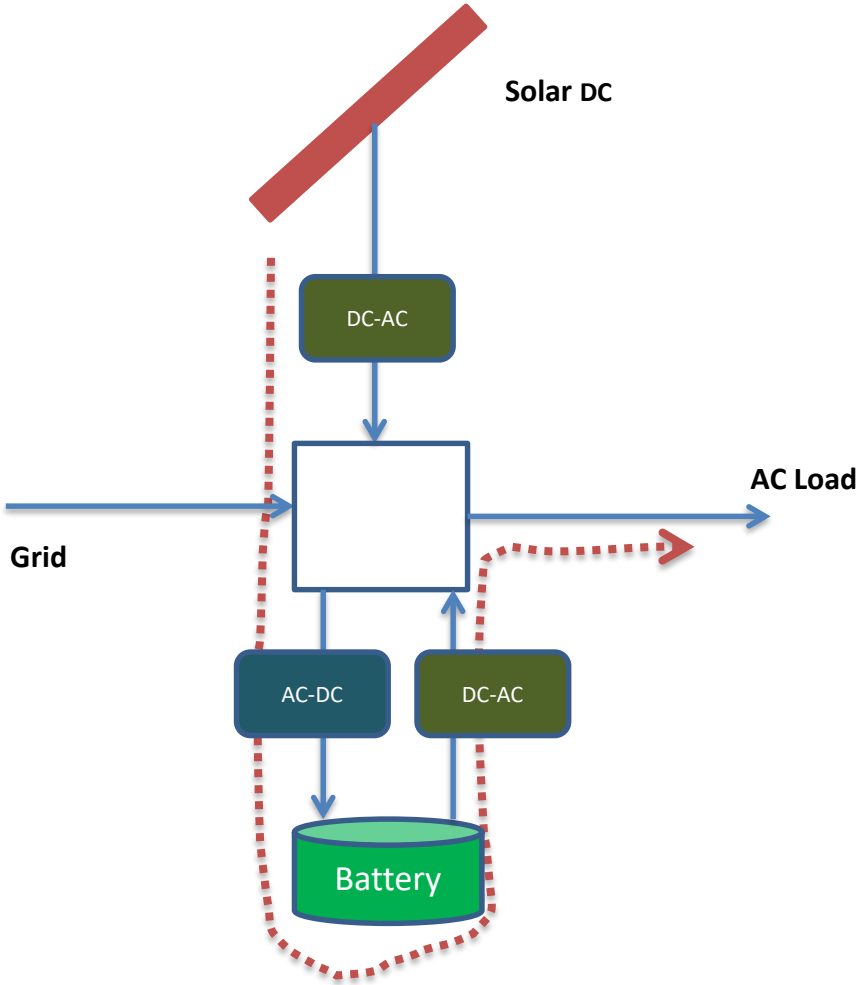
But AC Power won 125 years ago!

- In an AC Vs DC power-line debate between Tesla (for AC) and Thomas Edison (for DC) in 1880's
  - AC won decisively due to transformer's ability to step-up and step-down voltages easily
    - And reduce line losses

- AC dominated ever-since
  - Transmission lines became all AC
  - Homes and offices were wired on AC line (230V AC in India)
  - All appliances became AC
  - All R&D focused on AC: R&D on DC virtually stopped

- So why are we talking about DC today?

Decentralised Solar Power at Homes



- Solar PV gives DC Power
  - But load is AC
  - Needs a DC-AC converter
- Now if we add a battery
  - Battery stores only DC
    - Require an AC-DC converter for charging
    - Require a DC-AC converter during discharging
- For *low power (say 100W)*, each converter can have 10 to 15% loss
  - Solar with battery may have up to 45% loss + battery loss

And it gets Worse

- As one realises that home-loads have been slowly moving towards DC

Fans	AC fan	BLDC fan
At full Speed	72W	30W
At speed 1	60W	9W
Lighting	**CFL Tube light**	**LED tube**
At Max. Intensity	36W	15W
At Lowest Intensity	NA	4W

Volume prices similar for fans

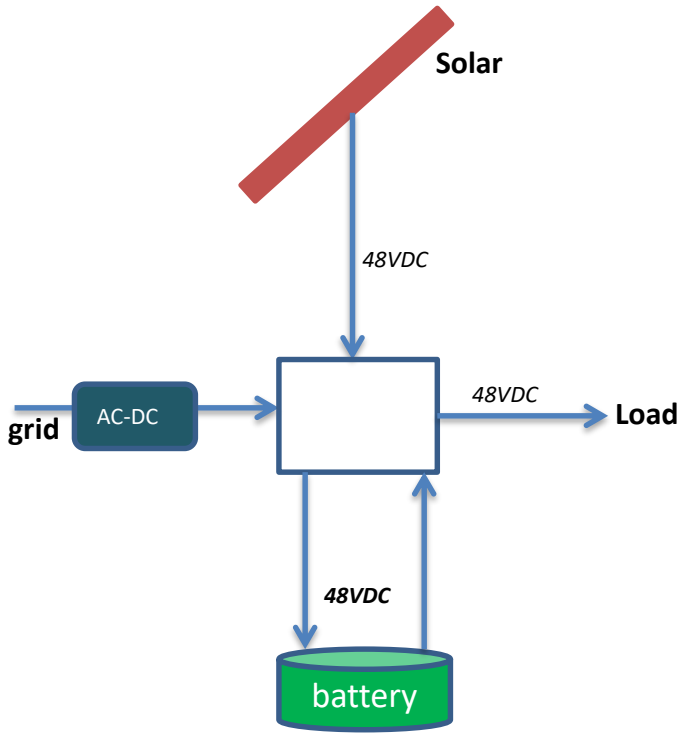
LED tube life much longer (DC powering enhances reliability)

- All Electronics devices work on low-voltage DC
  - TV (LED/LCD), laptops. Cell-phones, speaker-phones, tablets, speakers
    - AC to DC conversion has losses from 20% to 50% in each device

- Even the refrigerators, air-conditioners, washing machines are now using BLDC or SR motors

- DC-powered DC-appliances are energy-efficient
  - Consumption down by 50%

Are we ready to take a leap and move to Solar-DC



- DC Micro-grid connecting
  - Solar Panel
  - Battery
  - DC Appliances
- Highly efficient usage of Power
  - Low-power from grid alone converted from AC-DC
- 48V DC chosen due to
  - Safety considerations
  - Lower cable losses compared to 12V/24V DC systems
- But design non-trivial
  - Solar MPPT voltage varies
  - Battery needs independent charge voltage
  - Load is at some fixed voltage
  - DC-DC converters will add similar losses

IITM designed Solar-DC Inverterless

125W panels
- Upto 500W possible

Designed as an expandable product, still keeping losses low

230V AC

125W to 500W 48V DC (and possibly 150W uninterrupted AC) Power with BLE prepaid recharge

Monitored using Bluetooth (moving to GPRS)

Special 1 kWh VRLA battery with 1600 cycles for 50% DoD
- Up to 5 kWh possible

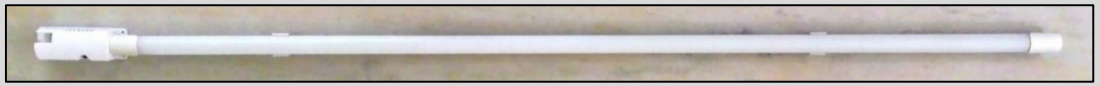
$1 = ₹64

And worked with start-ups to build Appliances

LED Bulb
- 5W instead of 30W bulb

Cell phone Charger/Socket
- DC charger with USB port

BLDC Fan
- 30W instead of 72W AC fan
- 9W at lowest speed



LED Tube light
- 15W - dimmable to 4W, instead of 36W fluorescent tube

Remote Control for Fan & Tube light
- ON/OFF and for dimming

Cost: ₹20000 for 125W SP + 1 kWh Battery+ appliances

Energy-efficient DC appliances being expanded

DC Desert Cooler

- Consumes 120W instead of 180W AC cooler

DC Mixers

- Consumes 150W, whereas AC Mixers consume 350W

DC-powered Colour TV

- Consumes 30W along with set-top box

Butter-churner and atta-chakki, sewing machines, roti-machines

- getting ready

Refrigerator, charkha and Stove

- Still experimental

Deployment in 15000 homes

- Electrified 4000 off-grid homes in Jodhpur and Jaisalmer districts of Rajasthan
  - Tough terrain, no road connectivity, sandstorms, lack of local resources
- 7500 homes in Assam being taken up in hills
  - 12000 more homes being take up
- Grid-connected installations in states of Orissa, Karnataka, Tamil Nadu, Telangana, Andhra
  - Where power cuts > 8 hours /day




Changing lives in deserts

IEEE awards solar-DC as 2017 Technology of the year in service of humanity

Villagers thrilled

- *"Apne Vidyarthiyon ko ghar ka kaam dene laga hu. Khush hu ki is baar garmiyon mein bhi bachhe mann laga kar padhai karenge."* *[now I give my students home-work. Happy that even in summer they will now be able to study]*

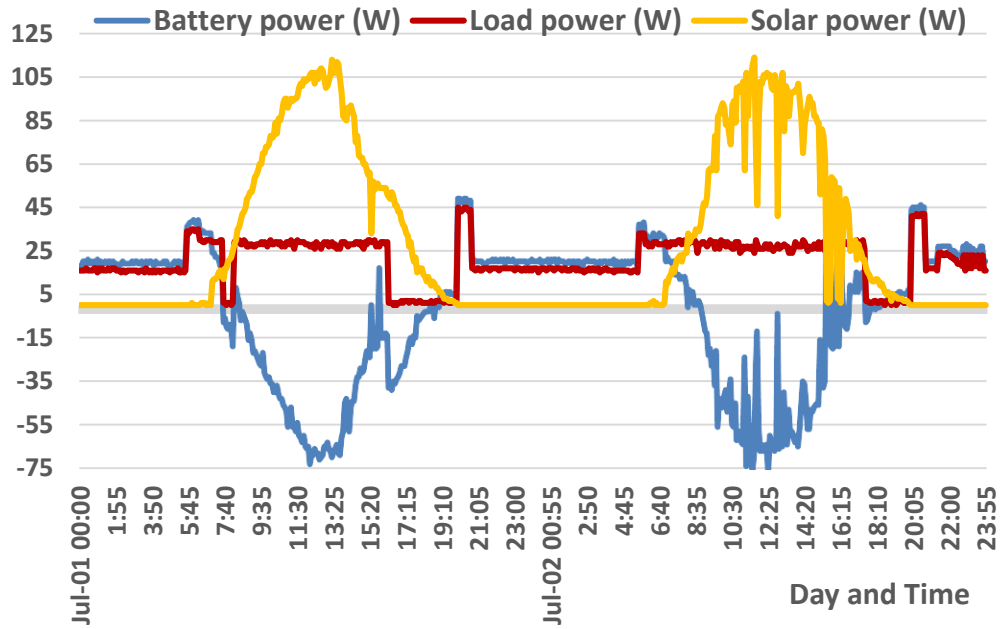
  - Masterji

- *"Sab ko utshah se apne ghar ka Solar system dikhata hu ji, hamare ghar mein bhi pankha, light aur remote hai"* *[show my solar system to everyone at home. Have fan, light and remote]*

  - Dunga Ram

- feedback: https://youtu.be/NF6EgdRsBXk

Monitoring to ensure health



Measurements from a home in Bhom Ji ka Gaon, Jodhpur from 9am to 5pm

- Understanding use of solar Power and losses
- Is customer using more than what solar provides? Is she using less? Is power being wasted?
- Grid-power usage to be minimised

But what can one do with 100 Watts?

- 100 Watts DC: Can support 3 lights + 2 fans + cell-phone charging
  - Or 3 lights + 1 fan + TV (24" LED/LCD) + cell-phone charging
- Equally important for grid-connected homes: huge cost savings
  - Draws less from grid: reduces power-bill
  - Provides back-up power: frees homes from load-shedding, grid-fault
  - Enables decentralised roof-top solar to become affordable
- 500W solar power (50 sqft) with DC appliances can take care of most essential loads in middle class homes
  - Except washing machines, air-conditioners
- 240M homes with 500W solar panel produces close to total domestic consumption in India in a year
  - 240Mx0.5 kWx1550 solar hrs/year = 190,000 GWh /year

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Small AC / DC Home Power Costs

Device	Numbers deployed	Operation hrs/ day
Tubelights	2	6
Fans	2	12
Bulbs	2	10
Phones	1	4
TV	1	10

Cost / day includes depreciation and interest for solar panel and battery assuming grid costs of ₹5 per unit

	AC Home		DC Home	
	Energy/ day kWh	Cost per day ₹	Energy / day kWh	Cost per day ₹
AC Grid + 0 LS	3.27	16.3	1.29	6.45
AC +Battery + Solar + 4h LS	3.75	28.9	1.35	7.3
off-grid + Battery + Solar	4.9	50.6	1.33	12.6

Off-grid home power-costs with solar-DC (₹12.6 per day) less than the cost of on-grid AC homes with no power-cuts (₹16.3 per day)

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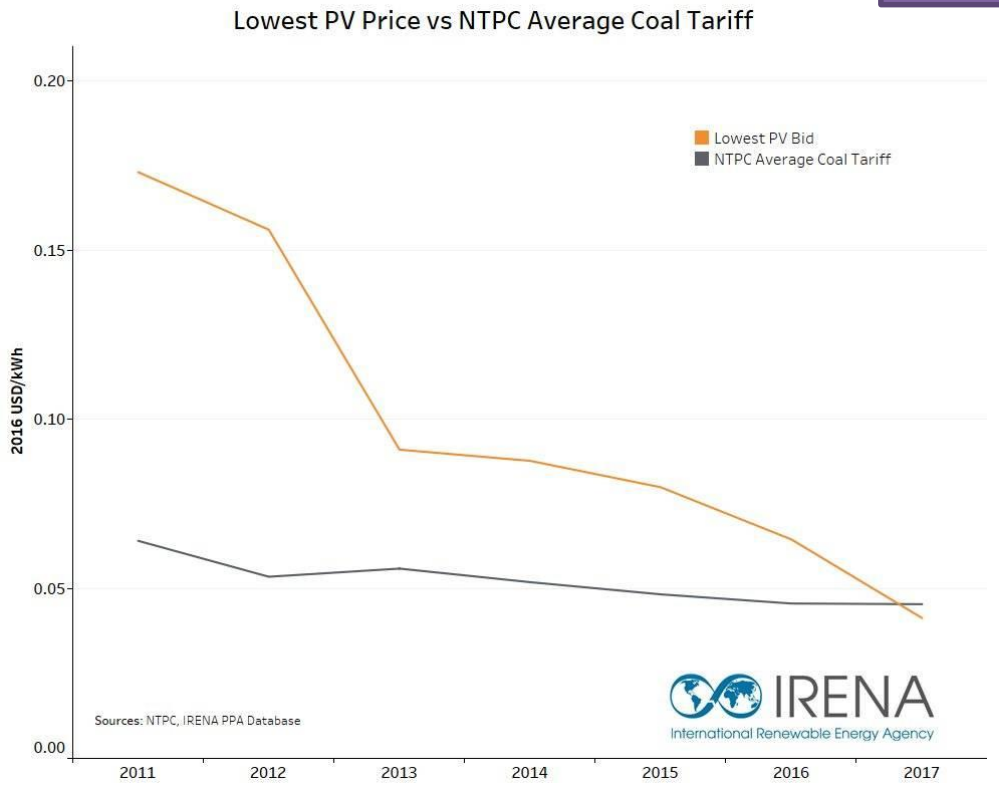
May 9, 2017:
Bhadla Solar bid
at ₹2.62 per unit

May 12, 2017:
Rewa Solar bid at
₹2.45 per unit



INDIA'S RENEWABLE ENERGY MARCH

As Renewable energy costs drop below that of Coal, does Solar-DC fit in?

$1 = ₹64

Renewables can grow rapidly in India

- Can displace Coal as a major source for power generation
  - We do not have much of hydro, gas and nuclear energy
- But Renewable energy is intermittent
  - To match load instantly with generated power, grid requires storage
  - storage cost more than ₹15 per unit due to high finance cost in India
- How does one match supply and demand with increasing renewables?

Renewable Compulsion

- For renewable power to become an unfettered dominant supplier to power-grid
  - requires some kind of large-scale storage
    - where costs are independently affordable in context of the specific application of the stored energy
  - Batteries at each home with solar-DC
  - Batteries in commercial buildings
  - EV is a large scale storage
    - At the end of life in a vehicle, batteries can be re-used for grid-level storage

EV is now scaling in many countries driven by subsidies

EVs: Hamare yahan hota to hai, dikhta nahee hai, dikhna chahiye

Subsidies is possible, but not at scale

HOW DOES ONE MAKE ELECTRIC VEHICLE START SCALING IN 2017?

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*

- Zero pollution levels if renewables used
  - when electricity is produced with current thermal plants
    - No tail-pipe emission
    - CO_2 pollution down by 50%

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 three to five years, EV capital costs will be less than that of petrol vehicles
  - with acceptable range and operational costs a fraction of that of petrol vehicles
- But if we wait, India will import most EV subsystems and batteries instead of oil

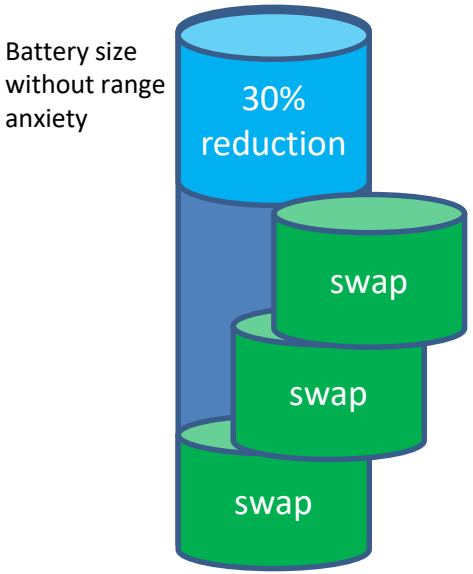
Falling battery costs

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

Strategy towards EV scaling starting 2017

- Battery price dominates EV costs
  - use innovative techniques to offset high battery prices
- Intervene in Public transport segment
  - Private vehicles will follow
- Get Volumes: volumes reduce costs
  - Concessional GST and road-tax for THREE years only
- Develop usable and affordable technology in the Indian context

Challenges and Approach



- Battery most expensive component of EV
  - Focus to enhance efficiency (kms/ kWh) at 20 kmph
    - higher motor efficiency, better tyres, aero-dynamics and light-weight materials: 30% improvement in many cases
  - Still costs too high
- Introduce Swapping
  - Divide into smaller parts so that each part not as expensive
  - Purchase enhanced efficiency vehicles without batteries
    - Capital costs less than equivalent ICE vehicle costs
  - Energy Business: battery ownership, swapping & charging
    - operation costs (cost per km) no more than that for ICE vehicles

Three wheelers: e-rickshaw, e-auto, e-auto (large)

- Current e-rickshaws of poor quality: uses Lead-acid batteries
- Use swapping: 50 km range battery
  - Quality electric vehicles at price level same as petrol/CNG vehicles today
  - Charged Li Ion hire price per kms less than that for petrol/CNG vehicles
- 60 manufacturers, battery manufacturers, potential battery swappers and vehicle aggregators working towards
  - *Possible launch in October – November 2017*

Everything other than battery cells made in India

$1 = ₹64

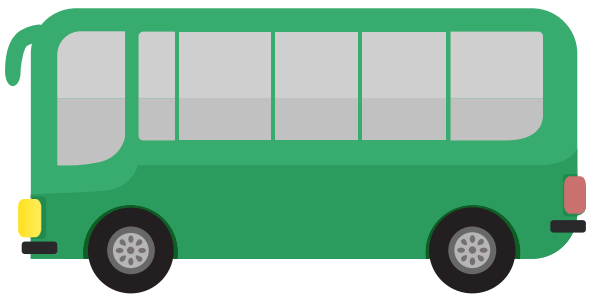
Careful design to make Energy Business viable

Battery costs per km		
	size of battery kWh	3.00
	Li Ion Battery cost per kWh in ₹ K	18
	Battery Life cycles	3000
	Number of cycles per day	1.5
	interest rate in %	10%
	Vehicle Wh/km	45
	battery cost per km	0.49
	Nos of battery per vehicle for swap	1.25
	swapper battery cost per km	0.61
Charging costs per km (including fast charger and infra)		
	unit cost of electricty in ₹	6.00
	infra cost per unit in ₹	1.50
	charging costs per km	0.38
Total cost per km for battery-swapper in ₹		0.99
O&M costs and margins in %		20%
Customer costs per km in ₹		1.16

- Battery costs per km comparable to the CNG / petrol costs per km
- Cost of maintenance would be lower
- 20% margin on day 1 (including distribution margin)
  - As battery prices fall, business becomes more robust

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
- Choose 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 less than today's buses
- Some 30 manufacturers, battery manufacturers, potential battery swappers
  - Working towards December 2017 launch



4-Wheelers: needs Fast Chargers

- Focus on Taxis and Government Vehicles
  - Economics work out as Cost per km comparable to that for petrol vehicles

- Have a range of 110 kms: going up to 160 kms by July 2018
  - Overnight slow AC charging at homes
    - two hour AC charging while parked at office can extend range to 150 kms
  - DC fast charger for one to one and half hour charging

Tasks

- Bharat Charger Specs defined: more definitions required
- Make Charger business viable like STD-PCO
- Set up Charging Infrastructure and use it for grid balancing

Get going at Speed

- Build Volumes
  - Prices depend much on volumes
  - Focus on Make in India
    - Everything other than battery cells are manufactured in India
- Will enable personal vehicles to take off
  - Two-wheelers can use the same battery module as used in 3-wheelers
- Other vehicles in future
  - Long-distance buses, Tempos, Trucks, Agricultural Equipment and vehicles

Cell to Pack Manufacturing
2017 – some 15 companies

Cell Manufacturing: 2019 -20

India has little Li, Mn, Co
Battery Recycling to recover 95% of Li, Mn and Co

India's Energy Transition to Renewables

2016 Estimates	Installed Capacity (GW)	Projected annual Generation (BU)	PLF	% Energy
Thermal	188.2	927	0.56	74.71
Gas	25.1	50.7	0.23	4.09
Nuclear	5.8	38.1	0.75	3.07
Hydro	43.1	142.5	0.38	11.48
Renewable	46	82.5	0.20	6.65
Total	308.2	1240.8		

from 81% Conventional today

- To 50% Renewables in Energy terms by 2030
  - 75% in terms of Power Installed

2030 Source	Installed Capacity (GW)	Annual Generation BU	PLF	%Energy
Conventional	280	1839.6	0.75	49.59
Hydro	55	240.9	0.50	6.49
Solar	700	1103.76	0.18	29.75
Wind	300	525.6	0.20	14.17
Total	1335	3709.86		

India's Energy Vision 2030

Electrical Vehicles

- India has negligible Electrical Vehicles today
  - 200 million vehicles

- By 2030, all its vehicles will become Electrical
  - 400 million vehicles
    - 700 Billion units consumption per year

India's Energy Vision 2030

Batteries available in 2030: Renewables will happen

- Electricity in 2030: 1350 GW installed = 10000 GWh per day
  - EV is one such large scale storage: 400 million vehicle x 5 kWh use each day = 2000 GWh per day [20%]
    - Say only 50% stationary at any point of time
    - At the end of life in a vehicle, battery can be used for grid-level storage
      - In 15 years, we can have 2000 GWh per day [20%] of second-use of battery
  - Batteries at each home with solar-DC can be another large-scale storage: 250 million x 3 kWh = 750 GWh [7.5%]
  - Batteries in commercial buildings an industries would be a significant storage [10 to 15%]

To Conclude

- The vision is so large that
  it looks impossible today
- But the leadership is all about not only set up tough targets
  but also go about to achieve it
- We have done setting the tough targets today
  all we need is to go on to achieve them