Can we dream of 50% of India's Power in 2030 from Solar PV?

Decentralized Approach: Game changer

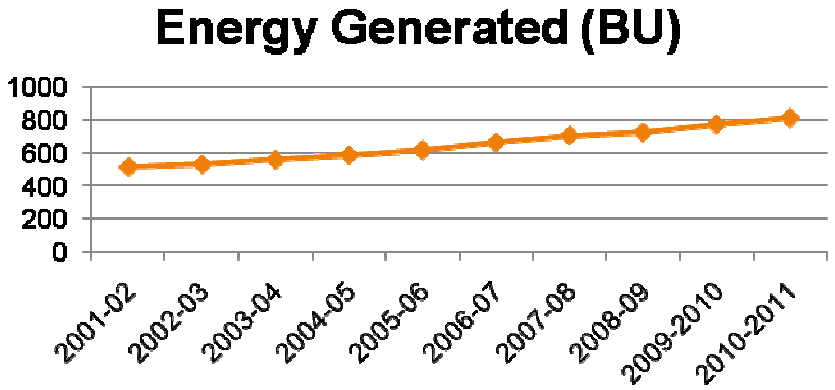
100th Indian Science Congress, Kolkatta

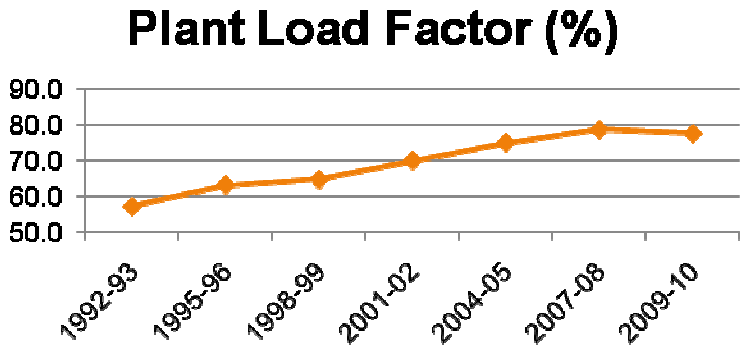
Ashok Jhunjhunwala, IIT Madras,
ashok@tenet.res.in

As India's Economy continues to grow

- India's average GDP growth during 2006-09: 8.6%
  - 7% world's GDP with 17% population
  - Increasing demand for energy from a low base
    - But **affordability is the key:** solutions that sell in india have to be at Indian prices
- Generation capacity continues to increase
  - Keeping pace with country's rapid (8 to 9%) economic growth

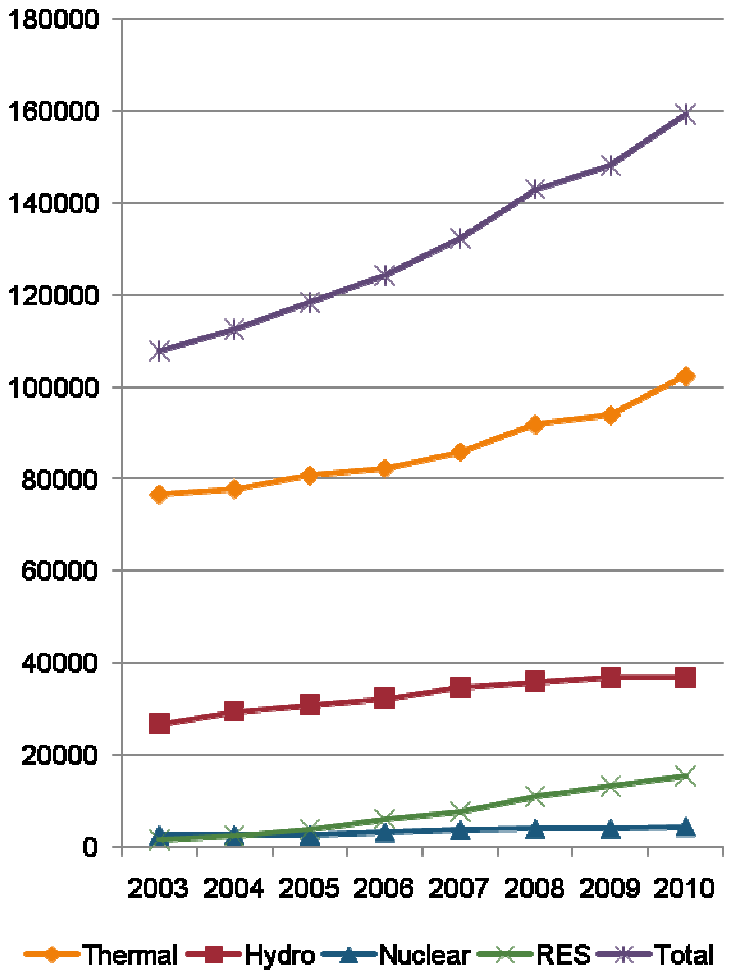
Consumption	India	World
per-capita electricity (kgOE)	704	2752
average energy (TOE)	0.53	1.82





- Even Plant Load Factors have also continued to increase along with generation
  - Plant load factor still low

India's Fuel-wise Generation-Capacity (MW)



- Coal: good for base-load
  - significant domestic reserves
    - proven reserves of 105 billion tonnes
    - could last 200 years at current production level
      - Not good for environment
- Natural gas share up from 4.4% to 10% in last 15 years
  - emit half as much CO2 per kWh as compared to coal-based plants
- Hydroelectric potential of 600 billion kWh per annum
  - Capacity of 148.7 GW
  - only 23% realised so far
  - High initial costs and developmental risks
- Nuclear: small

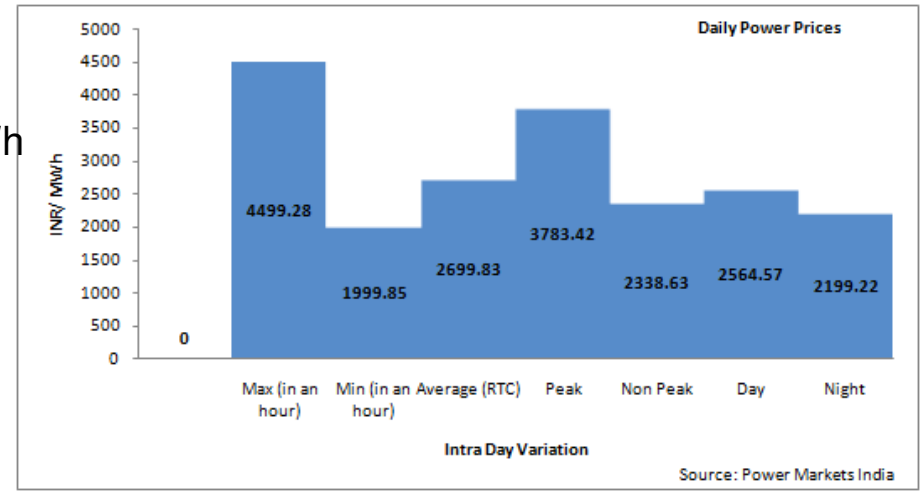
Power Supply Shortage

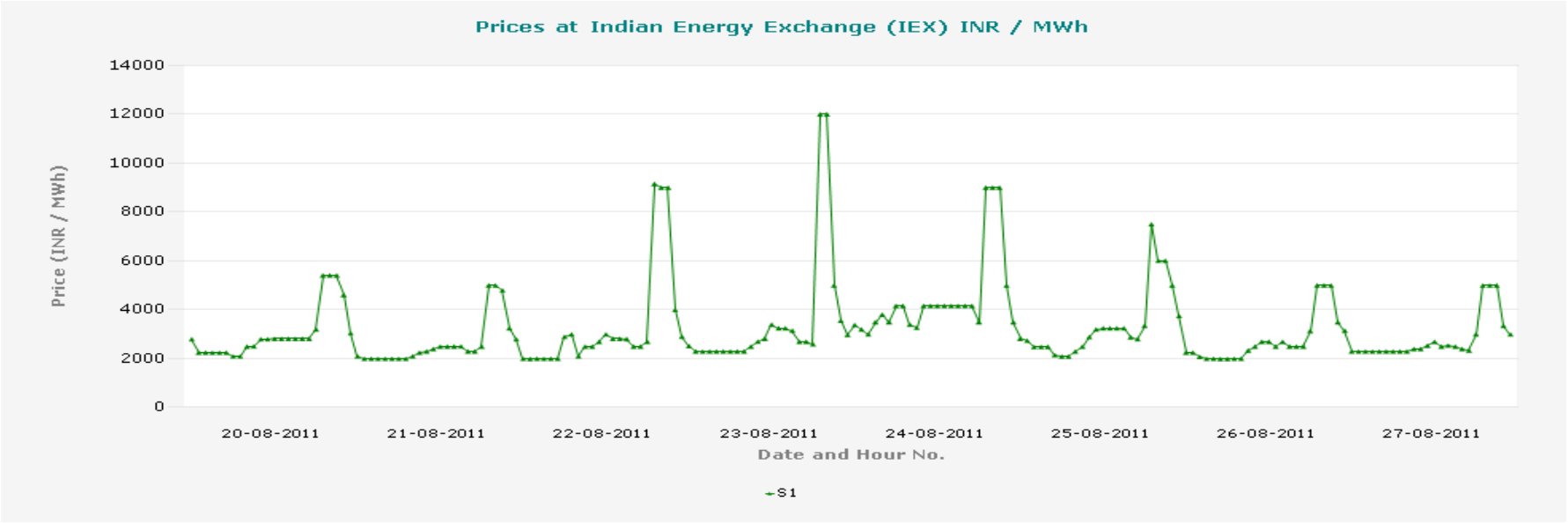
	Energy (MU)	Peak (MW)
Requirements	933741	136193
Availability	837374	118676
Surplus	-96367	-17517
Surplus %	-10.3%	-12.9%

- Cities and towns have huge power-cuts
  - Meerut (50 Kms from Delhi) routinely has 12 hour power-cuts in summer months
- Most of 600000 villages connected
  - 17% villages unconnected
  - Over 60% have power for 4 to 10 hours; Quite a few have power for less than 4 hours a day

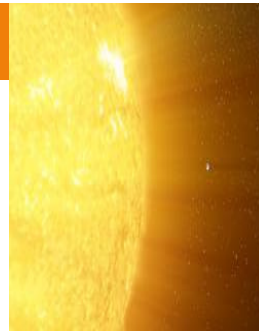
But average deficit is deceiving

- As evident from the fluctuating prices at Power Markets
  - Day variation of Rs 2000 to 4500 per MWh
  - Prices vary from Rs 2000 to 12000 per MWh in one week
- Huge power shortage during peak hours





Is there a solution?



Sun shines brightly over India

- India can certainly use solar energy, as capital goods prices fall
  - Solar photo-voltaic provides DC power for about six hours a day
    - Rs 60 per W capital cost: with 10% interest and payback in 20 years, amounts to Rs 7 per year (not computing costs of land)
      - Costs a little over Rs 4.35 / kWh assuming 10% losses **assuming no land cost**
        - **Assuming DC Power can be directly used**
      - As opposed to **Rs 3 to 8 per kWh for grid power**

Solar PV power price computation			
PV cost per kWp	60000	sun-hours per day	6
interest rate %	10%	sun-days / year	300
depreciation (yrs)	20	total units gen per year	1800
yearly payment	Rs. -7,047.58	Losses	10%
	price per unit	**Rs. 4.35**	

Energy Storage

- Batteries are expensive proposition for back-up
  - Lead acid battery: 1500 cycles if operated between 60 to 100% capacity
    - 1 kWh back-up will cost Rs 14/ kWh assuming single charge / discharge per day
      - Assuming Rs 6000 per kWh battery and 10% interest rate
  - LiFePo battery: 5000 cycles if operated between 10% to 90% capacity
    - 1 kWh back-up will cost Rs 15 per kWh assuming single charge per day
      - Assuming Rs 25000 per kWh battery and 10% interest

Lead acid battery

Battery cost (per kWh)	Rs. 6,000.00
discharge	40%
Number of cycles	1500
interest rate	14%
cycles used per day	1
Losses	10%

Battery cost (to deliver 1kWh)	Rs. 15,000.00
depreciation (years)	4.11
Storage cost per unit	-Rs. 15.35

What are the options when power fails?

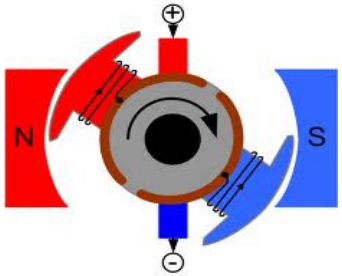
- Power-Sources:
  - Grid: Rs 5 per kWh: ram-bharose (as per god's will)
  - Diesel generator: Rs 17 per kWh (Rs 25 without subsidy) when diesel is subsidized, when generator runs at 80% load: instantaneous
    - Much higher costs at lower load..
    - Primary use today in organizations / offices
  - Solar PV: under Rs 5 per kWh when dc is used: day time only
    - Conversion to AC may add Rs 2 per unit; land may add ???
  - Electrical battery back-up: storage costs over Rs 15 per kWh

- Usage
  - Electrical Load: lighting, motor and electronics
  - Cooling Load

Appliances are AC: Can one use DC?

- Lighting
  - CFL is four times more energy efficient than tungsten bulb and neutral to AC or DC power
  - LEDs, 4 to 10 times more efficient than CFL, use only DC power

- Motor: a small BLDC motor can be twice more energy efficient as compared to an AC motor
  - Historically brush replacement needed – but not anymore
  - A fan is primarily a motor – a dc fan also allows better speed control
  - A refrigerator is essentially a motor
  - An air-conditioner has a motor (even-though it involves cooling)
  - A washing-machine / grinder is a motor



- Electronics: all electronics (mobiles/TV/Computers) use low voltage
  - Need an ac/dc power adaptor to charge

- World switched to AC primarily for transmission of power
  - Any ac / dc conversion or vice-versa implies 7 to 15% losses

Has time come to switch back – at least at customer's premises?

Decentralized Solar PV

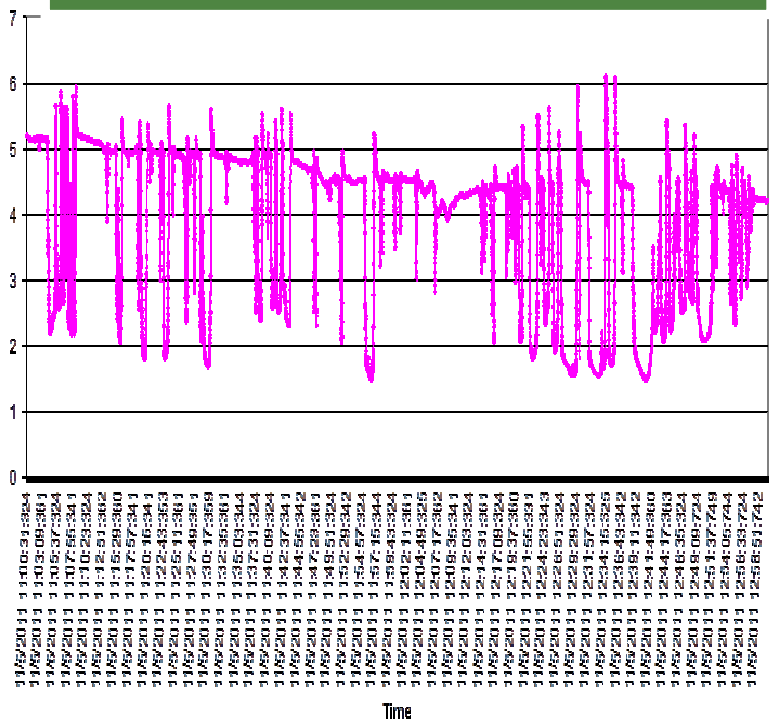
- Would be ideal in day time: complement grid
  - Direct usage in offices / shopping malls can reduce the day time peak load requirement to a considerable extent
    - Makes economic sense today, provided there is space for solar PV installation
      - no additional land cost; T&D losses controlled
        - Excess demand can be drawn from grid / excess generation can feed to grid
    - Gradual shift to DC usage will add cost and energy-efficiency

- What about evening peak loads? Solar can not help
  - Reducing consumption by **introduction of time of day metering**
    - Can one start and close office early!!
  - Reducing load by enhancing efficiency
  - Using some storage

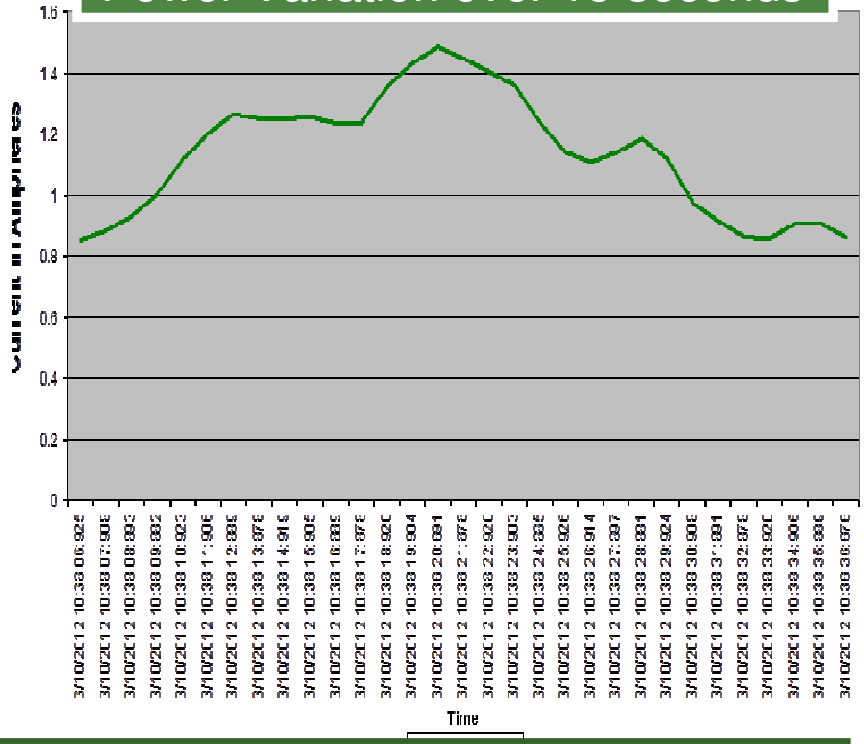
Problems to solve

I. Dealing with Solar PV Power variation

Power Variation over two hours



Power Variation over 15 seconds



Over the day power generation starts at 6 AM, peaks at noon and goes down by 6 PM

Power variation and Supply-Load Match

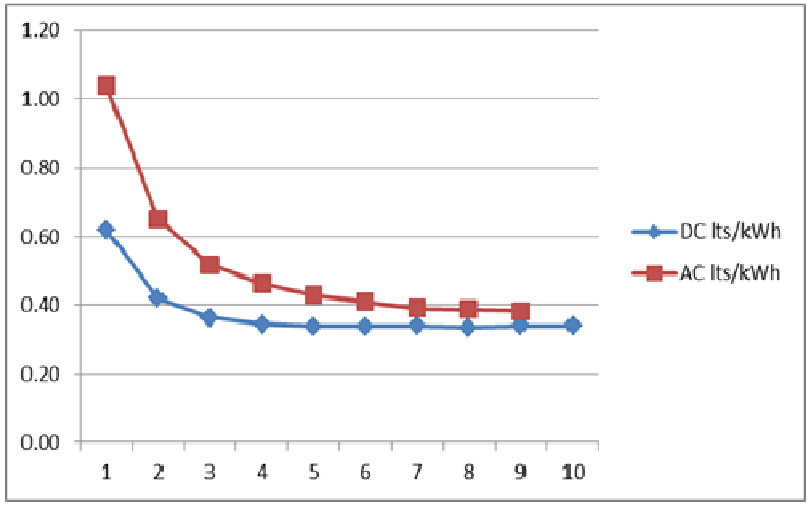
- Variation will remain even when one converts to AC
  - Combining with an infinite source (grid) could help
    - But if power variation for all solar cells in an area is correlated
      - Combining with grid may cause grid-instability
- Need Power Electronics and combining with alternate source of power (grid / generator / battery)
  - or would require load control
    - **Smart controller**: India's smart-grid component Combining multiple power sources
      - Reduce power usage, if possible, to match generation
        - Reduce fan-speed or pump-motor speed; increase air-con temperature; cut-off one line
- Natural Supply-Load Match helps
  - When cooling is most required, solar power generation is at its peak

II. Work on alternative storage

- Flow-battery may be answer to storage
  - Work required on Redox flow-battery to make it inexpensive
    - Vanadium or Zn- Bromide Redox-flow battery
- New Lithium Ion battery promises Rs 7 per unit costs
  - New Lead Acid battery promises similar advantage
  - Need Validation
  - Need Intelligent Power Electronics to manage each cell
- Is it possible to store heat / coolness
  - Can even generate during off-peak hours and use it during peak hours.

III. DC Sources and Loads

- Diesel generator generates 3 kWh of power per litre of diesel
  - only if generator works at 80% load
    - efficiency drops with lower loads
  - Not so with DC diesel generator
    - May be ideal as evening solution in absence of battery / grid



- DC Motors
  - BLDC motors for all kinds of applications
  - Ferrite and Rare-earth Magnets: efficient power-electronics

- DC Powered Air-conditioners
  - Solar PV with MPPT and VFD driving
    - New Power electronics and robust motor required
  - New type of air-con with energy-efficient DC motors (BLDC or SRM)
    - consumption of 55-60% of regular AC (but 30% more expensive)
    - when sun is brightest, it is expected to be hottest and vice-versa
      - Natural Load – Demand Match
- Also DC Powered Air-coolers

DC Sources and Loads

- DC Powered cold-storage: Technology and Economics
- Solar Agricultural Pumps (10 million)
  - Water can be pumped when sun is there
    - More water when sun is strong; during rainy seasons, lesser requirement of water: natural Load-demand match
  - Efficient power-electronics for solar PV to directly drive pumps
- DC Fans and Lights: costs and availability
  - Need to figure out right DC voltage
    - Wiring losses: Can they use existing wiring harness? Speed / brightness control
    - DC power protection; earthing
    - Minimize dc-dc conversion – losses and costs
      - Design and proliferate SME for manufacturing and distribution
- DC Powered-Electronics
  - What should be the right voltage? Standards?

IV. Higher efficiency solar-PV and panels

- Require cost-effective solar panel with higher efficiency
  - From current 13% to 20% efficiency at panel costs Rs 40 per W(p)
    - When can we get 30% efficiency at similar costs?
  - Need long term financing at lower interest costs
    - Priority-sector financing
- Solar cells are very thin and are light
    - Almost paper-like, but may be brittle
  - Panel Mounting at lower costs
    - For mounting on all roofs, aesthetics is equally important
  - Needs periodic water spray and scrubbing

DECENTRALIZED SOLAR PV

Short-term (2 to 5 years) possibilities

Solar powering of Agricultural Pumps

- Significant savings possible of subsidized electricity
  - Important that it is not subsidy driven but commercially viable for farmers
  - Current pump-sizing determined by 1-2 hour power availability
    - Solar Agricultural pumps could be run for 10 hours
    - Need much smaller sizing pumps : will pump required water
      - Would reduce solar array size
      - Minimise costs as well as minimal shaded agricultural land
  - Solar water pumps along with drip-irrigation desirable

Solar-powered Commercial Buildings

- Primarily used in day time
  - Roof-top Solar PV can play a major role in complementing electrical grid
    - Drawing shortage from grid and feeding excess to grid
    - Take advantage of natural Supply–demand match for air-cooling
  - Smart-controller helps: when sun-light is poorer, reduce consumption
  - Use of dc fans, lighting, electronics air-conditioners will help
    - Can one use DC distribution (grid) within the building
- Can be used in schools, colleges, campuses
  - And even in manufacturing industry
- Also Solar powered homes

Solar village-electric plant

- Solar PV based RESCO (Rural Electric Supply Company)
  - a PV plant to feed electricity in the village?
  - Excess can be fed to grid; Shortage can be picked up from grid, if available
  - Evening powering needs alternatives
    - Some Storage: at village level / home level
    - Will Diesel generators be economic?
    - Can wind energy / bio-mass energy / micro-hydel help?
  - Can also power agricultural pump-set
- Does it make more sense to have DC grid?
  - 200V DC as primary feed
- Converted if needed at each home: can feed fans, lighting and electronics / TV
- Can we get state government to use this instead of free electricity
    - architecture, economics, protection

Rural Cellular Base Stations

- Remote Base-stations providing communications
  - Electrical grid is off for 16 to 20 hours
  - Primary operation costs for operators: diesel costs
  - How to use battery back-up, diesel generator and solar power optimally to operate the base station?
    - Will DC generators help?
  - Can we save energy at base station?
    - Especially energy needed for cooling
    - Will DC motors (for exhaust fans) and CFL / LEDs help?
    - Can chiller be used instead of air-con?
- Report: Powering Cellular Base Stations: A Quantitative Analysis of Energy Options -- solar PV, Diesel Generators, Batteries and Electrical Grid http://tcoe.in/download/1/Download-Section_190/1/1.html

Need Intensive R&D

- Solar panels: leverage world's availability
  - Continuously evolving technology
  - Need R&D to catch up with the world
  - Manufacturers willing to set up solar cell manufacturing in India
- Power Electronics, smart controller, combining grid-solar-battery judiciously, system design, protection
  - India has the ability
  - Need focused work
- Storage
  - Research needed on new electrical batteries
  - Storing energy in other forms: for example heat / coldness storage

Policy Issues

- Long-term financing of decentralized solar panels at lower interest rate
  - Such Solar panels should be included in Priority-sector lending
- Subsidy
  - Should enable early commercial viability, rather than making subsidy and end-game
- Time of day metering
  - At least for commercial and industrial load for day time peak
  - Evening peak also to be priced high so as to shift power usage pattern

To sum-up

- Solar PV today is a god-sent opportunity for India
  - A year to two of work can make solar power work for us – dc power usage will help
    - at least in the day time; **storage solution will be another game-changer**
    - Use as much natural load-demand match at possible
- Smart-grids for India
  - Key is to match load with available power
  - At local-level as far as possible – if necessary by selective power-shedding
- Number of technical challenges need to be overcome
  - System design issues are critical
  - pilot deployments are key to prove viability
    - Early pilots are three to four months away
- Policy actions to promote solar PV – instead of subsidy
- **One can dream of getting 50% of India's power requirements using solar PV by the year 2030 or so**
  - Can transform India