EN 216
EN 301 (/M)

Renewable Energy Technologies

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About Course (resources-technology-power generation)

- Introduction to world and India energy scenarios, Open discussion
- Renewable energy resources
- Radiation, Solar Geometry, radiation models;
- Solar Thermal, Optical efficiency, thermal efficiency, concentrators, testing procedures, introduction to thermal systems (flat plate collector), solar architecture
- Wind, Introduction, types of wind machines, Cp-λ curve & Betz limits
- wave energy, ocean energy, Power generation
- Photovoltaic; Introduction to semiconductor physics, doping, P_N junction, Solar cell and its I_V characteristics, PV systems components, design of a solar PV systems
- Economics of RE
- Biomass, Biomass resources, pyrolysis, gasifies, biogas, bio-diesel, ethanol

References

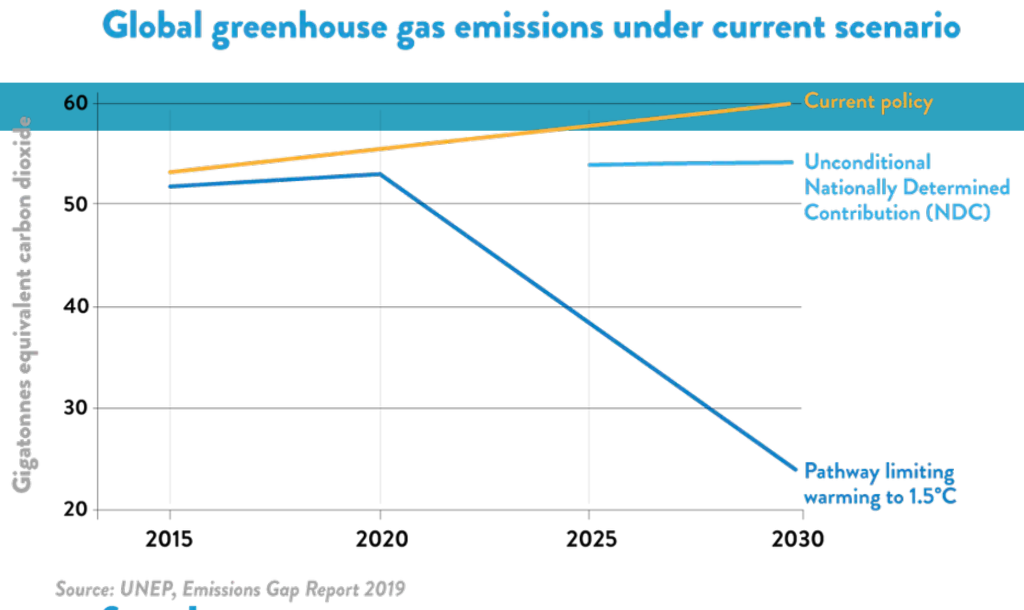
- S. P. Sukhatme, Solar Energy - Principles of thermal collection and storage, second edition, Tata McGraw-Hill, New Delhi, 1996
- J. A. Duffie and W. A. Beckman, Solar Engineering of Thermal Processes, second edition, John Wiley, New York, 1991
- D. Y. Goswami, F. Kreith and J. F. Kreider, Principles of Solar Engineering, Taylor and Francis, Philadelphia, 2000
- D. D. Hall and R. P. Grover, Biomass Regenerable Energy, John Wiley, New York, 1987.
- J. Twidell and T. Weir, Renewable Energy Resources, E & F N Spon Ltd, London, 1986.
- M. A. Green, Solar Cells, Prentice-Hall, Englewood Cliffs, 1982.

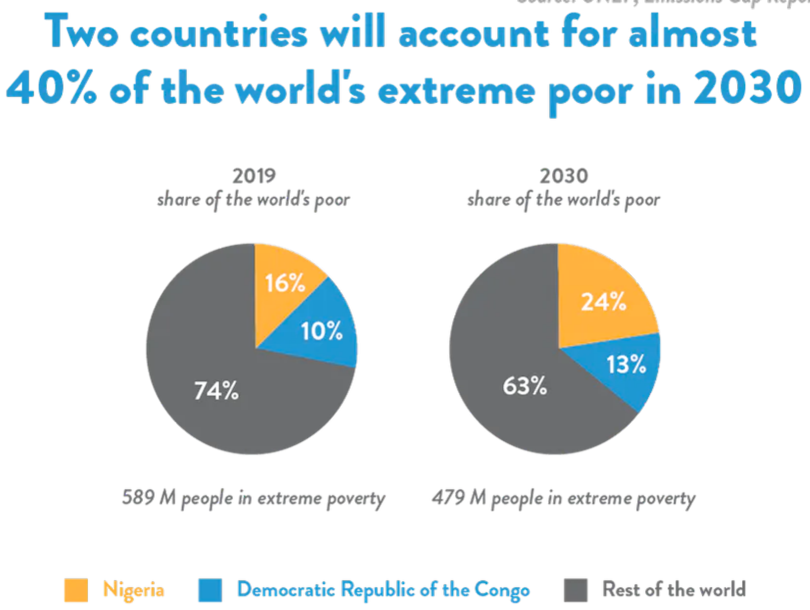
Course Evaluation

- Quizzes (every week one quiz for 15 mins)
- Mid semester exam
- End semester exam (30-40 %)
- Attendance-must (5%)
- Technical presentation on given topic and QnA

Top three problems to Humanity

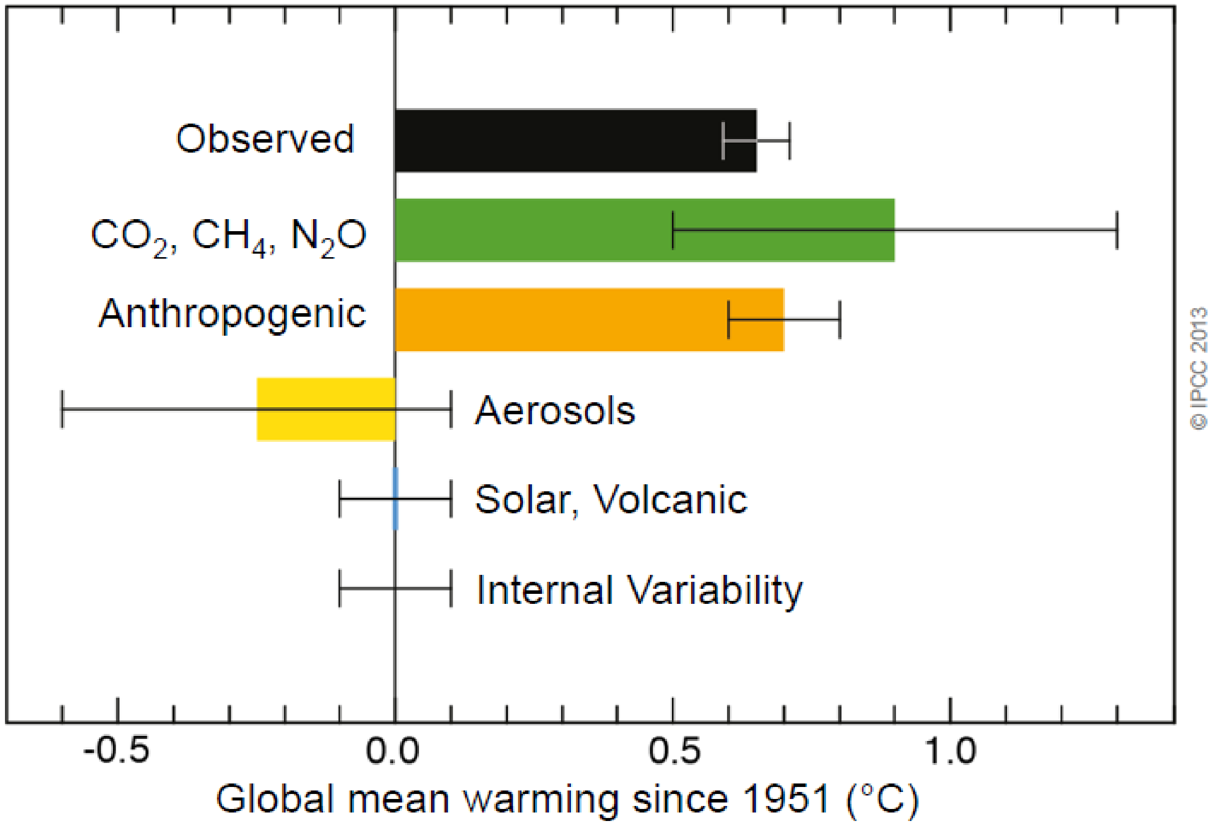
- Climate Change and green house gas emission
- Sustainable Solution to live
- Poverty





https://unfoundation.org/blog/post/5-global-issues-to-watch-in-2020/

Why this change

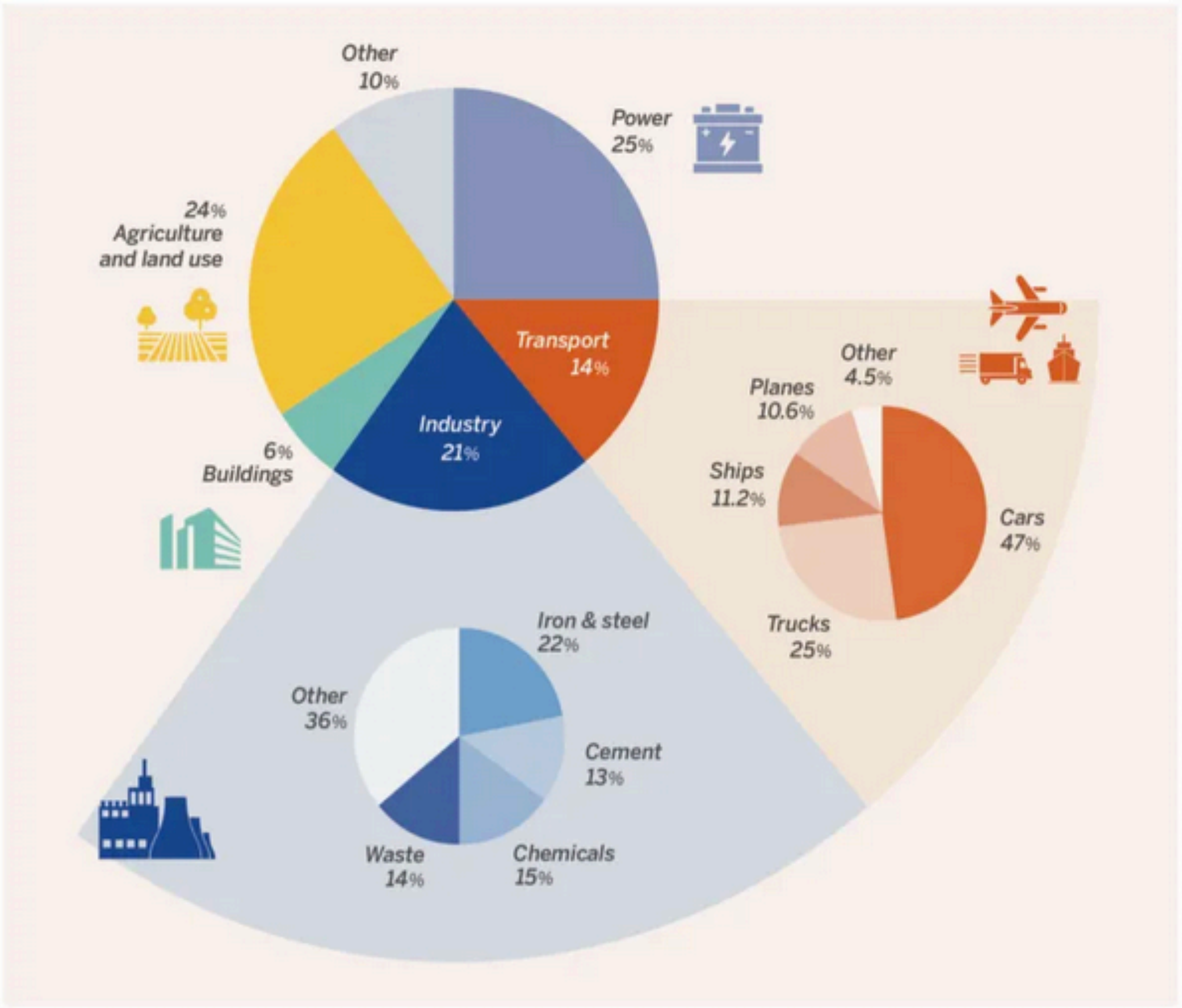


It is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century.

Global green house emission

- Power sector
- Agriculture and land use
- Transport sector
- Industry

FIGURE 12: GLOBAL EMISSIONS BY SECTOR



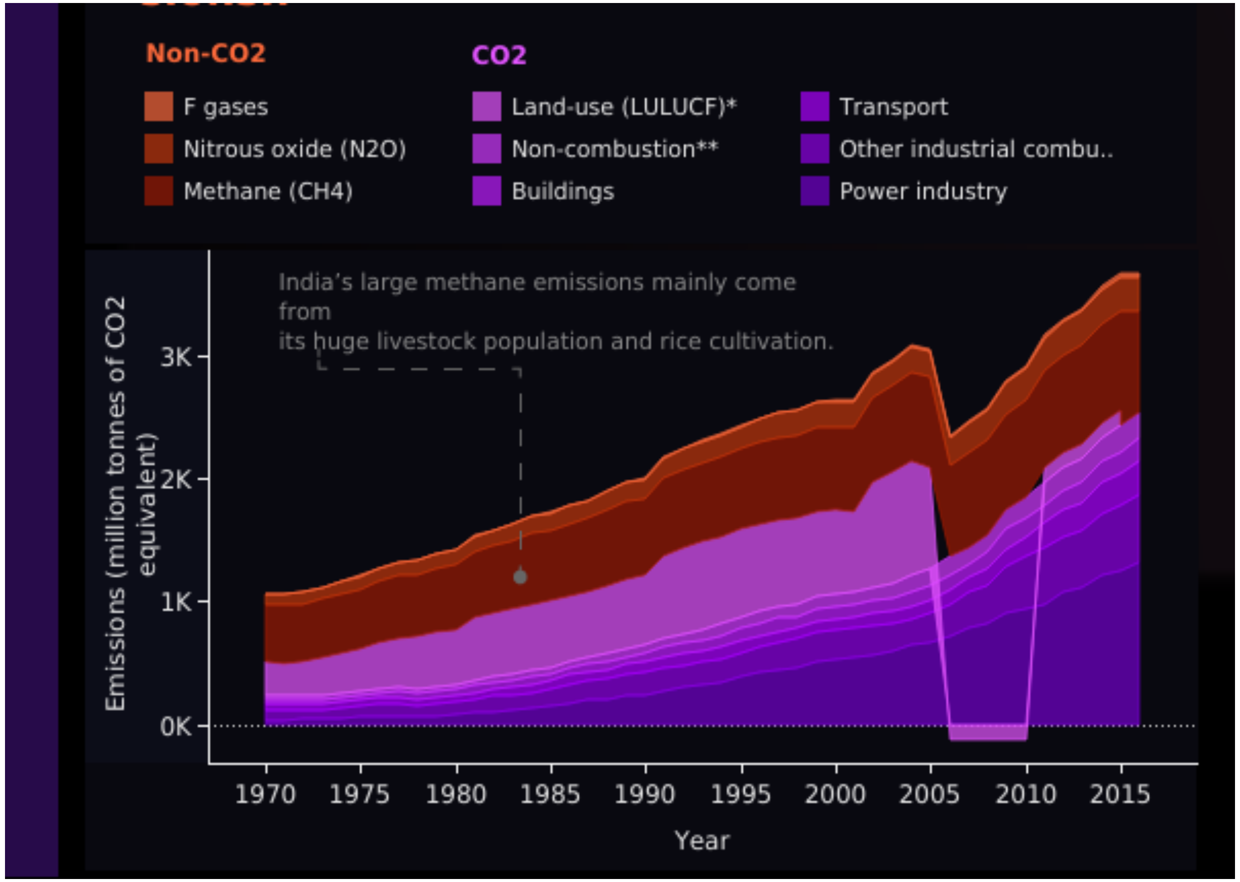
Source: Emissions data is from the IPCC's Fifth Assessment Report, Working Group III, 2014, and refers to shares of total global greenhouse gas emissions. The split between cars and trucks in road transport emissions is based on the IEA's Energy Technology Perspectives, 2017, since this is not given in the IPCC source.

IPCC, 5th Assessment report

India green house emission

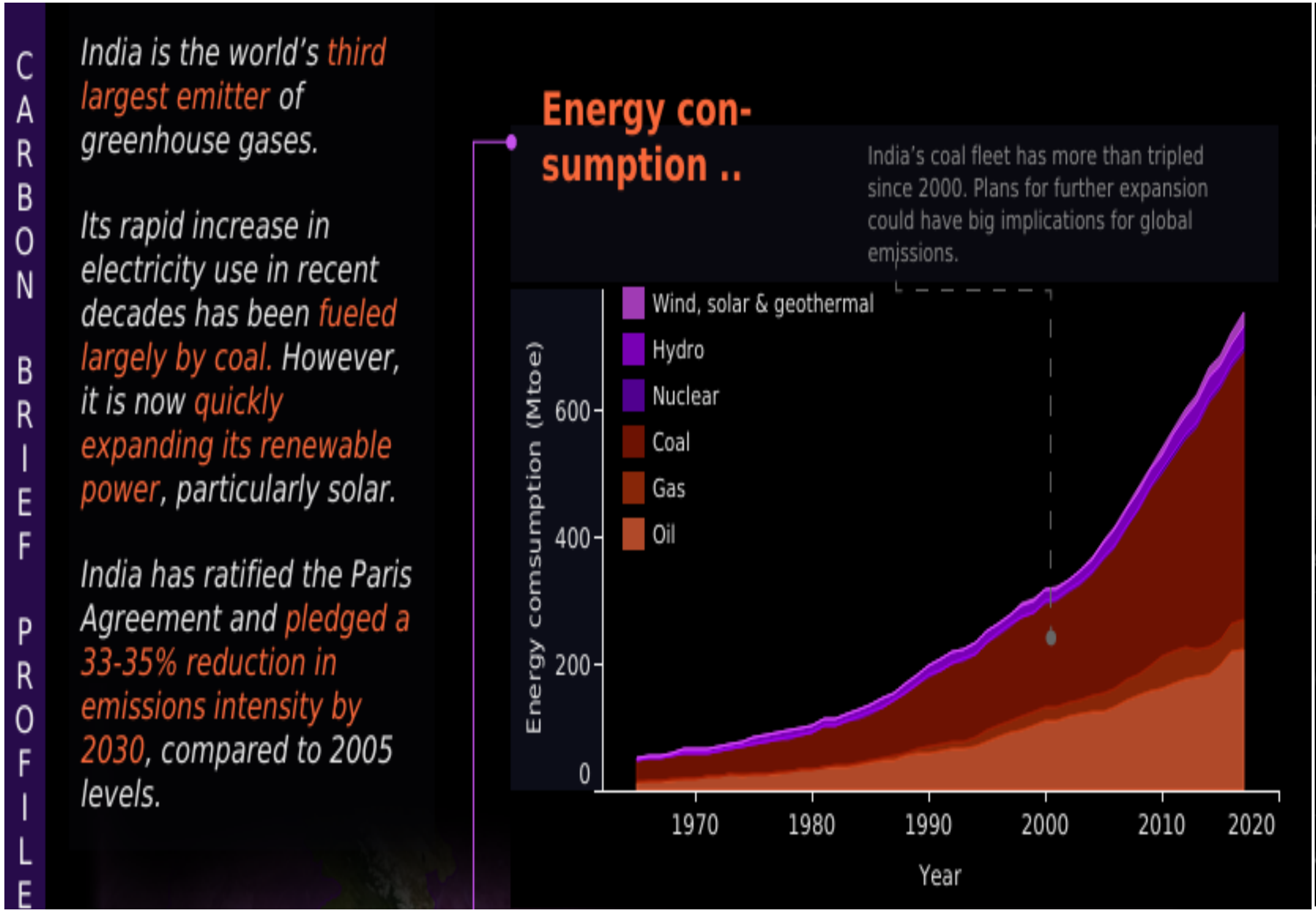
- Power Industry
- Industrial Contribution
- Transport sector

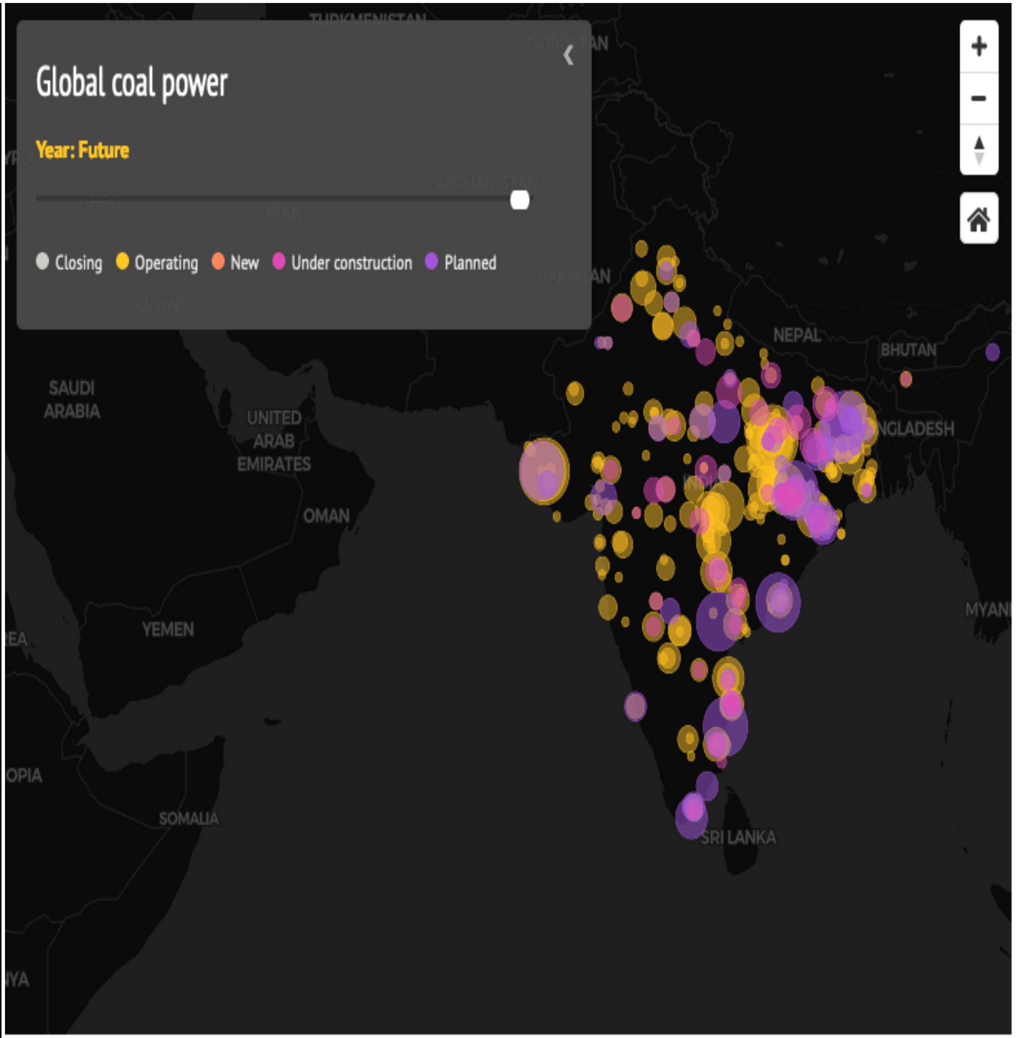
The country could achieve its 40% non-fossil power capacity target more than a decade early, through the use of hydroelectricity and nuclear power. India's emissions intensity in 2030 will be around 50% below 2005 levels.



https://www.carbonbrief.org

Energy Consumption source wise





Electricity sector in INDIA (installed capacity 370 GW as of March 2020)

Coal
55.4 %

Hydro electricity
13.6 %

Wind+ PV+Bio masss
22.3 %

30 177 MW

Natural gas
6.7 %

Nuclear
1.8%

Off grid
973 MW

India needs 400-900 GW of new generation addition by 2030 to meet economic development goals

Industry
382670 MWh (44.87 %)

Domestic
185858 MWh (21.79 %)

Agricultural
140960 MWh (17.95%)

Commercial
71019 MWh (8.33 %)

Traction
15431MWh (1.81 %)

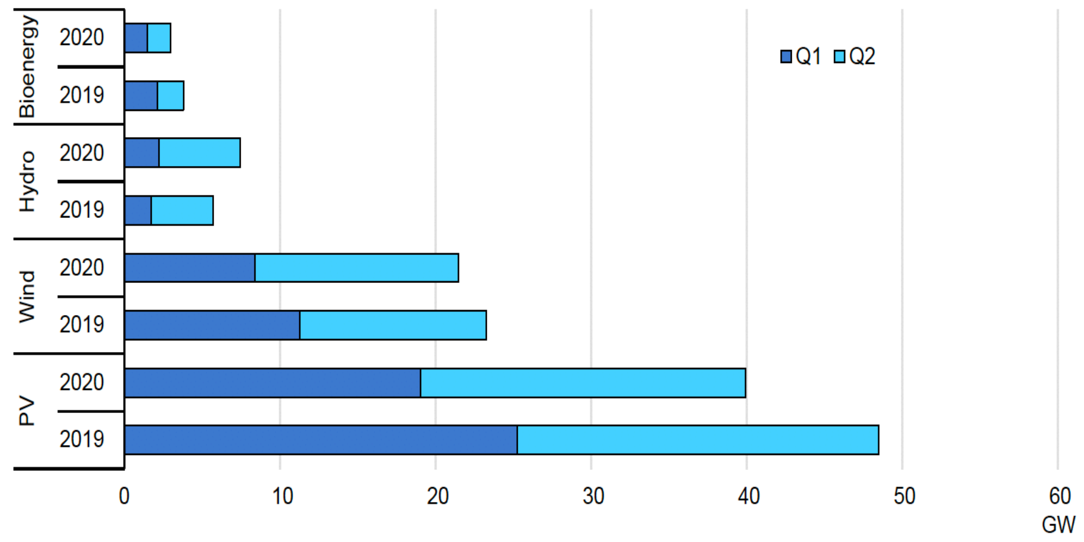
Then Pandemic started
Few Silent features due to Covid 19

- The Renewable industry has adopted quickly to challenges of the Covid crisis
- Europe and India will lead a RE surge in 2021
- Increasing Policy certainty is boosting the RE markets
- RE are set to lead the Global Energy Sector by 2025
- Biofuel industry has been strongly impacted in Covid Crisis

IEA report 2020

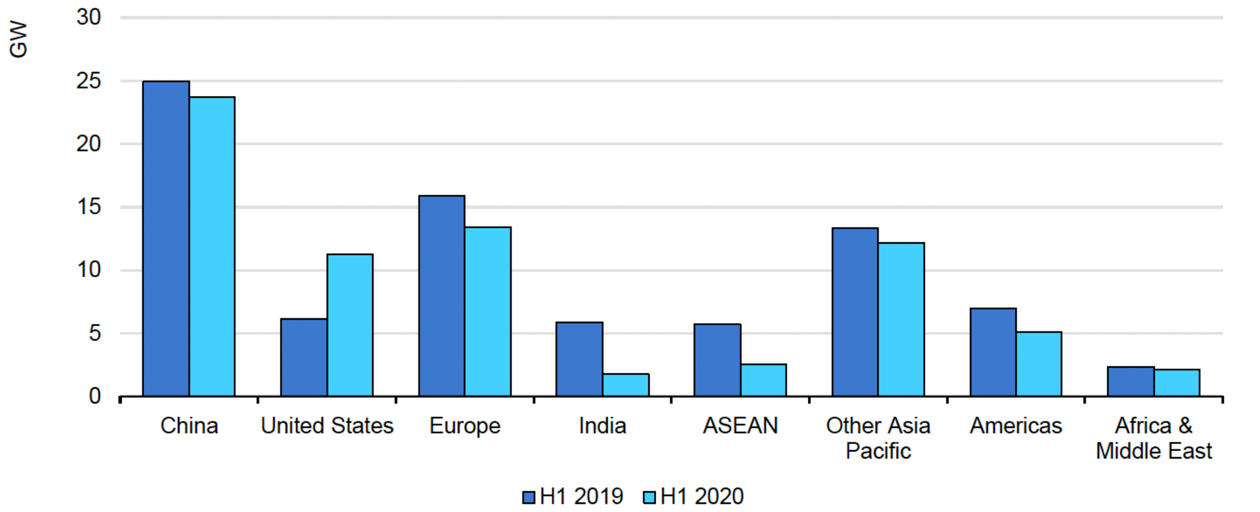
Jan to June 2020 RE electricity capacity additions

Figure 1.2 Renewable capacity additions by technology, Q1 and Q2 of 2019 and 2020



Note: Actual data collected from governments and industry associations cover Argentina, Australia, Brazil, Chile, China, France, Germany, India, Italy, Japan, Korea, the Netherlands, Poland, South Africa, Spain, Sweden, Chinese Taipei, Turkey, the United Kingdom and the United States. These sources represent 75% of total global capacity additions in 2019, with remaining additions estimated based on actual annual data and forecasts.

Figure 1.3 Renewable electricity capacity additions, H1 2019 and H1 2020 by region



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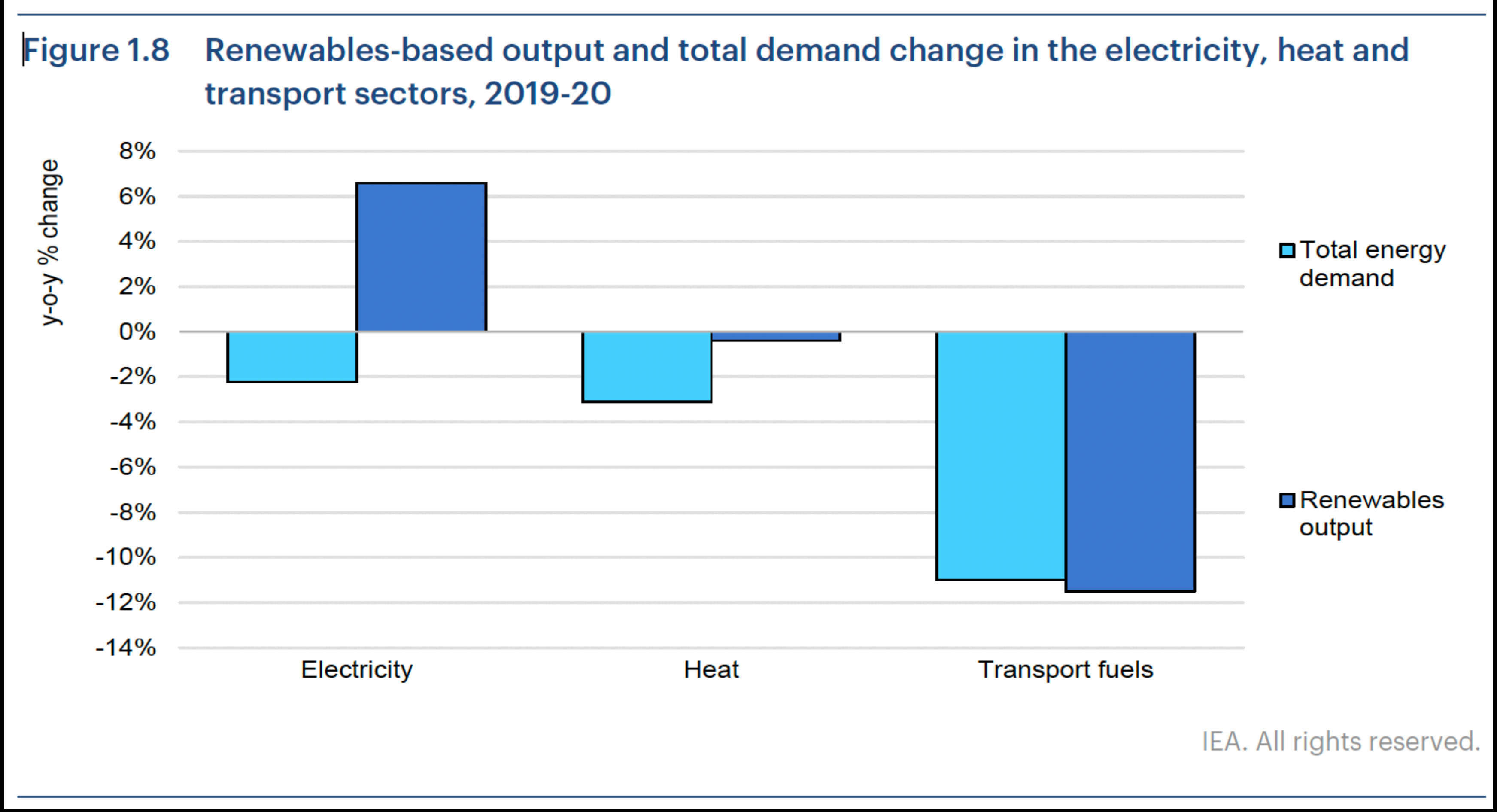
IEA report 2020

Due to Covid-total RE based output change in the electricity



IEA report 2020

Multiple challenges-Indian Energy sector

- Constrained transmission and distribution capacity
- Unmet energy demand
- Low energy access in rural areas
- Continue to depend on coal-based generation

Solution

Use of Renewable energy

Combustion of fossil fuels produces

- CO_2 primary green house gas-contribute to global warming
- NO_x and Hydrocarbons: smog
- CO- Toxic
- SO_2-acid rain
- PM-adverse health effects

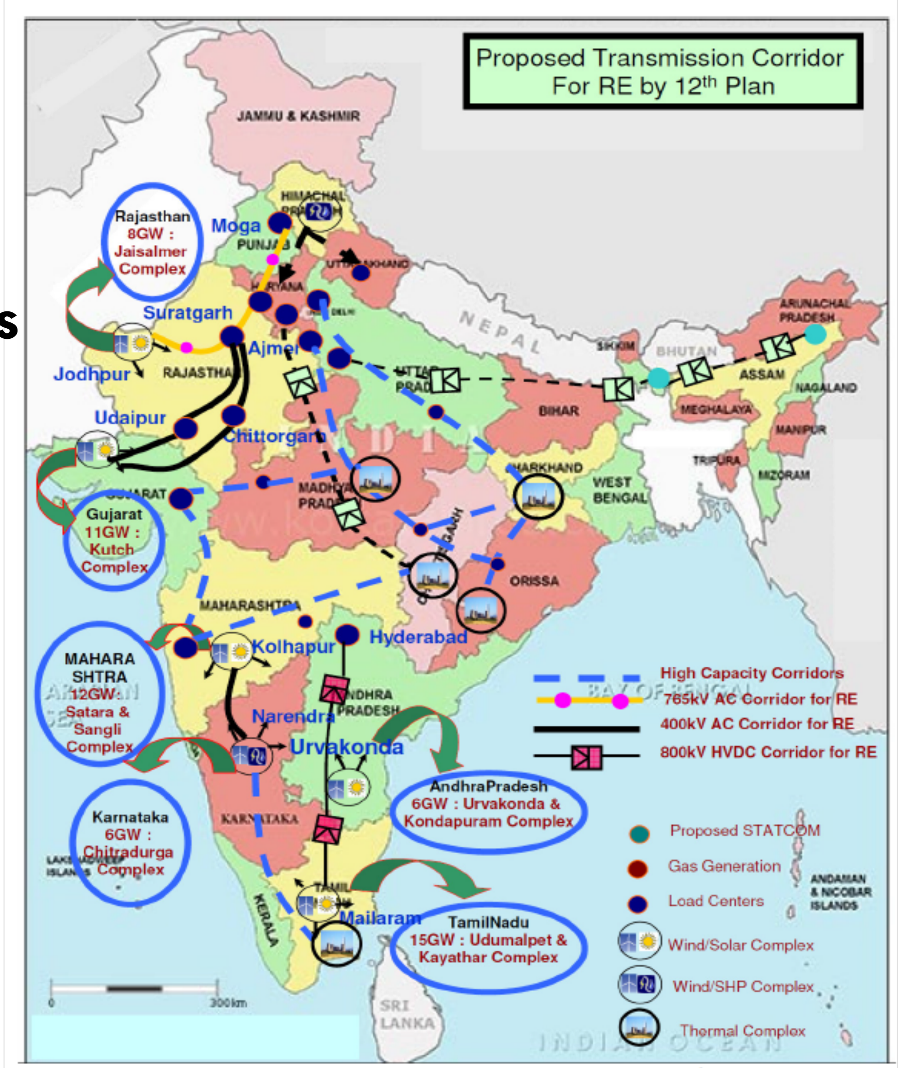
Perspective transmission plan for RE by 2030 (green corridors)

❑ **Green corridors planned for Tamil Nadu, Gujrat, Rajsthan Karnataka, Andhra Pradesh, Maharashtra, HP and Jammu Kashmir**

❑ **The transmission system costing about Rs. 32, 000 crores ($ 900 Mn) have been planned to establish 32 GW RE Additional capacity program**

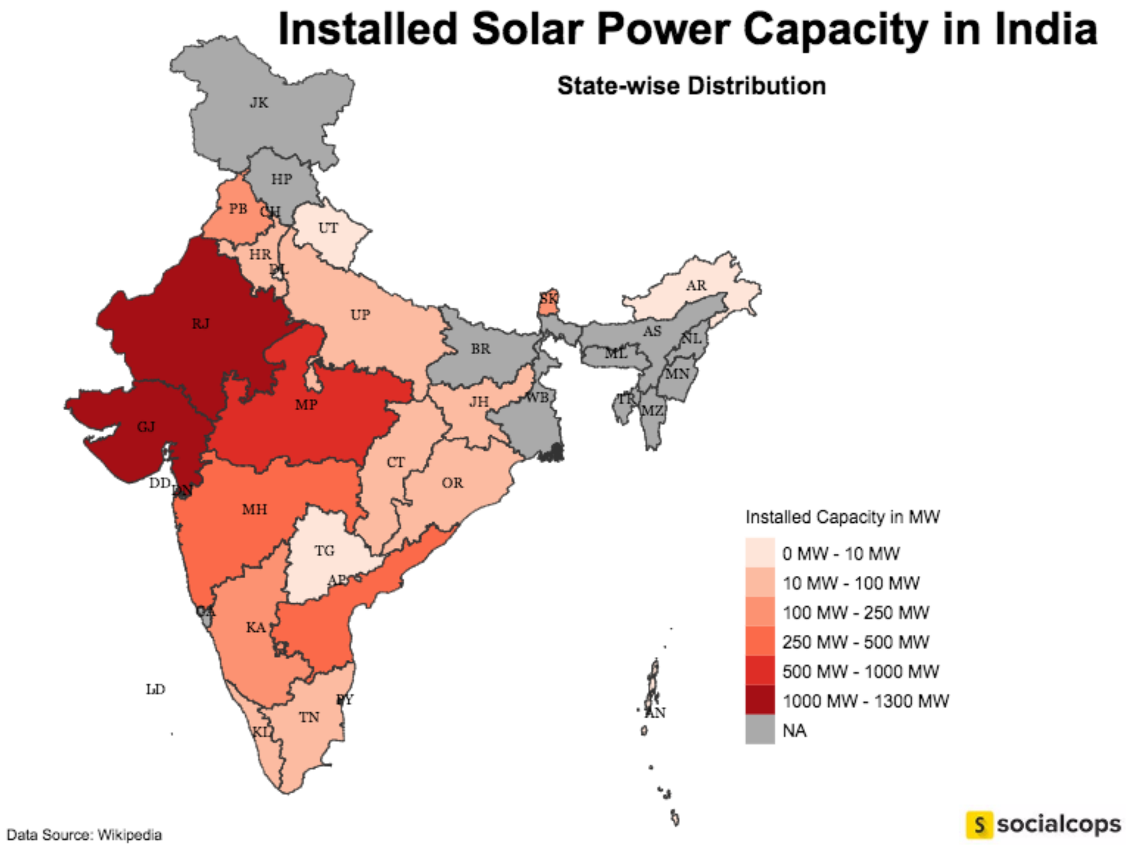
❑ **Rs. 2000 crores ($ 350 Mn) investment anticipated for Energy storage**

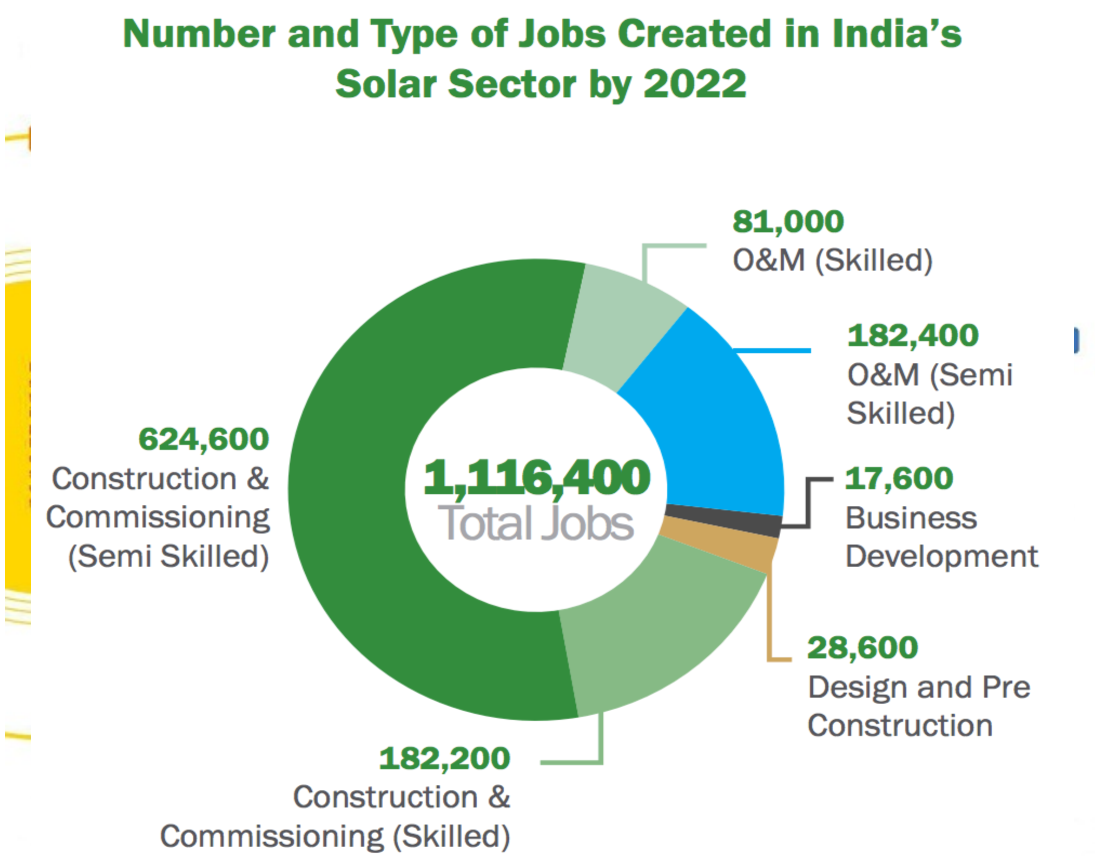
❑ **India is currently investigating 1-5 MW pilot demonstration projects for Storage Technology validation**



Solar Energy

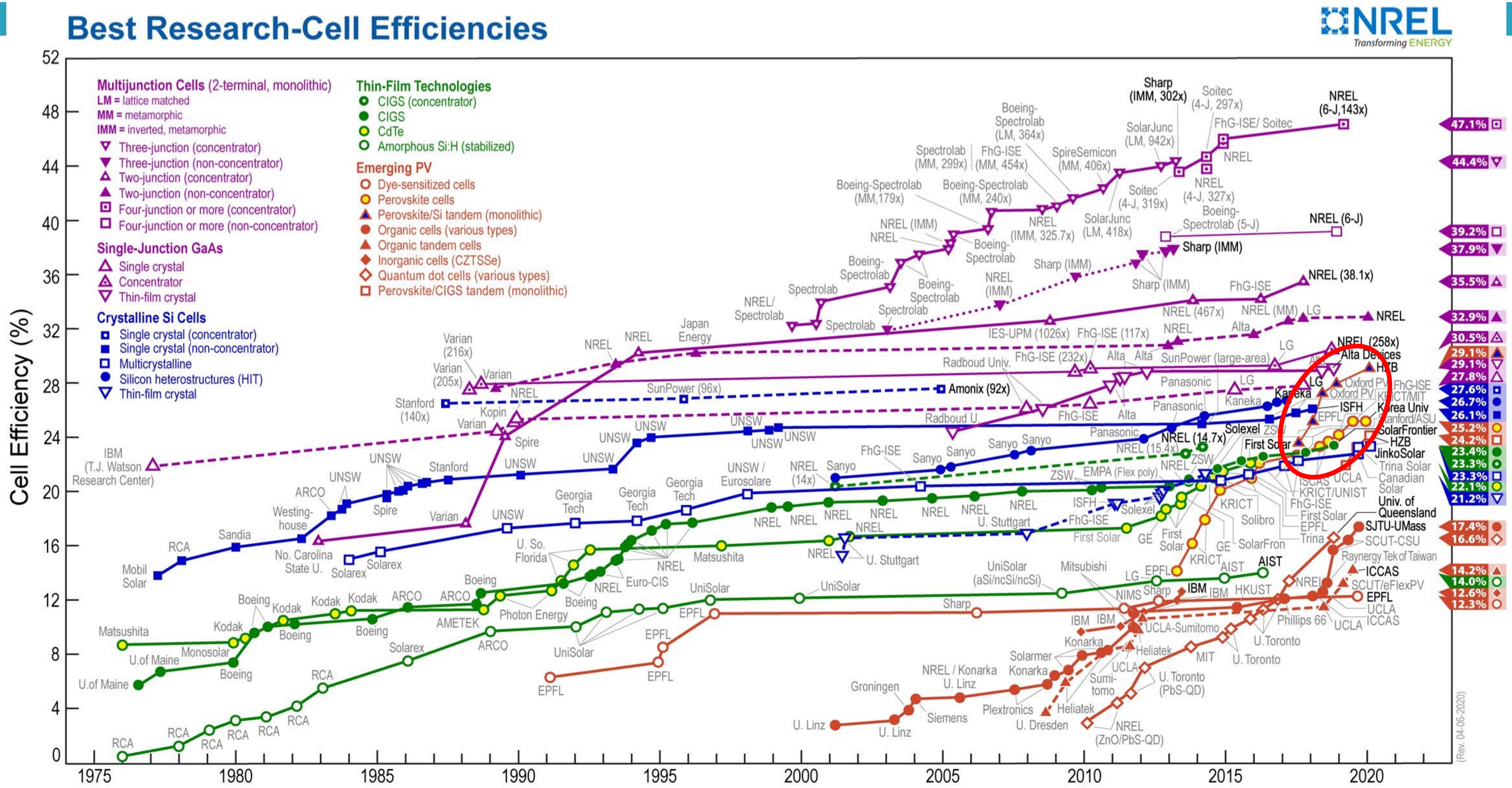
Geographical Advantage



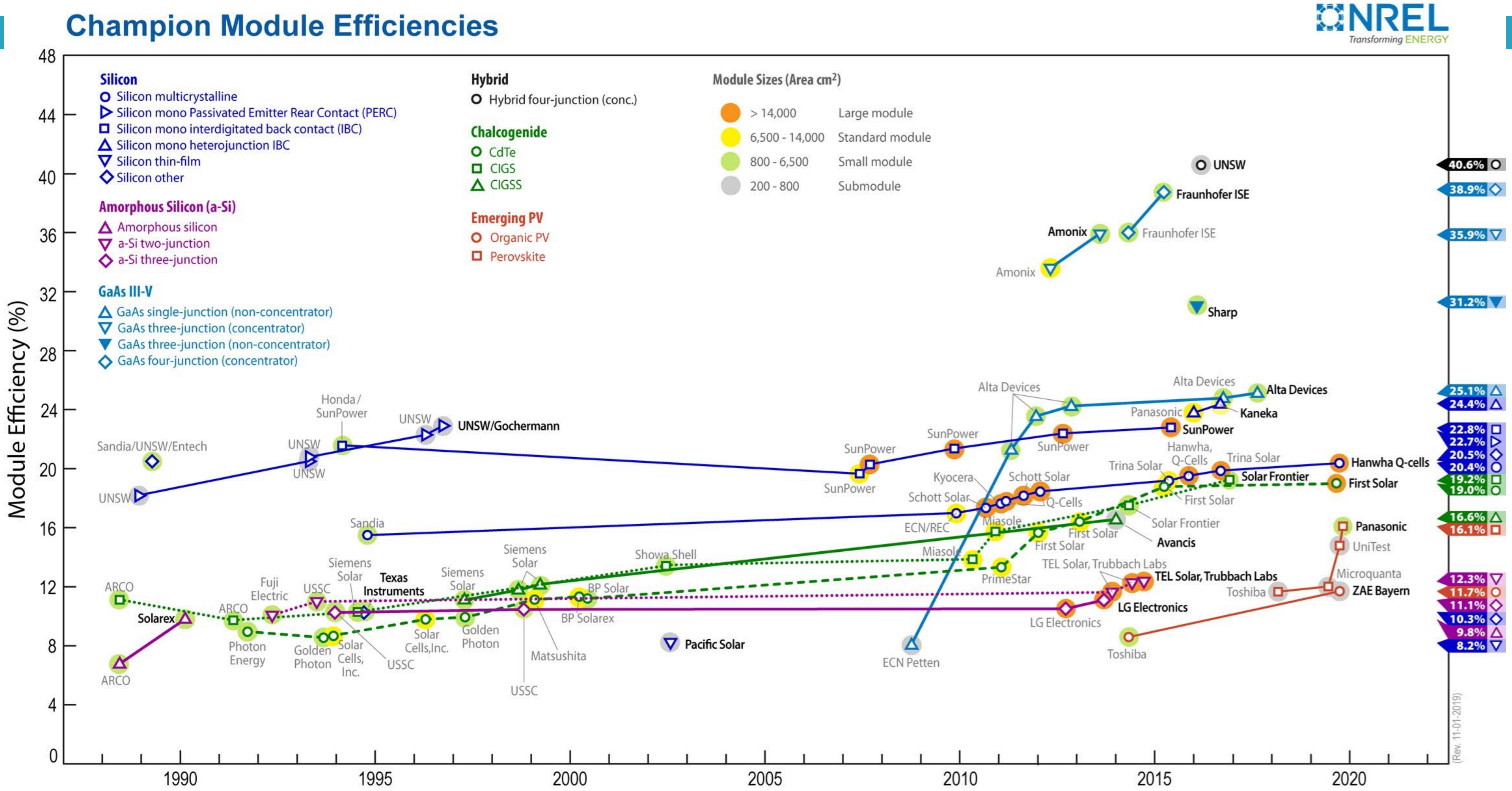


Ref: MNRE website

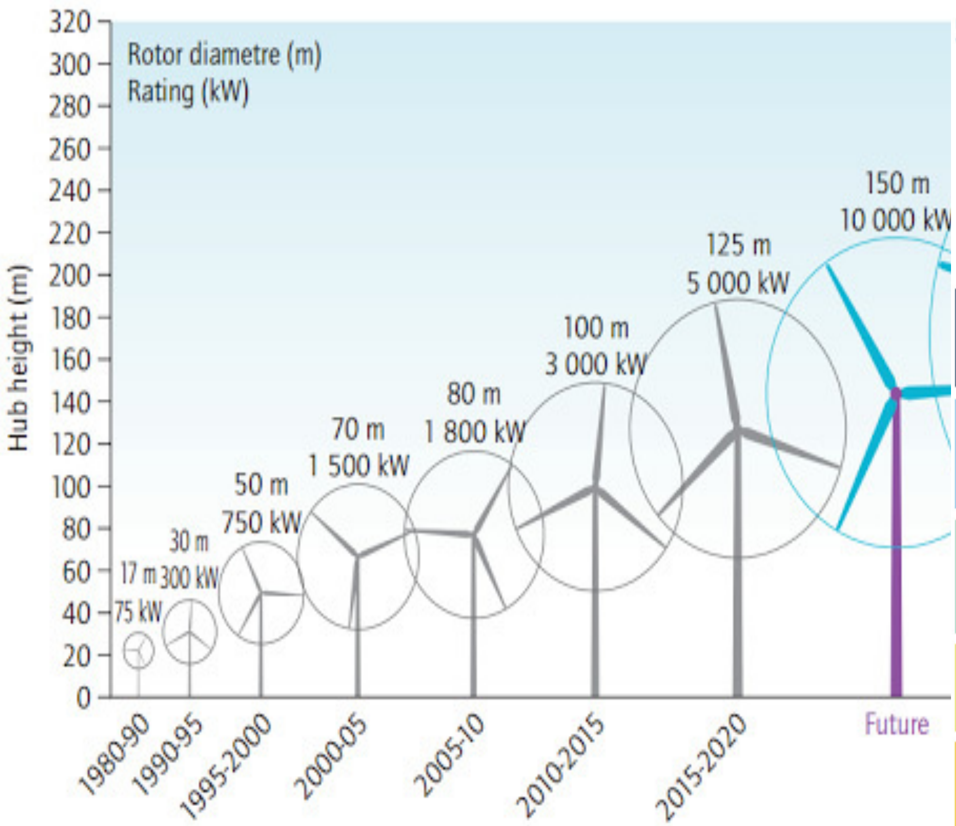
Solar cell Research and current Status-cell



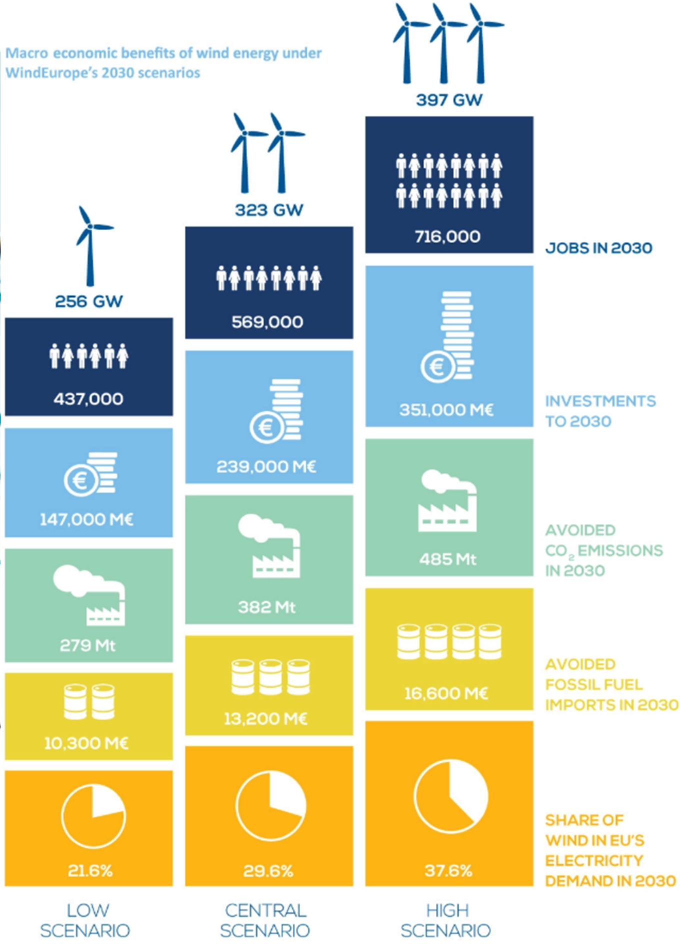
Solar cell Research and current status in Module

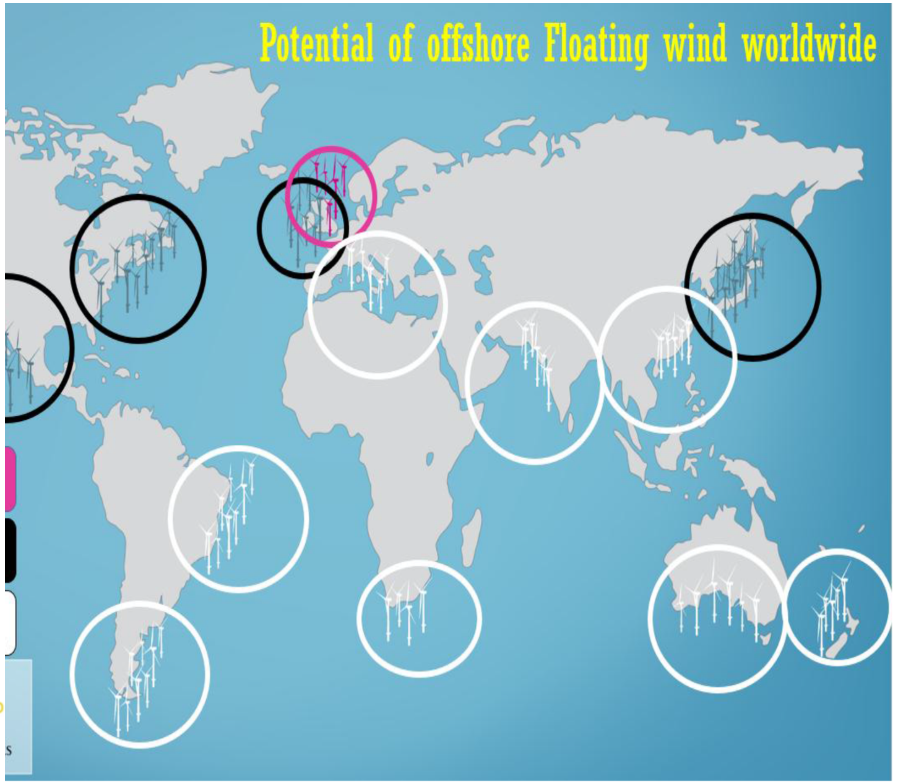


Wind Energy Research-Current Status



Source: adapted from EWEA, 2009.





Renew. Energy Environ. Sustain., 5 (2020) 7

Storage as enabler for Solar

Why Renewable Energy

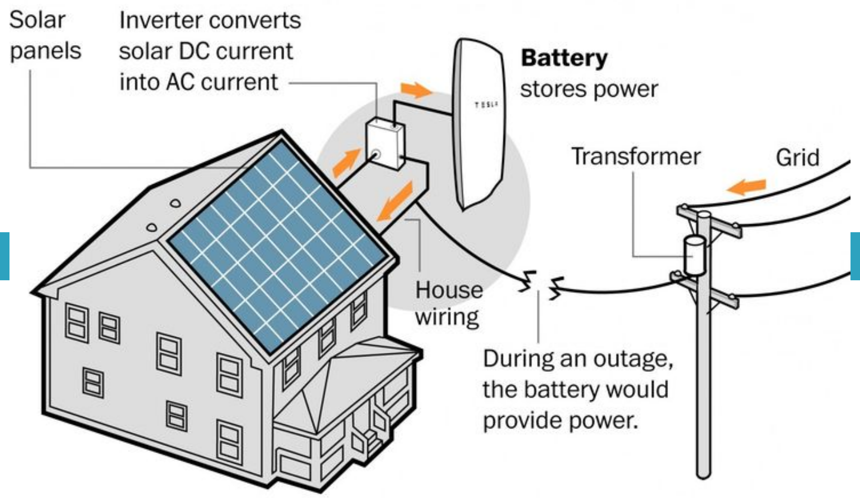
- With sanctions being laid on Coal usage the government has called for more renewable energy usage
- Abundantly available resources
- No carbon footprint

Issues with Renewable Energy

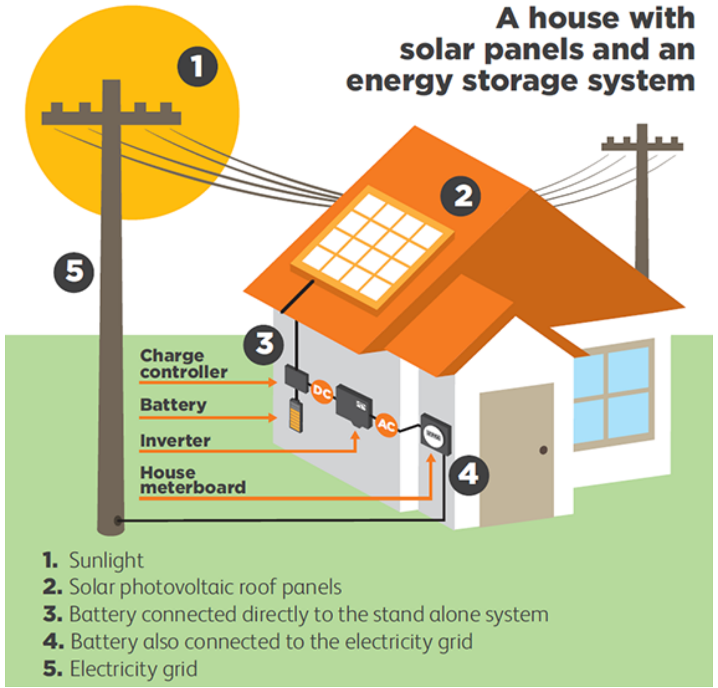
- Intermittency issues like clouding
- Shortage in solar generation can cause stress on the grid
- Lower power generation capacity than fossil fuels
- Low efficiency as compared to coal

Need for Energy Storage

- Power outages
- Energy bank to compensate when renewable energy is unavailable
- Peaking shaving
- Highly efficient systems
- Grid stabilization (balance between energy supply and demand)



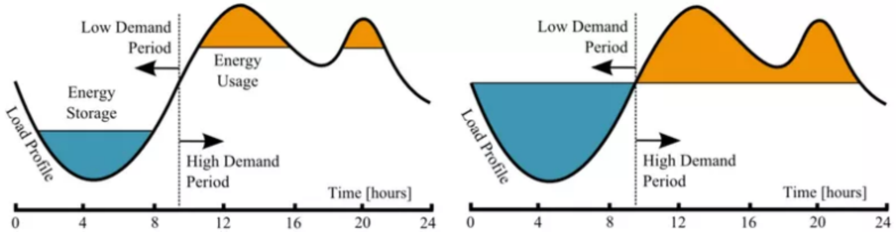
Sources: SolarCity, Tesla, U.S. Energy Information Administration, staff reports
THE WASHINGTON POST



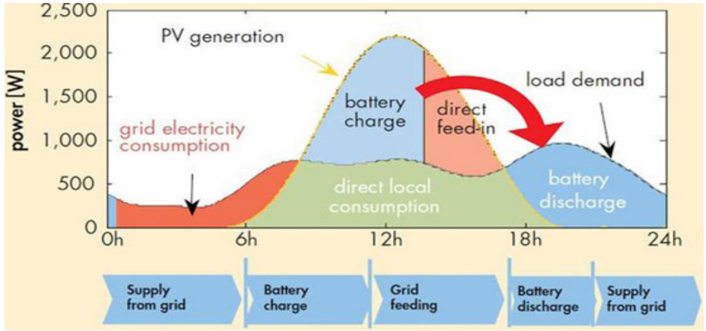
Energy storage application in Solar PV Plant

Energy storage application	Description
Peak shaving	Fast Moving clouds and Partial shading results in power Fluctuations. This creates voltage instability at the PoC. BESS with Peak Shaving shaves off the power fluctuations due to solar by absorbing/ releasing energy at required ramp rates.
Time shifting	Charging BESS during Solar hours, Utilizing this energy whenever required for longer duration discharges. Hence reducing the demand on Utility.
Frequency regulation	Maintaining frequency at PoC within the tolerance limits (±5%) by injecting controlled power through BESS

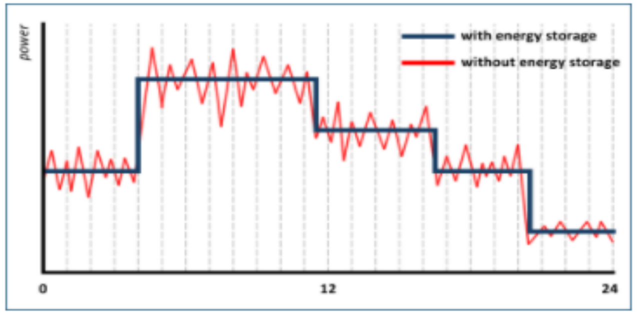
Peak shaving



Time shifting



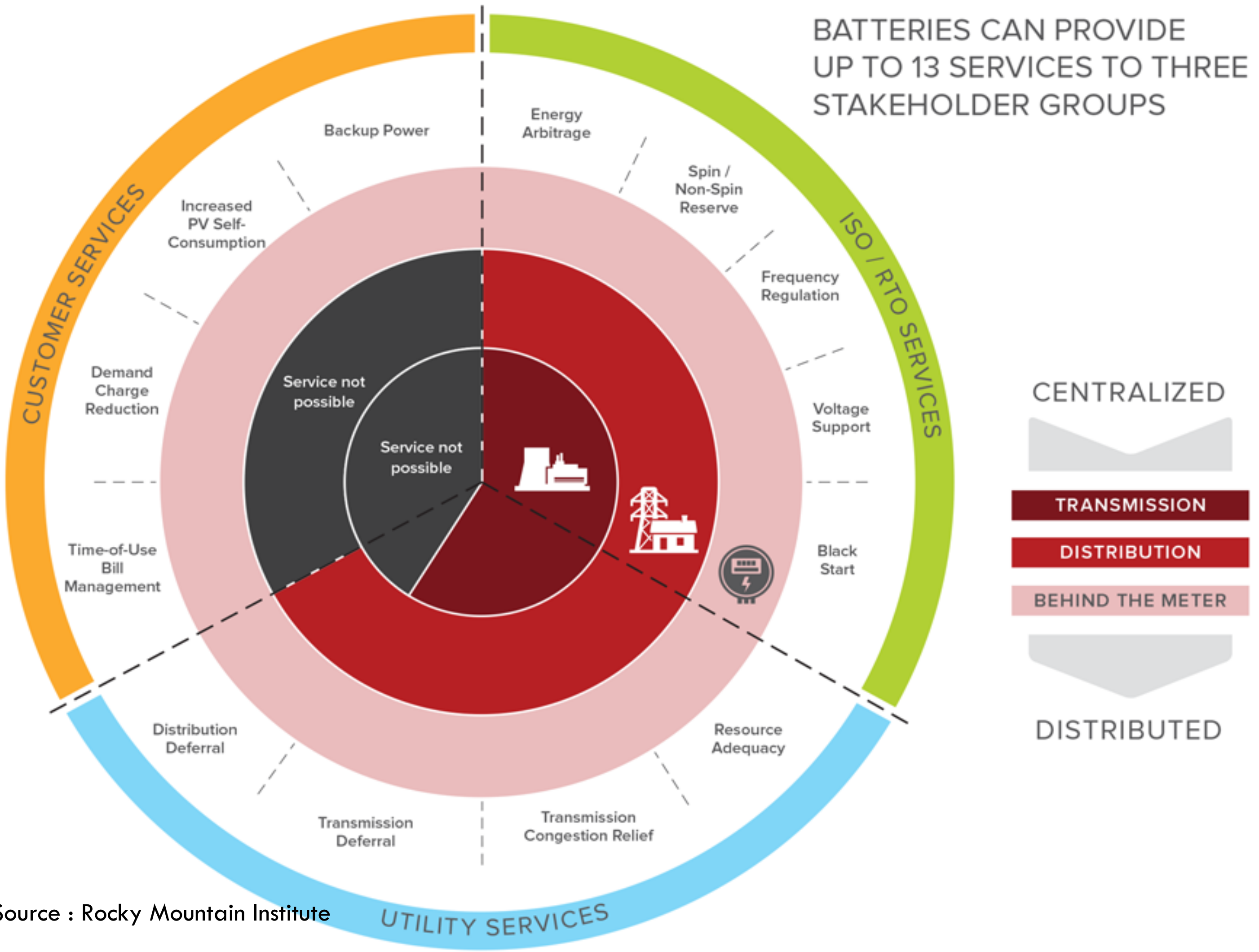
Frequency regulation



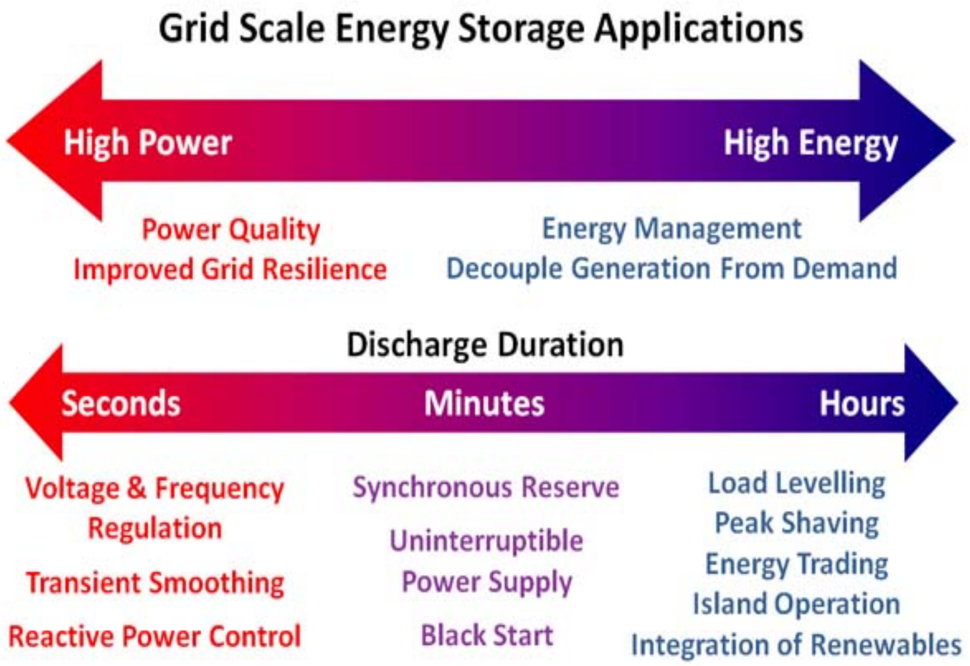
Why Energy Storage across - World?

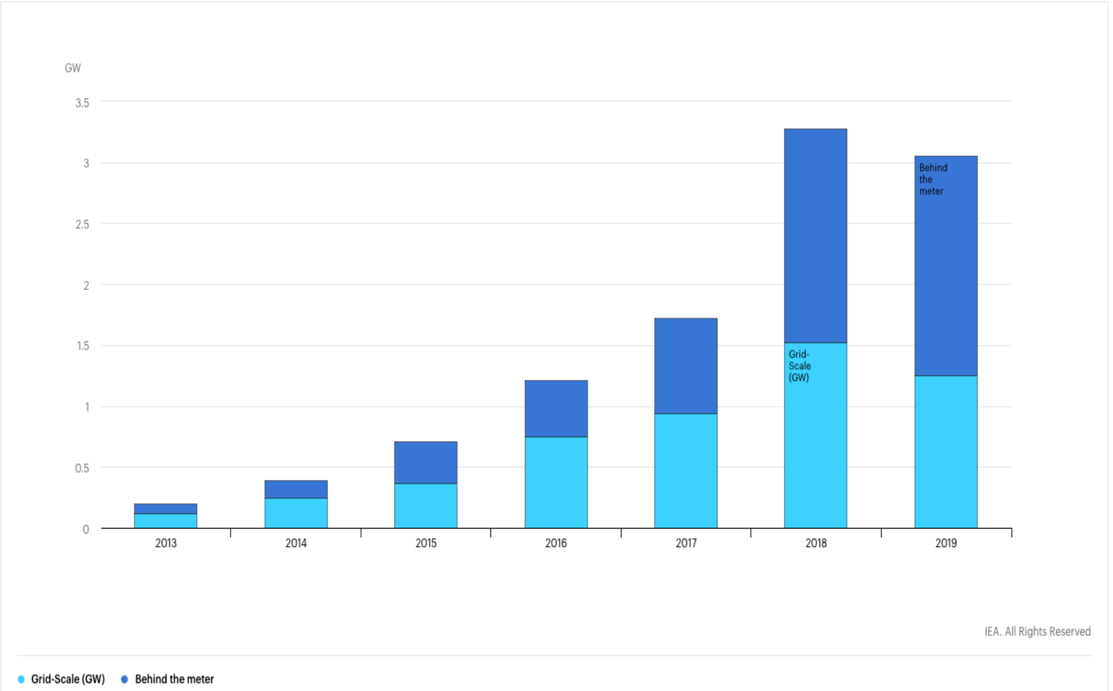
- **Reliability:**
  - Load Management - By 2040 there could be up to 500 million electric vehicles (EVs) globally, this will transform the way we consume and interact with energy and will have a drastic impact on domestic and global energy networks.
- **Dependency:**
  - energy storage can help to address the intermittency of solar and wind power
  - Installing and maintaining renewable energy resources can be viewed as an “essential service”, according to the California Solar + Storage Association (CALSSA)
  - After bushfires, batteries seen as wise investment in Australia
- **Reducing Cost:**
  - Due to reduction of Manufacturing cost and Due to exponential scale up of Manufacturing driven by Electric Vehicle Market
  - BNEF predicts that prices for lithium-ion batteries may fall as low as $73/kWh in 2030, which could open up the market to other revenue streams.
  - The US Department of Energy (DOE) has announced an interim price target of $125/kWh by 2020

Applications of BESS

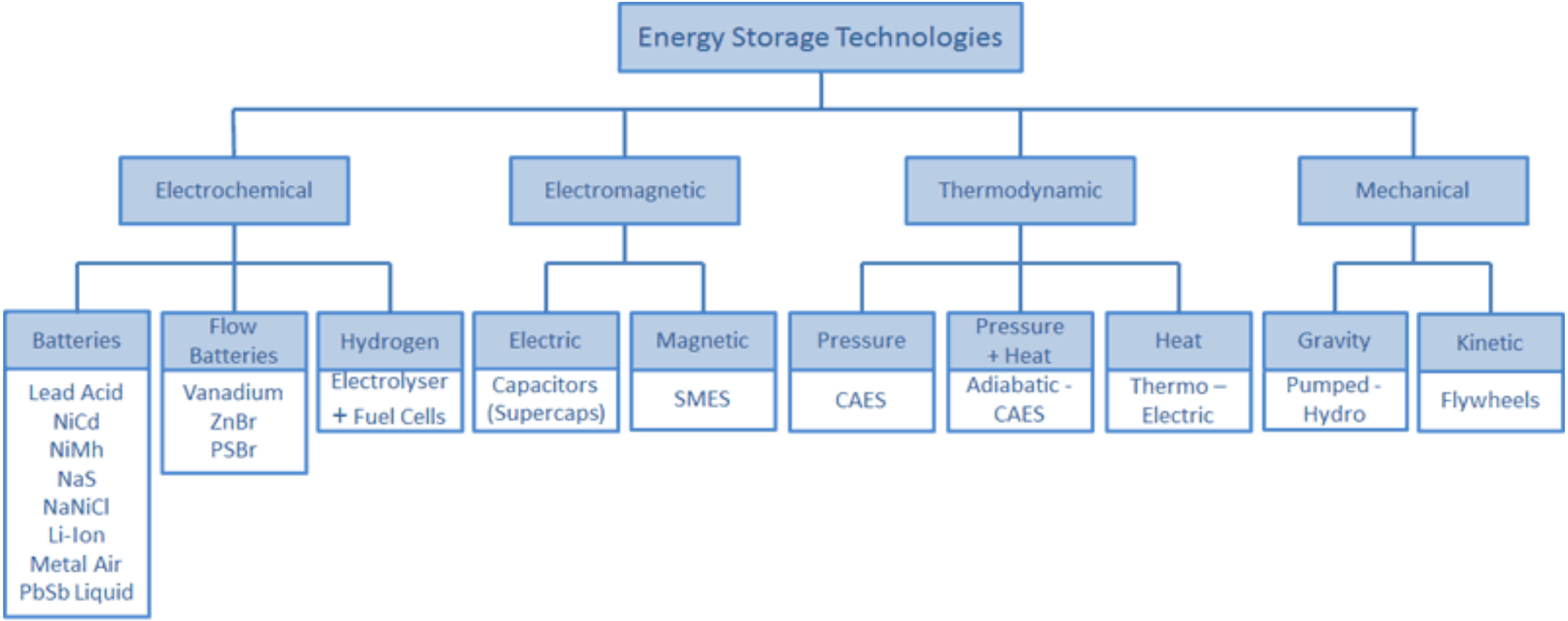


Source : Rocky Mountain Institute





Energy Storage Technologies



IS LITHIUM THE NEW OIL?

Shifting of RE is happening in record base and Lithium is the core of the shift

- The way the lithium industry is booming –similar to the Oil boom
- Lithium required complicated extraction refinery-similar to Oil refinery
- Lithium is shaping geopolitics-like Oil
- Lithium ion battery is driving cars like Gasoline

So the question is lithium is the new Oil and will end the dependance of Oil on earth?

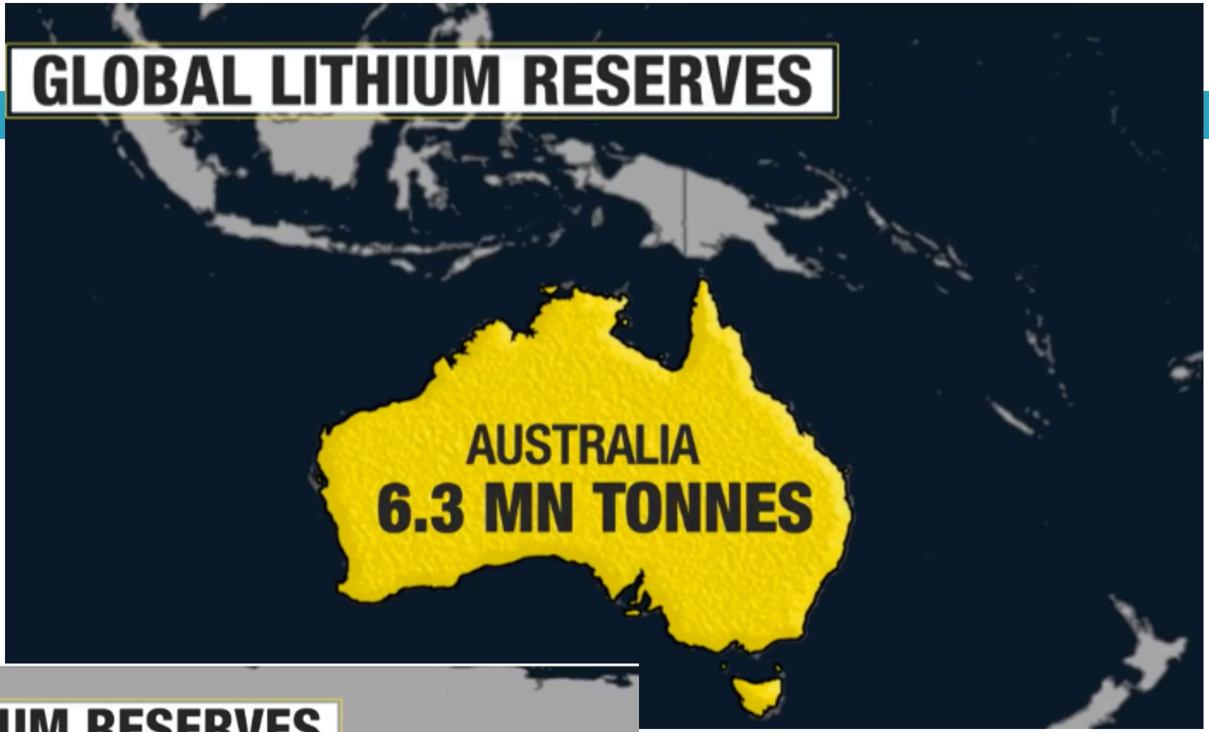
About Lithium

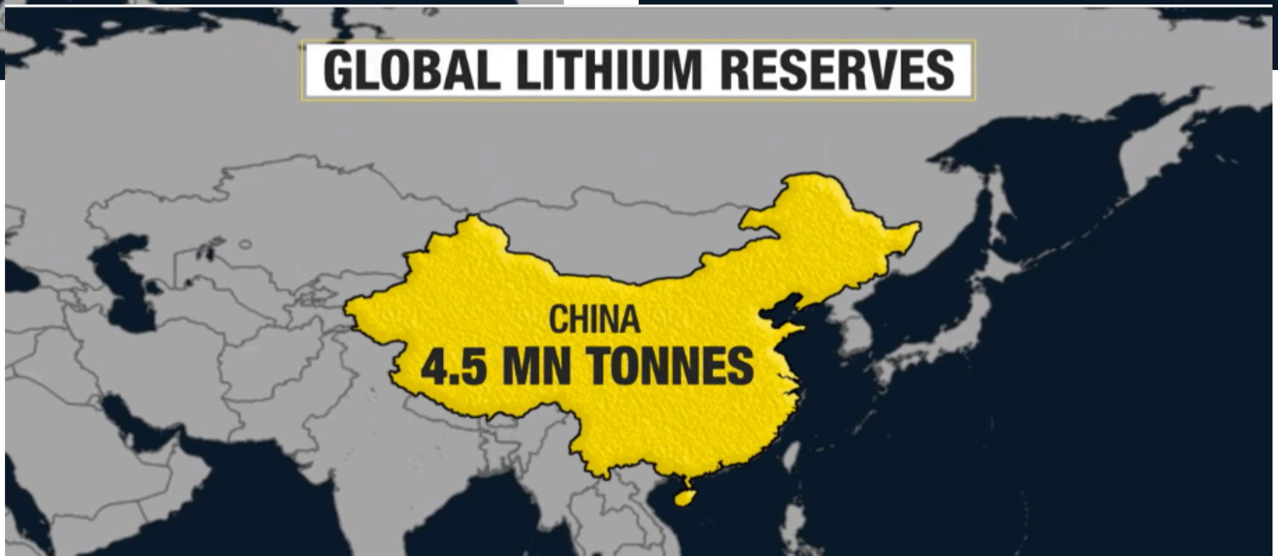
- It is lightest metal on earth and lowest density of all metals (2 times than that of water)
- Lithium was discovered in 1817 by Johann Arfvedson (Swedish Chemist)
- Multiple uses (rechargeable Lithium ion battery, Li2O used in special glasses, Lithium stearate is used as Temperature lubricant, LiH is used as a Fuel, LiCl is used in drag)

Lithium availability in Lithium Triangle

Ref: WiON.com

Other Parts of the World





Ref: WiON.com

Road Map of India in Hybrid Energy Storage: the ESS requirement based on estimated penetration of solar PV (both ground mounted and rooftop) likely to be connected to the MV and LV grid

Estimates	2018-19	2022	2027	2032
Generation (GW)				
Thermal	226	NA	NA	NA
Hydro	45	NA	NA	NA
Nuclear	6.7	NA	NA	NA
Solar	26	109	251	359
Ground Mounted Solar	25	69	151	210
RTPV	1	40	100	149
Connected to EHV	15	41	91	126
Connected to MV	10	28	60	84
Connected to LV	1	40	100	149
Wind	35	NA	NA	NA
Small Hydro	4.5	NA	NA	NA
Biomass & Biopower	9.2	NA	NA	NA
Peak Load (GW)	192	333	401	542
Energy (BUs)				
Annual Energy Requirements	1192	1905	2710	3710
Storage Recommended (MWh)				
Battery for LV Grid	209	6000	15220	22294
Battery for MV Grid	1050	3645	8793	12095
Total Storage (MWh)	**1,259**	**9,645**	**24,013**	**34,389**

Source: IRENA

Key Consideration:

- Peak Load and Annual Energy Requirements are taken from CEA Estimates (18th Electric Power Survey).
- RE target of 175 GW by 2022, and 300 GW by 2030, the calculations were done on the basis of 100 GW Solar, out of which 40 GW is RTPV, 20 GW is medium size installations and 40 GW is from large solar parks.

Energy storage pilot project plan overview

- **Grid support for greater renewable integration:**
- Expected that another 33 GW capacity of RE will be added by 2017
- This project is being carried out to find suitable battery technologies for grid scale storage system in India (project location-Puducherry, IN)

Project Overview: 3 pilot projects (1.5 MW)

- supply, installation, testing and commissioning of battery storage systems using (Advanced lead acid, Lithium ion, Flow battery, others)
- **Storage size:** 250 kWh, 500 Wh
- **Primary application:** frequency regulation

Application of BESS in Solar Domain

❖ Utility scale ground mount / grid connected SPV Power plant:

PV Smoothening/ capacity firming

RTC: Round the clock application

hybrid source integration:

- Solar+wind+BESS (Virtual Grid / concentrated)
- Solar+Thermal+BESS
- Floating Solar+BESS
- Solar+DG/GAS PP+BESS

❖ Off-grid Solar Applications:

- Micro grids
- C&I segment
- Rooftop – residential storage

❖ EV Charging Infra & V2G:

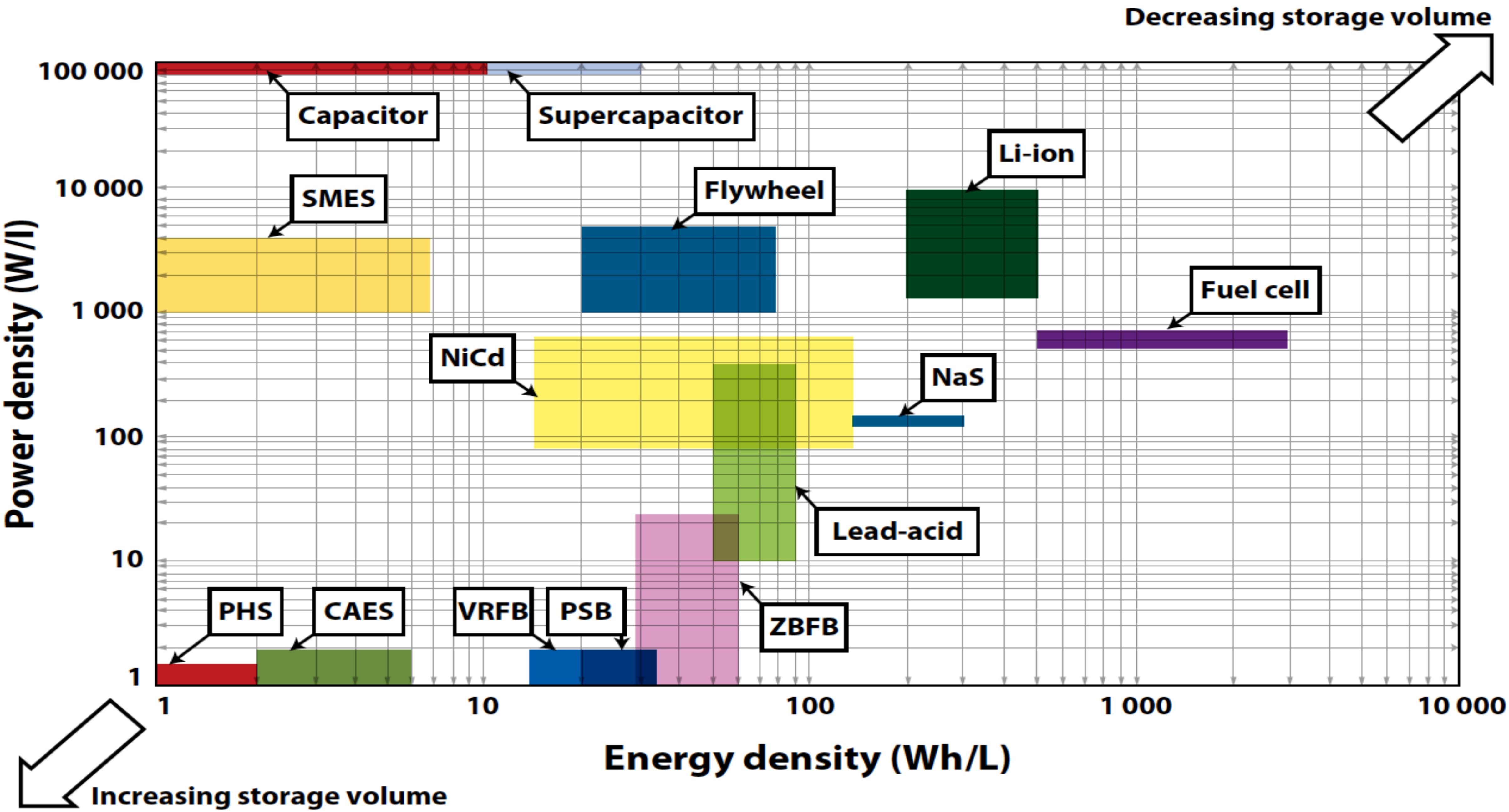
- Hybrid solar EV charging stations
- Solar carports with V2G Concepts

Battery sizing principles

- Battery sizing is determined on the basis of following performance requirements / parameters:

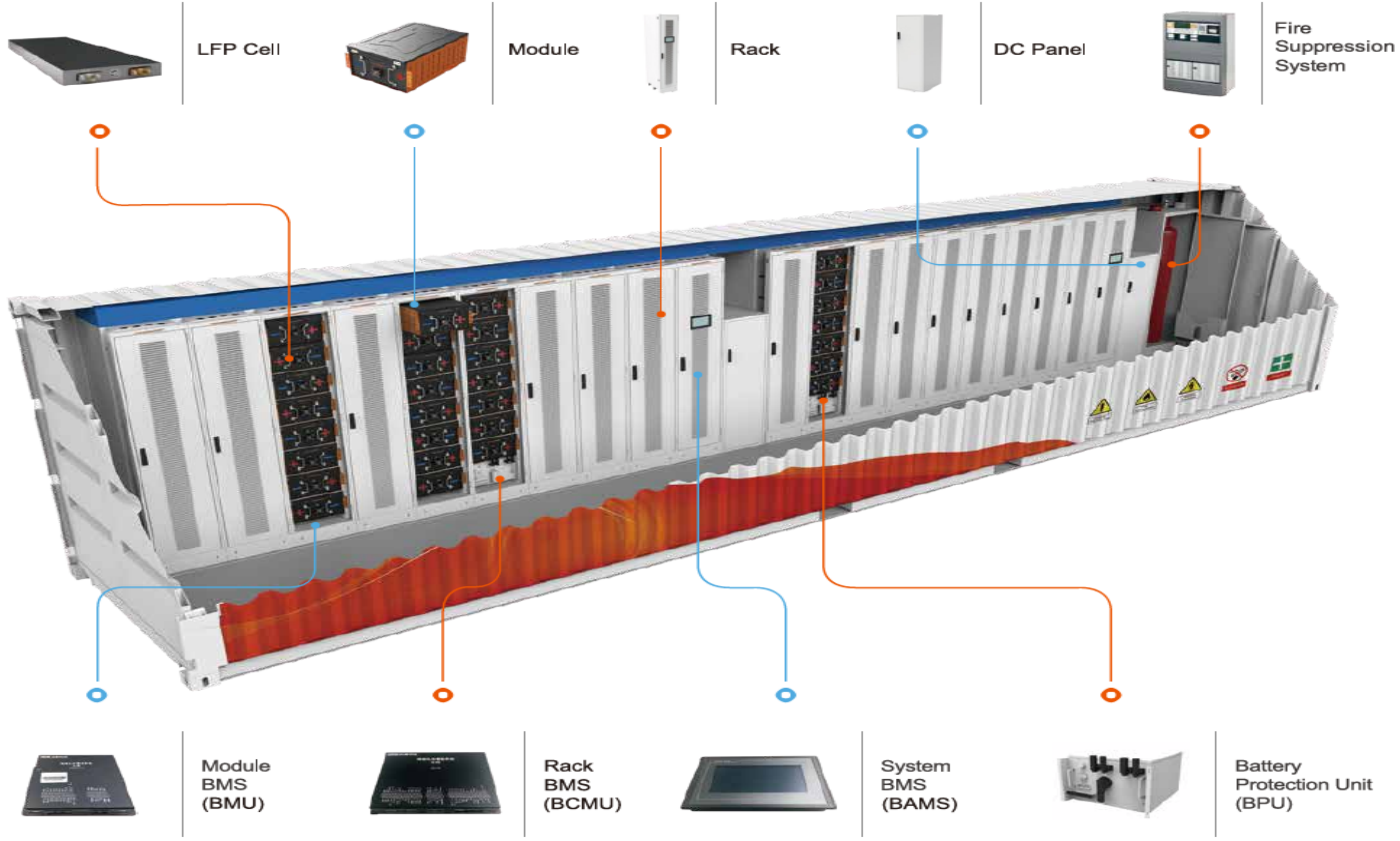
  - System round trip efficiency
  - Battery energy efficiency
  - SOC/DOD requirement of application
  - Power/C-rate requirement of application
  - Expected life of application and degradation rate of battery used

- Based on these parameters, battery bank needs to be oversized to achieve all performance requirements
- Commercial comparison of different types of batteries comes in once the battery bank is sized for different chemistries



Source: Luo *et al.*, 2015.
Note: SMES = superconducting magnetic energy storage; NiCd = nickel cadmium; NaS = sodium sulphur; PHS = pumped hydro storage; CAES = compressed air energy storage; VRFB = vanadium redox flow battery; PSB= polysulfide bromine flow battery; ZBFB = zinc bromine flow battery.

Cell->Module->Rack Conversion-> BESS



- Single or Multiple Battery Racks along with other auxiliary components are assembled into an outdoor container to Build a large containerized BESS

Performance Indicators of Li-Ion Batteries

Following are the top performance indicators of Lithium Ion Batteries numbered in order of their importance in Energy Storage Applications.

1. **Cycle Life** : Cycle life indicates the number of charge/discharge cycles the battery can withstand before it permanently degrades below 80% of original design capacity. Cycle life gets affected by several factors like Charge/discharge Rate, operating temperature, Storage SOC.
2. **C-Rate** : C Rate directly indicates the output power limit that the battery can support.
3. **Thermal Performance:** Intrinsic heating of cells during charge/discharge, Highest & Lowest temperature that cells can withstand without considerable degradation in other performance indicators.
4. **DOD**: Depth of Discharge. The battery must support higher DOD without affecting the cycle life adversely.
5. **Energy & Power Density**: Depending on the application, a higher energy density or a higher power density cell and battery are selected.
6. **Self Discharge Rate** : This indicates charge holding capacity of the battery.
7. **Efficiency**

Factors to be considered for battery selection

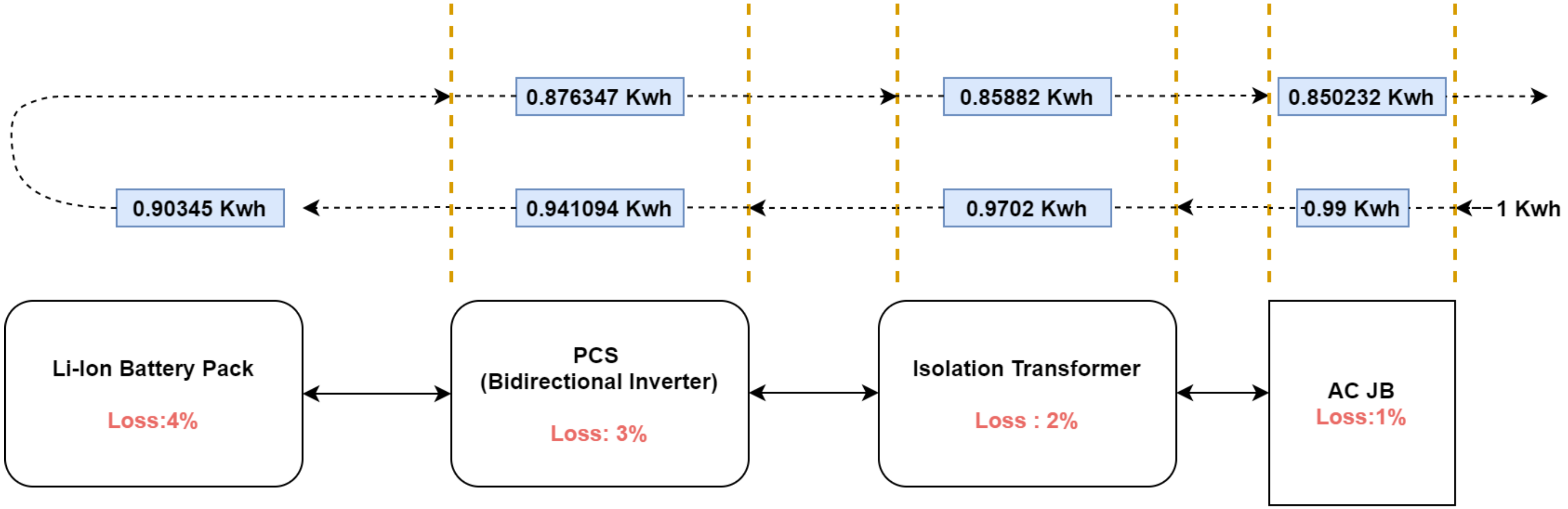
- Technical specifications
- Budget
- Size and weight
- Project life span (Charge cycles)
- Charger cost (PCS)
- Maintenance / warranties
- Ease of availability of base raw material

- **Certifications:**

- IEC TC 21: Secondary cells
- IEC SC 8A: Grid Integration of Renewable Energy Generation
- IEC TC 59 WG 15:Connection of household appliances to smart grids and appliance interaction
- IEC TC 120: Electrical Energy Storage (EES) Systems
- BIS Certification Marking (currently only for Lead acid batteries)
- BIS certifications are still evolving for technologies for large scale grid storage
- All international standards have corresponding BIS codes

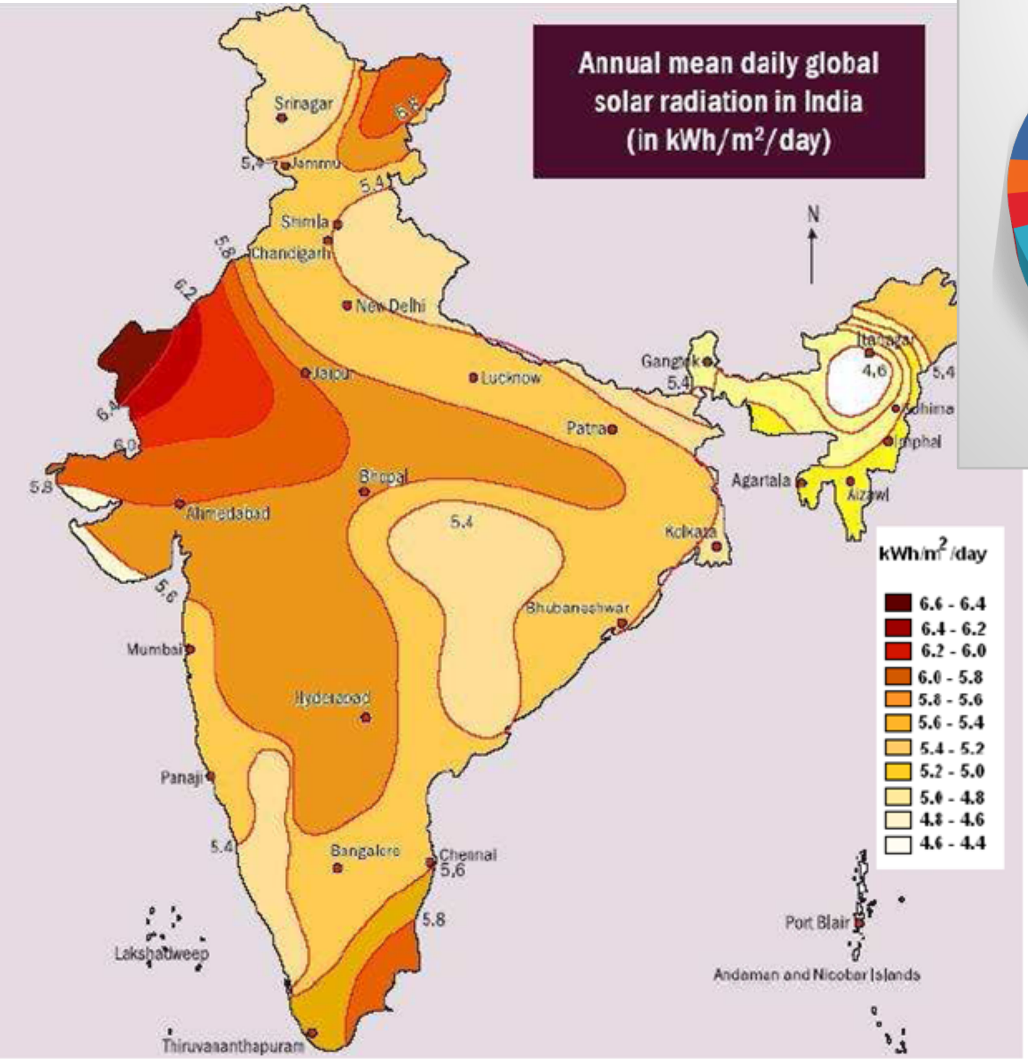
Round Trip Efficiency

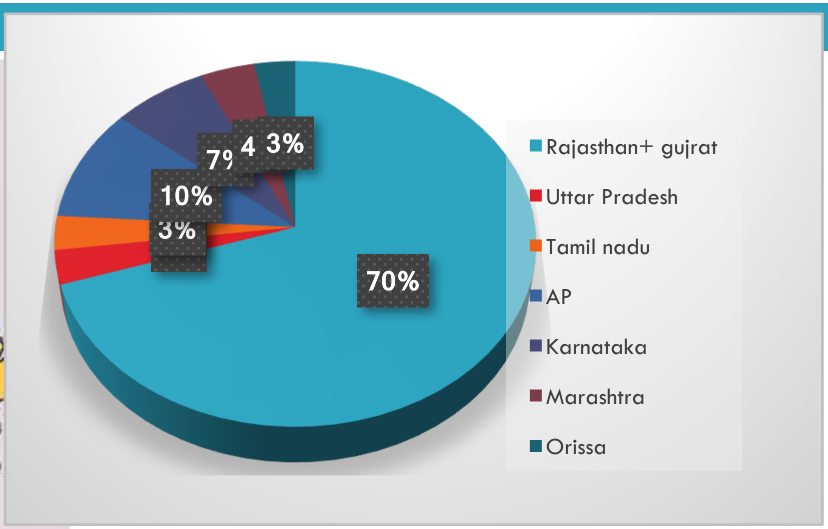
Round Trip Efficiency (RTE) indicate the efficiency of BESS system as a whole while in use as an Energy Storage system. In the example given below, when 1 Unit or 1 Kwh energy is stored into the system, only 0.85 Kwh can be extracted out of it. The remaining 0.15 Kwh is lost in in-efficiencies and losses. The measure of inefficiency and losses differ system to system.

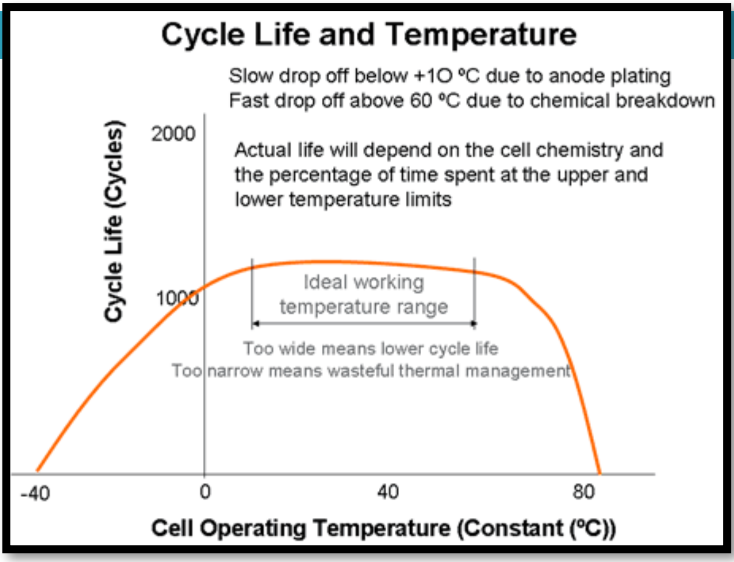


Total Round Trip Efficiency = ~85%

Solar PV installation-location and Storage

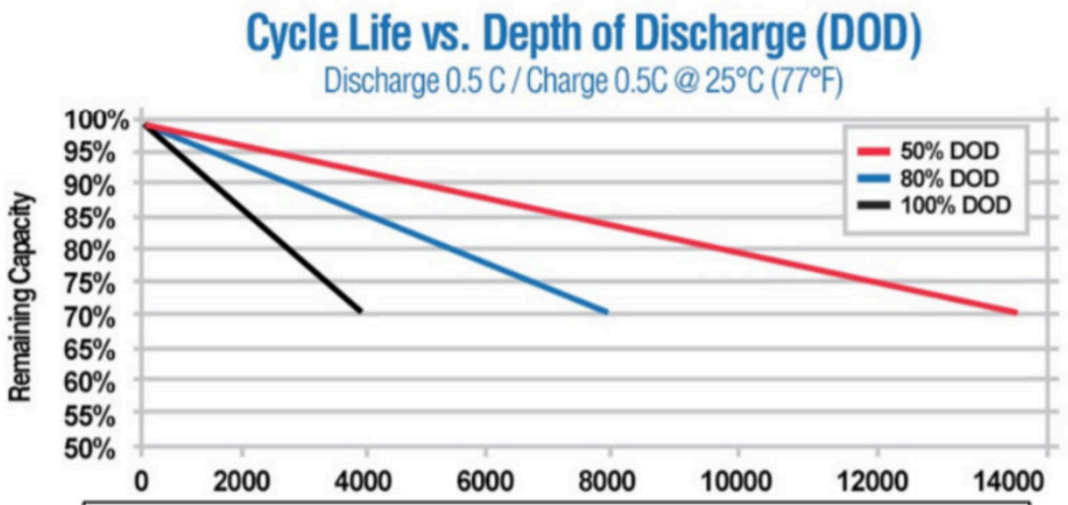


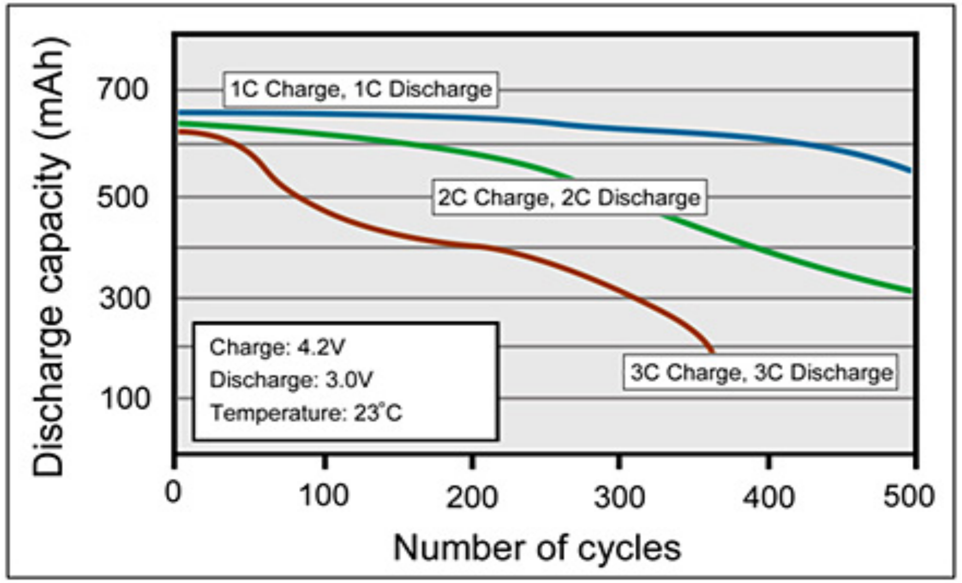


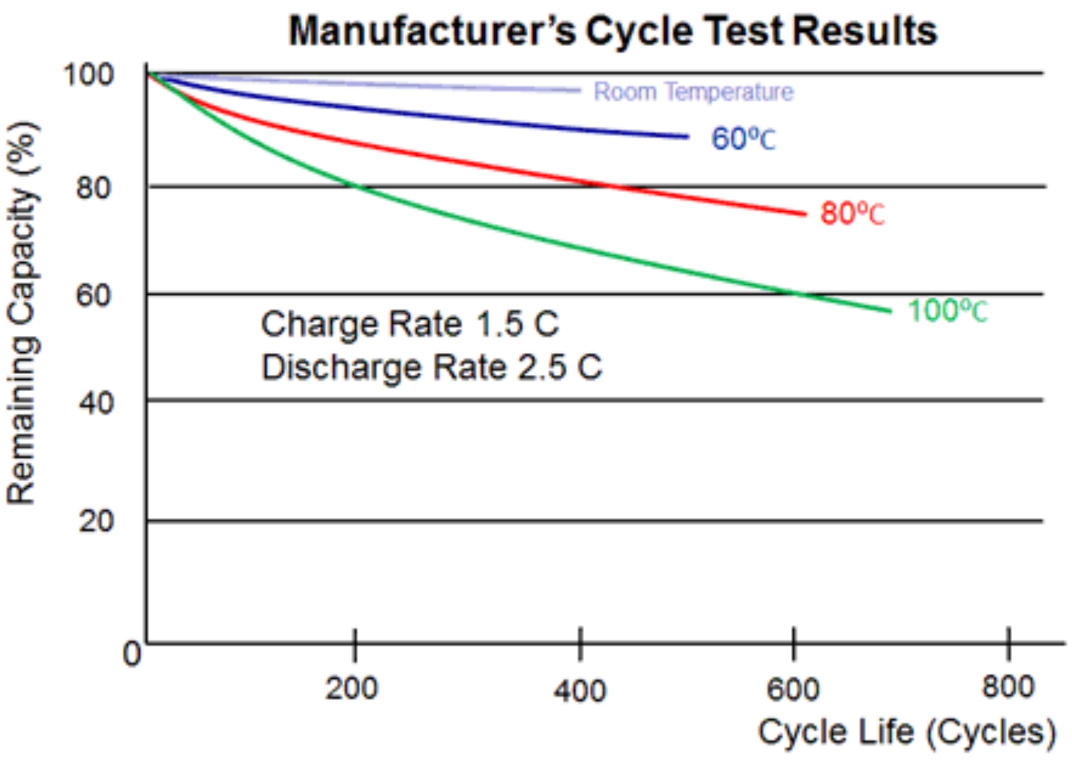


Month	Max temp	Min temp	max	Min	Average temp
January	22.6	4.5	37.7	4.5	29
February	25.8	9.6			
March	33.9	15.7			
April	37.7	22			
May	41.8	27.1	43.7	26.8	36
June	43.7	29.3			
July	38.4	28.1			
August	36.5	26.8			
September	36.7	25.2	36.7	5.4	28
October	35.8	20			
November	30.4	12.4			
December	24.7	5.4			

Cycle Life Dependence







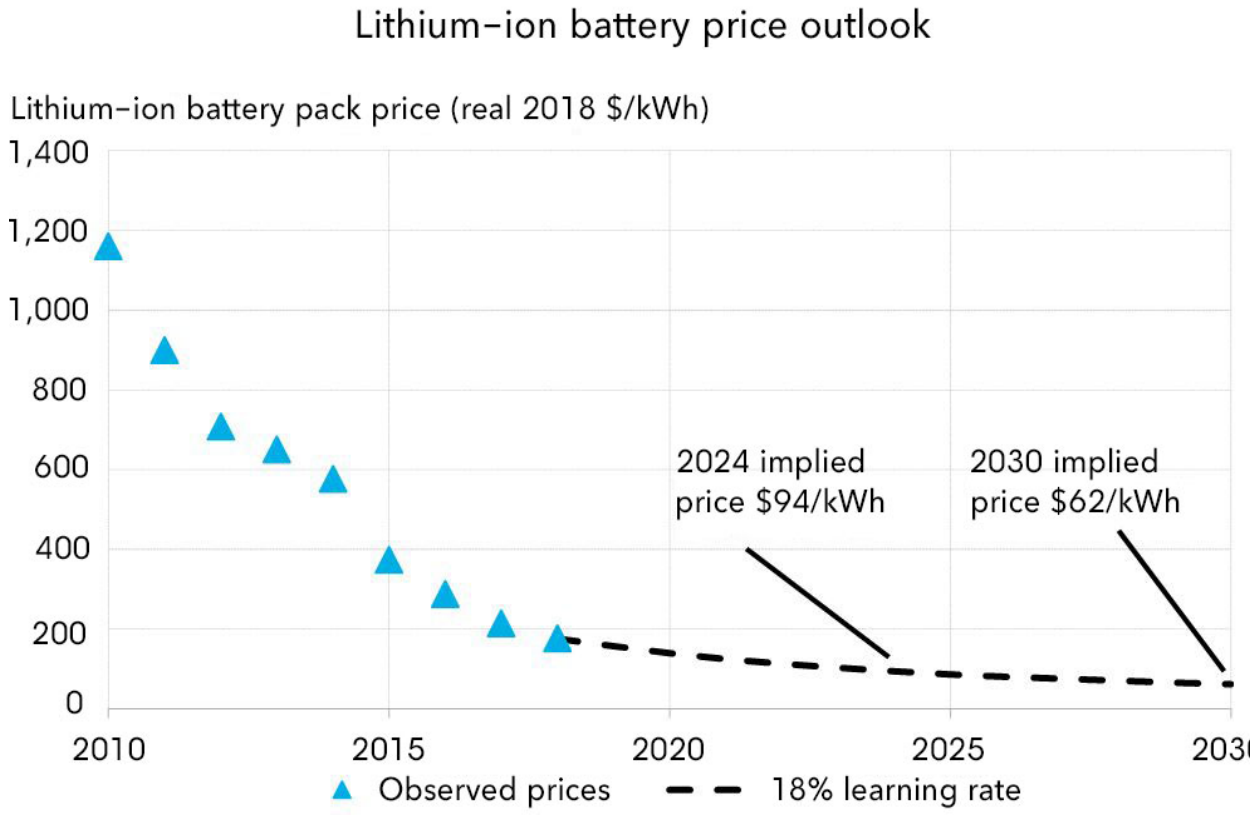
These are example graphs from different cells and there is no correlation of these graphs with each other. Please refer to them only for correlating the effect of temperature, C-Rate and DOD on battery cycle life.

Types of Li-Ion Chemistry

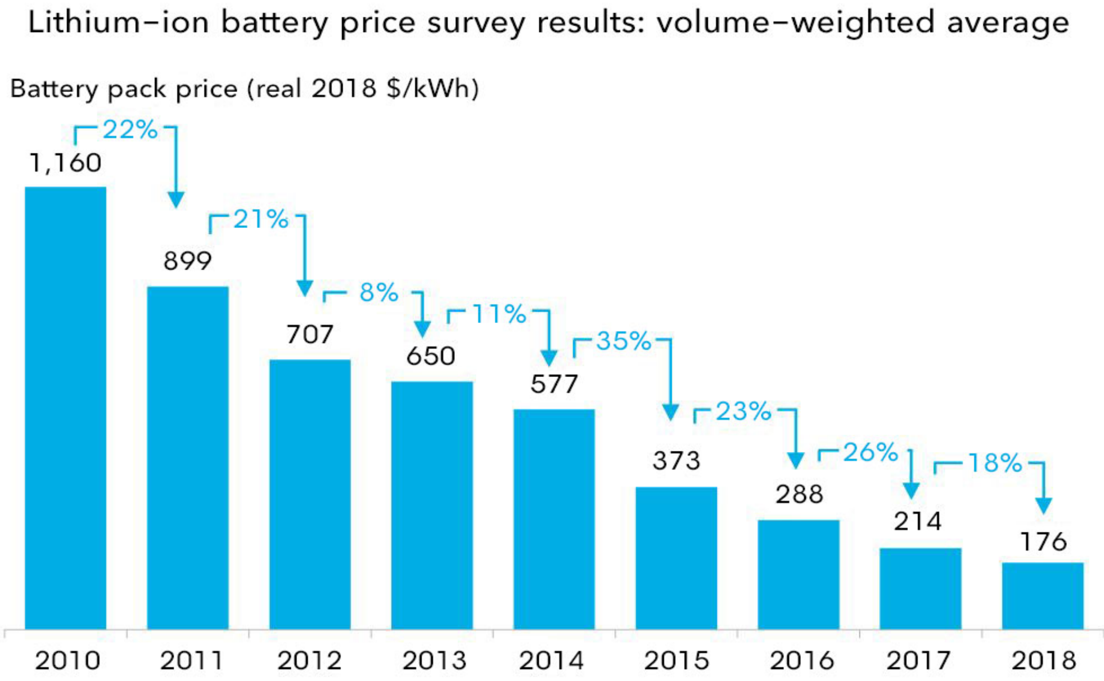
Common Name	Cathode	Anode	C-Rate (C|D)	Cycle Life	Specific Energy (Wh/Kg)	Cell Votlage (V)	Specialty / Application
LCO (Li Cobalt Oxide)	$LiCoO_2$	Graphite	0.7 to 1 | 1	500-1000	150-240	3.6 (3-4.2)	High specific energy, It's an Energy Cell. Fit for portable electronics.
LMO (Li Manganese Oxide)	$LiMn_2O_4$	Graphite	0.7 to 1 | 1-10C,30C pulse	300-700	100-150	3.7 (3-4.2)	High Power, Less capacity. Used in Power tools
NMC (Li Nickel Manganese Cobalt Oxide)	$LiNiMnCoO_2$	Graphite	0.7 to 1 | 1-20C	1000-3000	150-220	3.6 (3-4.2)	Best suited for Electric Vehicle due to good balance of Energy density and power density
LFP (Li Iron Phosphate)	$LiFePO_4$	Graphite	1 | 1-5	2000-4000	90-120	3.2 (2.5 – 3.65)	One of the safest Chemistry, Flat discharge curve. Best suited for Energy Storage Applications.
NCA (Li Nickel Cobalt Aluminum Oxide)	$LiNiCoAlO_2$	Graphite	0.7 | 1	500-1000	200-260	3.6 (3-4.2)	Used in Electric cars owing to it's high energy density. Tesla and Panasonic uses it.
LTO (Lithium Titanate)	LMO or NMC	$LiNiCoAlO_2$	1 to 5 | upto 10, some cells go upto 20	7000-12000	50-120	2.4 (1.8-2.85)	Ultra Fast Charge capable and Excellent low temperature operation. Fit for installations in cold climates and urban electric transportation.

*Lot of fundamental research is going on on NMC, LFP, LTO and NCS chemistries for their performance improvement. As a result we often come across datasheets of cells that exceed performance numbers given in above table.

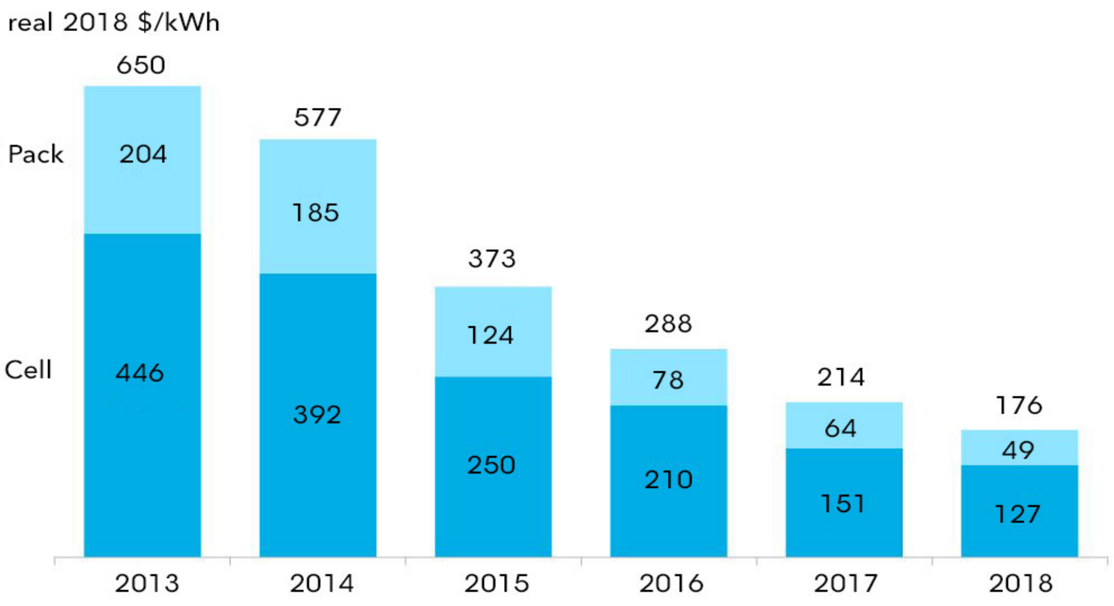
Price Trend (LFP):



Source: BloombergNEF

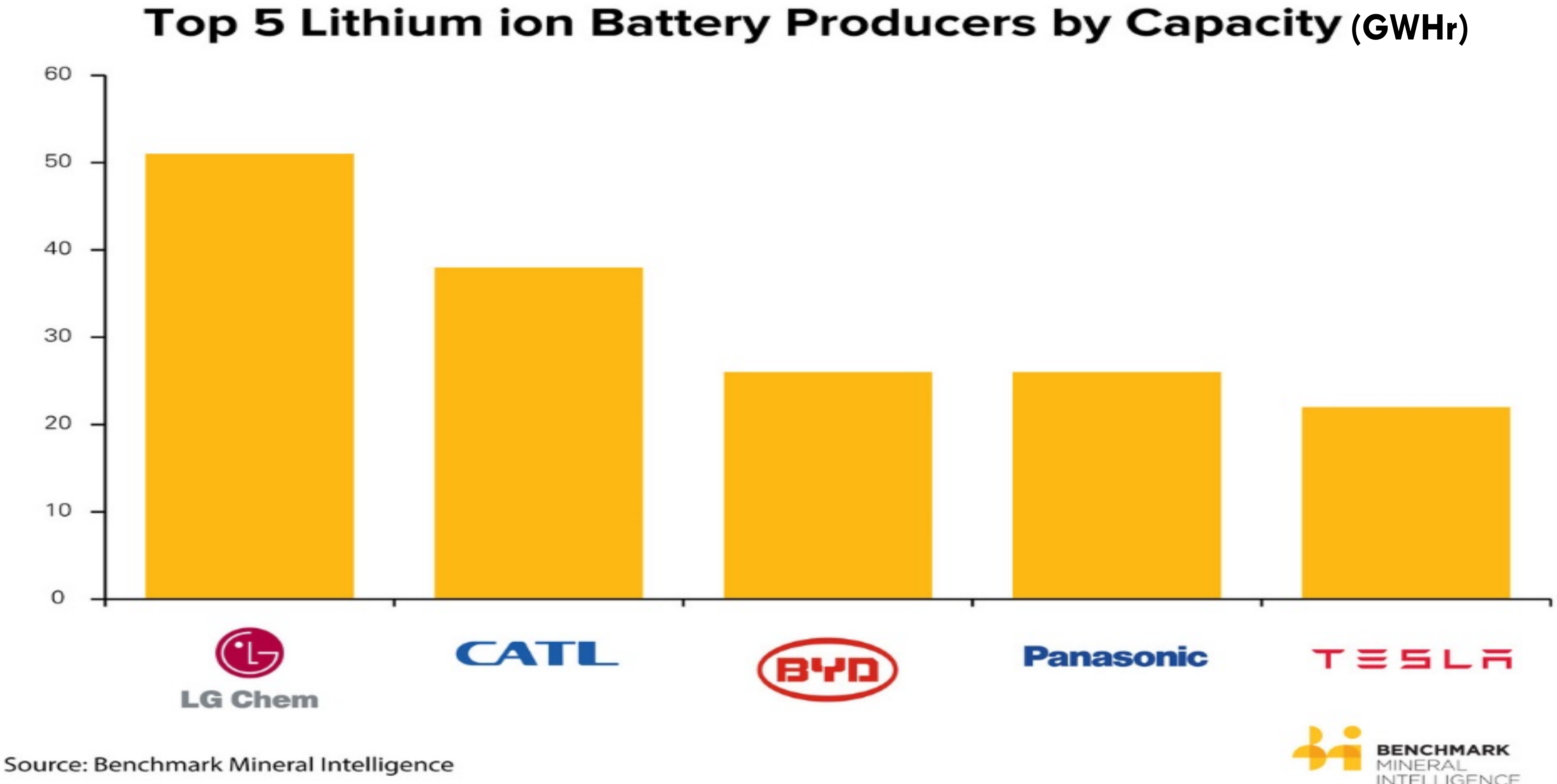


Source: BloombergNEF

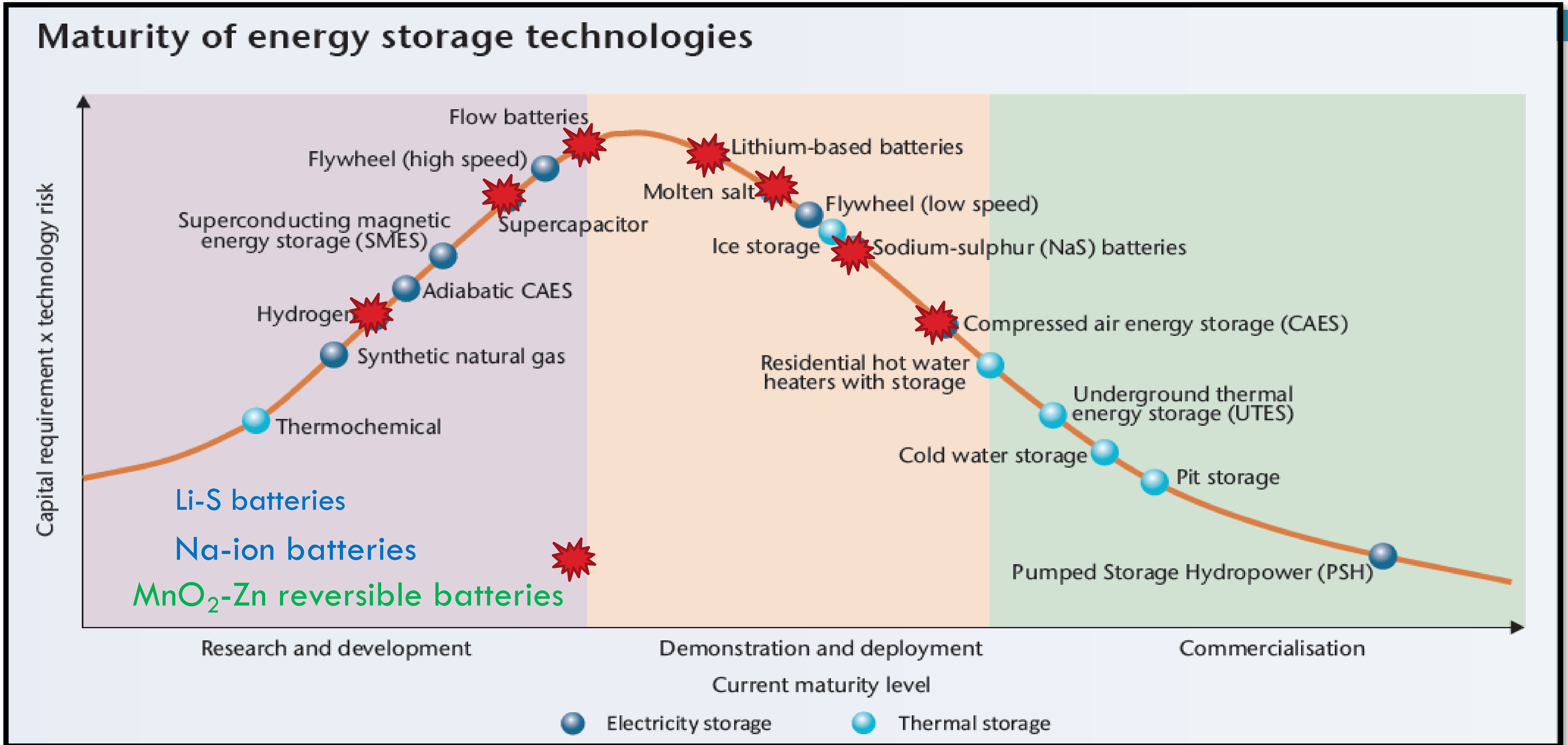


Source: BloombergNEF

Li-ion Battery Producers



Storage Road Map



Summery: battery recommendation w.r.t Use cases

- There are multiple factors in choosing battery type for PV System applications and sometimes a combination of more than one type as well.

Case 1: Residential Storage (Home applications)

- Past: Lead Acid (Pro: cost effective, cons: Very low product life 3-5 Yr)
- Present: LFP (cost effective considering LCOE for Guaranteed life)
- Future: Nickle Metal Hydride / Zn – Air (only for limited applications – one time use)
- Key Advantages of NiMH:
  - High energy density w.r.t Lib (2200mAh vs 1500mAh) Std sizes AAA or AA whereas LFP is dependent upon manufacturers
  - Safer as compared to Lib High DOD

Case 2: Hybrid EV Chargers with Solar & Energy Storage:

- Present: LFP
- Future: LTO/NMC in combination with Super Capacitor
- Key consideration:
- Slow charging from solar whereas fast discharge required – NMC (3W-EV'S OR Passenger Cars)
- Sow charging from Solar whereas ultra fast discharge required (E-BUSES) – LTO + Super Cap.

Utility Scale Solar Power Plants

- **>500 MW Size SPV Plant – Standalone:**

□Case 1: Key application as Energy time shift: Flow batteries

- Better LCOE in comparison with LI-Ion Batteries
- Longer cycle life
- Power capacity decoupling
- Avg. RTE
- Low maintenance in long term

- **<500MW Size Plant – Li-Ion Batteries:**

□Case 2: Hybrid project in high altitudes (Leh / Siachin):

□Factors considered for BESS Selection:

□Light wt. - Transportation

□Low temp. application

□Long duty cycles

□Preferably avg. power densities

□Battery Considered: LTO

- **<500 MW Size SPV Plant:**

Case 3: Key application as PV Smoothening:

- Battery proposed: NMC
- High discharge in short span required (high C rate)
- Second option: LFP with oversizing considering cost advantage if C rate is not exceptionally high

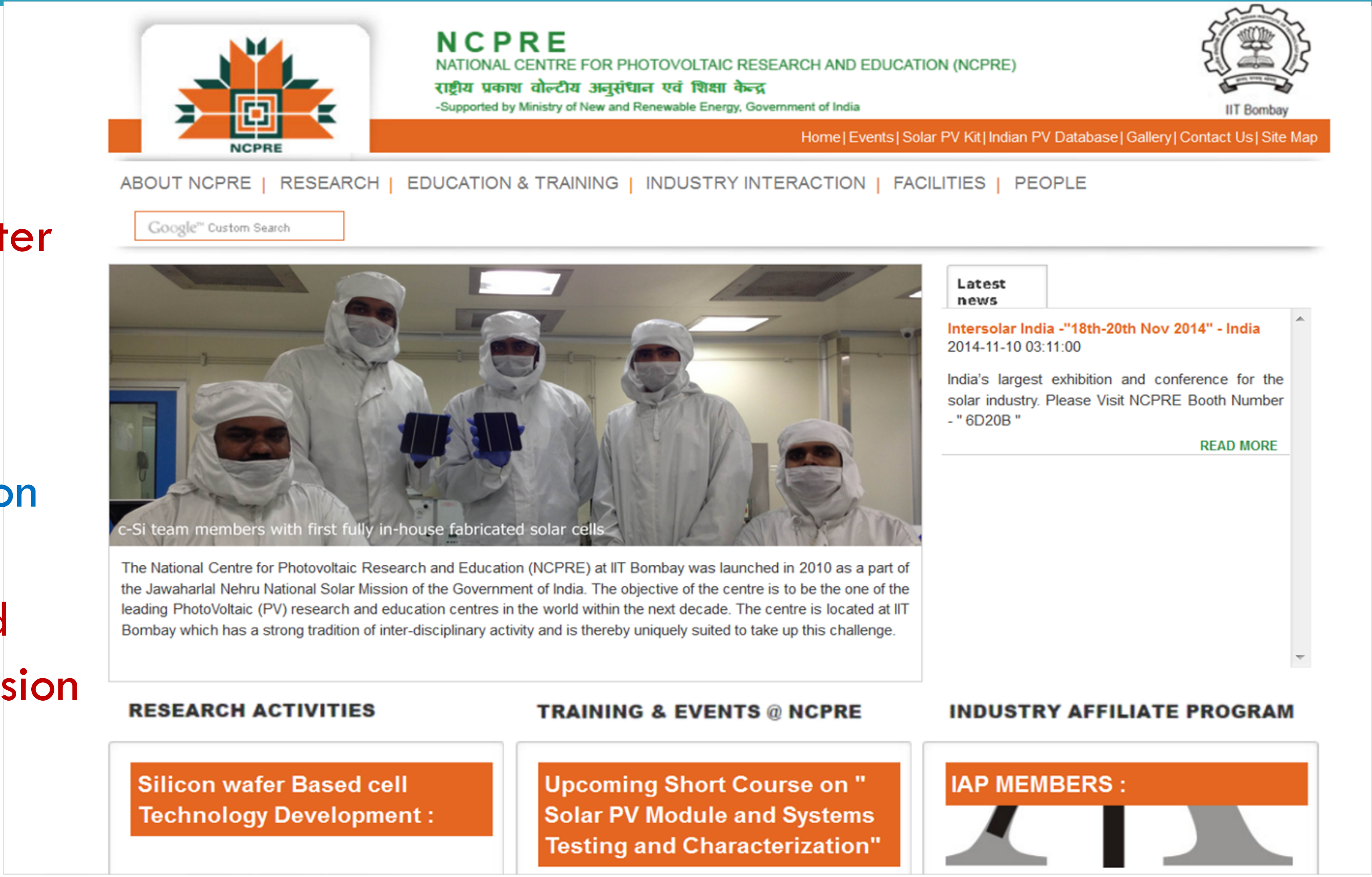
- **Other factors influencing decision on battery selection**

- Supply demand gap – NMC is available with premium cost wrt LFP for energy storage applications as the primary customers are EV industry
- Regional factors – raw material avalibility: China propose LFP for Energy storage whereas Korean companies such as LG Chem/ Samsung sdi proposes NMC.
- Battery life: augmentation vs oversizing
- Cost competitiveness etc.

□ **Selection of battery depends on multiple factors life, cost, C rate, DOD, temperature, altitudes, supply chain, logistical issues, Sizes, mobile vs standalone applications and combination of more than one constraints.**

National Centre for Solar Photovoltaic Research and Education (NCPRE) (110 Cr, for 2010-2015 and 2016-2021)

- ❑ developing technology for 20 % efficiency Silicon solar cell
- ❑ cost effective solution for inverter Technology
- ❑ developing lost cost energy Storage solution and demonstration
- ❑ development of new advanced Materials for solar energy conversion
- ❑ training manpower for RE development



SM Group Research

Lithium Storage-Technology-Redefining materials and reinventing technologies

TRANSPORTATION

$100/kWh

400 Wh/kg 400 Wh/L

800 W/kg 800 W/L

5000 cycles

80% DoD C/5

15 yr calendar life

GRID

$100/kWh

95% round-trip efficiency at C/5 rate

7000 cycles C/5

20 yr calendar life

Safety equivalent to a natural gas turbine

Basic Research: Physics and Chemistry of Materials
Modeling and Simulations (need collaboration)

Applied Research: Materials Synthesis and Characterization
Cell Chemistry Optimization

Engineering: Materials Processing for large scale, Cell Fabrication Technology, Cell Modeling and Diagnostics (need collaboration)

Cell and System Evaluation: Performance, Cycle Life, Calendar Life (Need Collaboration)

- Long cycle life low-cost Lib; 300 Wh/kg battery chemistry for Evs; Na-ion based Battery development for Solar Storage; Room temperature Na-S battery; Li-S Battery for EVs

Google images used

Battery Trends: Requirements and Technology

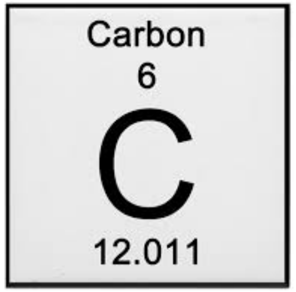
Capacity

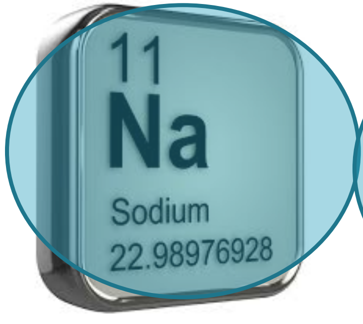
Safety

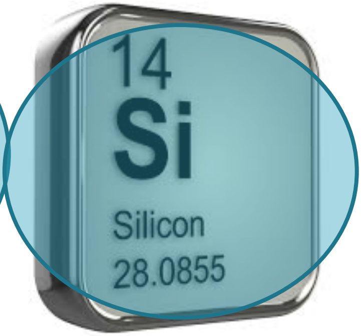
Fast Charge

SUSTAINABILITY INITIATIVE

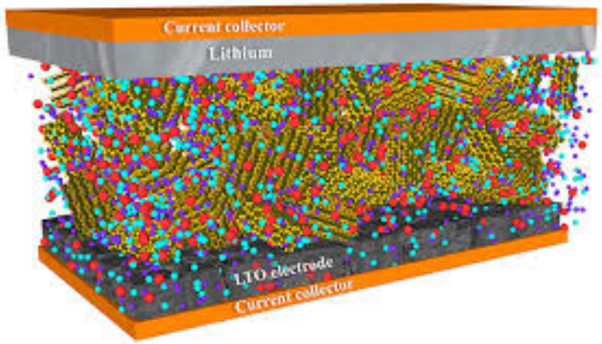
Sustainability

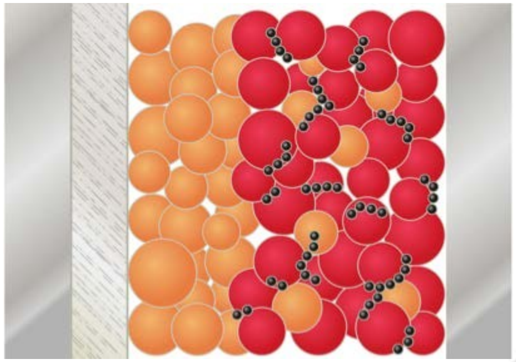




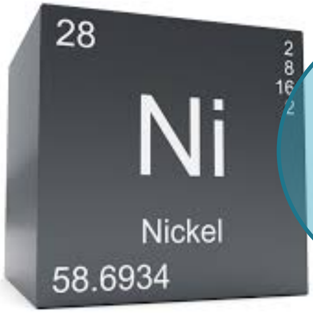


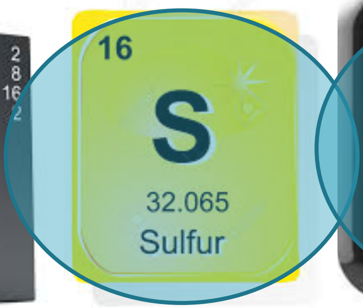
Anode





Electrolyte





Cathode

SM’s Battery Prototype Lab

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Projects we are ON

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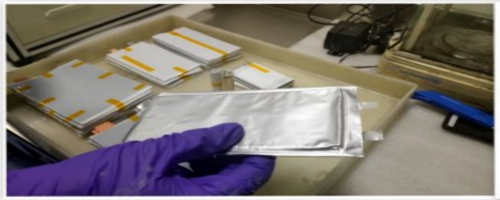
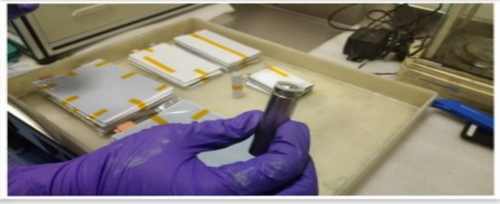
- 300 Wh/kg battery chemistr
- Na-ion based Battery development for Solar Storage
- Li-S Battery for Evs
- Room temperature Na-S battery



Pouch cell : Capacity - 2.5 Ah, 7 Ah and 10 Ah



Cylindrical cell : Capacity - 2.5 Ah

Ultra safe Lithium-ion Batteries- Prof. S Mitra and Prasit Dutta

AIT '18 Winning Moment

1st

➢ Competitive Analysis

Technology transferred to

Virya Batteries Pvt. Ltd. (SINE incuba

Registration No. CIN – U29300MH2018

➢

Lithium-ion battery technology has been in talks in recent years, mostly for safety concerns.

Thanks to

SM group in 2019

- National Centre for solar Photovoltaic Research and Education-MNRE, Govt. India
- Department of Science and Technology, Govt. India
- Industrial collaborations
- Monash University and Shiv Nadar University-collaborations
- IIT Bombay central facilities
- Department of Energy Science and Engineering, IIT Bombay

http://www.ese.iitb.ac.in/faculty/sagar-mitra