Importance of energy and powering aspirational India

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Structure of the talk

- Global issues
- Estimating demand in India and supply options to bring out the role of nuclear.
- Economics – system costs
  - External costs
- Tariff on electricity from nuclear power plants in India
- Options for growth
- Readiness
  - Characteristics of industry
  - Policies; closed fuel cycle
  - Managing waste
- Comparative risks
- Summary

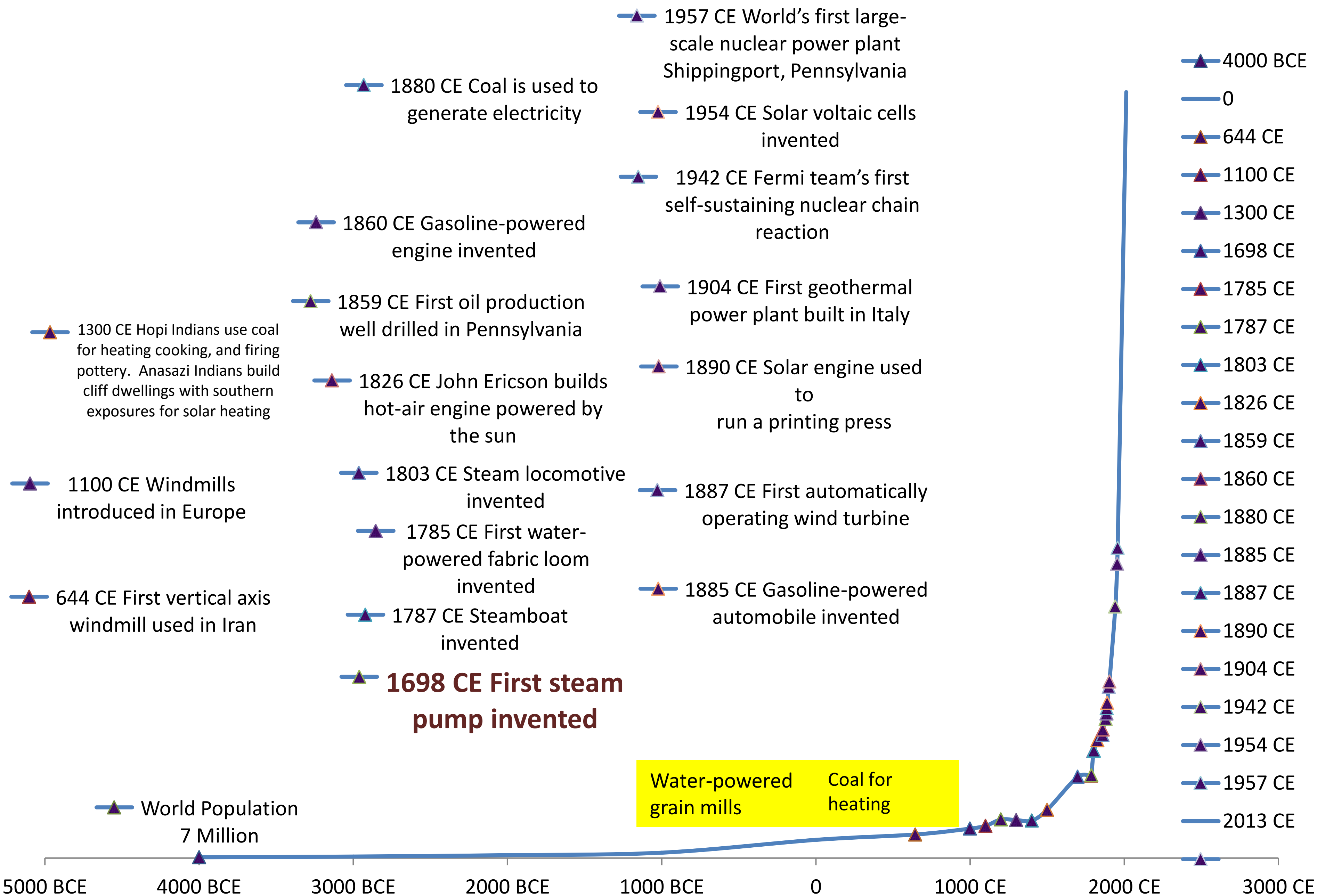
What bent the curve of human history?

Ian Morris, Why the West Rules – For Now: Patterns of History and What They Reveal About the Future, 2010

Engine of Progress

- Industrial revolution, which was the sum of several nearly simultaneous developments in mechanical engineering, chemistry, metallurgy and other disciplines.
- Industrial revolution was made possible by large scale availability of coal, which in turn was made possible because of invention of steam driven mine dewatering pump in 1698. (Invention of Davy Safety Lamp in 1815 made mining further safe.)
- Work done by James Watt during 1765 and 1776 increased the efficiency of steam engine from about 1 % to more than 3 %.
- The ability to generate massive amount of mechanical power was so important that, in the words of Morris, it "made mockery of all the drama of the word's earlier history."

Energy technologies and use timeline



Electricity: Estimating Demand

- Fixing the right reference,
  - Reference is continuously evolving,
  - From an agrarian to urban society,
  - Household consumption in middle class homes in Delhi is close to that with OECD countries.
- Efficiency of use, (Labelling).
- Affordability.
- Access to electricity is a pre-requisite for the achievement of health (longevity).
- Estimating demand
  - Regression analysis; use GDP growth data and energy elasticity of growth; bottom-up approach i.e. estimate demand based on equipment saturations, efficiency and usage.
  - Key World Energy Statistics for the year 2015;
    - Average per capita per annum = 3052kWh;
    - OECD = 8016 (8026 in 2014);
    - India = 859; Singapore = 8949; Malaysia = 4656; Thailand = 2621.
- Aim for 5000 kWh in India; population 1.6 Billion; losses = 7 %. Total requirement = 8600 Billion kWh (or TWh).
- Generation in India during 2017-18 was about 1500 TWh (including generation from non-utilities). India's current population is about 135 crores. Therefore, in per capita terms, generation was 1110 units.

Electricity: Meeting Demand

- For the past one decade, electricity generation has been growing at a CAGR of close to 6%. Looking at the trend, generation will be ~ 8600 TWh by the middle of century.
- This is about 5.7 times in terms of total generation and about 4.5 times in terms of per capita generation in 2017-18.
- Issues to be considered to meet the demand
  - Availability of energy resources,
  - Technologies for their efficient utilization,
    - Comparison of technologies has to be on a common basis, (capacity factor, land & water requirements, dispatchability and system effects; comparison on the basis of levalised cost does not capture all issues),
  - Environmental impact, particularly,
    - Climate change, and
    - Health externalities.
- Security, reliability and resilience of supply

Supplying Electricity: Role of Nuclear

- Potential of small hydro, solar and wind
  - Total 900 GW (MNRE-2017)
    - Wind = 102 GW at 80 m mast height (302 GW at 100 m mast height);
    - Solar = 750 GW if 3% waste land is made available. Rooftop solar is additional to it.
    - Small hydro = 20 GW
  - Assuming a capacity factor of 20%, it can provide 1752 billion kWh.
- Large hydro provided 126 billion kWh in 2017-18. Additional potential is available and all efforts should be made to harness it. Hopefully India will realise the remaining potential in coming decades.
- Thus, the total electricity that can be provided by hydro, coal and wind is of the order of 2000 billion kWh.
- To provide a major part of the balance 6600 billion kWh, nuclear is one option that needs to be pursued vigorously.

Economics of electricity generation: aspects to be considered

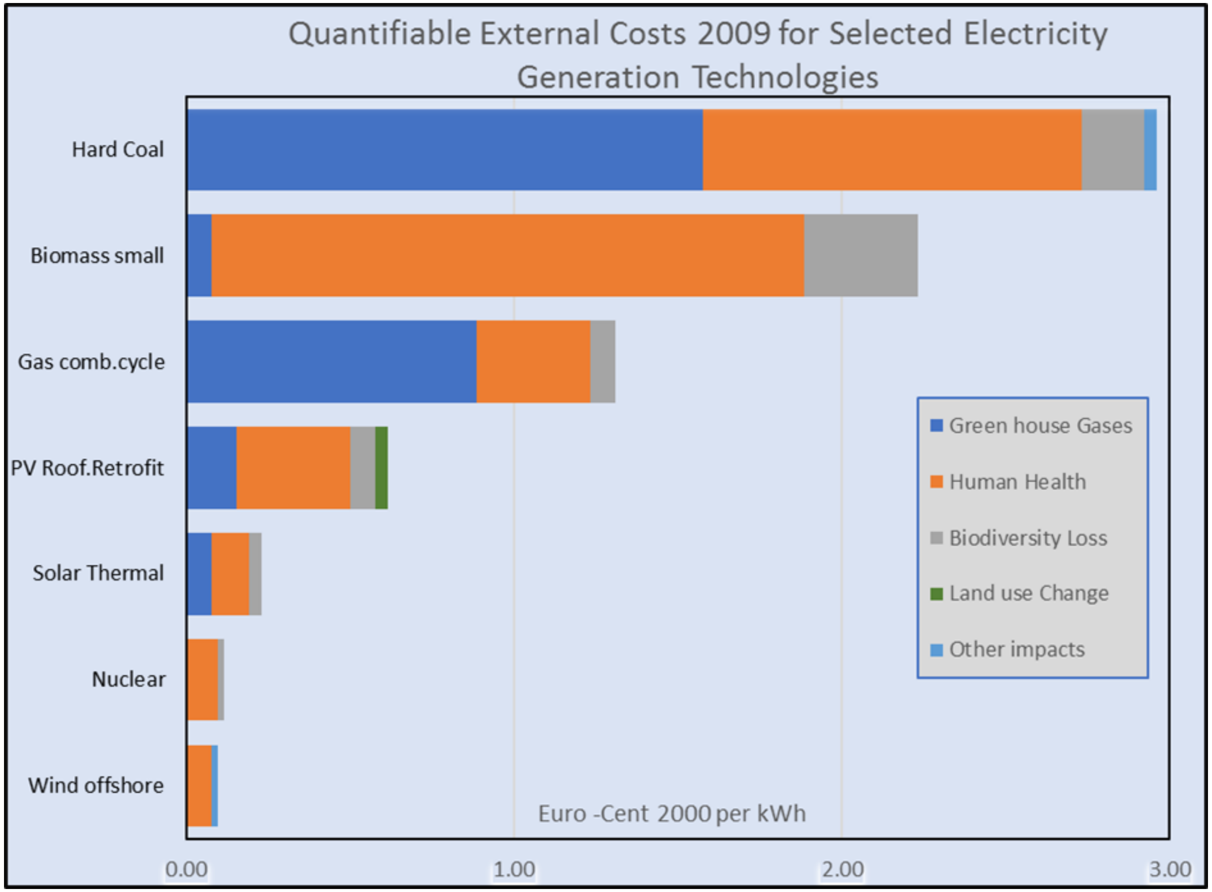
- Capital cost of setting up of power plants
- Generation costs
  - Cost of capital (Debt + equity; sensitivity to interest rate)
  - Cost of fuel (coal + transportation; uranium + fuel fabrication)
  - O & M cost (including heavy water lease charge in case of PHWRs)
- System cost
  - Plant level costs: Capital cost and generation cost
  - Grid level costs: Grid connection, extension, reinforcement, balancing cost, replacement cost
  - Other system costs: External costs, Net energy gain, Security of supply

External cost

- External costs denote the costs that the party responsible for generating emissions does not account for and consequently consumers of electricity do not pay for.
- External costs are paid in terms of health effects (deaths, serious illness, minor illness) by those who are exposed to emissions.
- Studied extensively under the project ExternE. Details can be seen in Markandeya A and Wilkinson P, (2007), “Electricity generation and health”, Lancet; 370:979-90. (This is an open access paper)

EU data: External costs of various electricity generation technologies

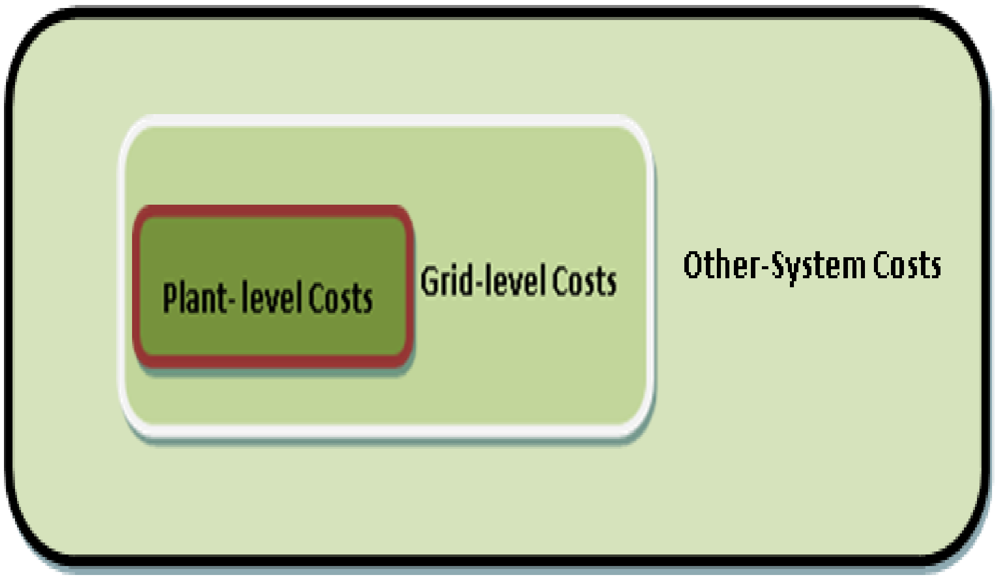
New Energy Externalities Development for Sustainability (Ricci A, 2009)



There are similar reports from the USA

System Cost

Capital cost and generations cost are plant level costs



Grid level costs are

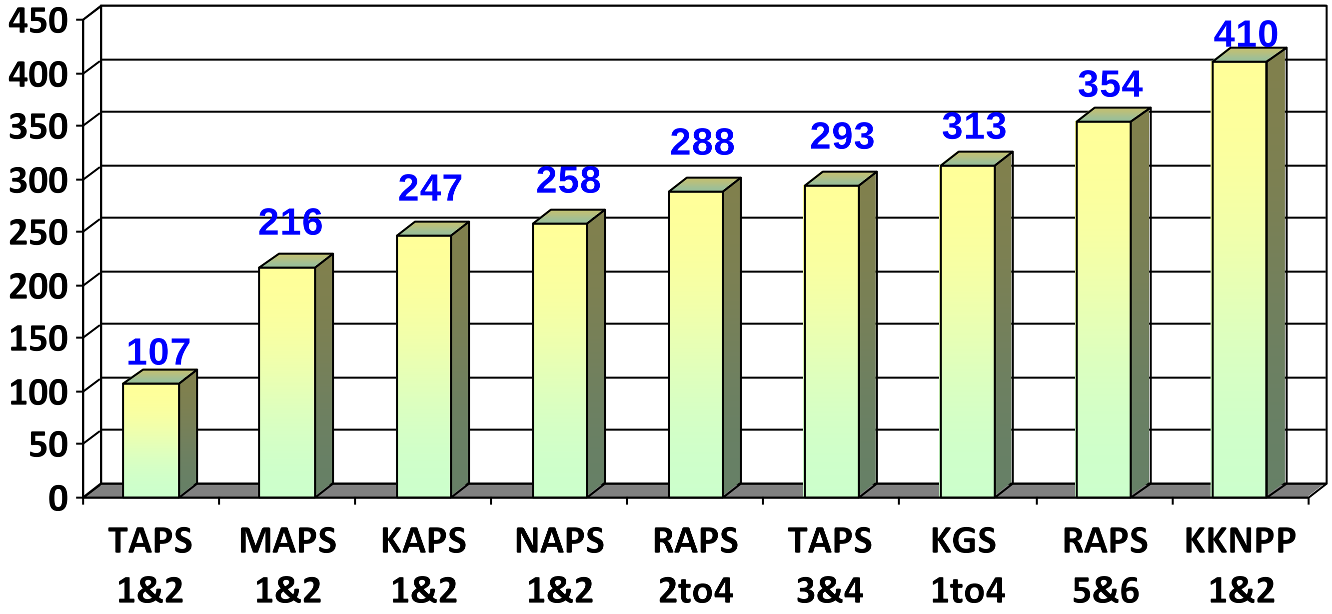
- Grid connection,
- Grid-extension and reinforcement,
- Short-term balancing costs, and
- Long-term costs for maintaining adequate back-up supply

Other system costs consist of (i) Health externalities arising from environment effects, (ii) Benefit and loss of integrating new capacity (the cost of creating new capacity and integrating it into the grid, and loss to existing players because of integrating new capacity.), (iii) Other externalities such as security of supply, cost of accidents and net energy gain.

Recent reports on system effect: a summary

- National Electricity Plan, January 2018,
  - VRE transform daily load profile into a duck curve;
  - Low capacity factor for coal-fired plants; Rapid ramp up in the evening;
  - Loss of generation efficiency; Higher maintenance due to cycling and ramping;
  - VRE sources need high grid integration cost.
- Economic Survey 2017, Vol II,
  - Social cost of carbon to denote effect of green-house gas emissions;
  - Health costs, cost of intermittency, stranded assets and incentives;
  - Total social cost of renewable was ₹11 per kWh, around 3 times of coal.
- Electricity markets and Reliability, August 2017, DOE, USA,
  - Distortion of daily load profile, role of inertia and loss of reliability;
  - "Society places value on attributes of electricity beyond those compensated by the current design of the wholesale market." (EO & Capacity market).
- Nuclear Energy Agency: quantification of system cost,
  - At 10% penetration, solar=₹2.32; Nuclear=0.02; coal=0.01;
  - For VRE sources, it rises with penetration.

Tariff of electricity from nuclear power plants in paisa/kWh



Options for growth of nuclear electricity generation in India

- Pursue an aggressive programme to locate more uranium resources in the country
  - This was taken up in the beginning of this century and is now showing results.
- Take policy initiatives to open up international trade in uranium and
  - Import uranium and set up more PHWRs based on indigenous technology, or
  - Import uranium and set up LWRs in technical collaboration with other countries, and recycle spent fuel in fast breeder reactors
  - This option was pursued and resulted in relaxation of NSG guidelines in 2008.

Results of relaxation of NSG guidelines

- Agreements have been signed with France, USA, Russia, Kazakhstan, Namibia, Korea, Canada, Australia, Japan, Bangladesh, Sri Lanka etc.
- Uranium has been imported and has been used in existing PHWRs resulting in improved capacity factors and increased electricity generation.

Year	CF	Generation
– 2009-10	61%	18831 MU
– 2010-11	71%	26473 MU
– 2011-12	79%	32455 MU
– 2012-13	80%	32863 MU
– 2013-14	83%	35333 MU
– 2014-15	82%	37835 MU
– 2015-16	75%	37456 MU
– 2016-17	80%	37674 MU (40000 including infirm power)
– 2017-18	70%	38336 MU

In parallel domestic supplies have grown due to opening of new mines in Jharkhand and in Andhra Pradesh.

Nuclear power plants: in operation, under construction and approved

- Plants under operation: 6780 MW.
- Plants under construction: 2x700 MW at Kakrapar; 2x700 MW at Rawatbhata; 500 MW PFBR; 2x700 MW at Gorakhpur, Haryana (2024-25), 2x1000 MW at Kudankulam (Mar/ Nov23).
- Projects already approved: 2x1000 MW at Kudankulam (Mar-25, Dec-25), and 10x700 MW PHWR.

Project	First pour of concrete	Criticality	Commercial operation
Chutka-1&2	Dec 2019	U-1: Dec-24 U-2: Dec-25	U-1: Mar-25 U-2: Mar-26
Mahi Banswara-1&2	Sep-2020	U-1: Sep-25 U-2: Sep-26	U-1: Dec-25 U-2: Dec-26
Kaiga-5&6	Sep-2021	U-1: Sep-26 U-2: Sep-27	U-1: Dec-26 U-2: Dec-27
GHAVP-3&4	Sep-2023	U-1: Sep-28 U-2: Sep-29	U-1: Dec-28 U-2: Dec-29
Mahi Banswara-3&4	Sep-2024	U-1: Sep-29 U-2: Sep-30	U-1: Dec-29 U-2: Dec-30

Projects under planning

- 6x1200 MW at a new site (AP, site under approval); all VVERs to be set up in technical collaboration with Russia, first two units likely to be completed before 2026-27 and the remaining before 2031-32.
- 6x1100 MW at Kovvada, AP, all AP1000, to be set up in technical collaboration with Westinghouse; USA. Dialogue ongoing.
- 6x1650 MW at Jaitapur, all EPRs to be set up in technical collaboration with France. Dialogue ongoing.
- 2x600 MW FBRs at Kalpakkam and 4x600 MW FBRs at a new site to be constructed by Bhavini.
- Reactors at additional sites already approved: 2x700 at Bargi (MP), 4x700 at Bhimpur (MP), and 6x1000 at Haripur.
- 6X1594 MW at Chhaya Mithi Virdi, all ESBWRs, to be set up in technical collaboration with GE-Hitachi; USA.

Readiness for large scale expansion of nuclear energy?

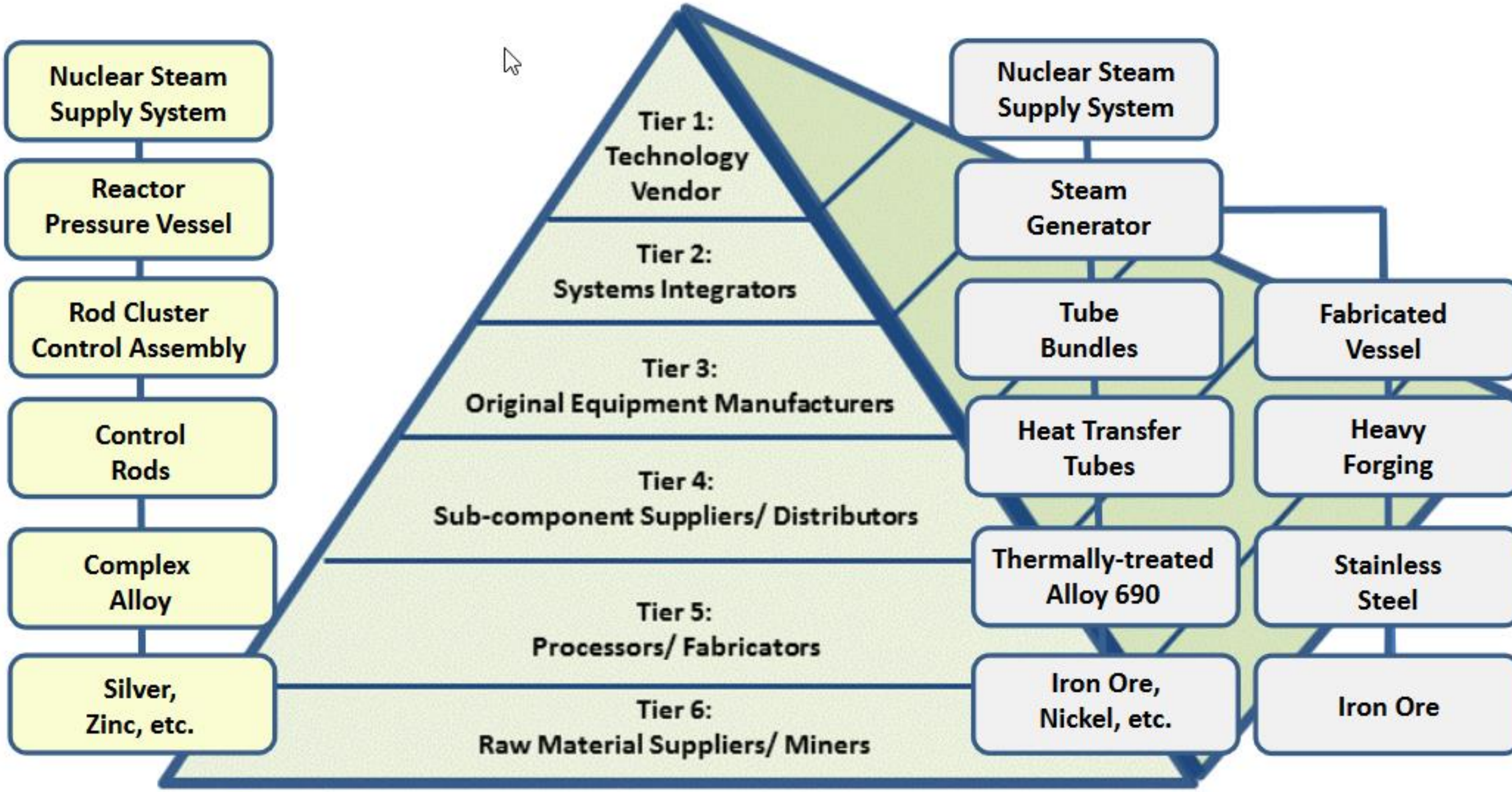
- Technology readiness,
  - Reactor design and development,
    - BWR, PHWR, FBR, Compact PWR,
  - Fuel cycle ,
    - Additional mines opened in recent past,
    - Fuel fabrication: Hyderabad plant operating and new plant near Kota,
  - Heavy water production – in excess,
  - Reprocessing: Plants operating at Kalpakkam and Tarapur,
  - Waste management.
- Industrial infrastructure to manufacture equipment and support construction exists in the country. Universities and institutes to provide engineering manpower (graduates and diploma holders) is also available.
- Human resource for design, development, operation and management,
  - Homi Bhabha National Institute,
  - Nuclear Training Centres.
- India added about 50GW during 11^{th} Plan (2007-12) and 130 GW during 13^{th} plan (2012-17). Most of it was based on coal. Once decided, India can ramp up nuclear installed capacity.

Characteristics of Indian Nuclear Industry

- R&D (fission) by research centres owned and operated by the Central Government. R&D (fusion) by a grant-in-aid institute.
- Research Reactors, fuel cycle facilities (fuel fabrication, uranium enrichment, heavy water production) and waste management facilities owned and operated by the Central Government.
- Uranium exploration by a R&D Centre and mining by a PSU.
- Power reactors owned and operated by PSUs. PHWRs and FBRs designed and constructed by PSUs and LWRs constructed in collaboration with vendors from other countries.
- Except for LWRs, most of the equipment and components manufactured by Indian industry. Forging facility has been set up as a joint venture (L&T, NPCIL).

Nuclear Supply Chain

All tiers need to be qualified to high standards



Source: WNA

Characteristics of Indian Nuclear Industry

- For PHWRs, NPCIL is the plant owner, technology vendor and system integrator and Bhavini for PFBR. Makes capital cost competitive.
- Similar situation in France and Russia. Not so in the USA and the UK.
- Atomic Energy Act, 1962 permits production of prescribed equipment by any entity, private or Government, but only a Government company can own and operate nuclear power plant.

A basic element of India's nuclear energy policy

- India has been and will continue to pursue an approach based on closed fuel cycle. This is a necessity from considerations of
  - Energy sustainability and
  - Credible waste management
- All Nuclear Cooperation Agreements signed by India provide for right to reprocess spent fuel that is being imported for use in reactors under IAEA safeguards.

Managing nuclear waste

- Nuclear waste is segregated into three categories: low, intermediate, and high-level waste. LLW can be compacted, incinerated and buried safely at a shallow depth. ILW needs to be shielded in concrete or bitumen before disposal.
- HLW: Store in a deep geological repository or partition and transmute. Technology is well known. The issue is public acceptance.
- Actinide Partitioning: engineering scale demonstration plant operational for spent fuel from thermal plants
- Transmutation in fast reactors

The risk of energy production

- Every activity has some risks: Deaths per TWh.

Coal average	161
Coal – China	278
Oil	36
Natural gas	4
Biofuel	12
Peat	12

Solar (Rooftop)	0.44
Wind	0.15
Hydro	0.10
Hydro world including Banqiao	1.4
Nuclear	0.04

Summary – 1

- From health, safety and environment considerations, nuclear and renewable such as solar, wind and hydro outperform fossil fuel sources.
- The relative advantages and drawbacks of nuclear and renewables are perceived differently by different technical, experts and stakeholders.
- One should support all low carbon sources that is renewable and nuclear. Also coal with carbon capture and sequestration.
- Fission based nuclear reactors have been around since the middle of the previous century, deployed on large enough scale for providing base-load electricity and subjected to much deeper scrutiny with regard to safety than any other electricity generating technology.
- Nuclear fuel has high energy density; nuclear power plants have large enough EROI, lowest external costs, low GHG emissions and competitive generation costs.

Summary – 2

- Site selection and public acceptance is a challenge.
- In negotiations with foreign vendors: arriving at technical terms and conditions that are mutually acceptable and enable a viable tariff regime is another challenge.
- India has multiple technology options at its disposal and can make a judicious selection based on economics and ease of implementation.
- India's electricity needs are very large and we need all technologies. 'Technology versus technology' debate has to stop as different electric power sources provide different elements of a balanced energy mix.

Thank You