SUSTAINABILITY CHALLENGES IN RENEWABLE ENERGY : BETWEEN A ROCK AND A HARD PLACE

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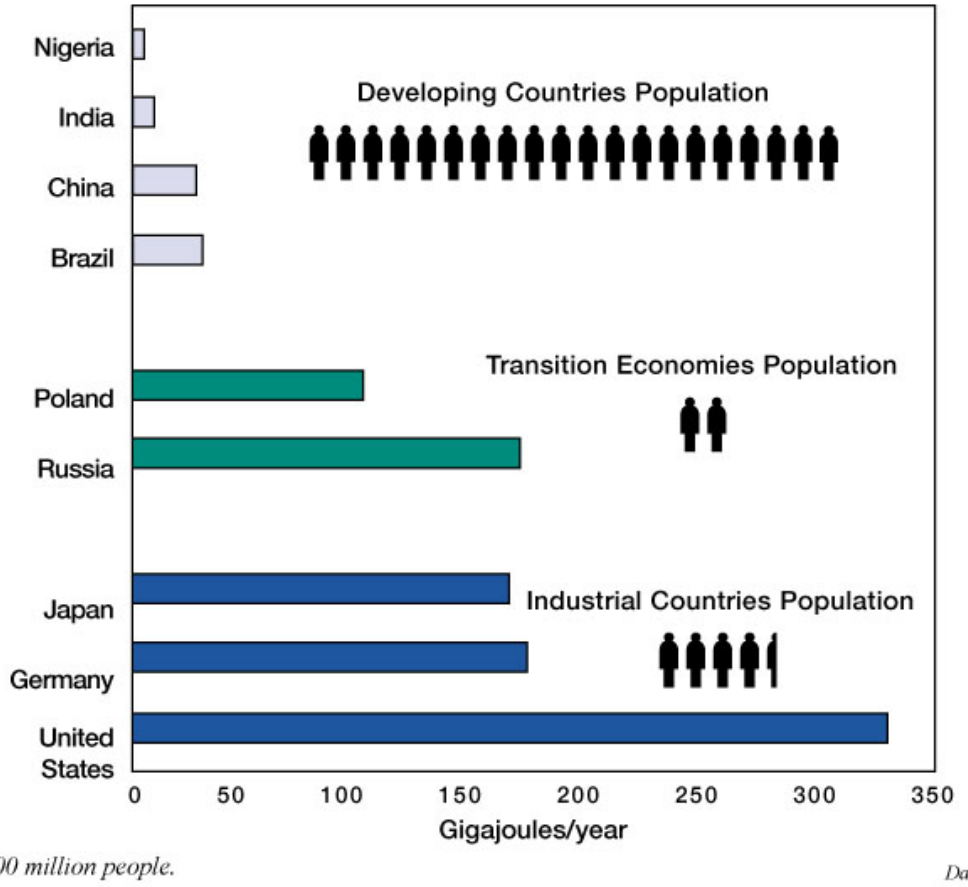
THE THERMODYNAMICS OF HISTORY

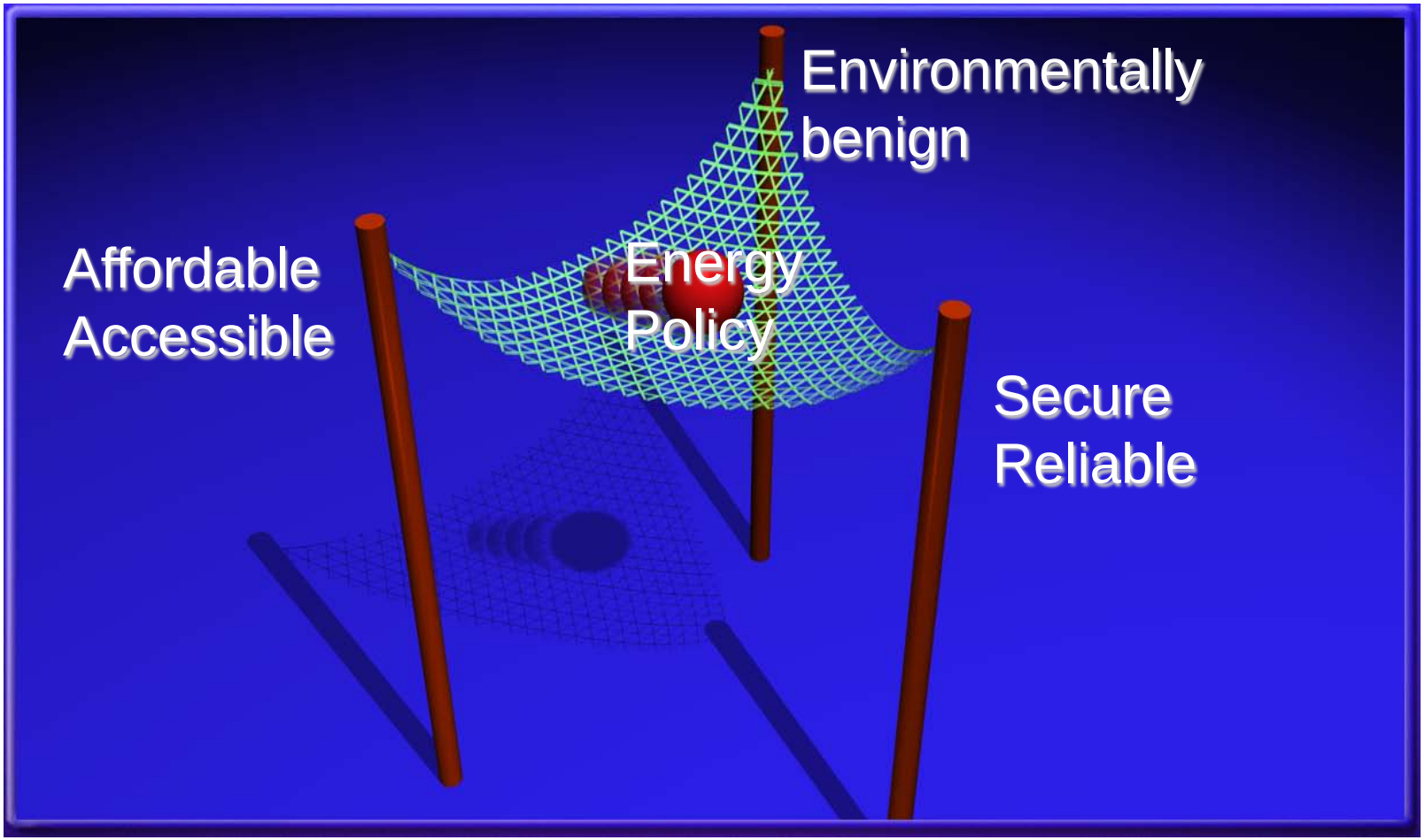
- Human history reflects the creation of increasingly complex technological and social arrangements for capturing free energy
- Collapse sets in when entropy can no longer be offset and the energy returns per capita diminish

THE ENERGY GAP

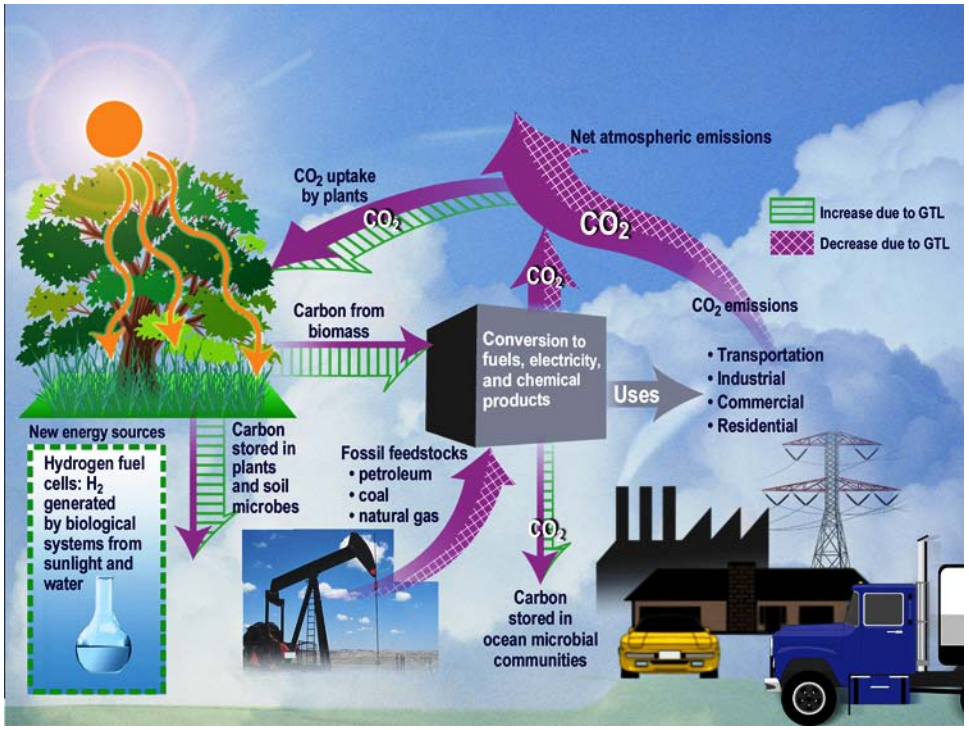


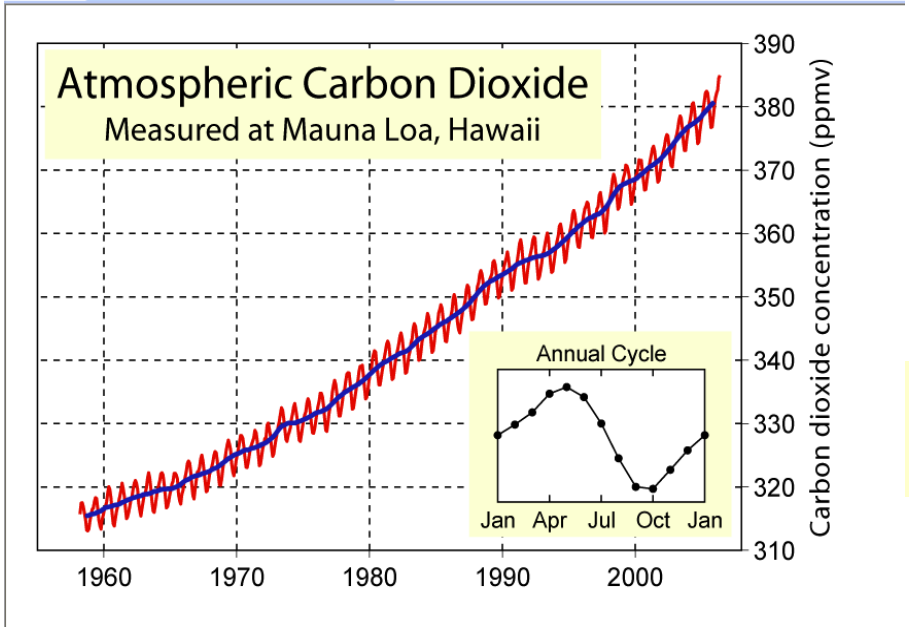
- Half the world's population subsists on agrarian or lower levels of energy access
- Their population density generally exceeds the carrying capacity of their environment

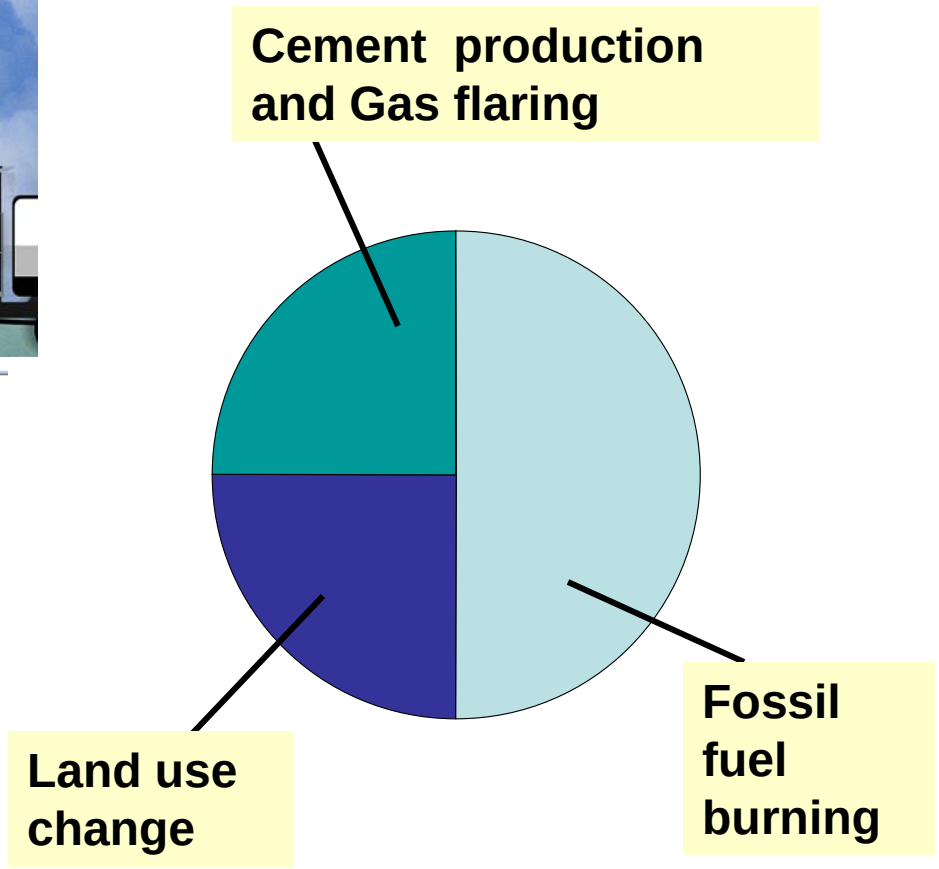
ENERGY TRILEMMA



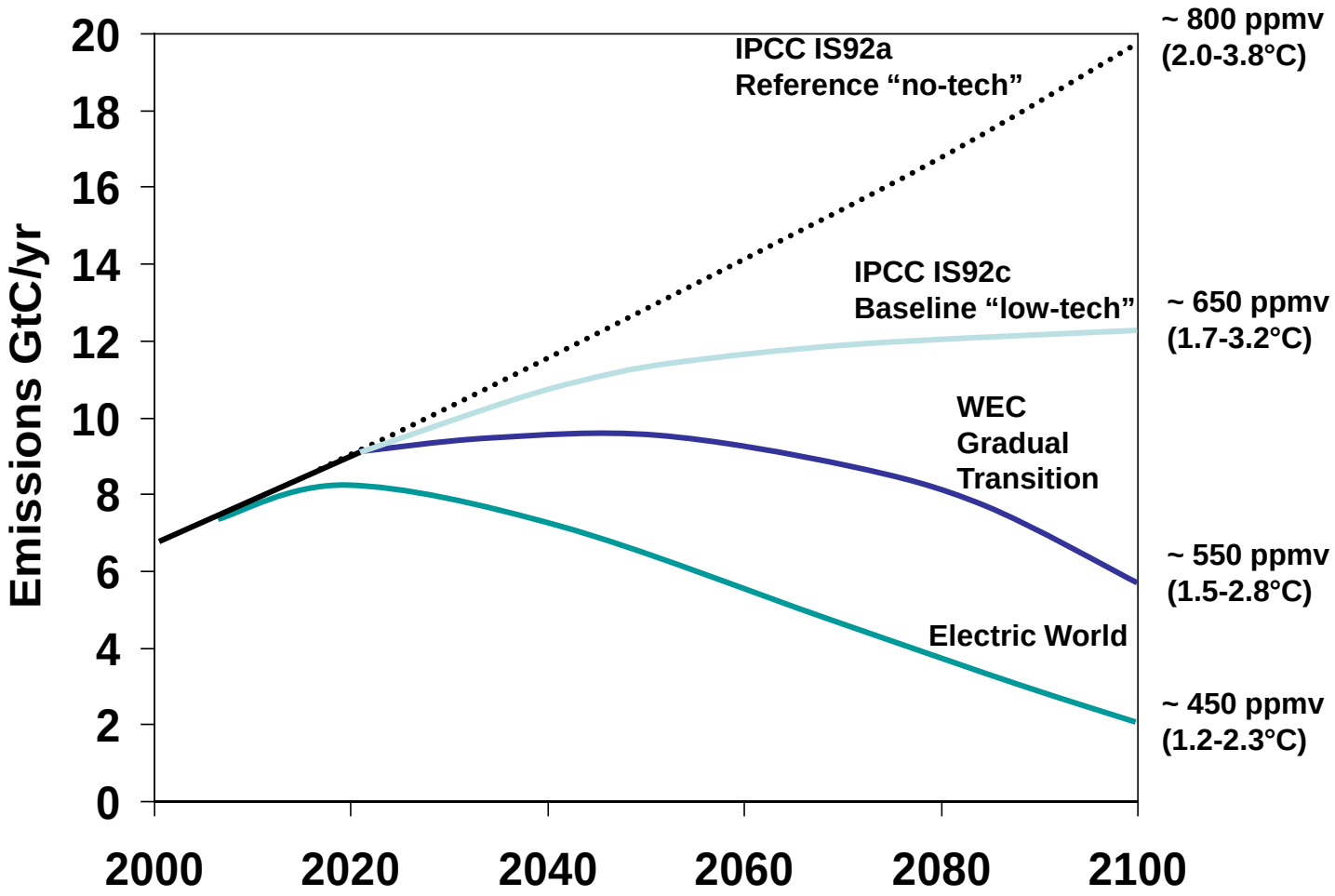
ANTHROPOGENIC CO_2 EMISSIONS







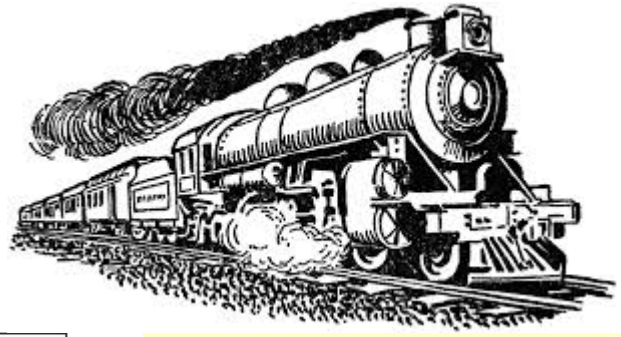
COMPARISON OF CO2 EMISSION SCENARIOS



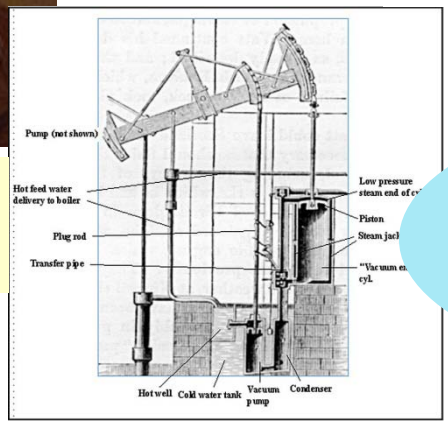
Even if we stop 80% of our fossil fuel emissions, the carbon dioxide emissons will not fall but only stop increasing

James Watt, 1763

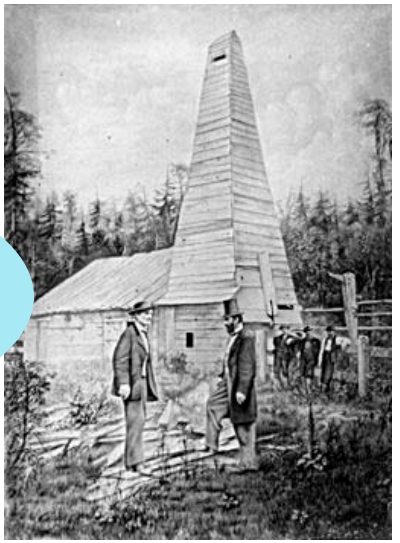
Industrial Revolution



Steam Engine, 1820



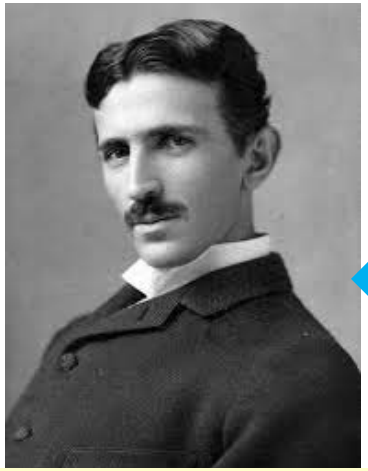
Energy transition in society is painfully slow !



First Petroleum well, 1859

Nikolaus Otta, ICE, 1861

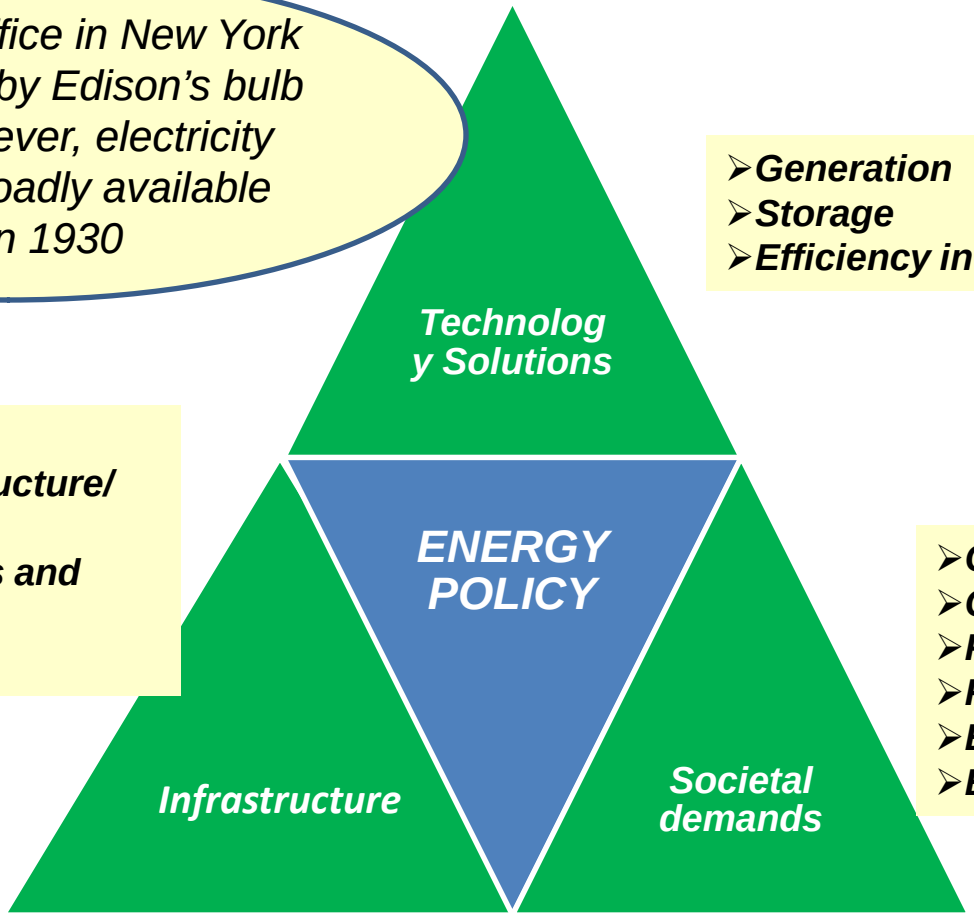
1879



Nicola Tesla, Turbine and AC,1893

EMBEDDED ENERGY INFRASTRUCTURE : DIFFICULTY IN PREDICTING ITS FUTURE ARCHITECTURE

JP Morgan's office in New York was electrified by Edison's bulb in 1882; However, electricity was made broadly available only in 1930



- ***Generation***
- ***Storage***
- ***Efficiency in use***

- ***Replacement cost***
- ***Embedded infrastructure/ systems / capital***
- ***Pricing, tariff, taxes and subsidies***

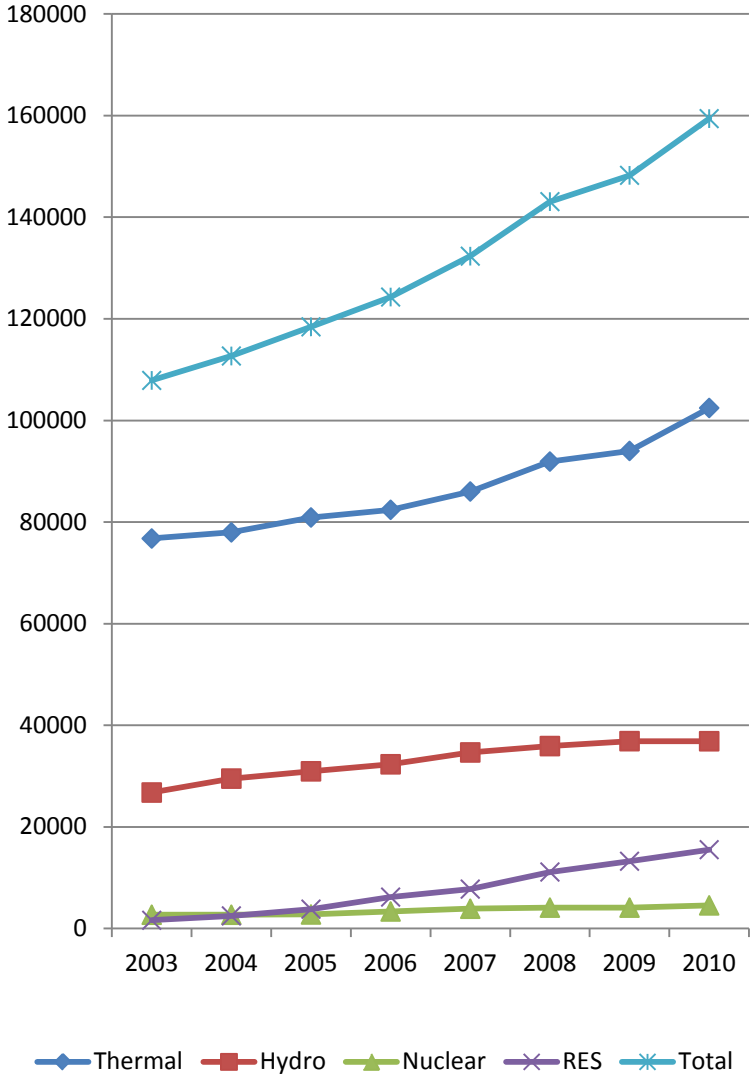
- ***Consumption pattern***
- ***Cost to consumer***
- ***Pay as you use***
- ***Reliability***
- ***Empowerment***
- ***Environmental impact***

Radical changes are possible only when technology and infrastructure gets locked in synergistic embrace

2050 Goals
The Electrified World

- > 2%/yr global productivity growth
- 30,000 cal/day equivalent per person
- 1,000 kWh/yr per person
- < 6 billion tons/yr of carbon emitted

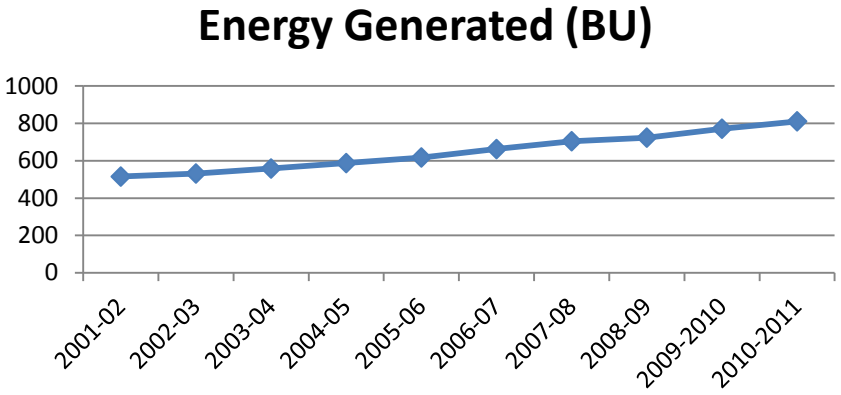
INDIA'S FUEL-WISE GENERATION CAPACITY (MW)

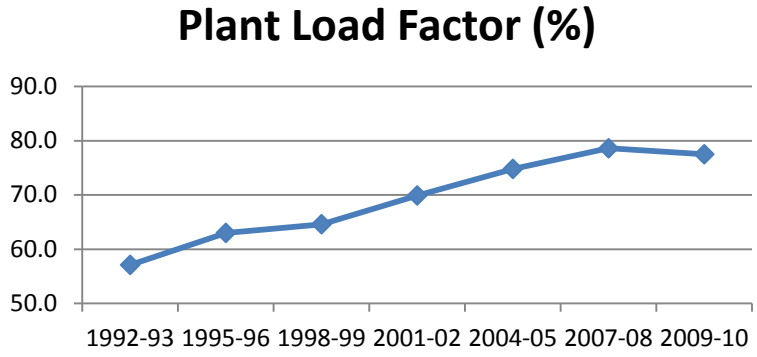


- Coal: good for base-load
  - significant domestic reserves
    - proven reserves of 105 billion tonnes
    - could last 200 years at current production level
- Natural gas share up from 4.4% to 10% in last 15 years
  - emit half as much CO2 per kWh as compared to coal-based plants
- Hydroelectric potential of 600 billion kWh per annum
  - Capacity of 148.7 GW
  - only 23% realised so far
  - High initial costs and developmental risks
- Nuclear: small

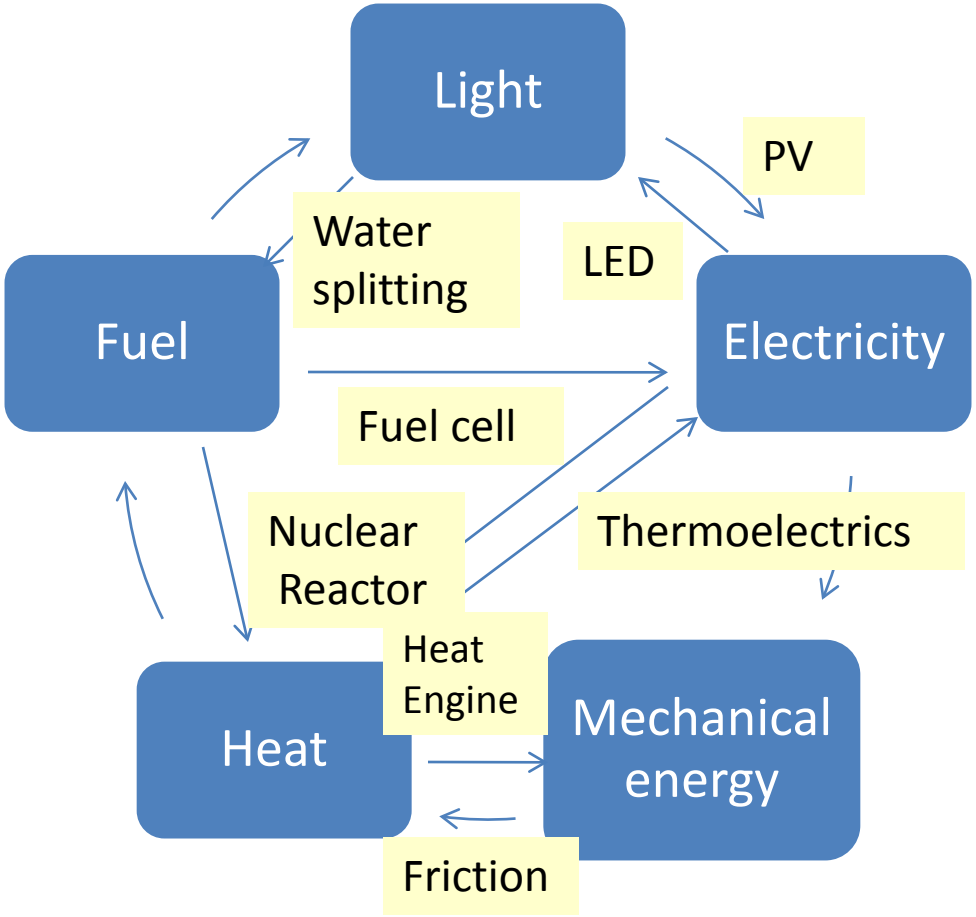
INDIA'S ENERGY INTENSITY IS LOW, EVEN AS IT RAMPS UP GENERATION

Consumption	India	World
Per-capita electricity (kg Oil Equivalent)	704	2752
Average energy (TOE)	0.53	1.82





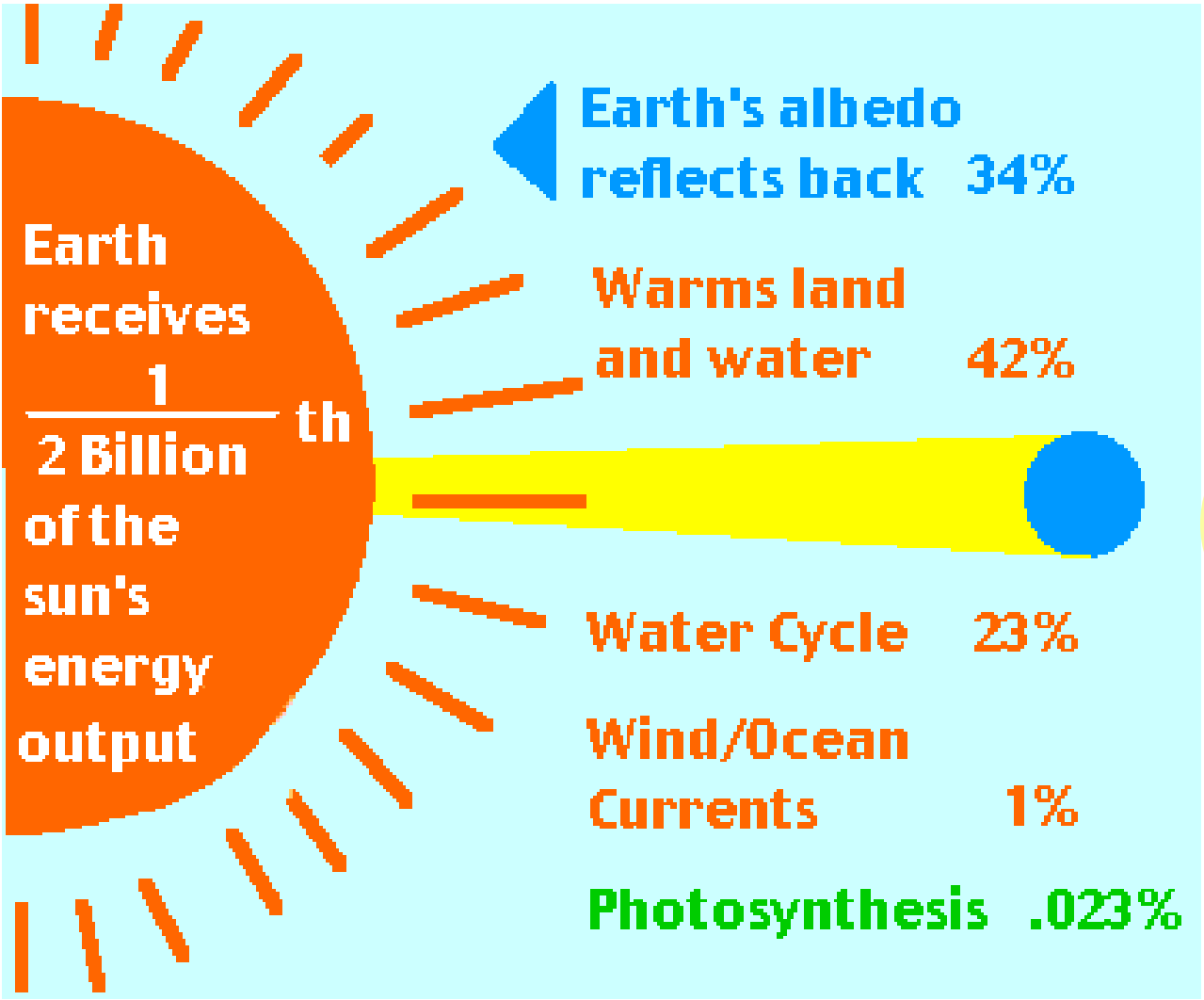
ENERGY INTERCONVERSIONS



If you want to find out the secrets of the universe, think in terms of energy, frequency and vibration

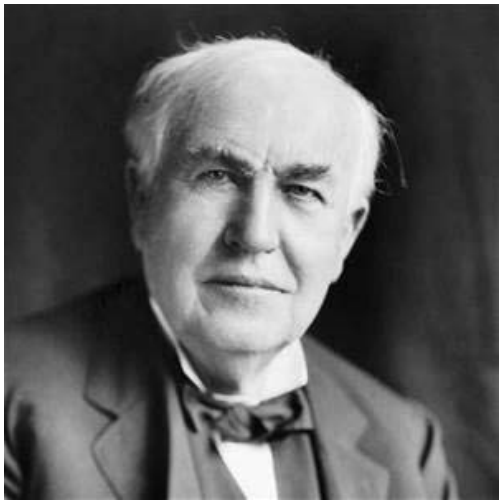
Nikolas Tesla

ENERGY FROM SUN



Frugal and Parsimonious

" I'd put my money on the sun and solar energy. What a source of power! I hope we don't have to wait till oil and coal run out before we tackle that "



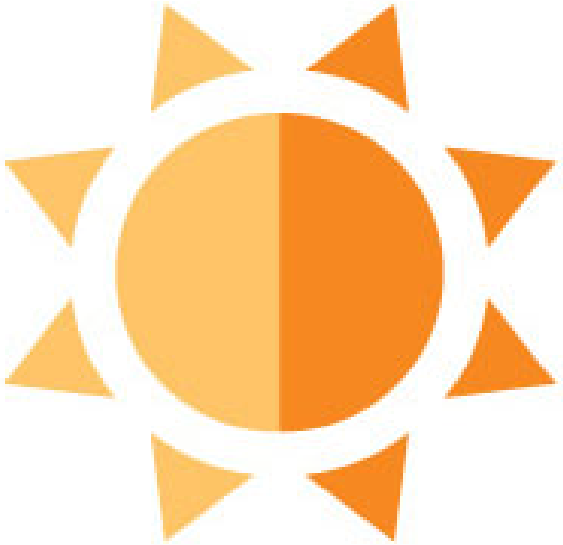
Thomas Alva Edison (1847-1931)

SOLAR ENERGY UTILIZATION

SOLAR PHOTOVOLTAIC (PV)

Uses a cell of semiconductor material which creates an electrical voltage when exposed to the sun's radiant energy.

- Small-scale: household rooftop solar PV panels
- Large-scale: which include large amounts of solar panels and sometimes mirrors are used to concentrate the sun's radiant energy onto the panels.



SOLAR THERMAL

Converts sunlight into thermal energy (i.e. heat)

- Small-scale: household rooftop hot water system
- Large-scale: mirrors are used to concentrate the sun's heat onto fluids or salts, heating them to create steam which can then drive turbines to generate electricity.

Solar Energy in India

- Solar Insolation : 300 days
- Average incident solar energy : 4-7 kWh per sq. meter = 1500-2000 sunshine hours per year
- Land area : solar power reception 5 petawatt hours per week = 600 Tw

SOLAR ENERGY SCENE IN INDIA

- 175 GW by 2020; 4 GW actual capacity in 2015
- If achieved 25 % of total electricity capacity by 2020
- Capital investment of $ 160 billion
- One of the top three markets in the world 500 mW project by Sun Edison at Ghani Solar Park, Kurnool, AP at Rs 4.63 per kWh (Reverse Auction, 3 November 2015, Economic Times)

Is this price sustainable and economically viable ? How much is the hidden subsidy ?

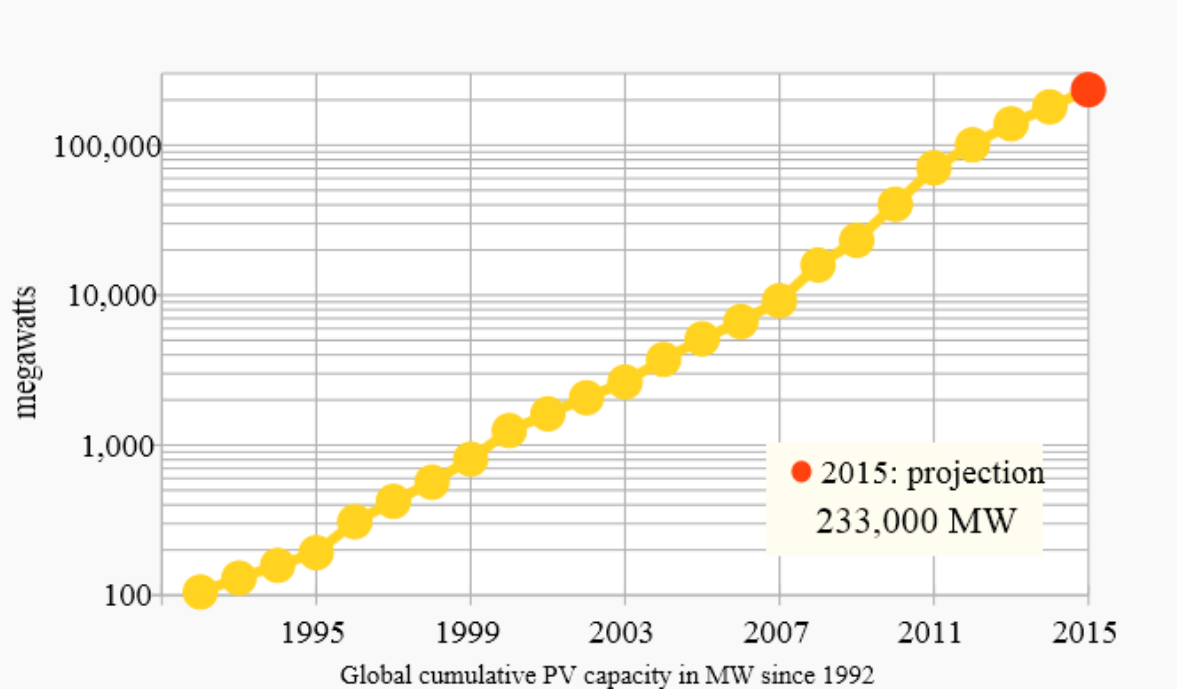
IS SOLAR ENERGY SUSTAINABLE ?

Issues to be considered

- Optimal size; < 5 MW and > 50 MW not optimal; 25-50 MW appear optimum
- Land use pattern, evacuation and habitat loss (3.5 to 10 acres per MW)
- Plant load factor only 20 % of conventional power plant
- Grid Integration and disruption management costs not trivial; transmission costs 5x greater than conventional power
- How will solar power coexist with conventional power plants? Will we idle conventional power plants by the day and operate only at night?
- Business risks (Financing, Ability of the SEB's to pay, Forex risks)
- Financial health of distribution companies
- Very poor understanding of both technology and business risks in India ; Foreign companies want to grow market share at unsustainable prices

WHY IS THE PRICE OF SOLAR PV POWER SO LOW ?

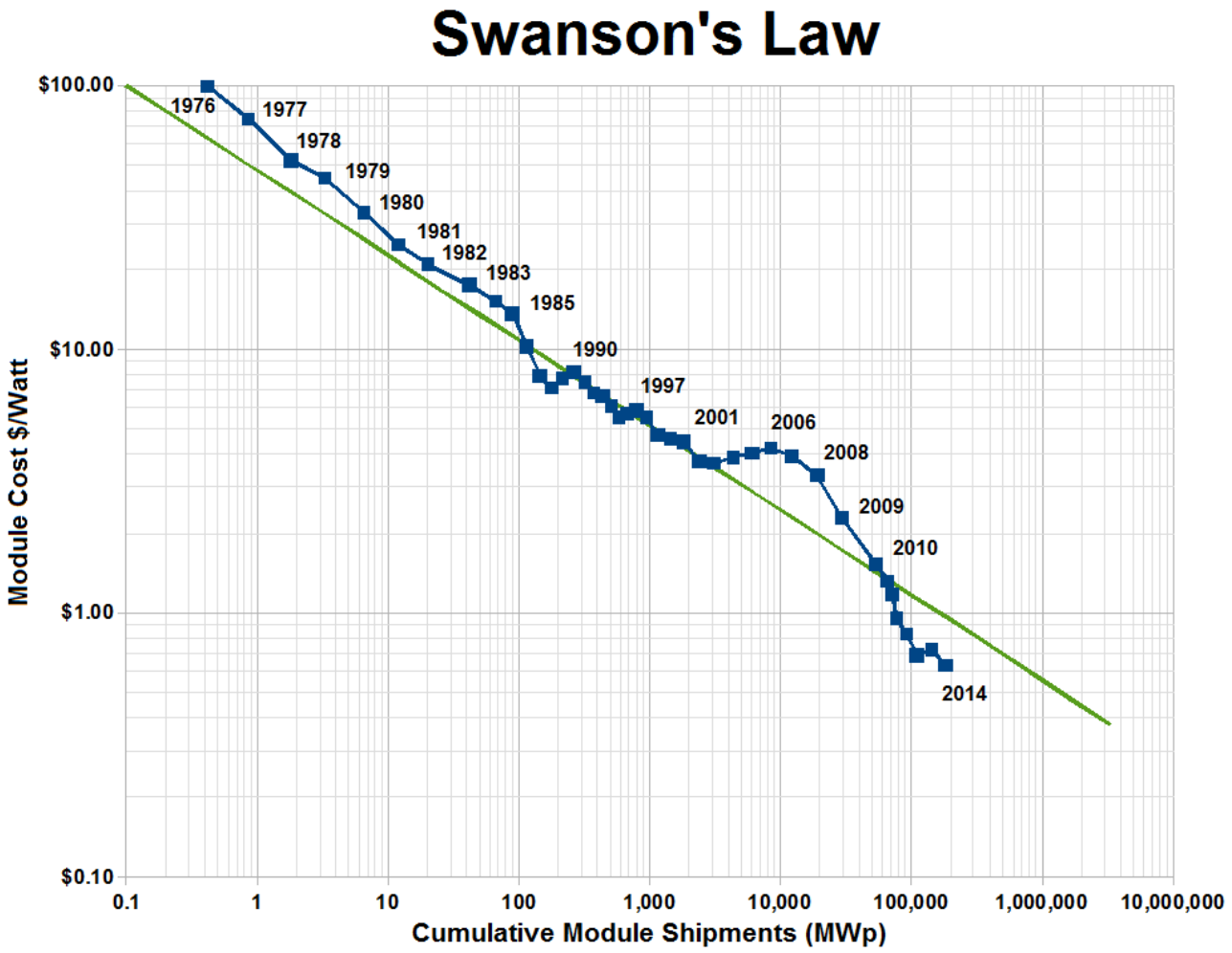
- Global PV power Capacity : 177 GW
- PV contributes today to 1 % of the total power capacity
- Solar silicon : 60 % capacity in China; Four of the five largest PV module suppliers are Chinese companies
- Current price : 60 cents / Wp



Price reductions due to unsustainable pricing or distress sale ?

HAS THERE BEEN TECHNOLOGY DISRUPTIONS IN SOLAR PV ?

- Is there an equivalent of a Moore's Law in Solar PV ?
- Has there been significant new innovations by industry ?
- Solar cell prices fall 20% for every doubling of industry capacity



The Economist, 18 November 2012

Cost reductions not driven by advances in technology

IS SILICON PV GREEN ENERGY ?

Consider the following facts

- Solar PV manufacturing processes involve converting quartz to metallurgical grade silicon and then to polysilicon ingots which are sliced to form wafers
- Every ton of metallurgical grade silicon production results in 4 tons of silicon tetrachloride; Material utilization efficiency is a mere 30%
- Solar cell fabricated with Siemen's process needs 6 years of operation to recover the energy used to make it
- 1 ton of crude silicon production results in 10 t of carbon dioxide; Purification process results in additional 45 t of carbon dioxide

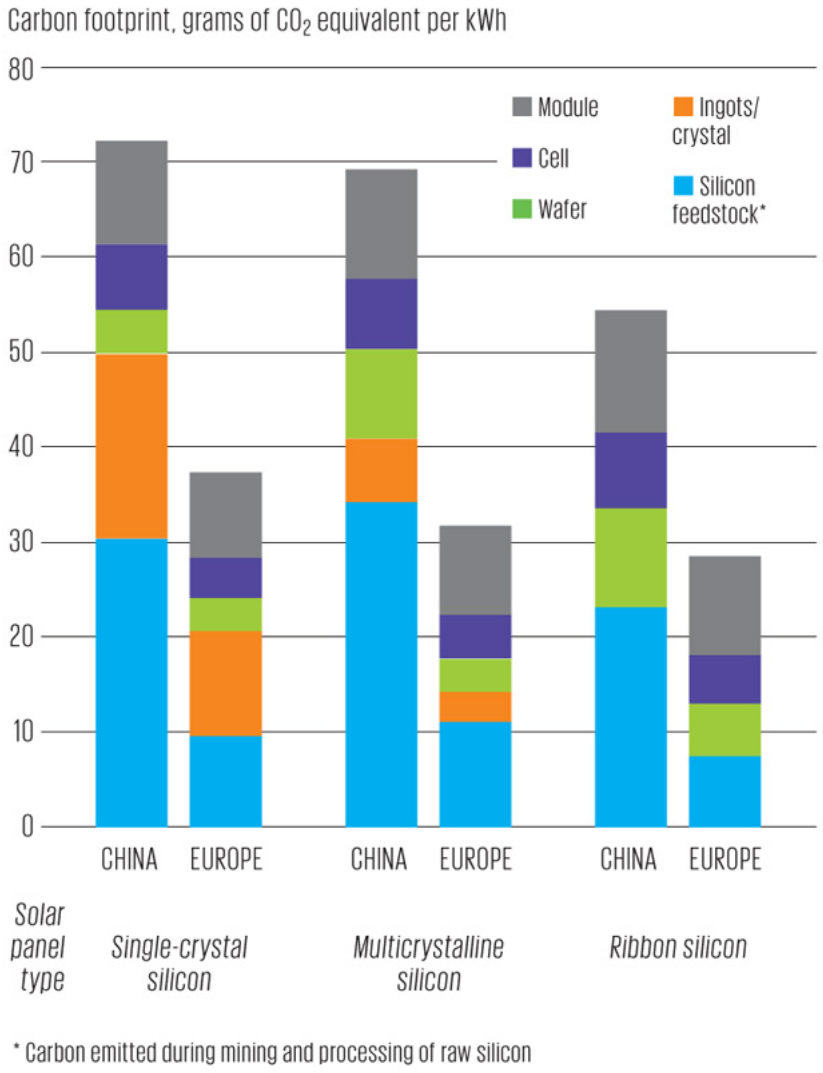
IS SILICON PV GREEN ENERGY ?

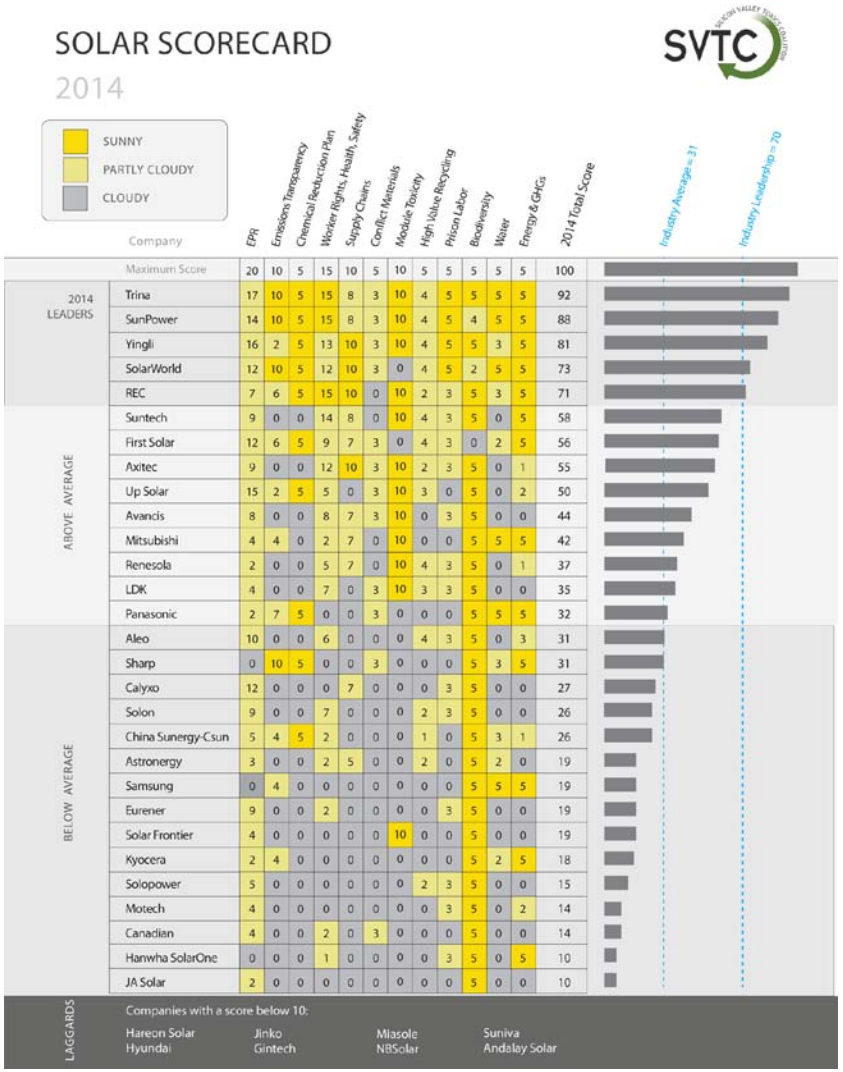
Consider the following facts

- Silicon production uses sulfur hexafluoride, HF, 1,1,1 trichloroethane and large quantities of strong acids
- Silver that is used for making panels at 5 % of current power demand will consume 50 % of current silver produced
- Little or no recycling of silicon in process waste or end of life panels

Ironic that we consider silicon PV as a clean and sustainable form of energy !

SUSTAINABILITY METRICS FOR SOLAR PV





THE CHALLENGE OF SOLAR CELL FABRICATION

- 5 TW of solar power generation

15% efficiency
250 w/sq m

- 250,000 sq km

30 year replacement

- 25 sq km of cells per day
- 1 billion cells (15x15 cm) each day

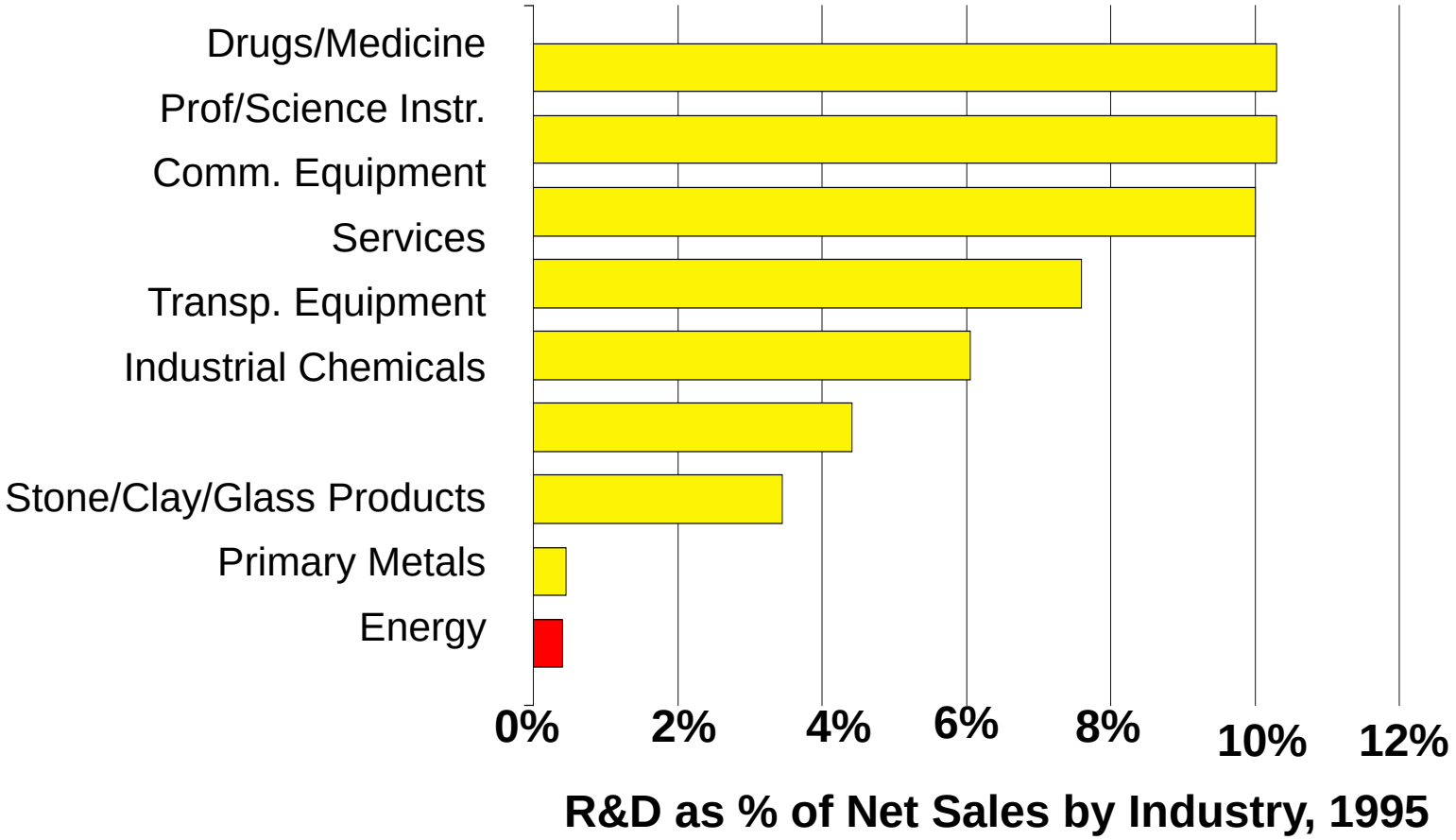
The current method of fabrication of silicon wafers from ingots not very relevant for large scale deployment ; clearly, there is a technology gap

SOLAR INSTALLATIONS CAN BECOME VIABLE IN DECENTRALIZED SOLAR INSTALLATIONS

- Solar water pumps
- Roof top solar PV; 1000 sq ft : 400 units of power per month
- Solar street lights and signages
- Small gadgets directly powered by solar power

Generate and consume locally ; shift capital investment to communities or individuals and away from state

R&D INVESTMENT: TOO LOW !



R&D as % of Net Sales by Industry, 1995

Source: Margolis and Kammen

SUMMARY

- The world is in the midst of unprecedented population growth made possible by mankind's increased ability to utilize energy.
- Broader access to energy is essential to resolving the world's demographic "climate change".
- This will require the transformation of what still remains a "Paleolithic" global energy economy. The technology portfolio to enable this transformation is feasible but lacks the needed priority and resources.
- Focus too much on supply side; Need to focus on demand side
- Three risks: Ability to prioritize and identify optimal solutions for India, risk of solutions imposed on by technology providers, risk of Government and policy driven adoption of sub optimal technologies
- Risk management : Geopolitical (oil), economic (renewable), psychological and perception (nuclear)
- Need to articulate tangible value proposition to alls stakeholders
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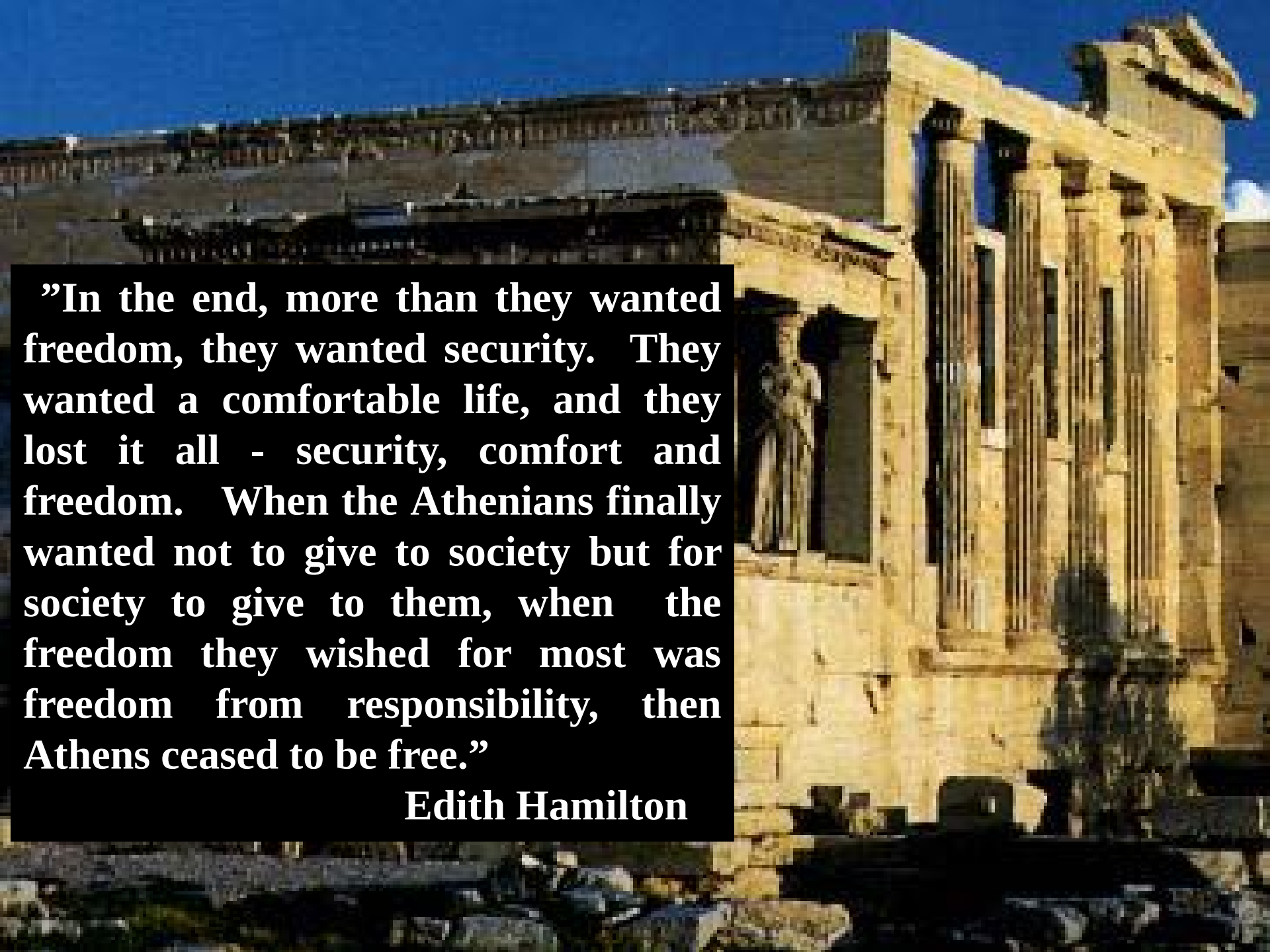

”In the end, more than they wanted freedom, they wanted security. They wanted a comfortable life, and they lost it all - security, comfort and freedom. When the Athenians finally wanted not to give to society but for society to give to them, when the freedom they wished for most was freedom from responsibility, then Athens ceased to be free.”

Edith Hamilton

THANK YOU