Commercializing a next-generation source of green CO<sub>2</sub>-free nuclear energy

## LENRs could enable Moore's Law for Energy

Exponential increases in our energy supplies are needed

To meet future demand from universal electrification and connectivity at a reasonable societal cost along with drastic reduction of CO<sub>2</sub> emissions



### **Lewis Larsen**

President and CEO Lattice Energy LLC November 19, 2014

"Energy, broadly defined, has become the most important geostrategic and geoeconomic challenge of our time."

Thomas Friedman New York Times, April 28, 2006



Contact us directly for further details: 1-312-861-0115 lewisglarsen@gmail.com

http://www.slideshare.net/lewisglarsen/presentations

Commercializing a next-generation source of green CO<sub>2</sub>-free nuclear energy



# Think different.

"Think different" was an advertising slogan for Apple Inc. (formerly Apple Computer Inc.) in 1997 created by the Los Angeles office of advertising agency TBWA\Chiat\Day

https://www.youtube.com/watch?v=GEPhLqwKo6g

Commercializing a next-generation source of green CO2-free nuclear energy

By the world very gradually switching power generation technologies from presently dominant chemical combustion processes to instead using transmutation of LENR Carbon-based fuels derived directly from petroleum and coal, oil companies have an opportunity to dramatically extend the effective longevity of today's remaining in-ground supplies of fossil fuels.

Achieving this goal could postpone mankind's day of reckoning on energy for thousands of years, enable high rates of sustainable global economic growth, and allow future consumers to enjoy abundant supplies of affordable, nonpolluting, CO<sub>2</sub>-free energy

Commercializing a next-generation source of green CO2-free nuclear energy

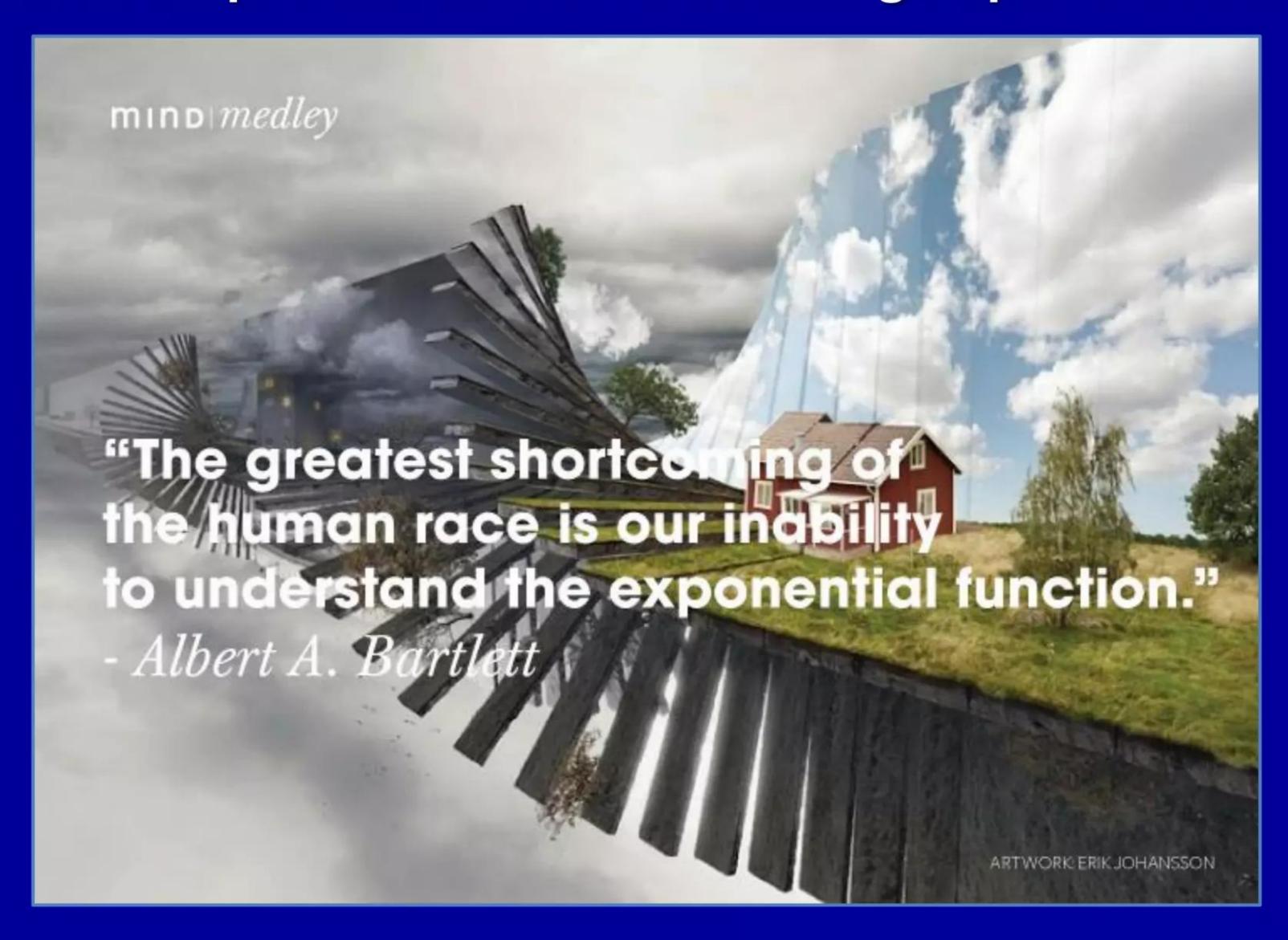
It is a risk to develop LENRs.

What if it doesn't work out?

Ah ..... but what if it does.

Adapted from a quotation of American book author Peter McWilliams (1949 - 2000)

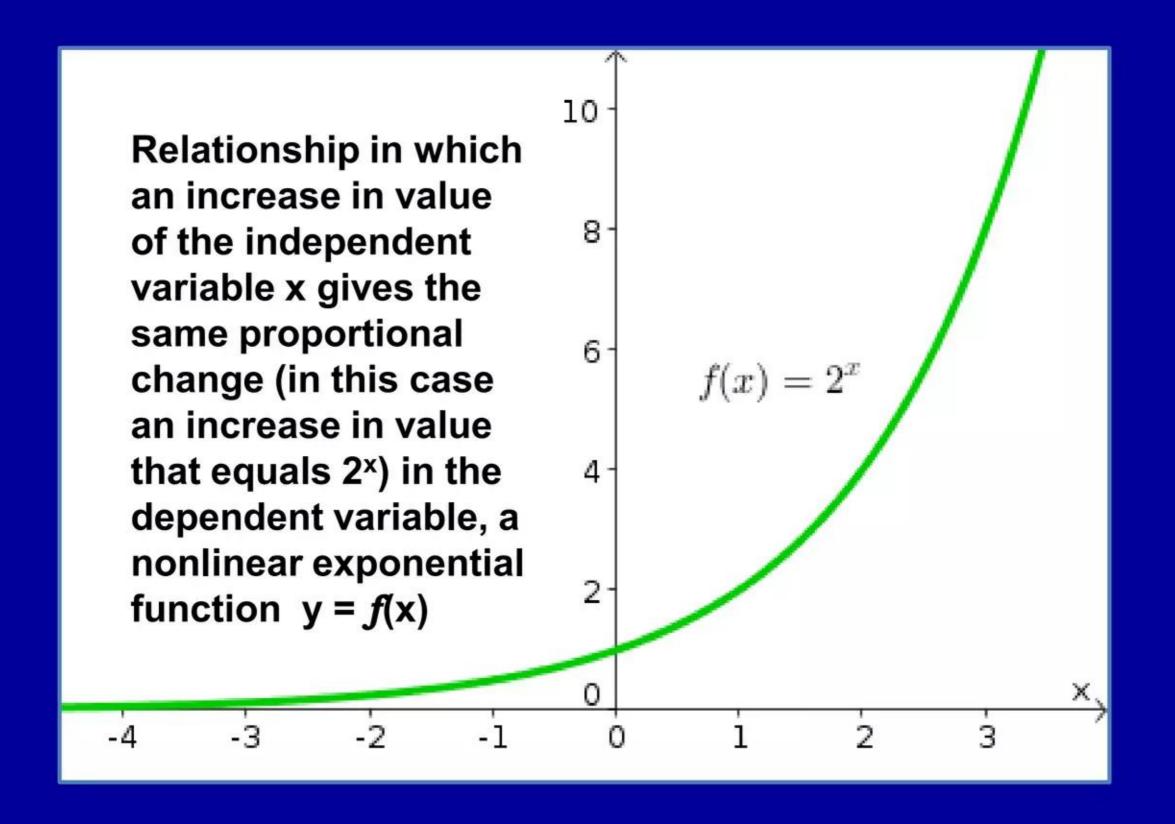
### Exponential processes can be hard to grasp without charts



### Exponential functions are nonlinear

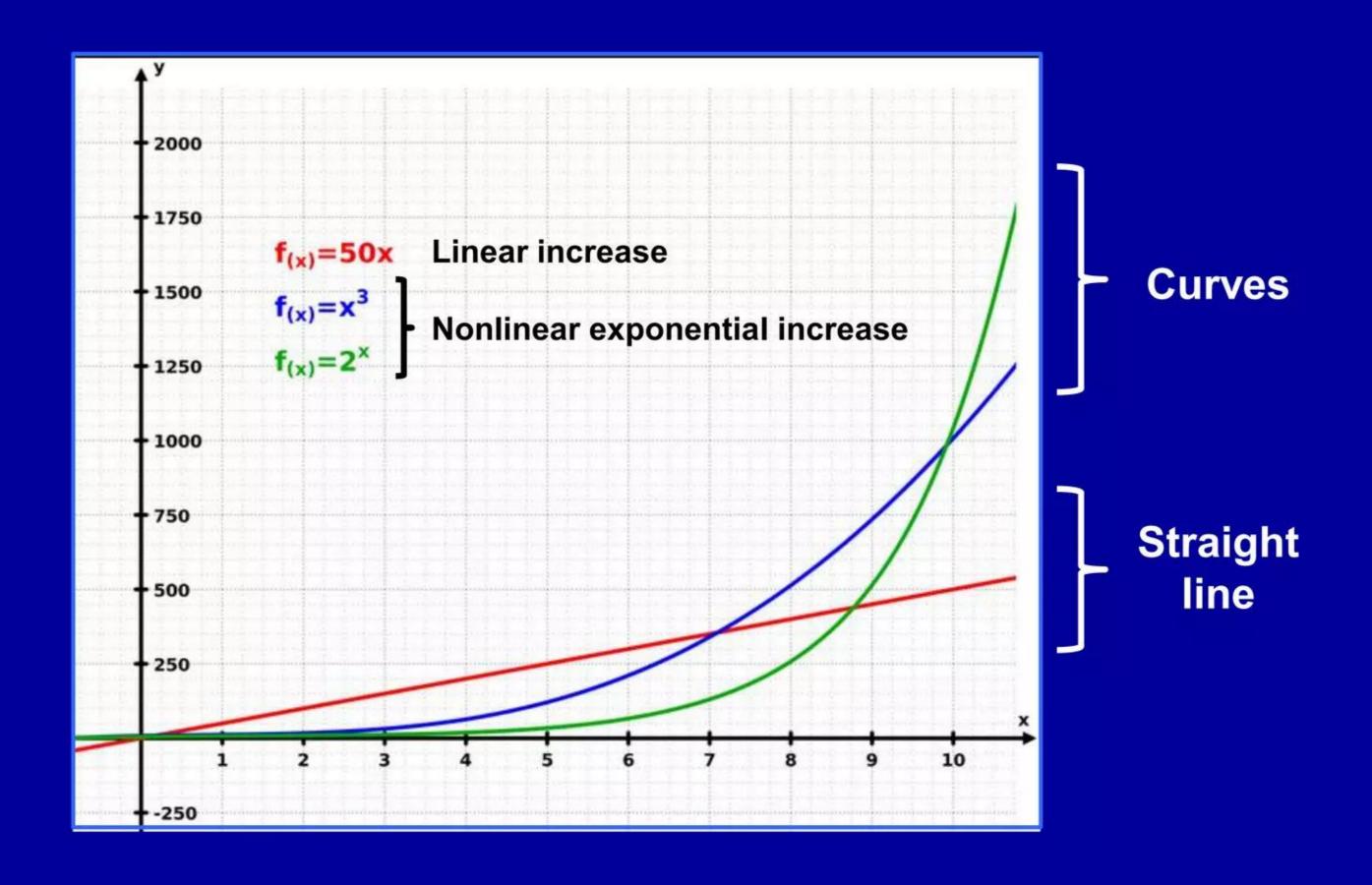
Nonlinear phenomena can rapidly increase or decrease in value

Great many natural and economic processes are driven by nonlinear dynamics



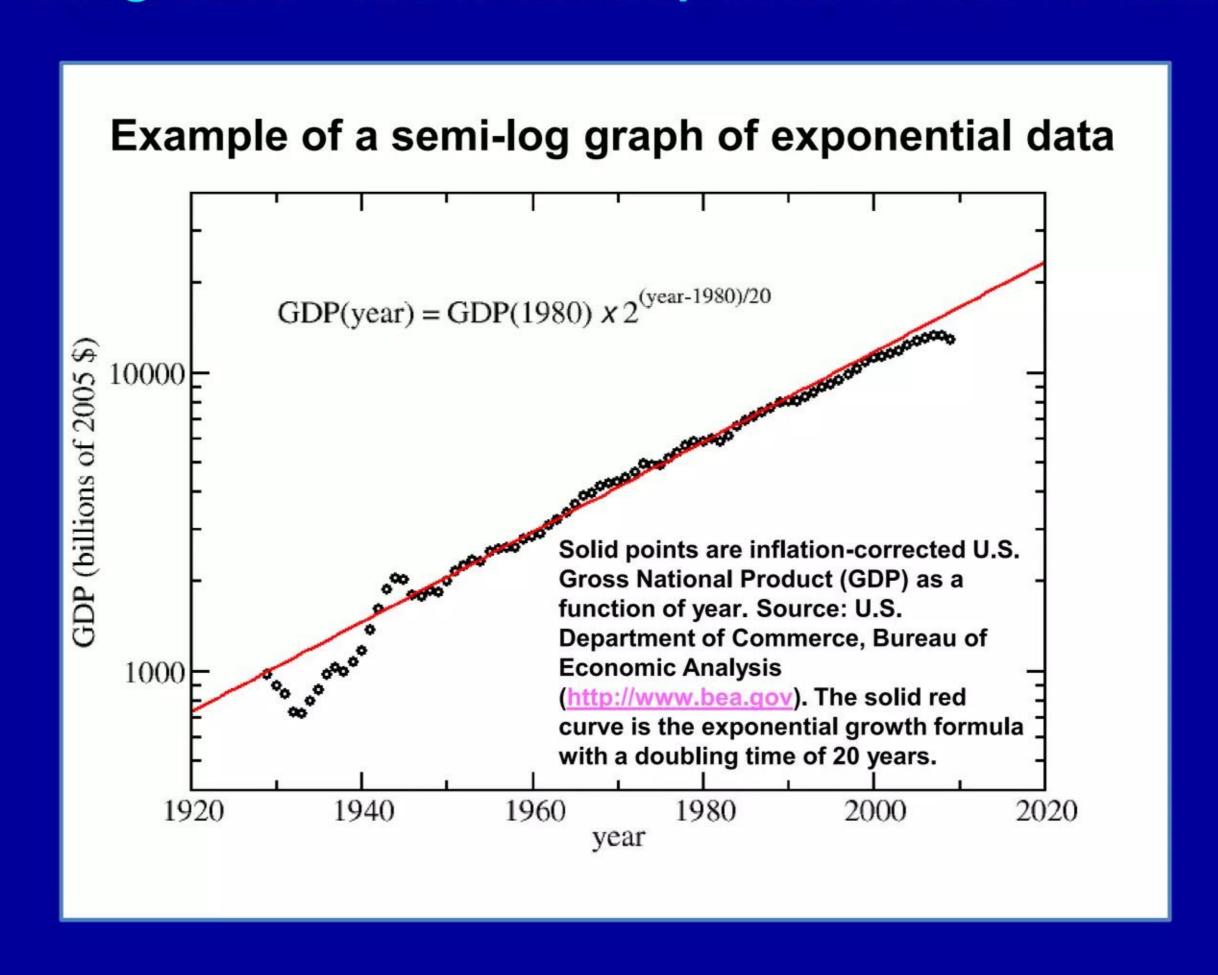
Plots illustrates one linear vs. two nonlinear datasets Numerical values of both x-axis and y-axis scales increase linearly

Nonlinear datasets plotted against linear x- and y-axes scales appear curved



US real GDP increased ~ exponentially from 1928 to 2010 If linear x-axis values plotted against y-axis values on logarithmic scale

And slope is ~ straight line then relationship between two datasets is exponential



# Moore's Law of integrated circuits hypothesized in 1965 Number of transistors per IC chip will increase exponentially over time

"The number of transistors incorporated in a chip will approximately double every 24 months."

Gordon Moore, Co-founder of Intel Corp. (1965 paper)

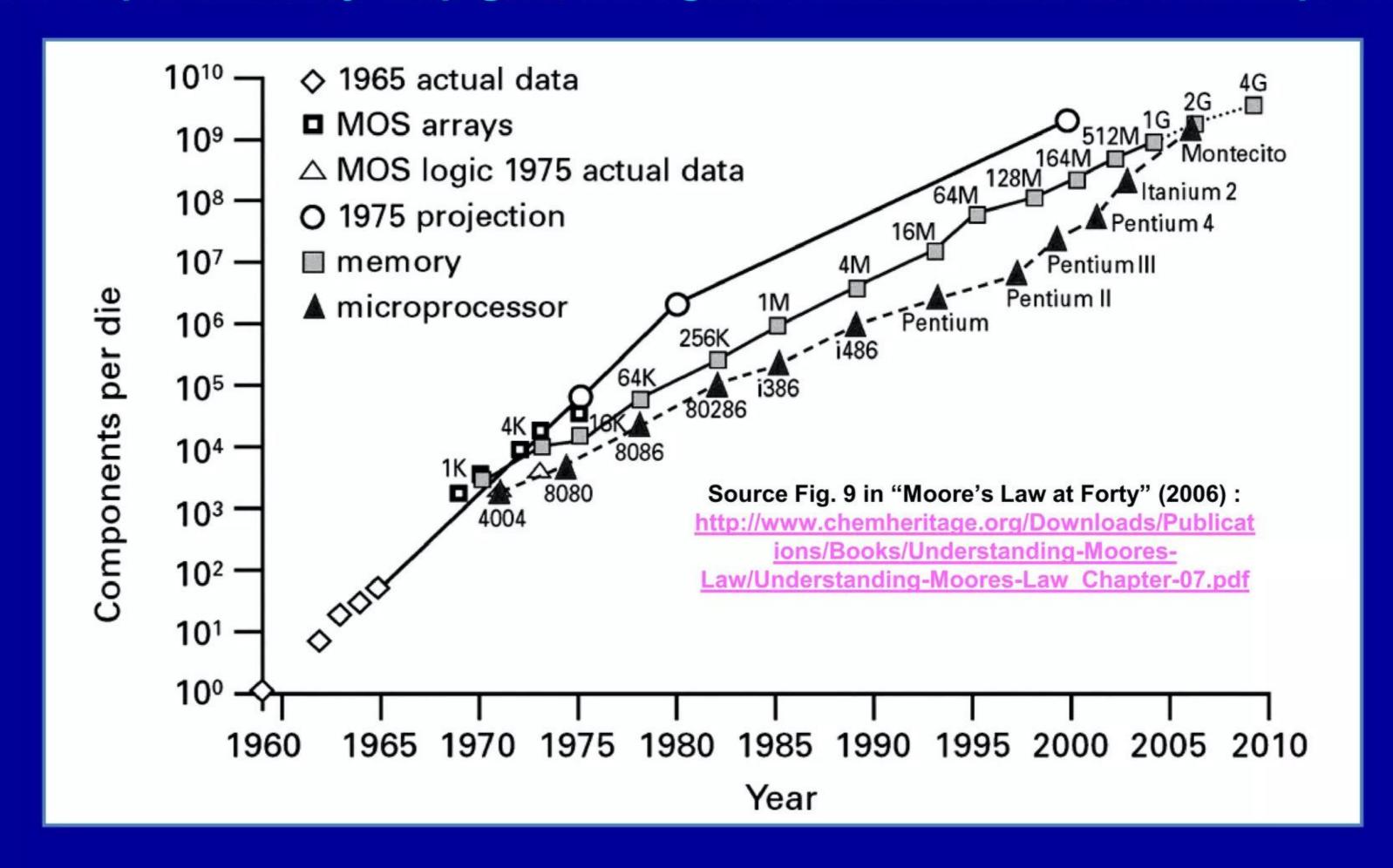
"This is *rapid* growth! In fact, there was even a period during the 1970s when the industry was *more than doubling* the total number of transistors ever made every year, so that more electronics were built each year than existed at the beginning of the year. The pace has slowed recently but is still on a good growth curve. Interestingly, there are no bumps and wiggles in this transistor output curve (Figure 2) as there are in the plot of revenue over time (Figure 1). Transistor output has steadily expanded. Today we have reached over 10<sup>18</sup> transistors a year. That is a hard number to contemplate. Patrick Gelsinger of Intel estimates that present transistor output equals the number of grains of rice produced globally each year. Over the years, I have used a variety of similar comparisons. At one stage, Edward O. Wilson, the well-known naturalist at Harvard, had estimated that there were perhaps 10<sup>16</sup> to 10<sup>17</sup> ants on earth. In the early 1990s, then, the semiconductor industry was producing a transistor for every ant."

Quoted from "Moore's Law at Forty" book chapter by Gordon Moore published in "Moore's Law - Four Decades of Innovation", David Brock, ed., Chemical Heritage Foundation pp. 68 (2006)

Source: http://www.chemheritage.org/Downloads/Publications/Books/Understanding-Moores-Law/Understanding-Moores-Law Chapter-07.pdf

# Chart compares Moore's 1975 projection vs. actual data Growth in total number of transistors per IC chip definitely exponential

Transistors per memory chip grew at higher nonlinear rate than microprocessors



What factors made Moore's 1975 projection work so well? Individual transistor size decreased while increasing total area of dies Industry crammed ever-smaller transistors onto larger areas of chip 'real estate'

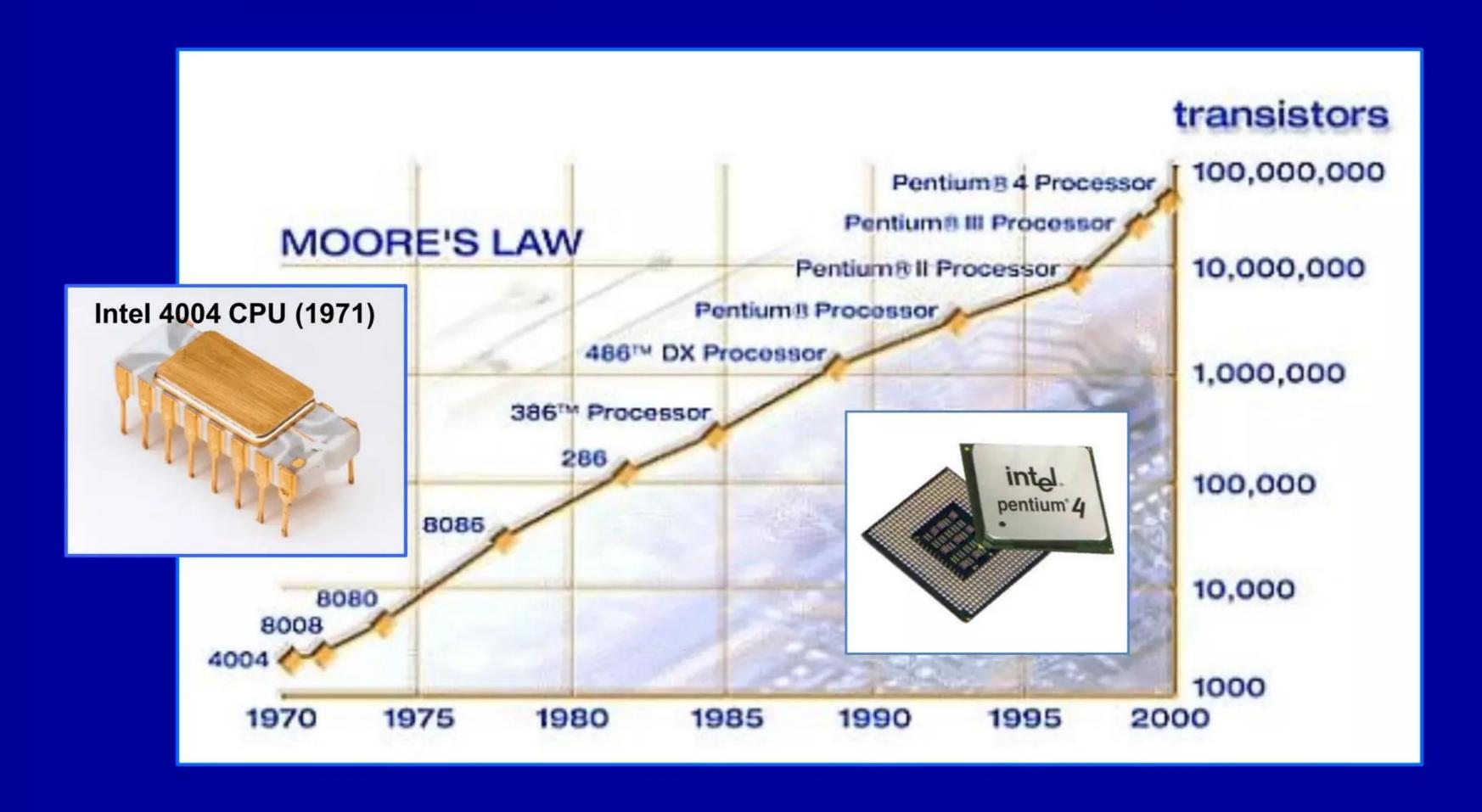
"One of the factors I named the 'die size contribution.' In the semiconductor industry, the term *die* is used for the area on a processed wafer that contains a single device [IC chip]. After a wafer is completely processed, the wafer is cut into many 'dice,' each containing a single integrated circuit [i.e., a fully functional microprocessor or memory chip]. The 'die size contribution' factor in Figure 7 reflects how the semiconductor industry was making larger devices (with increased die sizes) and therefore had more area onto which to put components. A second, slightly larger contribution to the complexity increase was 'dimension reduction.' This was the shrinking of component dimensions, which led to an increase in the density. Multiplying these two contributions results in a curve that represents the combined effect on complexity growth of 'die size and dimensions.' This combined contribution was responsible for more than half of the progress that the industry had made on the complexity curve, but there remained a very considerable element that came from some other factor. On the graph, I labeled this factor the 'contribution of device and circuit cleverness.' This factor I identified with squeezing waste space out of the chip, getting rid of isolation structures and a variety of other things."

Quoted from "Moore's Law at Forty" book chapter by Gordon Moore published in "Moore's Law - Four Decades of Innovation", David Brock, ed., Chemical Heritage Foundation pp. 73 (2006)

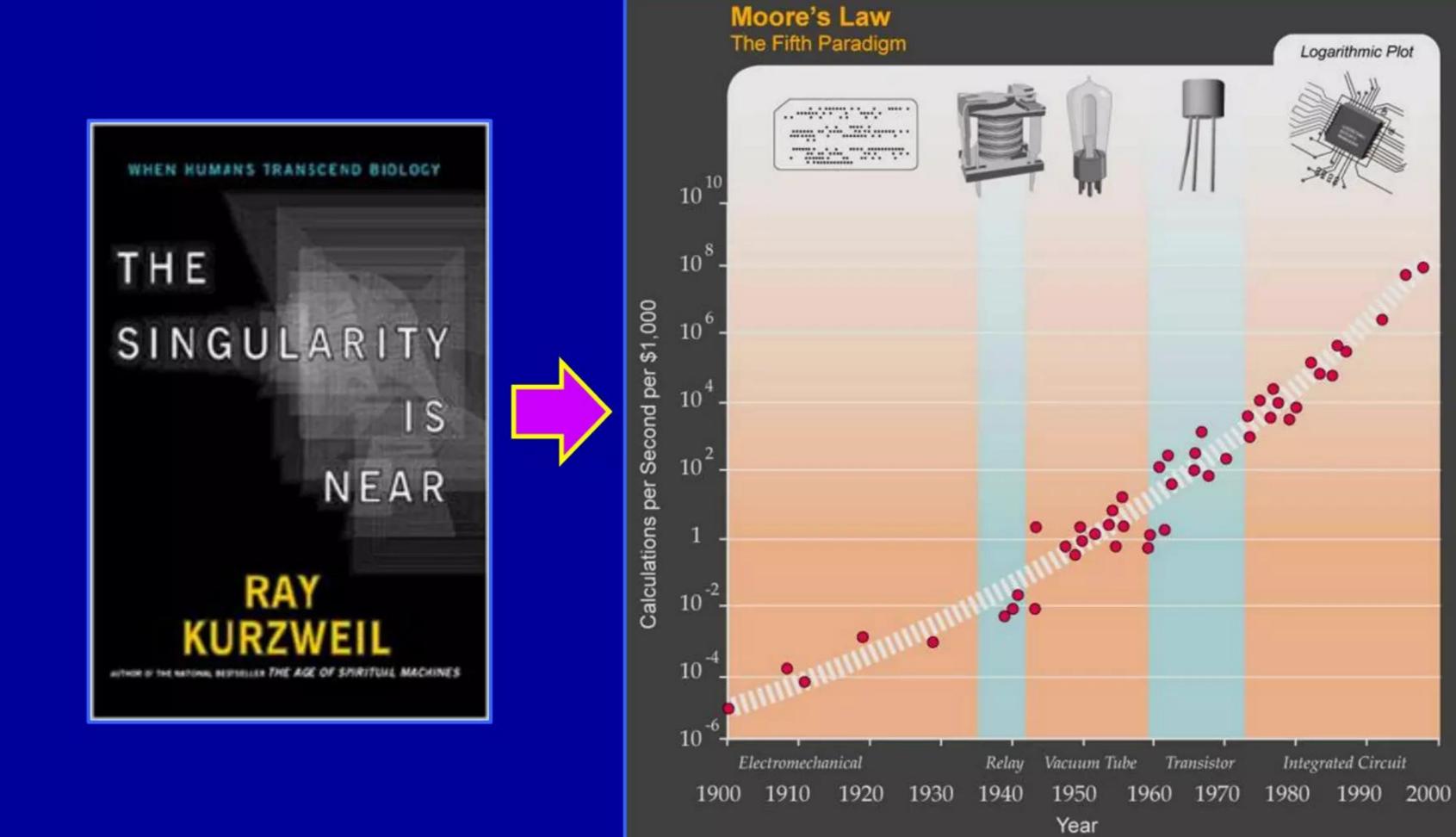
Source: <a href="http://www.chemheritage.org/Downloads/Publications/Books/Understanding-Moores-Law/Understanding-Moores-Law/Chapter-07.pdf">http://www.chemheritage.org/Downloads/Publications/Books/Understanding-Moores-Law/Understanding-Moores-Law/Chapter-07.pdf</a>

Moore's Law of integrated circuits is clearly exponential x-axis scale is linear and y-axis scale is logarithmic: plot ~ straight line

Microprocessor internal clock speeds also increased exponentially over this time



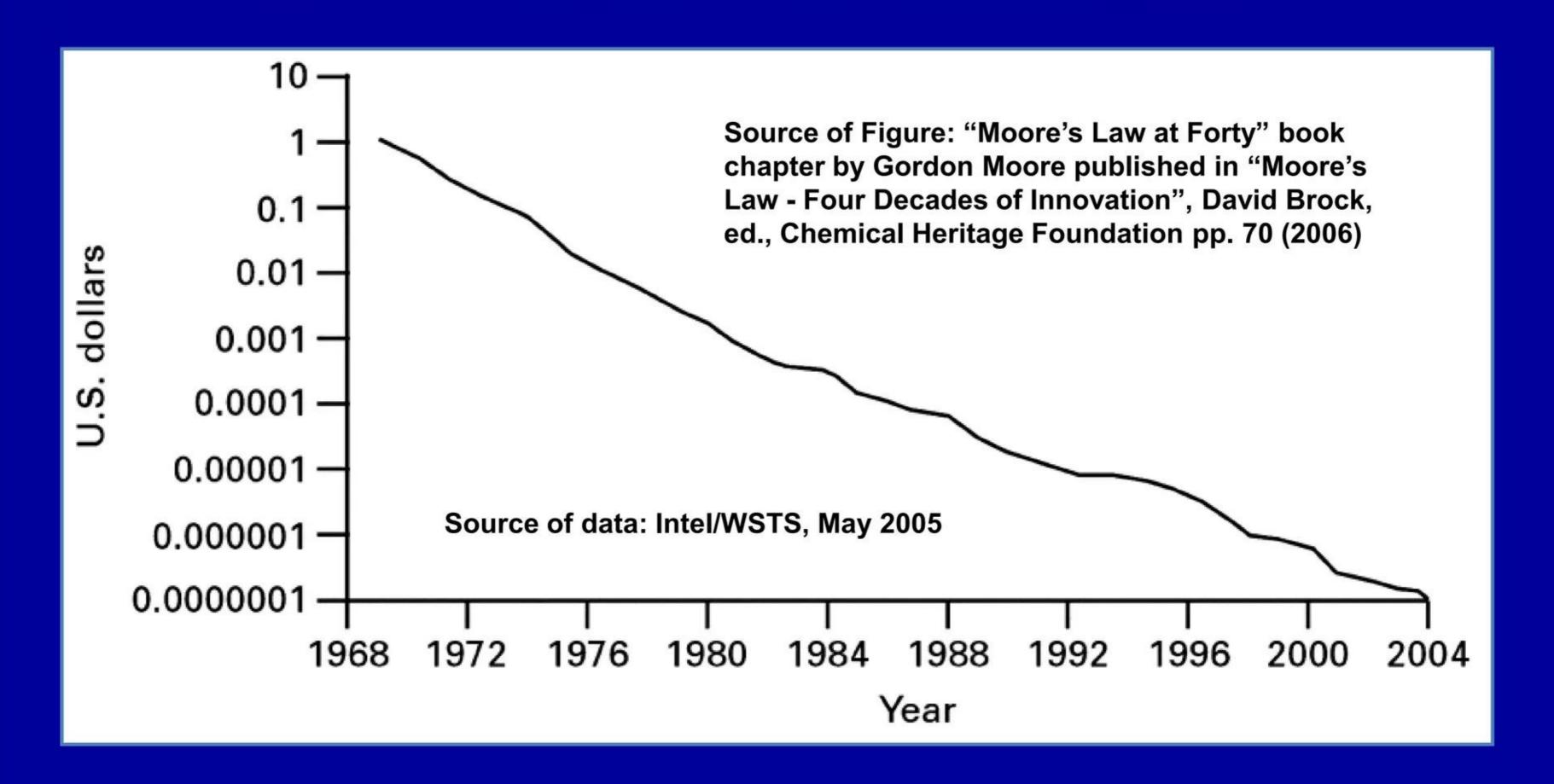
### Moore's Law from 1900 re \$ cost and speed of calculations



Source: http://www.singularity.com/charts/page67.html

Price drop from Moore's Law and Experience Curve Effect Price per transistor decreased exponentially over this time period

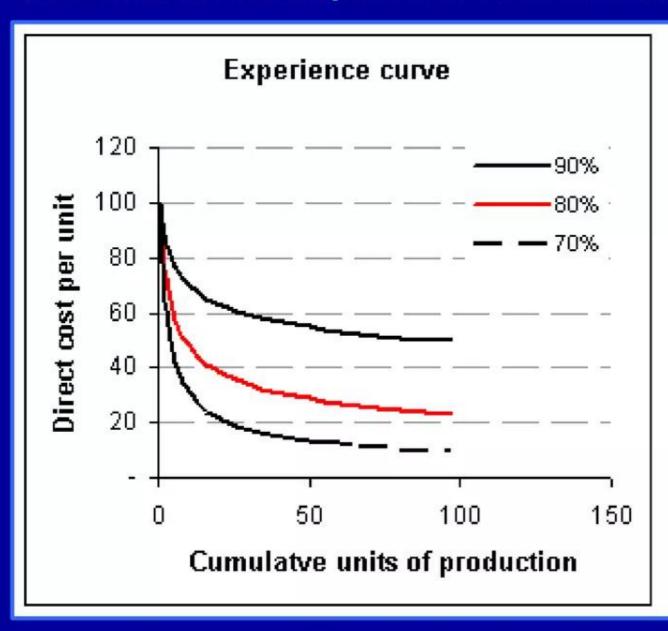
Figure 3. Average price of a transistor in US\$ (1968 - 2004)

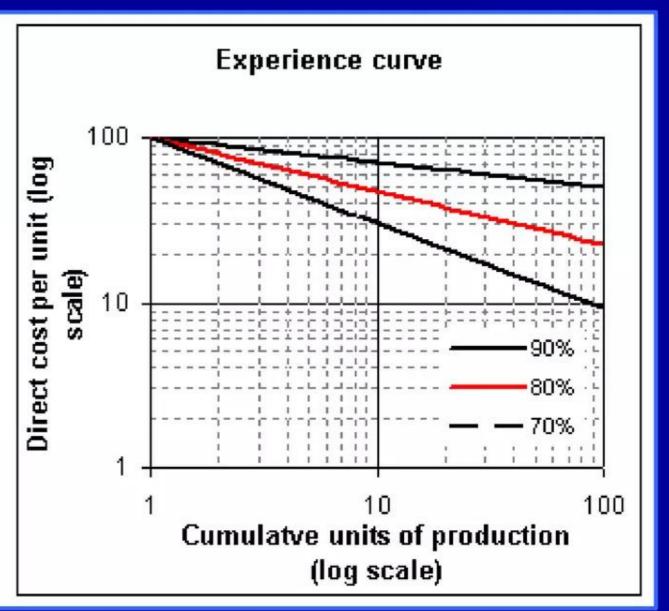


# Experience Curve effect can reduce real product prices Was developed and elaborated by Boston Consulting Group in the 1960s

An experience curve, which differs somewhat from a so-called "learning curve," is a graphical representation of a price phenomenon that was developed and widely publicized as a corporate strategy tool by Bruce Henderson, founder of the Boston Consulting Group. Concept refers to effect that manufacturers learn from doing, which means that the higher the cumulative volume of production, the lower the direct cost per new unit of produced product. Thus, experience curves are innately convex and have downward slopes, as shown in two graphs below:

#### Idealized relationship between direct cost/unit and total cumulative unit production



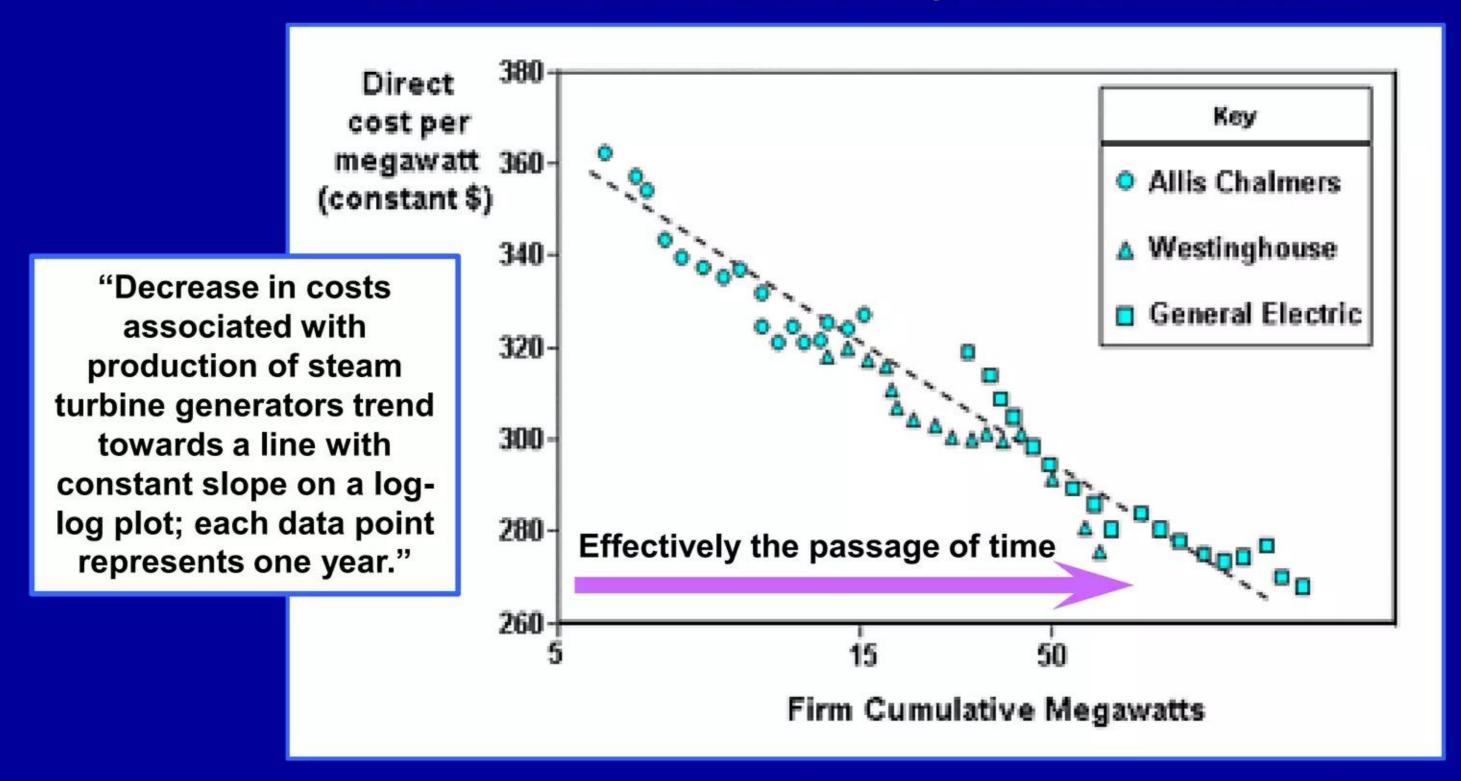


Source: Wikipedia - <a href="http://en.wikipedia.org/wiki/Experience curve effects">http://en.wikipedia.org/wiki/Experience curve effects</a>

# Experience Curve effect can reduce real product prices Cost/megawatt for steam turbines dropped as unit volumes increased

Empirical data shows that it applies to variety of different manufactured products

Total direct cost per megawatt (constant \$) vs. total cumulative megawatts of steam turbines sold and delivered by three OEM manufacturers



Source: Vectorstudy - http://vectorstudy.com/management-theories/experience-curve

Illustrates impact of Moore's Law and Experience Curves Enormous decreases in size with vastly greater raw computing power

CPU clock speed of today's 2014 Apple iPhone 6 is ~ 1.4 GHZ or 700x Osborne

"An Osborne Executive portable computer, from 1982 with a Zilog Z80 4 MHz (0.002 GHZ) CPU, and a 2007 Apple iPhone with a 412 MHz ARM11 CPU; the Executive weighs 100 times as much, has nearly 500 times as much volume, cost approximately 10 times as much (adjusted for inflation), and has about 1/100th the clock frequency of the smartphone."





# As of 2014 Moore's Law still has no end on the horizon New technologies under development can extend duration of this law

Quantum computing may provide next technological extension to Moore's Law

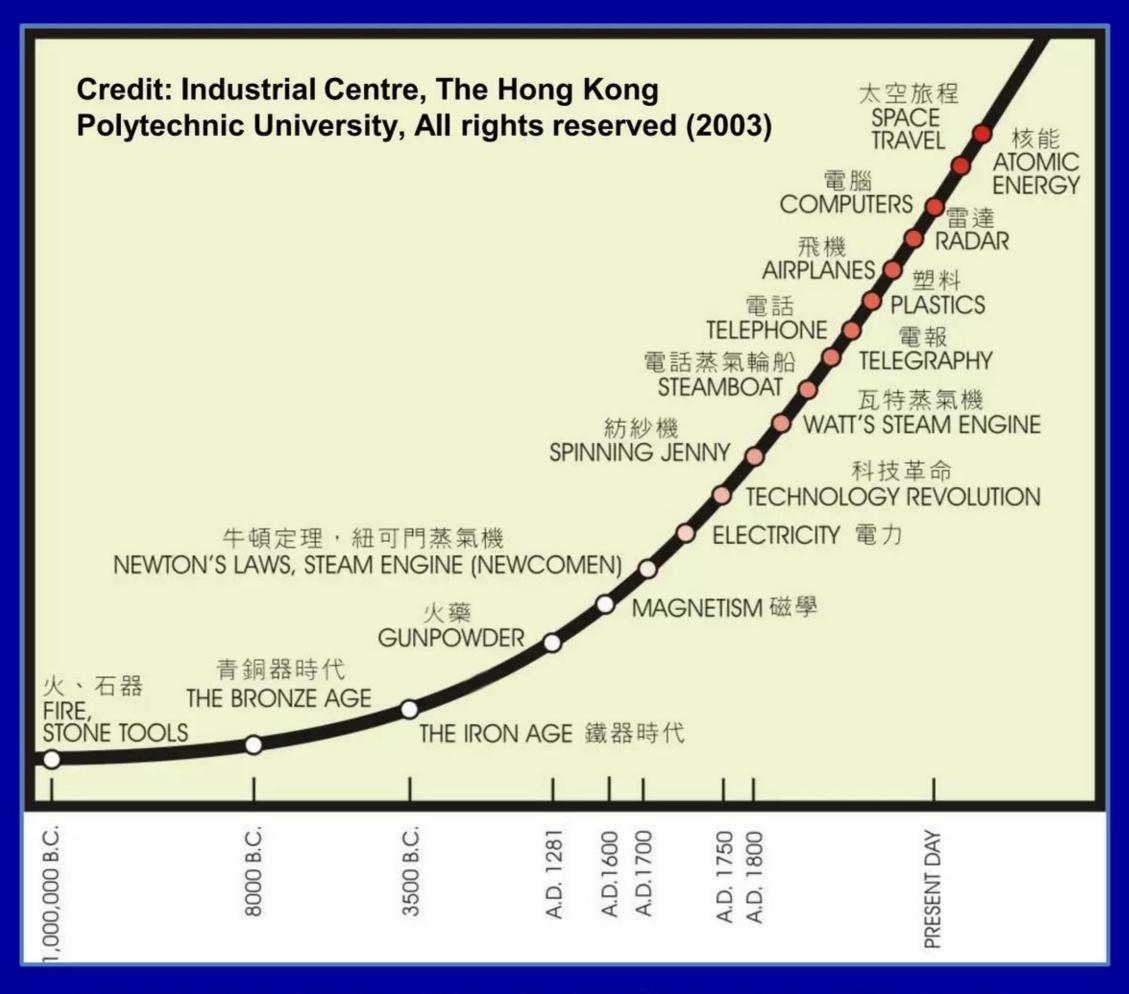
"Moore's Law is really about economics. My prediction was about the future direction of the semiconductor industry, and I have found that the industry is best understood through some of its underlying economics." [pp. 67]

"Having outlined my general approach to understanding the semiconductor industry and having identified some key factors for keeping on the complexity curve, one might ask, 'When is it all going to end?' I have been asked that question at least a hundred times this year. The answer is: 'Not very soon.' I can see the complexity curve lasting for at least as long now as I ever could in the past." [pp. 84]

Quoted from "Moore's Law at Forty" book chapter by Gordon Moore published in "Moore's Law - Four Decades of Innovation", David Brock, ed., Chemical Heritage Foundation (2006)

Source: http://www.chemheritage.org/Downloads/Publications/Books/Understanding-Moores-Law/Understanding-Moores-Law Chapter-07.pdf

### Growth of technology has also been exponential over time Subjective chart shows selected examples of improved technology



Source: http://tds.ic.polyu.edu.hk/td/theme1/t1 content e.htm

# Lag between invention and application can be substantial Chart reflects views of Hong Kong Polytechnic faculty on time interval

Lattice comment: lag time only shortening for certain kinds of products - not all

Name of Product	From Invention to Application	Duration	Name of Product	From Invention to Application	Duration
Steamer	1680~1780	100	Aircraft	1897~1911	14
Electromotor	1829~1886	57	Television	1922~1934	12
Telephone	1820~1876	56	Atom	1939~1945	6
Wireless Communication	1867~1902	35	Transistor	1948~1953	5
Vacuum tube	1882~1915	33	Integrated circuitry	1958~1961	3
Vehicle	1868~1895	27	Laser Machine	1960	1

Credit: Industrial Centre, The Hong Kong Polytechnic University, all rights reserved (2003)

Source: http://tds.ic.polyu.edu.hk/td/theme1/t1 content e.htm

# Lag between invention and application can be substantial Advances in theoretical physics sometimes enable commercialization

Maxwell's equations integrated electric and magnetic effects into coherent whole

Timeline of events suggests Maxwell's theory greatly helped to facilitate commercialization

- 1826 Ampere's Law discovered relates magnetic fields to flows of electrical current
- 1831 Faraday discovered Law of electromagnetic induction crucial advance in physics needed to develop a workable technology for commercial systems capable of generating electric power
- 1835 Gauss' Law formulated explains how electric fields behave in vicinity of electric charges
- 1865 Maxwell published his famous equations in seminal paper, "A dynamic theory of the electromagnetic field" in which he integrated Ampere, Faraday, and Gauss' work into single elegant, coherent mathematical framework that fully explained electromagnetic phenomena
- 1879 Edison invented the modern incandescent electric light bulb for illumination
- 1882 First coal-fired central station electric power generation plant: Edison's Pearl Street
   Station opened in New York City with total output of 600 kWh
- 1882 First hydroelectric central station power generation plant: Edison's Vulcan Street Plant at a dam on the Fox River in Appleton, Wisconsin with initial electrical output of 12.5 kWh
- We all know what happened after 1882: there was explosive exponential growth of electric power generation, first in the USA and then spreading across the entire industrializing world

Electricity is now much less costly than price back in 1882
Edison knew that mass production of electricity would reduce price
His bold vision was unquestionably the Henry Ford Model T of electricity

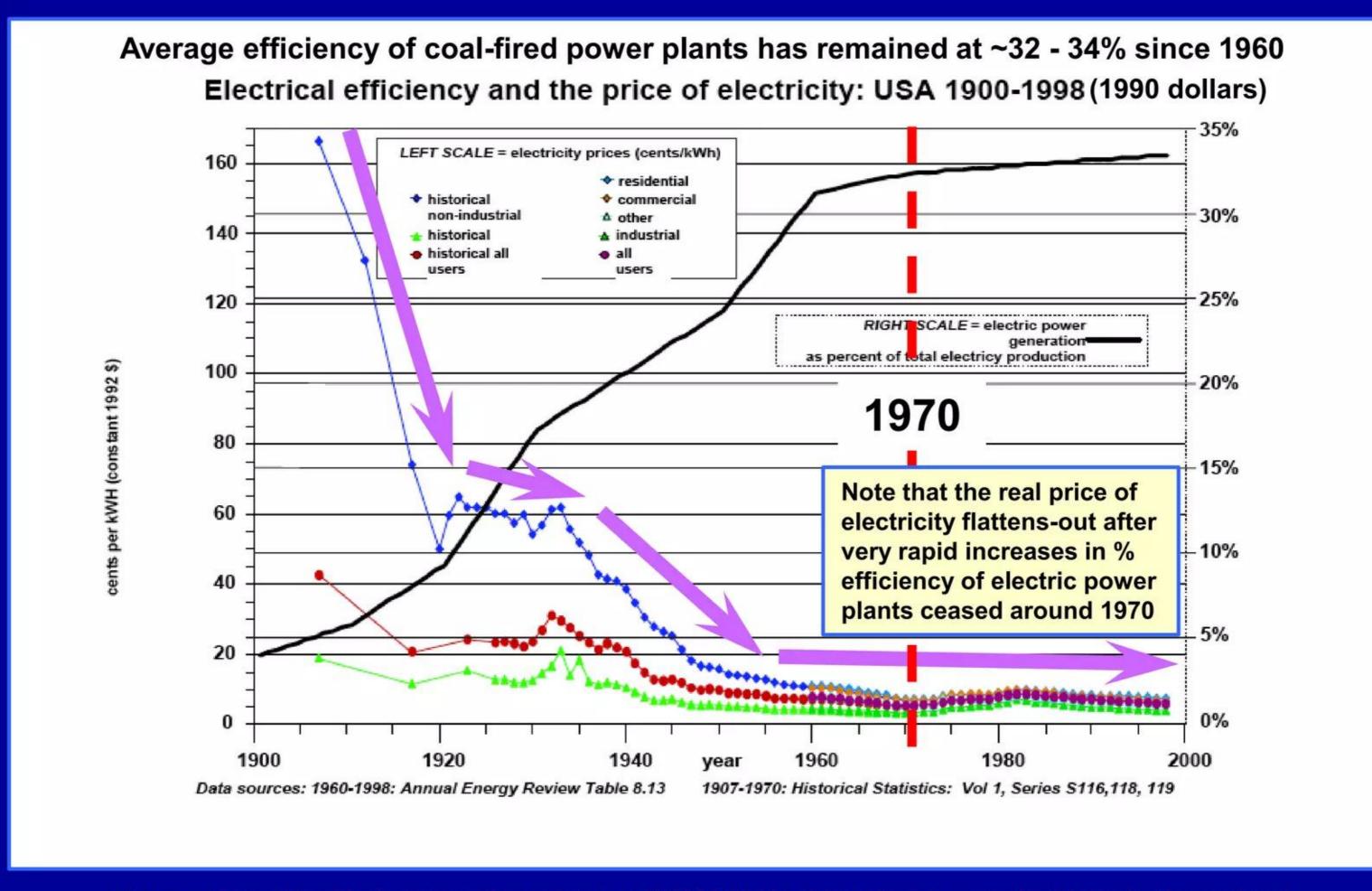
"Just wait a little while," prophesied Edison, "and we'll make electric light so cheap that only the wealthy can afford to burn candles." (*ca.* 1880)

"Edison lived [until 1931] to see lamps that gave four times as much light and cost one-fifth as much to buy."

General Electric Company newspaper advertisement February 4, 1954

### Edison's prophecy was right: exponential decrease in price

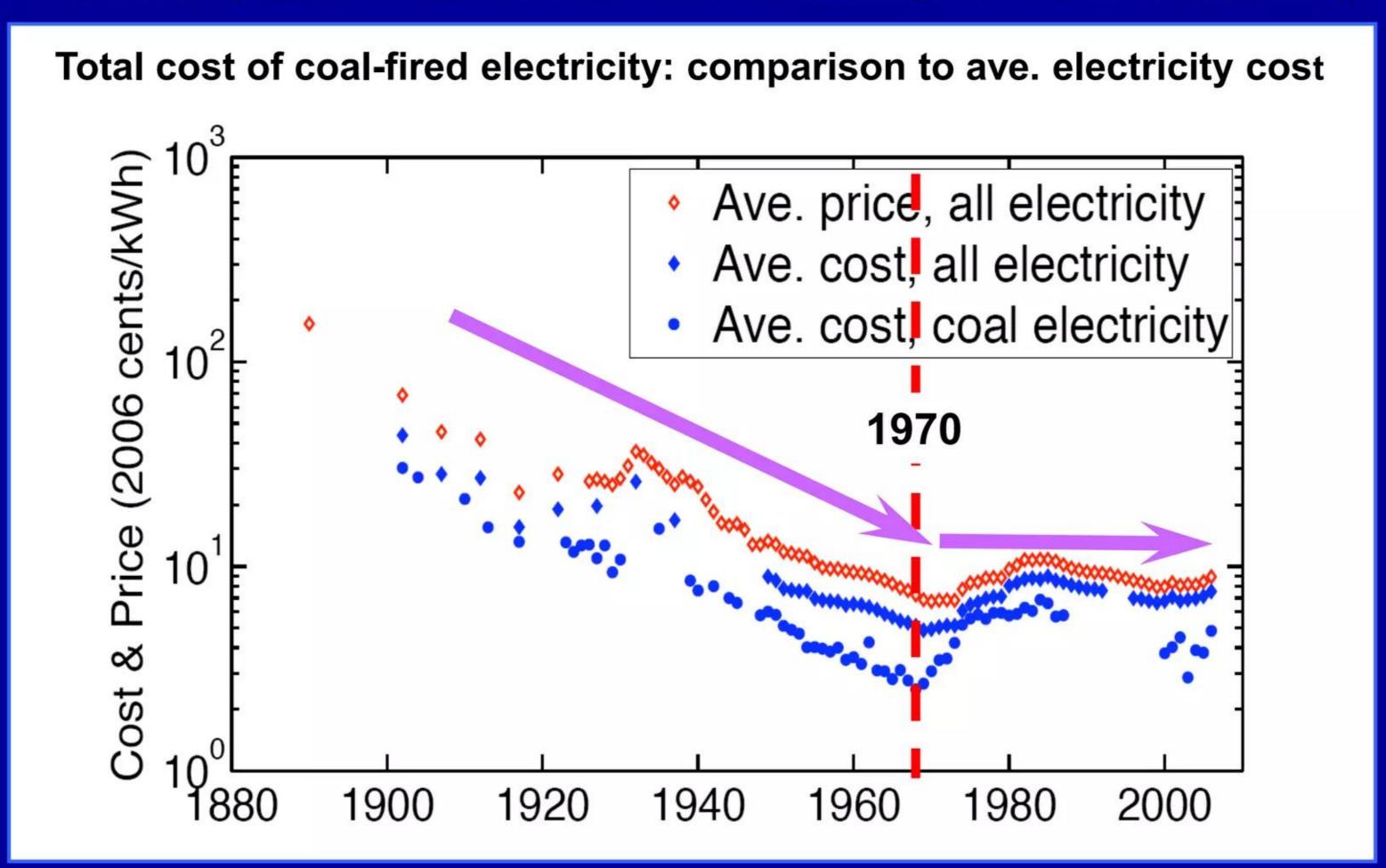
By 1910, the price of electricity was ~\$1.60 per kWh (1990 dollars); from 1920s through mid-1930s it mostly averaged around \$0.60 kWh; today, the price of electricity ranges from ~ \$0.05 to 0.12 kWh



Source: http://tingilinde.typepad.com/starstuff/2009/05/the-historic-price-of-electricity-in-the-us.html

### Exponential decrease in price from 1880 - 1970 then flat

Fig. 10 in "Historical costs of coal-fired electricity and implications for the future" J. McNerney, J. Trancik, and J. D. Farmer, SFI Working Paper: 2009-12-047 (2009)

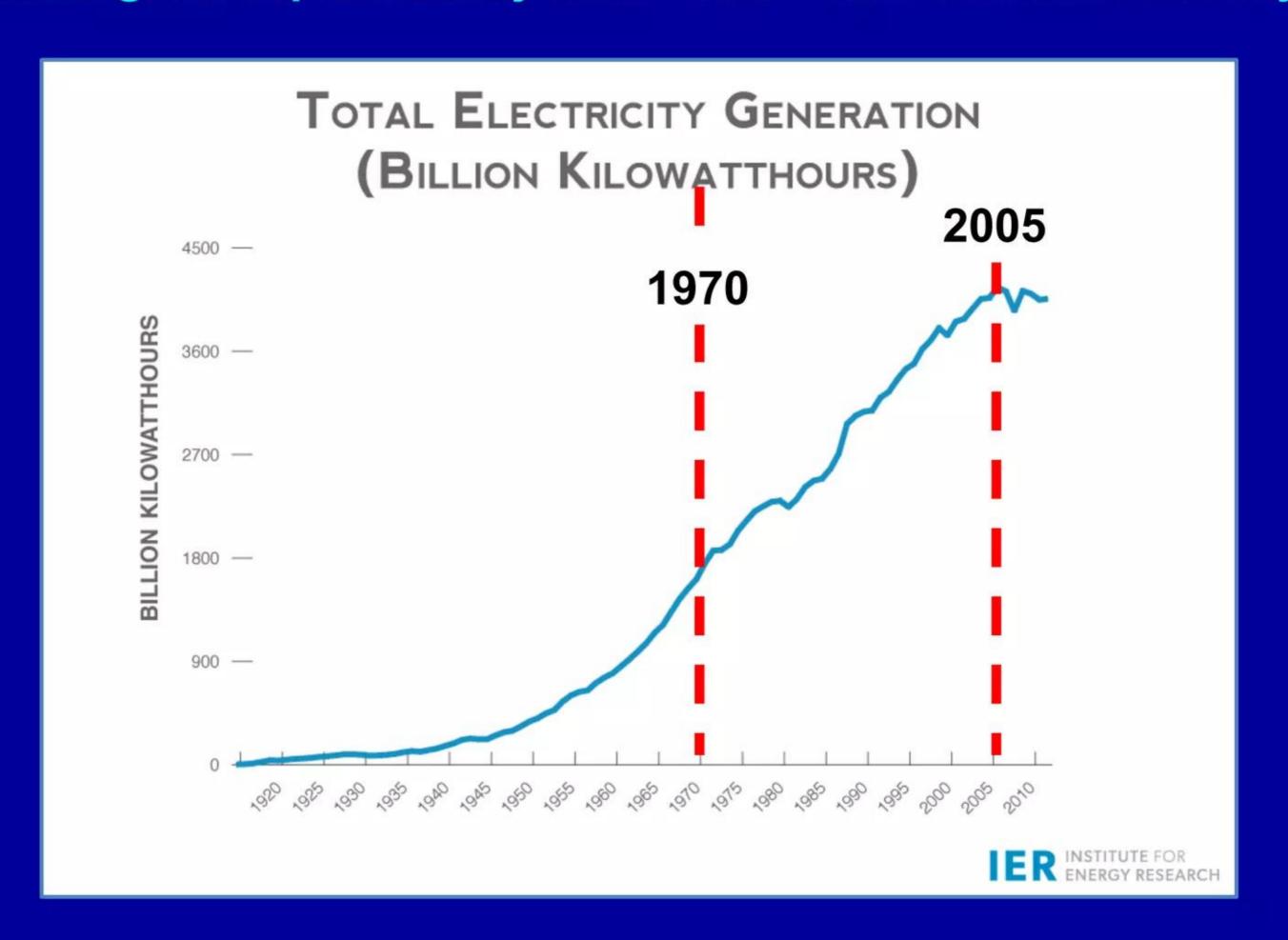


Source: Santa Fe Institute - working papers <a href="http://www.santafe.edu/media/workingpapers/09-12-047.pdf">http://www.santafe.edu/media/workingpapers/09-12-047.pdf</a>

Total annual US electricity production from 1915 - 2012

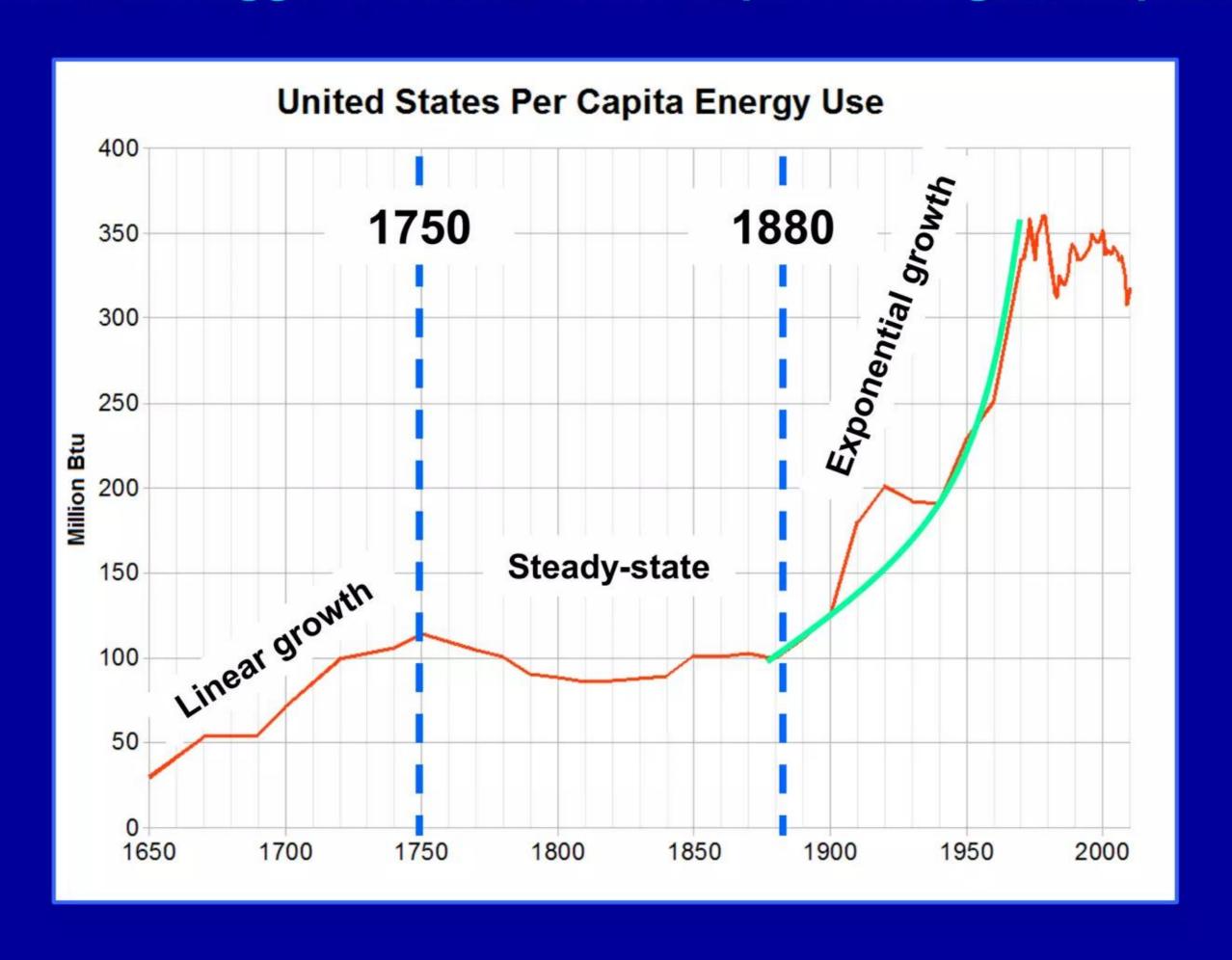
At the grid level electricity is non storable so generation = consumption

Total generation grew exponentially from 1915 - 1970 and then linearly thereafter



Rates of growth in per capita energy use can vary greatly USA went through a linear phase, steady-state, and exponential growth

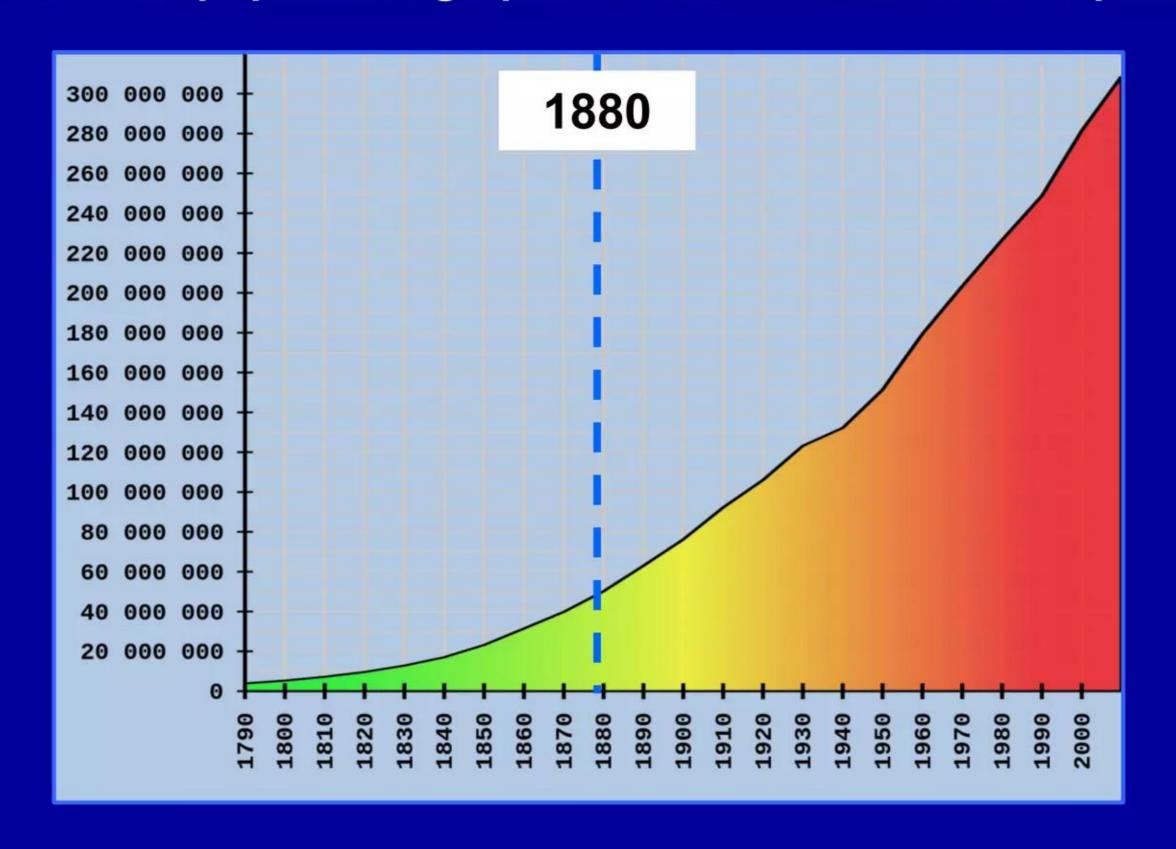
What causal factors triggered onset of the exponential growth phase in ~1880?



Population data doesn't explain changes in per capita energy US population growth has been uninterruptedly exponential since 1790

While population growth does affect energy usage it is just part of the story

US Census population graph from 1790: source is Wikipedia



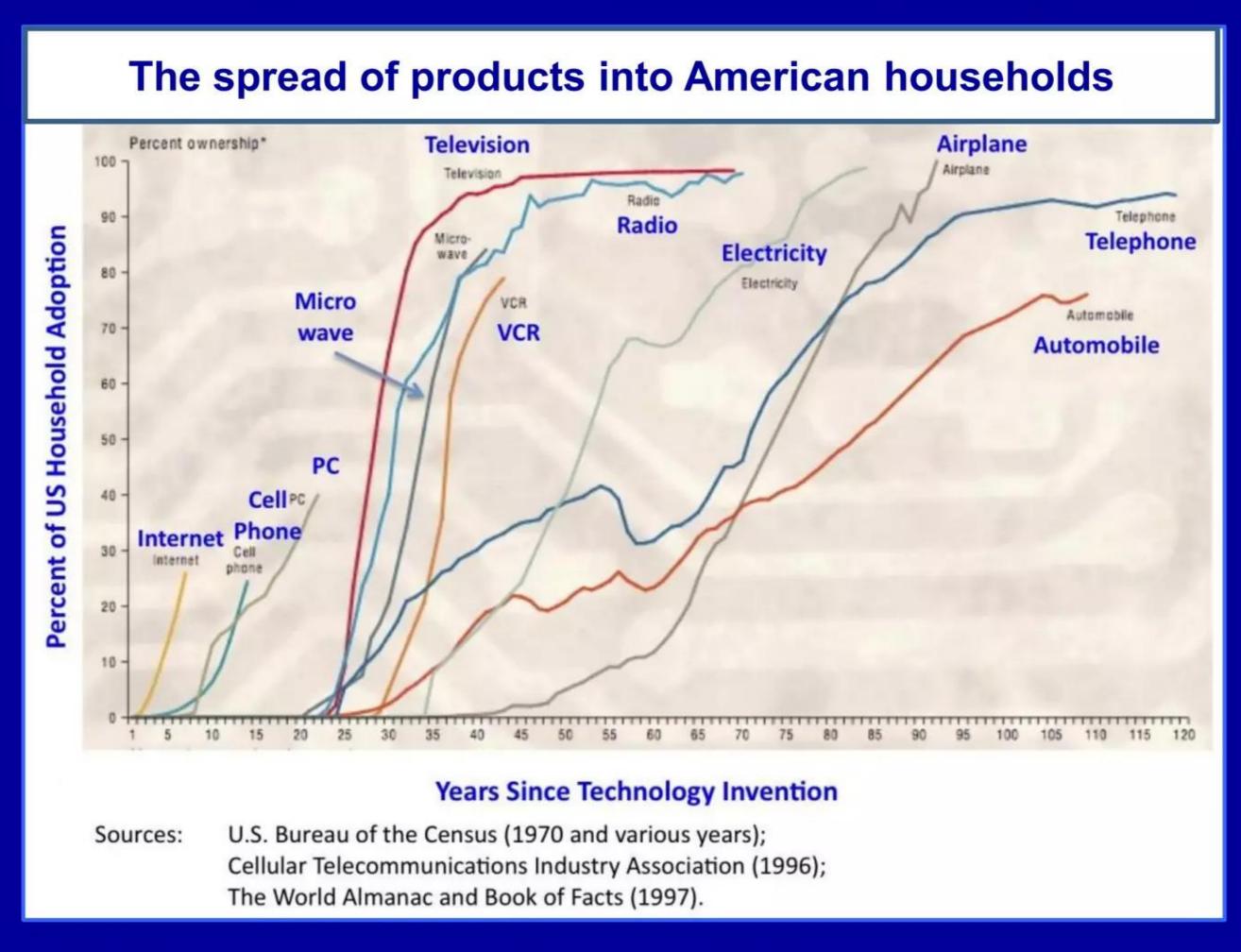
Cause: huge commercialization burst in new technologies Introduction of automobiles, urban electrification and electric appliances

Synergistic technologies catalyzed exponential growth in per capita energy use

Key examples - autos were single largest contributor to increased per capita energy use:

- 1859 Modern rechargeable lead-acid battery: Gaston Planté (France)
- 1876 Telephone: Alexander Graham Bell (USA)
- 1879 Modern incandescent electric light bulb: Thomas Edison (USA)
- 1882 Edison begins installing series of electric power generation stations and grids (USA)
- 1882 Electric clothes iron: Henry Seeley (USA)
- 1885 Automobile with gasoline-powered internal combustion engine: Karl Benz (Germany)
- 1885 First riveted steel coal furnace for convective central home heating: Dave Lennox (USA)
- 1886 Electric powered fan: Schulyer Wheeler (USA)
- 1889 Electric sewing machine: Singer Company (USA)
- 1891 Electric ovens go on sale to public (USA)
- 1899 Invention of radio: Guglielmo Marconi (Italy)
- 1904 or thereabouts home electric washing machine (USA): first inventor is unknown
- 1907 Portable electric home vacuum cleaner: James Spangler (USA)
- 1913 Electric refrigerator: Fred Wolf (USA)

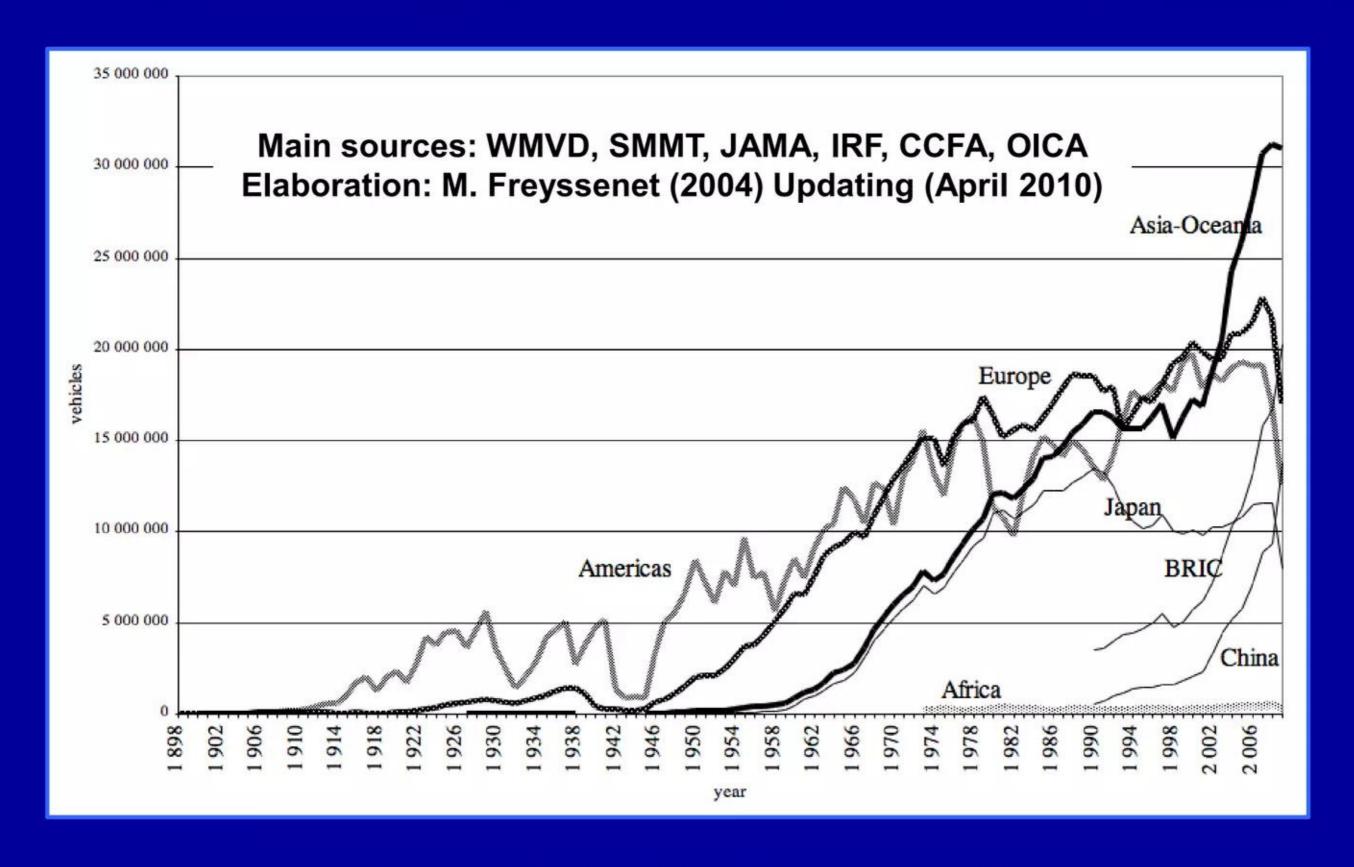
# % Household ownership vs. time since initial invention US market growth rates variable: television much faster than automobiles



Source: http://magicalcompendium.blogspot.com/2011/07/innovation-stagnation.html

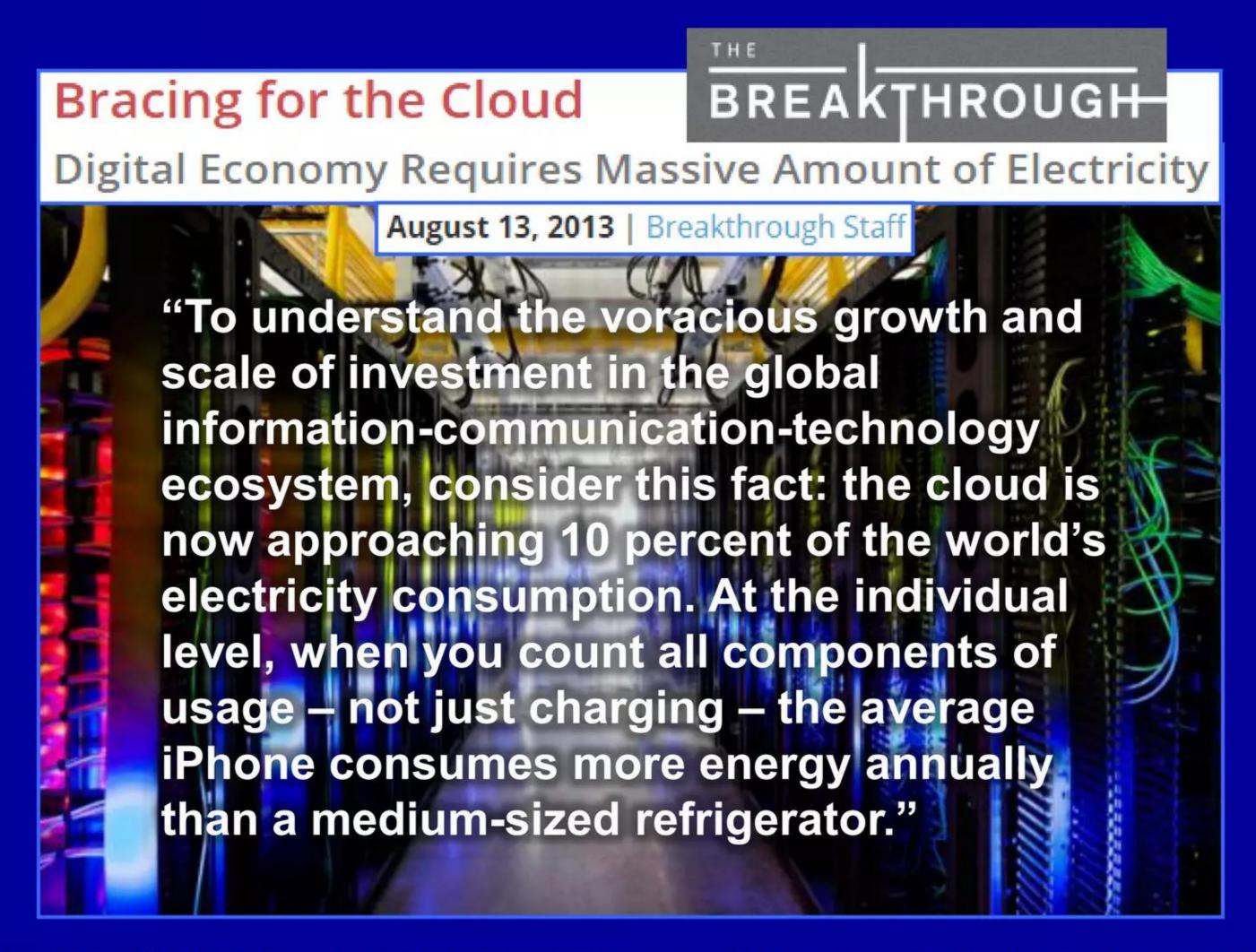
Data shows growth of vehicle ownership across world Former "Third World" countries are presently growing exponentially

World automobile production by continent and some large emerging countries



Source: http://revel.unice.fr/eriep/?id=3301

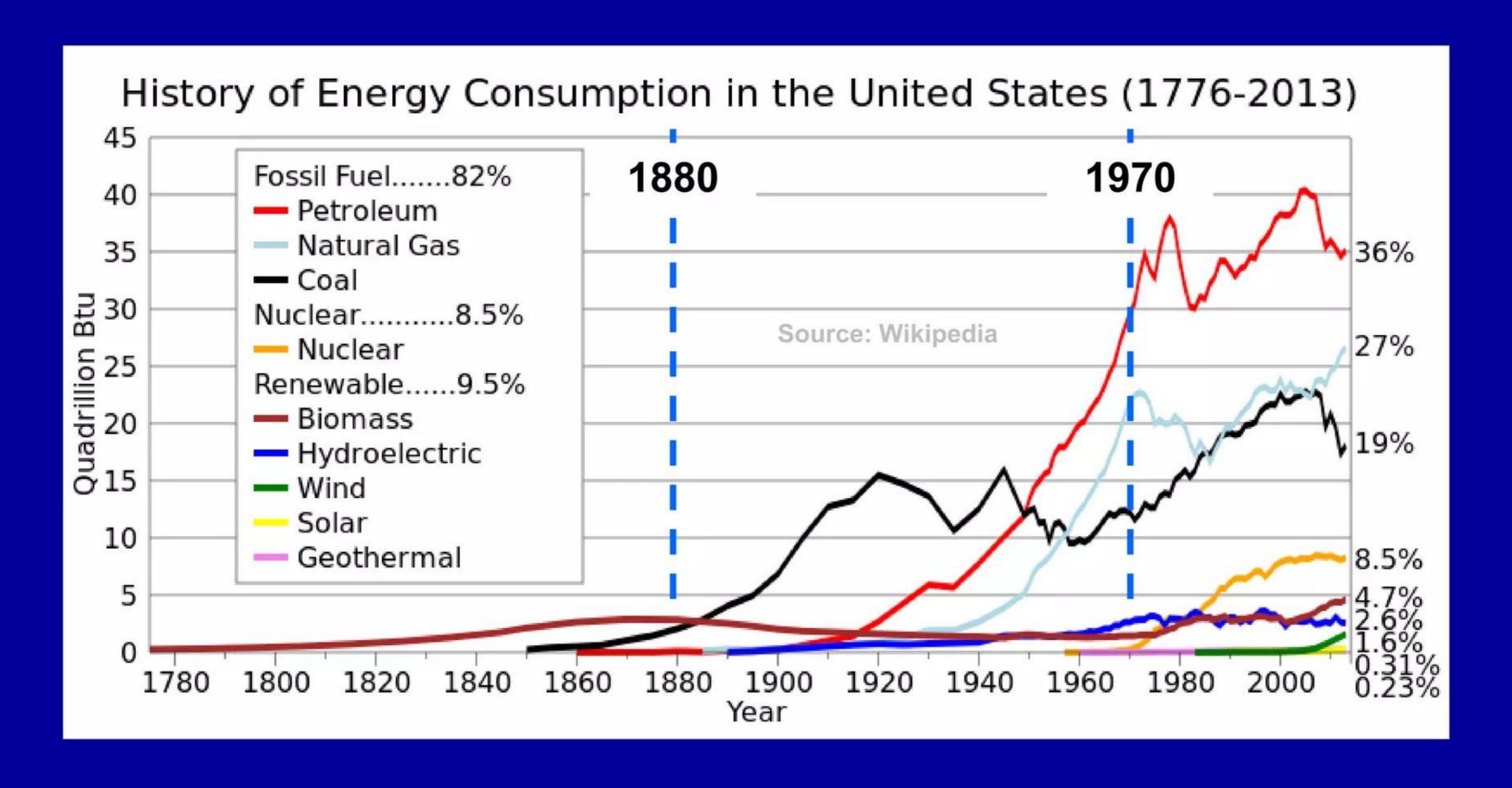
### Huge Internet growth since 1993 increases energy demand



Source: http://thebreakthrough.org/index.php/programs/economic-growth/bracing-for-the-cloud/

Annual US energy consumption by source: 1776 - 2013 Petroleum consumption grew exponentially until ~1975 then linearly

CO<sub>2</sub>-emitting fossil fuels accounted for ~82% of US energy consumption in 2013



### Future global demand for energy will be very strong Real GDP growth and increased demand for energy highly correlated

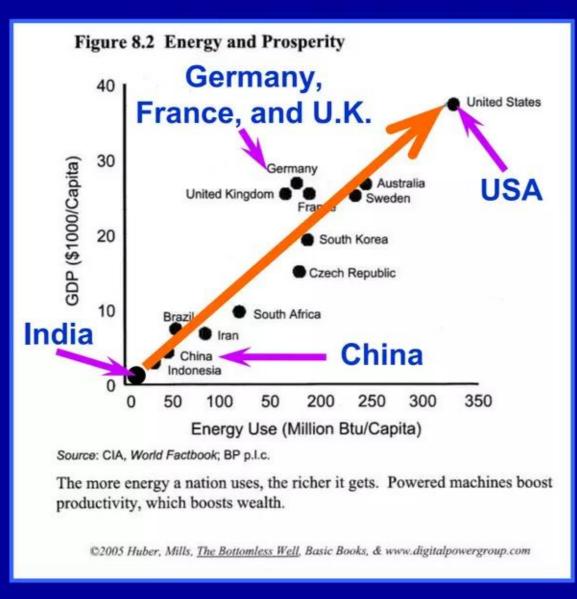
### Future demand cannot be met without vast improvement in energy technologies

Empirical data presented below (Huber & Mills - 2005; Brown et al. - 2011) shows that growth in per capita GDP (which is what also reduces population growth rates) is highly correlated with corresponding increases in total energy demand; in today's modern energy-intensive societies, this determines the overall standard of living. Measured against finite fossil fuel supplies and other non-renewables, ratcheting increases in demand for energy could exacerbate energy supply issues as global real GDP growth continues into the future.

India & China now account for ~39% of the world's population

Note: in 2008 India (not shown in Huber-Mills' chart) had est. GDP (\$1000/Capita) of 1.327 and Energy Use (Million Btu/Capita) of 12.6, placing it near origin of bold blue arrow in the lowermost corner of the left quadrant;

Upward progression of countries along the trajectory of blue arrow creates increases in total world energy demand. The faster GDP per capita rises in all countries, the faster total global energy demand increases.



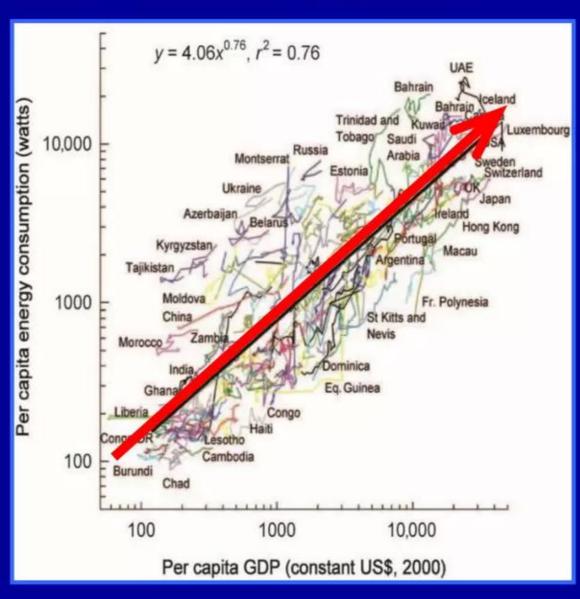


Fig. 1, pp. 20, Brown et al., "The relationship between per capita energy use and per capita gross domestic product (GDP; in US dollars), plotted on logarithmic axes, from 1980 to 2003."

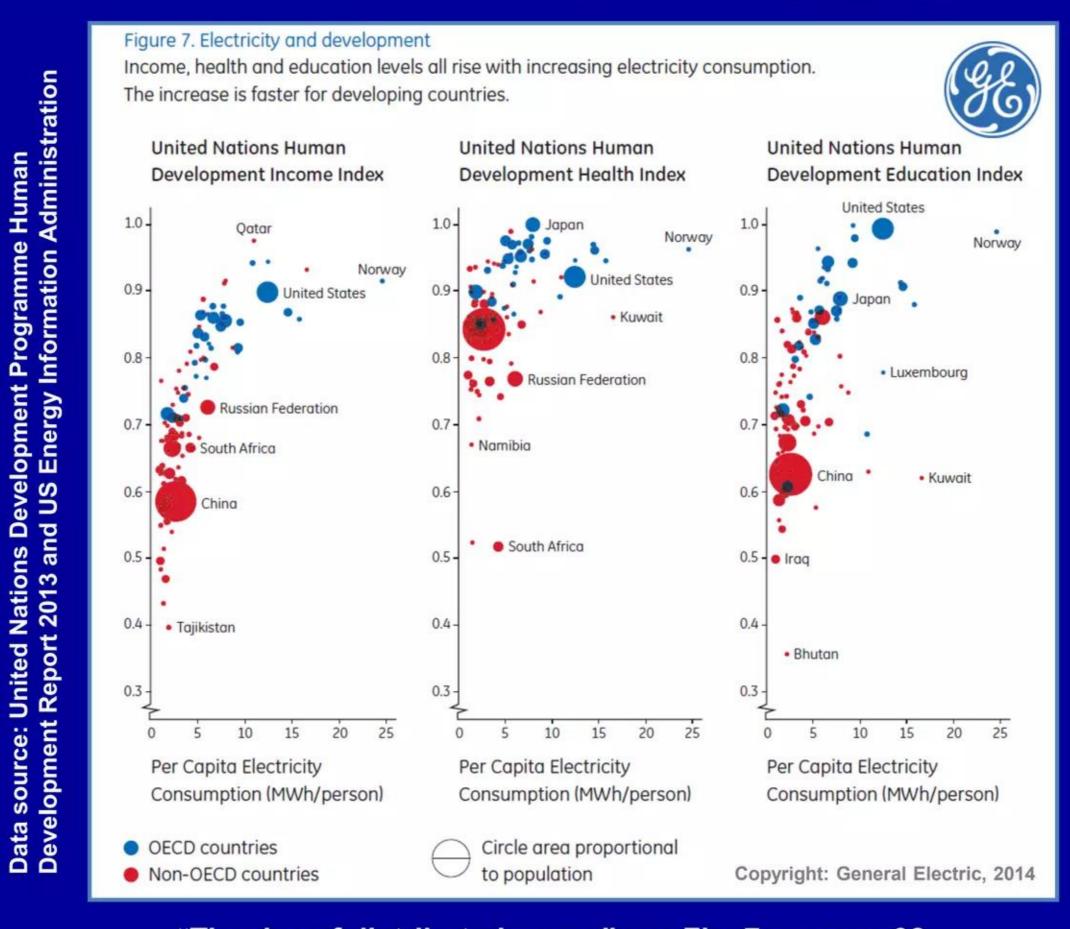
From: "Energetic Limits to Economic Growth"

J. Brown et al.

BioScience 61 pp. 19 - 26 (2011)

http://sev.lternet.edu/~jne kola/nekola%20pdf/bs-61-19-26.pdf

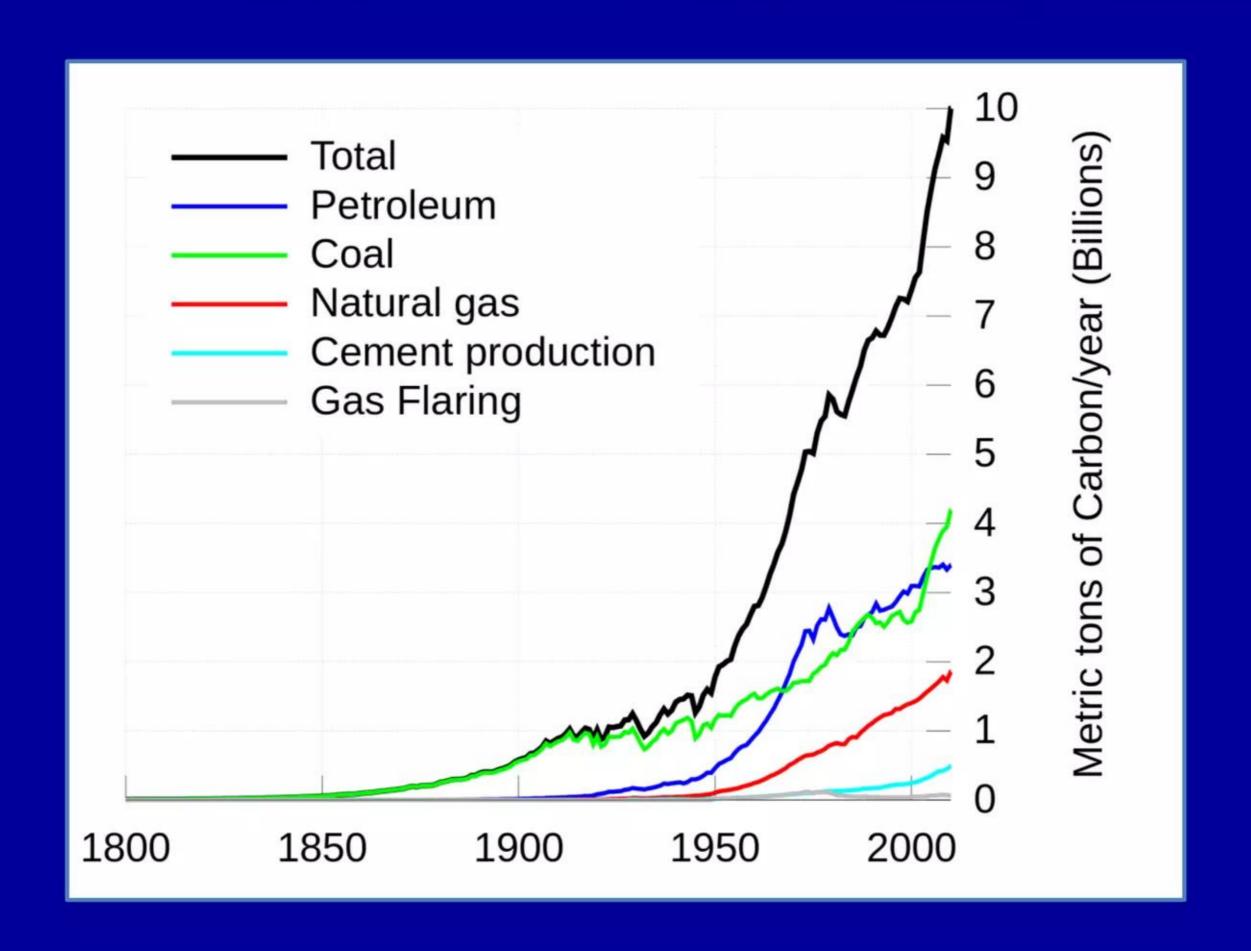
### Quality of life clearly better with increased use of energy This relationship contributes to strong underlying global energy demand



"The rise of distributed power" see Fig. 7 on page 32 B. Owens, General Electric - Ecomagination (February 2014) <a href="http://www.eenews.net/assets/2014/02/25/document\_gw\_02.pdf">http://www.eenews.net/assets/2014/02/25/document\_gw\_02.pdf</a>

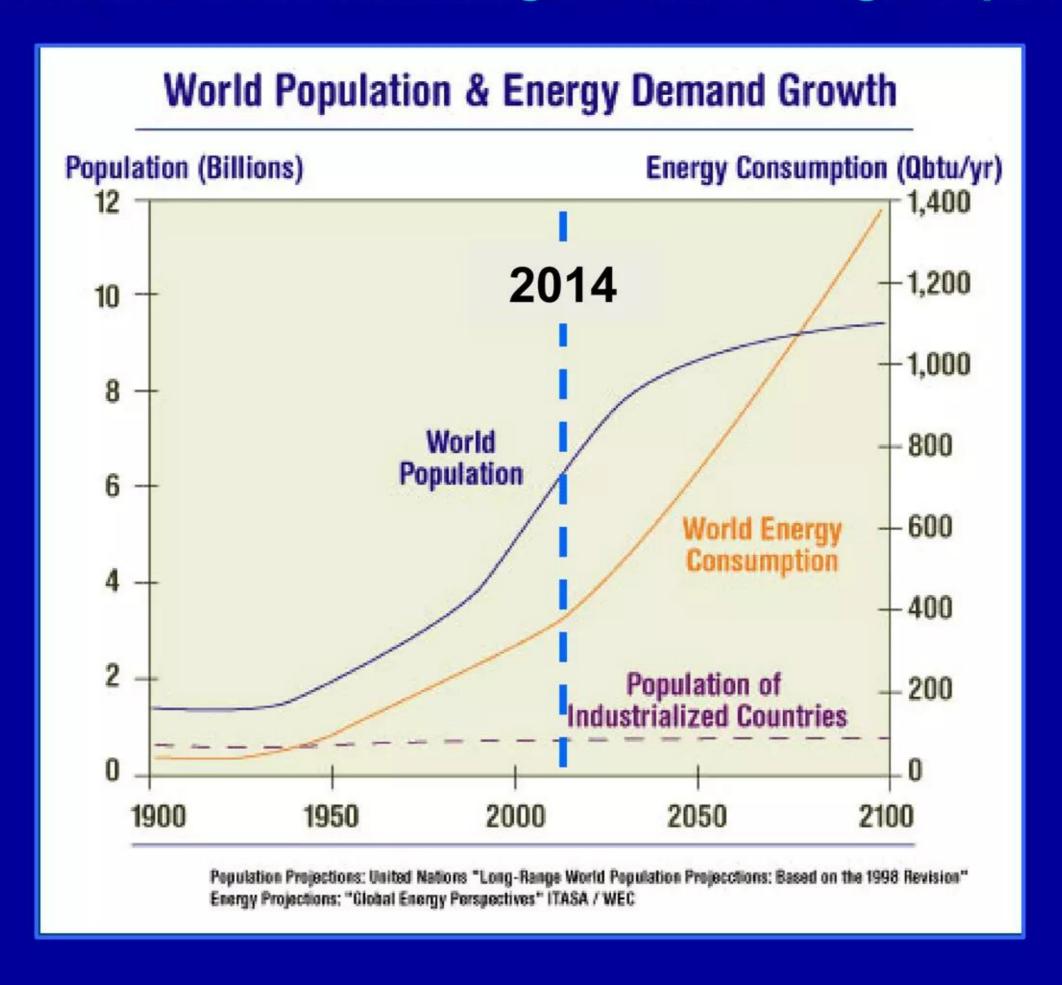
Global Carbon emissions by source from 1800 to today Growth in total Carbon emissions has stayed ~ exponential since 1850

Produced almost entirely by combustion of fossil fuels, i.e. burning with Oxygen



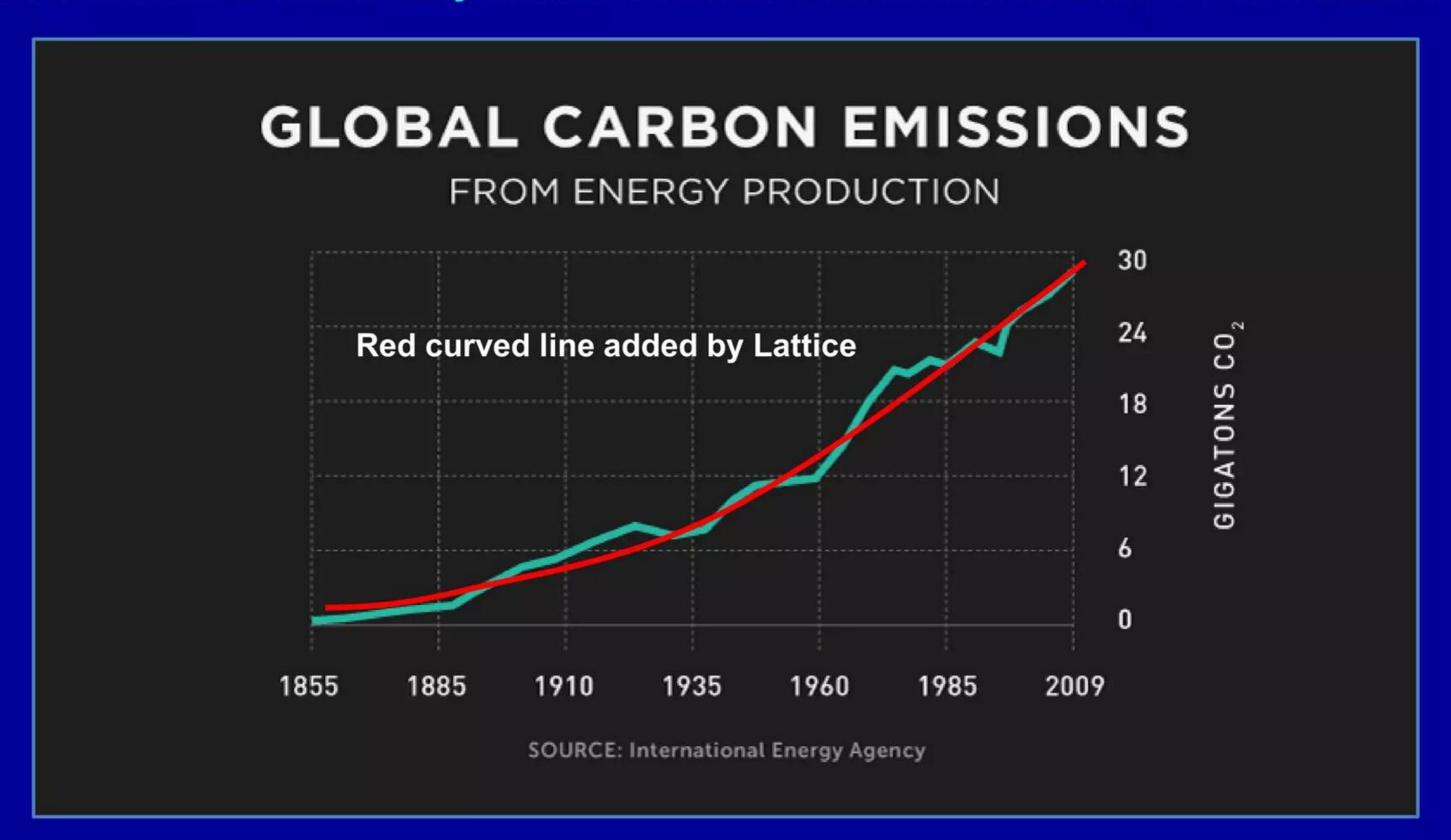
UN foresees continued exponential growth in energy use Latest data suggests that population growth is beginning to flatten-out

If this scenario is correct it sets the stage for new surge in per capita energy use



Growth in global Carbon emissions exponential since 1855 If present global warming is caused by O<sub>2</sub> combustion then must curb it

There could be a better way to use Carbon: transmutation instead of combustion



# According to data ~1.5 billion people now lack electricity Table 1. Electricity Access in 2008: Regional Aggregates (page 9)

Alliance for Rural Electrification	Population without electricity	Electrification rate	Urban electrification rate	Rural electrification rate	
	million	%	%	%	
Africa	589	40	66.8	22.7	
- North Africa	2	98.9	99.6	98.2	_1
-Sub-Saharan Africa	587	28.5	57.5	11.9	マニ
Developing Asia	809	77.2	93.5	67.2	
- China and East Asia	195	90.2	96.2	85.5	1
- South Asia	614	60.2	88.4	48.4	てニ
Latin America	34	92.7	98.7	70.2	
Middle East	21	89.1	98.5	70.6	
Developing countries	1453	72	90	58.4	
OECD and Transition economies	3	99.8	100.0	99.5	_1
World	1456	78.2	93.4	63.2	<b>\</b> _

Source: http://www.ruralelec.org/fileadmin/DATA/Documents/06 Publications/Position papers/ARE Mini-grids - Full version.pdf

LENR technology could someday help end energy poverty

In 2014 at least 1.5 billion people on our planet are living without any electricity.

Incredibly, this huge number is roughly the same as the world's entire population when Thomas Edison opened his first coal-fired central station electric power generation plant on September 4, 1882: the Pearl Street Station in New York City with a total electrical output of 600 kWh.

# British Petroleum believes the Oil Age only has 53 years left Published in "The Christian Science Monitor" on July 14, 2014



# How long will world's oil reserves last? 53 years, says BP

The world has 53.3 years left to find an alternative to oil before current proved reserves run dry, according to BP. Of course, nations are finding new oil – meaning that number is rising – but new extraction methods are costly and can pose environmental threats.

By Andy Tully, OilPrice.com ▼ JULY 14, 2014

According to BP, drivers whose vehicles rely on burning oil have a little more than a half-century to find alternate sources of energy. Or walk.

http://www.csmonitor.com/Environment/Energy-Voices/2014/0714/How-long-will-world-s-oil-reserves-last-53-years-says-BP

http://oilprice.com/Energy/Energy-General/BPs-Latest-Estimate-Says-Worlds-Oil-Will-Last-53.3-Years.html

http://www.bp.com/en/global/corporate/about-bp/energy-economics/statistical-review-of-world-energy.html

### Fossil fuel reserves will be exhausted within ~150 years

Solar PV/wind power: insufficient energy density to replace fossil fuels

World will still require dense energy sources for transportation & portable power

#### Comparison of intrinsic energy densities

Source	Joules per cubic meter
Solar	0.0000015
Geothermal	0.05
Wind at 10 mph (5m/s)	7
Tidal water	0.5-50
Human	1,000
Oil	45,000,000,000
Gasoline	10,000,000,000
Automobile occupied (5800 lbs)	40,000,000
Automobile unoccupied (5000 lbs)	40,000,000
Natural gas	40,000,000
Fat (food)	30,000,000

#### Petroleum energy density:

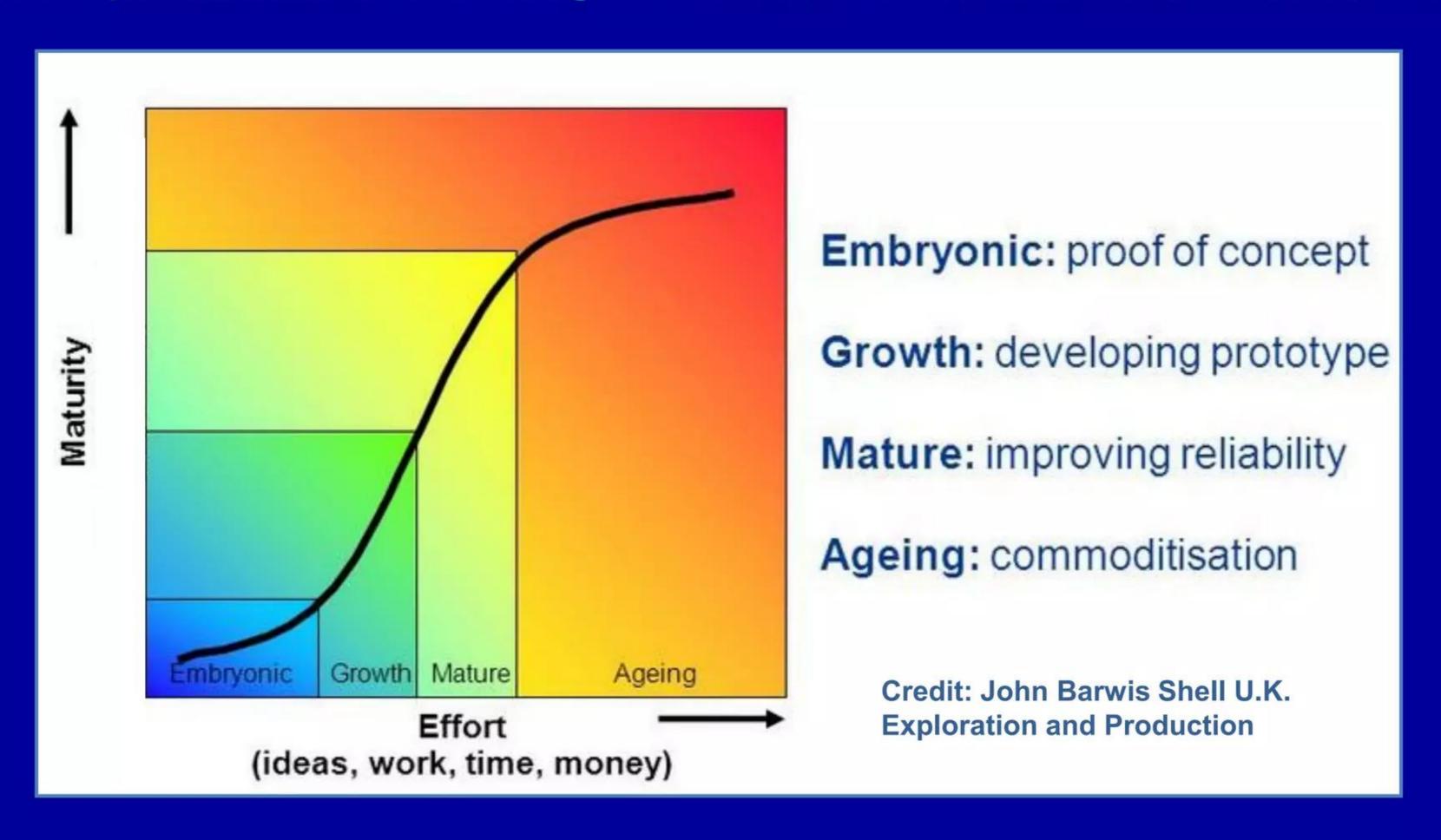
"A single gallon of gasoline contains approximately forty (40) megajoules of chemical energy. Dividing energy by volume yields an energy density of ten billion joules per cubic meter. Gasoline is ten quadrillion times more energy-dense than solar radiation and one billion times more energy-dense than wind and water power."

Reference: B.E. Layton, International Journal of Green Energy 5 pp. 438 - 455 (2008)

Source: http://www.drexel.edu/~/media/Files/greatworks/pdf\_sum10/WK8\_Layton\_EnergyDensities.ash

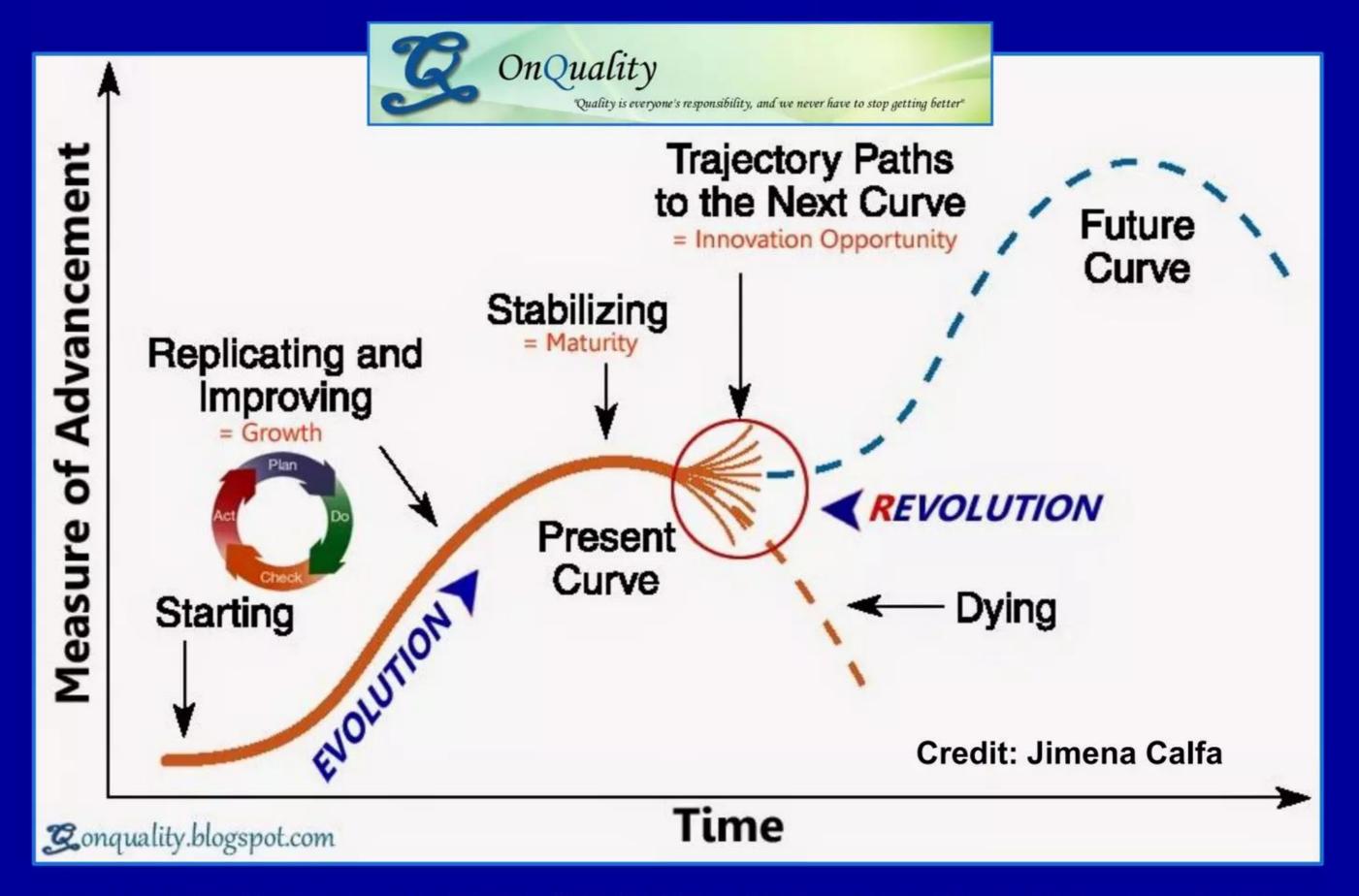
S-curves are sigmoid and describe an entire life cycle Exponential growth phase of life cycle is finite and doesn't last forever

Individual products and technologies form series of S-curves as markets evolve



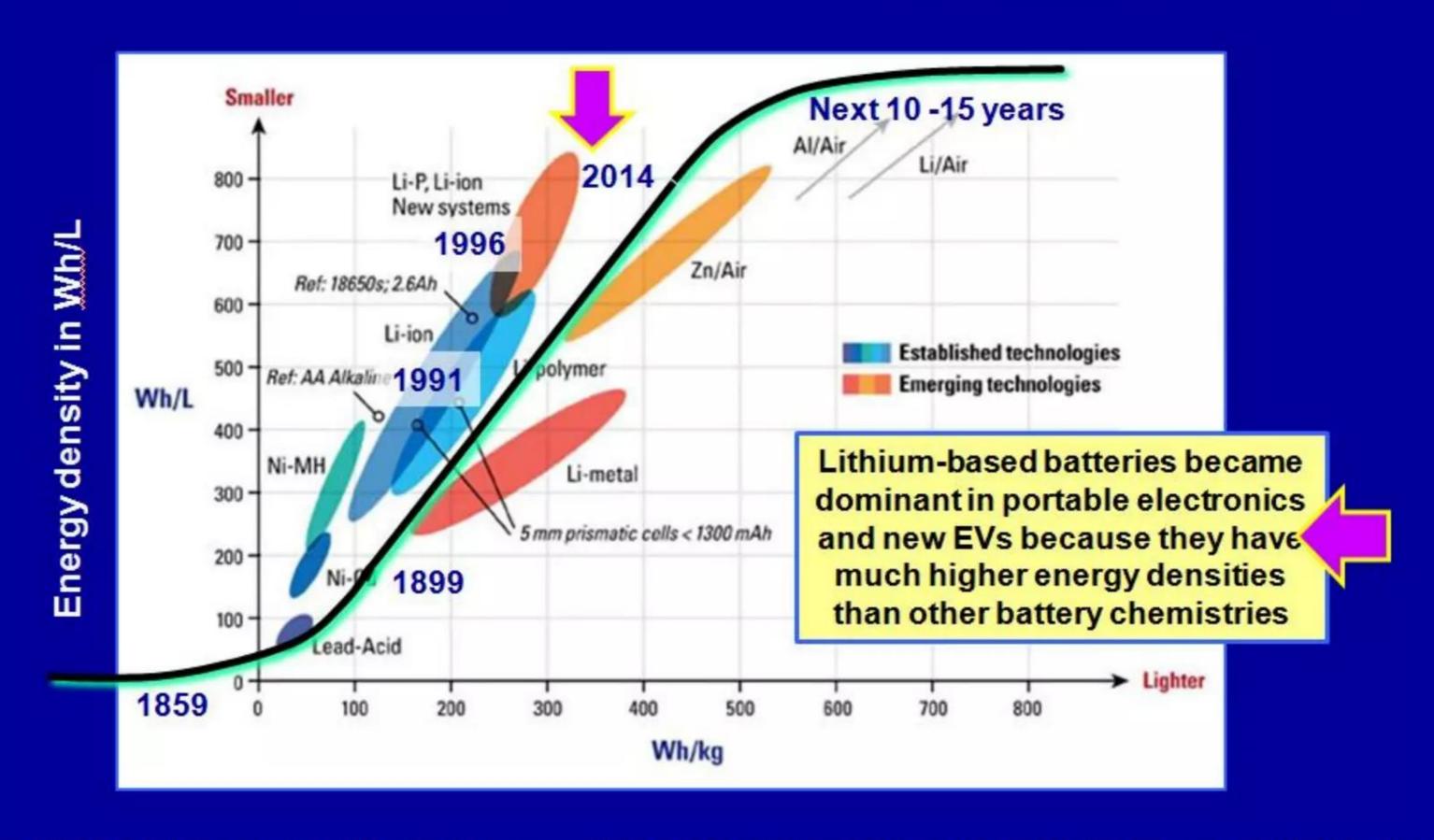
# S-curves are sigmoid and describe an entire life cycle Exponential growth phase of life cycle is finite and doesn't last forever

Individual products and technologies form series of S-curves as markets evolve



Source: http://www.onquality.info/2014/08/the-future-of-quality-evolutionary-or.html

Batteries cannot overcome the limitations of solar and wind Batteries' energy densities limited and the technology now maturing Will still need dense energy sources for transportation & portable power



Source: <a href="http://www.estquality.com/technology">http://www.estquality.com/technology</a>

Note: superimposed S-curve and dates were added by Lattice

Maturity of combustion and battery technologies is upon us

Creates opportunities for entry of newer and even better technologies

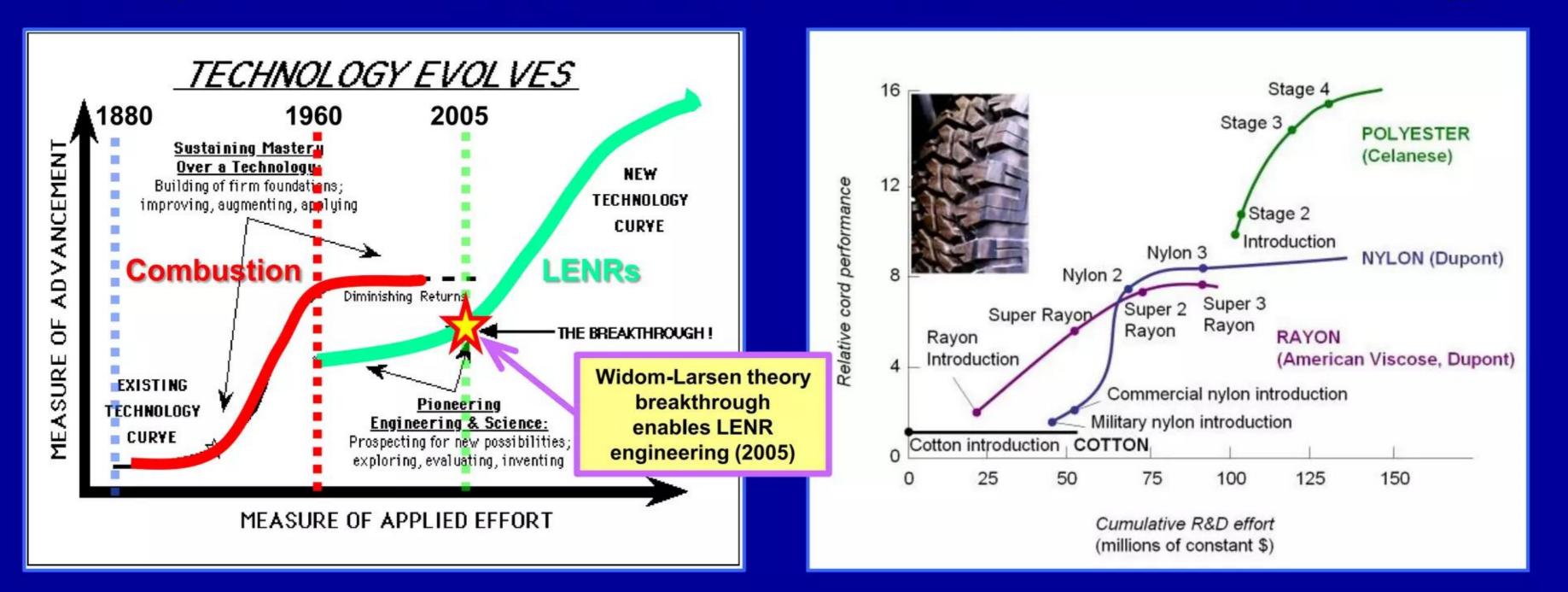
Wind/solar: CO<sub>2</sub>-free and renewable but low energy density and intermittent

To greatly reduce energy costs need breakthrough energy-dense technology: LENRs

LENRs complement wind and solar and are highly synergistic with them

Technology S-curves for combustion vs. LENRs:

S-curve concept and tire cord technology:



# Barring unexpected global economic or bio catastrophes Energy demand will probably grow exponentially for foreseeable future

- Recent downward moves in crude oil and gasoline prices appear to only be temporary corrections within a longer-term uptrend in real price of crude oil that has been operating since 1999. This suggests global demand for petroleum and its products still continues to increase faster than increases in total supplies. Much of this uptrend has been driven by comparatively high rates of economic growth and improved standards of living in populous countries of the former so-called "Third World", e.g. China and India
- ✓ Driving force underlying relatively persistent upward pressures on global energy prices is clearly revealed in charts presented on previous slides that demonstrate a very clear relationship between per capita energy usage (measured in BTUs or Watts) and GDP growth. Put another way, these charts show that increased per capita economic activity (as measured by GDP), in conjunction with improved standards of living for a given country's citizens, directly increases global demand for energy
- ✓ Importantly, if people living in countries currently located in the lower left quadrant of those charts are ever to attain and enjoy anywhere close to the standard of living that is now prevalent in Europe (let alone the United States), there will be correspondingly large increases in global demand for energy; e.g. China brought electrification to hundreds of millions of its citizens by hugely increasing coal-fired power
- ✓ All this data strongly implies that, barring a prolonged period of worldwide economic recession or depression or bio-catastrophes such as an Ebola virus pandemic, global demand for energy will likely continue to increase exponentially for the foreseeable future --- this will be an unavoidable result of continued GDP growth around the world, and to increasing degrees also in laggard sub-Saharan Africa
- ✓ Conclusion: if supplies of existing Carbon-based energy sources are not dramatically increased and new types of 'greener' energy technologies are not further developed and broadly deployed, the real price of energy broadly writ will inevitably rise to new levels that are vastly higher than we are seeing today

Energy demand will probably continue to grow exponentially

Given global warming if this happens CO<sub>2</sub> emissions must be slashed

What about needs of ~1.5 billion people who now live without electricity?

Oil supplies may be running-out within roughly 50 years. What do we do?

World needs a new type of energy source that will enable usage to continue to grow exponentially without exorbitant increases in energy prices and at the same time drastically reducing global CO<sub>2</sub> emissions --- a techno-explosion in energy.

### Nuclear energy density vastly >>> solar, wind, and batteries

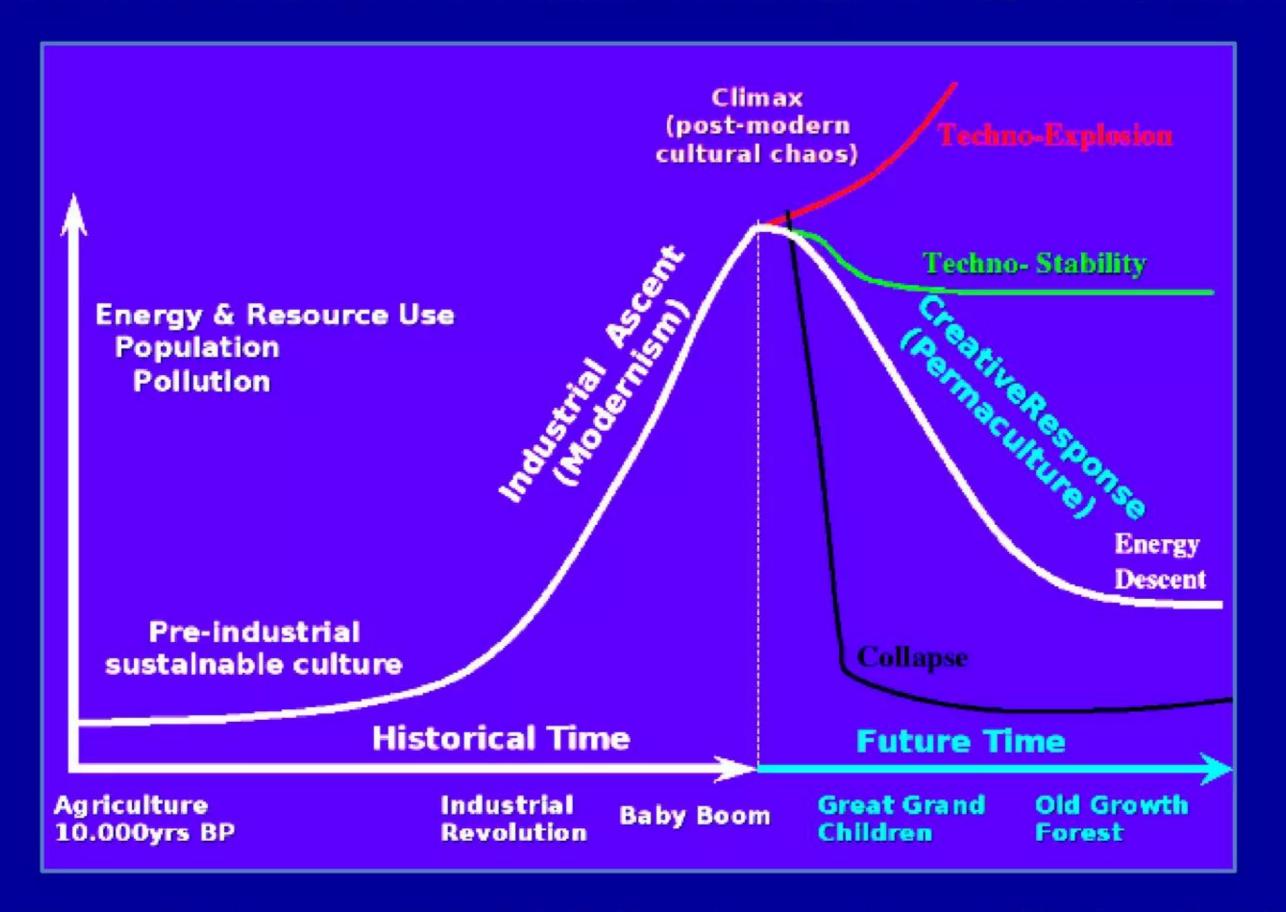
Existing nuclear fission or fusion have radiation and waste problems

Low Energy Neutron Reactions (LENRs): no deadly radiation or wastes

- ✓ Beginning with Hans Bethe's landmark paper published back in in 1939, the Holy Grail and longstanding dream of contemporary nuclear science has been to commercialize cleaner (vs. fission) fusion reactions that power stars and our Sun
- ✓ Less technically difficult fission technology was first utilized and deployed in commercial nuclear reactors; it has been fraught with safety, cost, and serious proliferation issues that are well-known *a la* Dr. Evgeny Velikhov's "vital risks"
- ✓ Both fission and fusion rely primarily on the strong interaction, emit biologically deadly hard radiation, and produce long-lived hazardous radioactive wastes
- ✓ Up until the advent of the collective many-body Widom-Larsen theory in 2005, the weak interaction was thought to be useless for large-scale power generation
- ✓ Thanks to Widom-Larsen theory, now know that radiation-free, truly 'green' LENRs based on the weak interaction are enabled by many-body physics in condensed matter and can occur at very substantial rates under exactly the right conditions
- ✓ LENRs are a game-changing paradigm shift in evolution of nuclear technology

# LENRs can provide a techno-explosion for energy David Holmgren has envisioned four alternative futures for energy

They are the techno-explosion, techno-stability, energy descent, and collapse



Source - David Holmgren, "Future Scenarios": http://www.futurescenarios.org/content/view/16/31/index.html

# LENRs can provide a techno-explosion for energy Enormous energy density advantage vs. ordinary chemical combustion

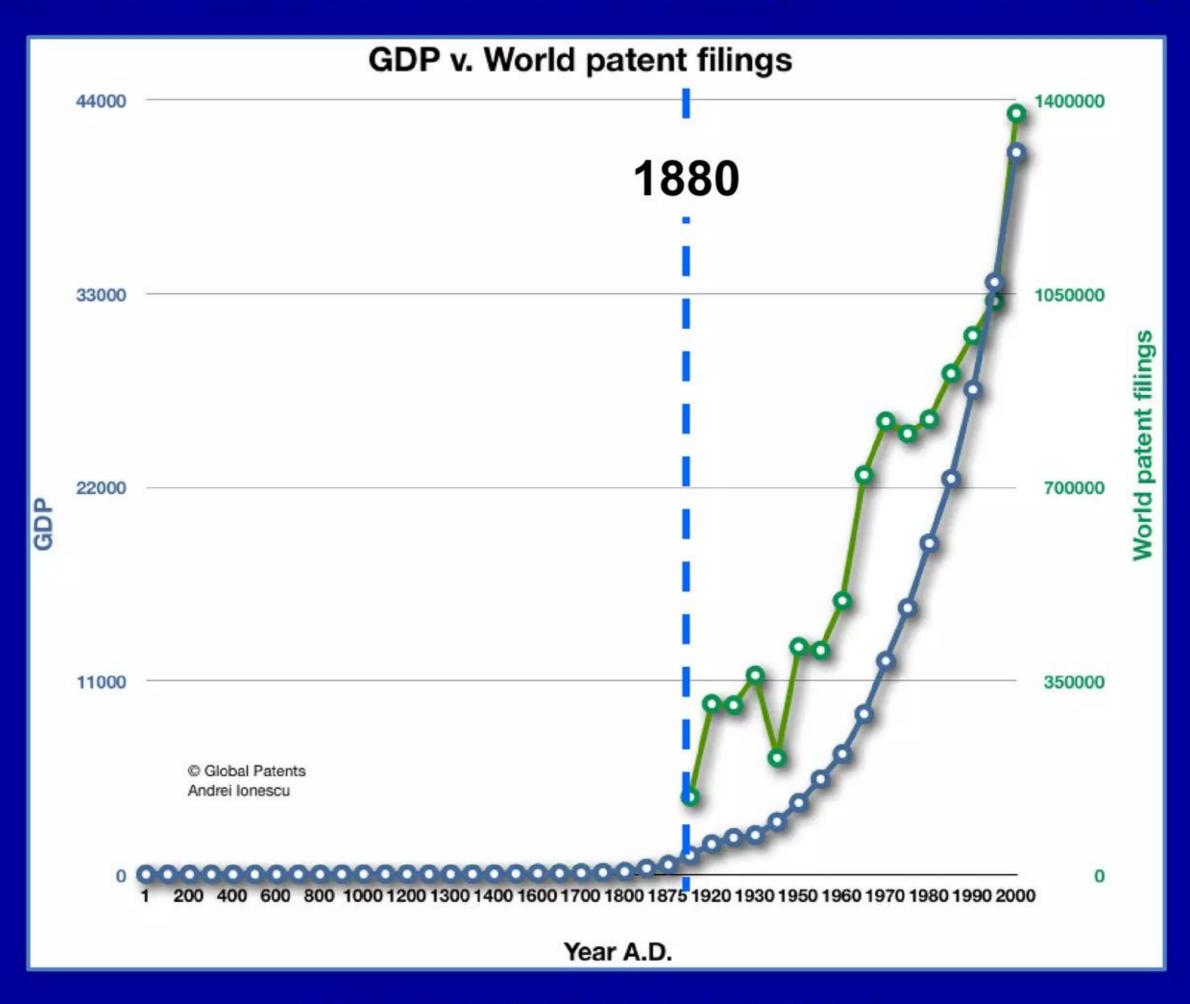
Do not emit any deadly neutron or gamma radiation and no long-lived radwastes

"Techno-explosion depends on new, large and concentrated energy sources that will allow the continual growth in material wealth and human power over environmental constraints, as well as population growth."

David Holmgren "Future Scenarios"

Source - David Holmgren, "Future Scenarios": <a href="http://www.futurescenarios.org/content/view/16/31/index.html">http://www.futurescenarios.org/content/view/16/31/index.html</a>

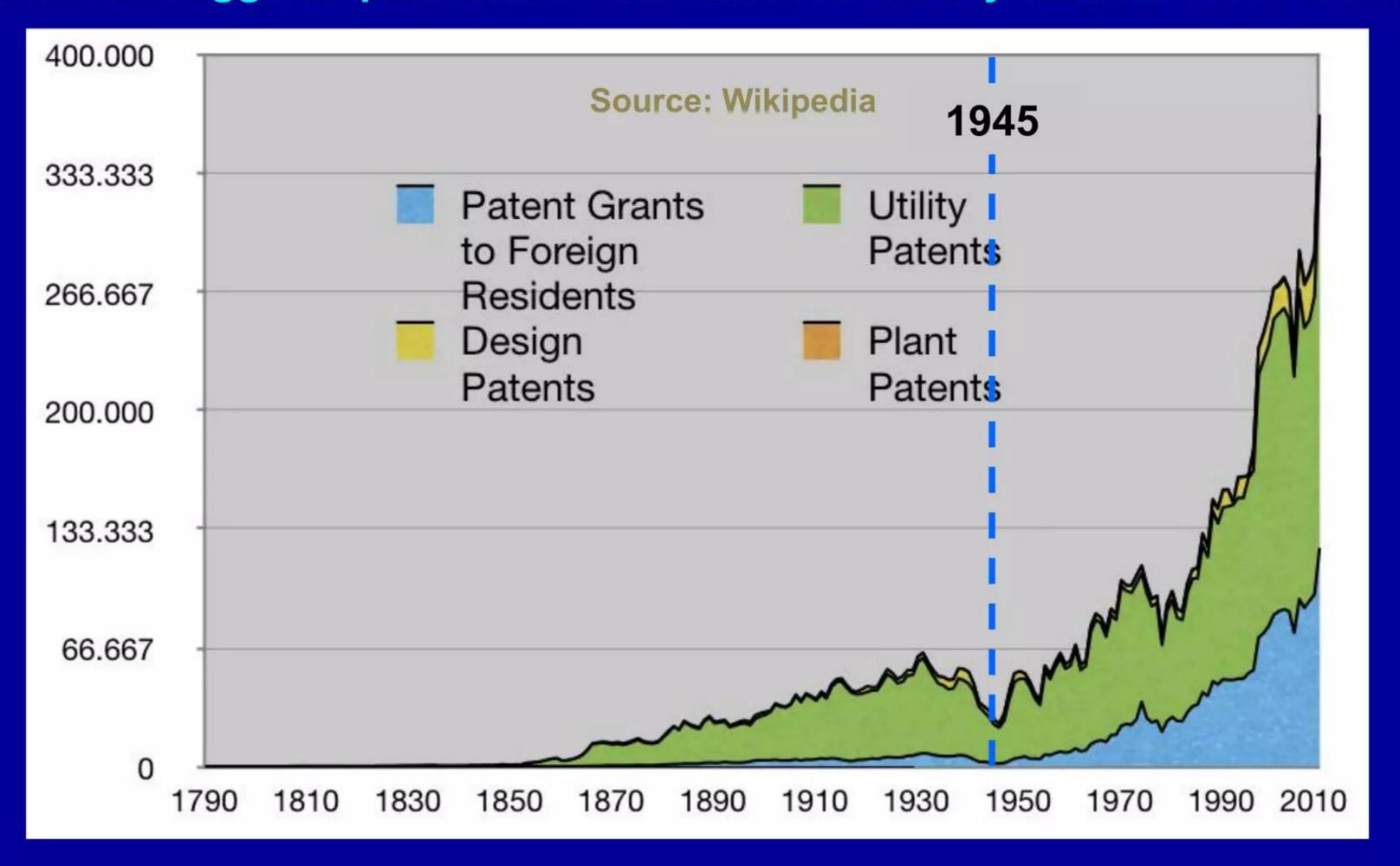
# World GDP somewhat correlated with world patent filings Patents can be viewed as quantitative proxy for technological progress



Source: <a href="http://globalpatents.ca/blog/">http://globalpatents.ca/blog/</a>

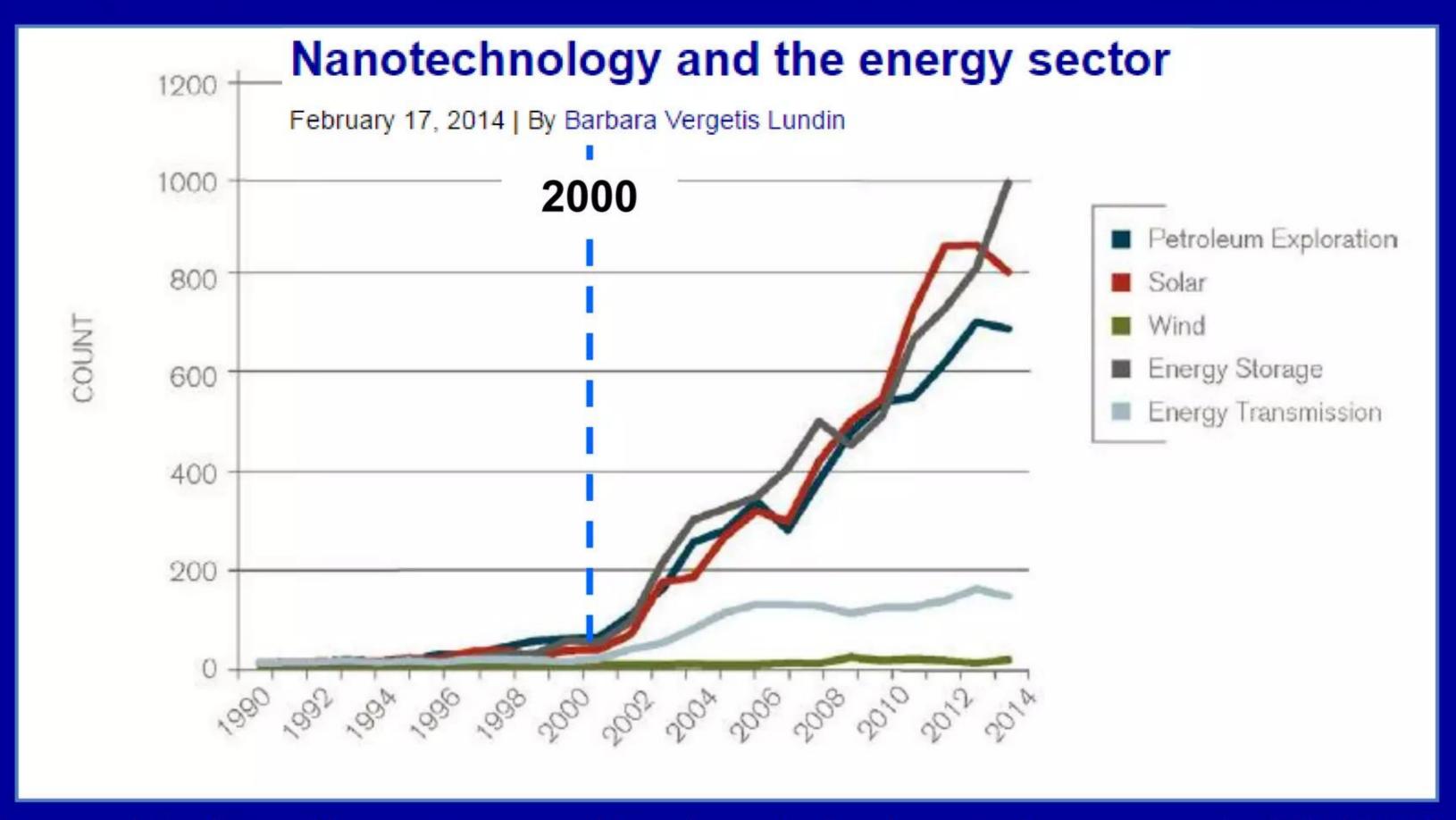
# From 1850 - 1929 issued patents increased linearly Patents increased exponentially ever since late 1940s after WWII

Recent data suggests present burst of innovation may exceed 1850 - 1929 era



Nanotechnology began with K. Eric Drexler's book in 1986 Total number of energy-related nanotech patents accelerated after 2000

Things become possible at nanometers that can't be done on larger length scales



Source: <a href="http://www.fierceenergy.com/story/nanotechnology-and-energy-sector/2014-02-17">http://www.fierceenergy.com/story/nanotechnology-and-energy-sector/2014-02-17</a>

Nanotechnology and LENRs are mutually joined at the hip

Large length scales

# What was formerly thought impossible becomes possible by utilizing applied nanotechnology

Nuclear-strength electric fields in  $\mu$ -sized LENR-active sites enable e + p reaction

Huge array of new technological possibilities and opportunities open-up at micron to nanometer length-scales

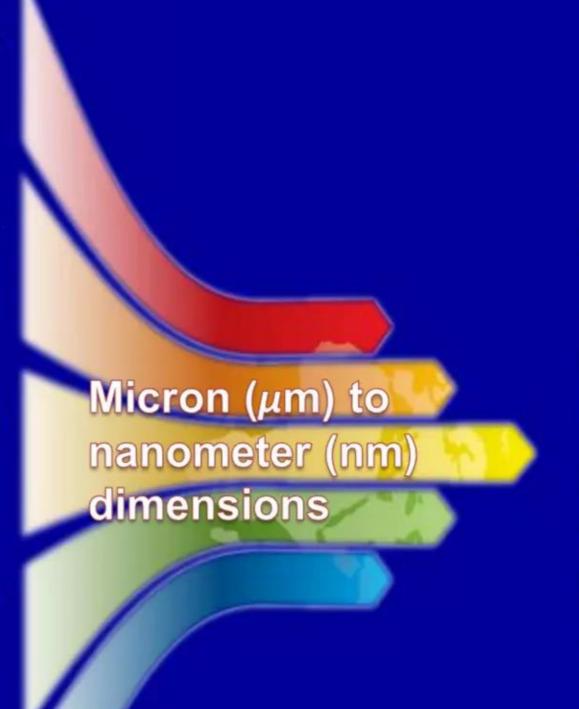
# Technology domains converging at nanometer length-scales Being driven to nm length-scales in a quest for higher energy density

Technology domain	Main purpose	Source of energy	Energy- scale	Typical rates of reactions	Temps in Centigrade	Representative examples
Electro- chemical batteries	Store electrical energy reversibly in chemical bonds	Chemical bonds	Electron Volts (eV)	Slow to moderate; typically diffusion rate-limited at various types of interfaces found inside batteries	Li batteries can generally be operated safely only at temperatures < 200° C	Large variety of different chemistries: lead-acid, alkaline, NiMH, Nickel-cadmium, Lithium-ion, LiFePO <sub>4</sub> , Lithium-oxygen, etc.
Energetic materials	Thermal igniters, explosives, propellants	Chemical bonds	eVs	Fast combustion processes w. O <sub>2</sub> , e.g., deflagration and detonation	Macroscopic peak temps max-out at ~5,000° C	Thermite reactions (burning of metals), dinitro-chloro-azido benzene, RDX, etc.
Low energy neutron reactions (LENRs)	Produce large amounts of CO <sub>2</sub> -free thermal energy from decay particles' kinetic energies and gamma conversion to infrared	Nuclear binding energy stored inside atomic nuclei	Mega- electron Volts (MeVs)  one MeV is equal to a million eVs	Nuclear reactions themselves are super-fast, i.e., picosecond and faster; decays of any resulting unstable isotopes can range from very slow on order of millions of years to fast, i.e., nanoseconds	Peak temperatures in micron- scale, short- lived LENR hotspot regions on surfaces and at interfaces typically reach ~4,000° to 6,000° C	Neutron captures on various elements and isotopes; for example, LENR neutron capture processes starting with Lithium as base fuel target can release ~27 MeV in short sequence of nuclear reactions that do not release any energetic neutron or gamma radiation

Widom-Larsen LENR theory is extremely multidisciplinary Theoretical breakthrough achieved by combining multiple disciplines

Analogous to Maxwell: integrates many LENR effects into coherent whole

Quantum electrodynamics (QED) Collective many-body effects Modern quantum mechanics Condensed matter physics Classical electrodynamics Modern nuclear physics Surface chemistry (H) Key nanotechnology Surface physics Plasma physics **Plasmonics** 



Science and technology of low energy neutron reactions (LENRs) in condensed matter systems utilizes knowledge from all of these varied disciplines

No new physics

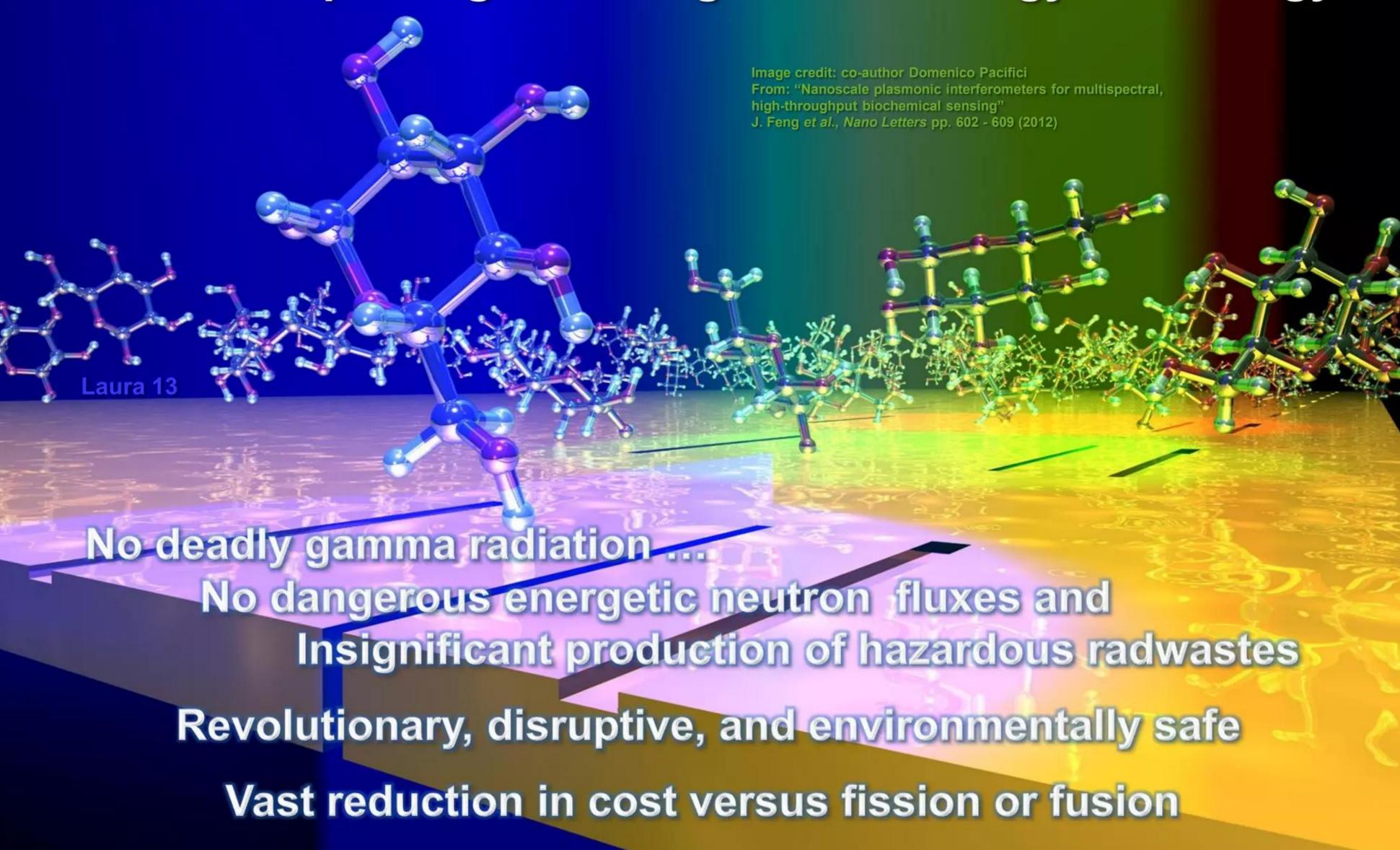
Widom-Larsen LENR theory is extremely multidisciplinary Theoretical breakthrough achieved by combining multiple disciplines

Analogous to Maxwell: integrates many LENR effects into coherent whole

Fully explains previously inexplicable characteristic features:

- Absence of deadly energetic neutron and gamma radiation
- ✓ No appreciable production of long-lived radioactive isotopes
- ✓ Plus an array of anomalous effects that have been observed and reported in various scientific journals for over 100 years

### LENRs are paradigm-shifting nuclear energy technology



Nanotechnology and LENRs are mutually joined at the hip

Guided by physics of the Widom-Larsen theory, an opportunity to commercialize LENRs as truly green CO2-free nuclear energy source has been enabled by a unique juxtaposition of very recent parallel advances in certain very vibrant areas of nanotechnology (esp. plasmonics), quantum entanglement, new innovations in nanoparticle fabrication techniques, as well as an array of new discoveries in advanced materials science.

### LENRs can increase safety and shrink size of nuclear power

Lack of hard radiation eliminates heavy shielding and containment

Opportunity to develop revolutionary portable nuclear power sources

Fission reactors need 1 foot of steel and 3 feet of concrete to protect humans from hard radiation and wastes emitted by reactor; makes systems intrinsically large and heavy

Fission emits deadly MeV-energy neutrons and gammas

LENRs enable devices something like this: small, portable battery-like power sources that are safe and disposable

plasma embodiments can potentially scale-up

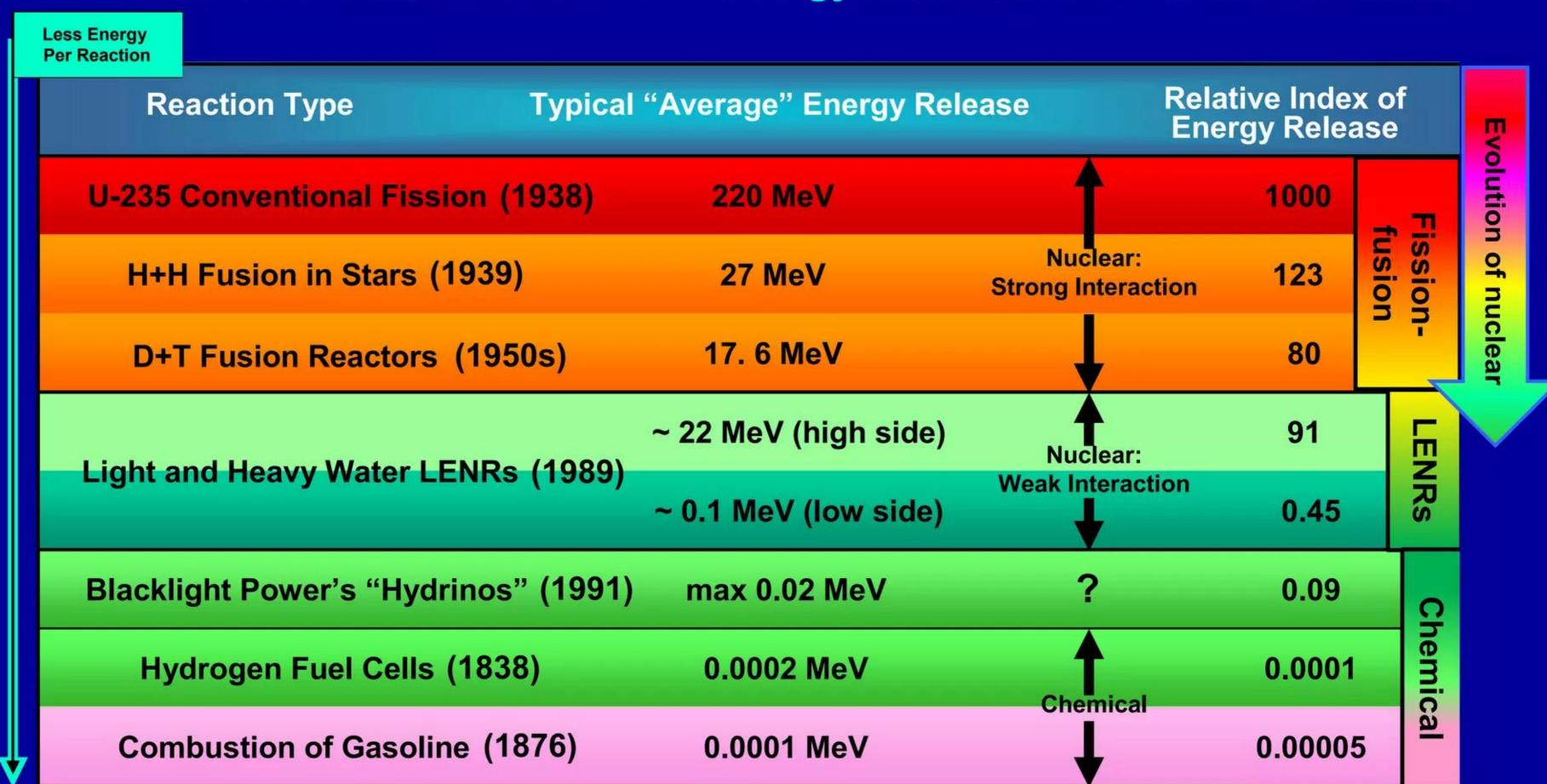
to megawatts; akin to today's power plants



### Nuclear energy releases are huge vs. chemical combustion

LENR energy release is between fission and chemical power sources

Some LENRs can release more energy than hot D+T fusion reactions



# Nuclear energy density is major competitive advantage LENR energy density is ~5,000 times larger than that of gasoline

LENRs Versus Chemical Energy Sources: E	Batteries, I	Fuel Cells, and Microgenerators	
Source of Energy	A	pproximate Energy Density (Watt*hours/kg)	*hours/kg)  164 329 460 1,680 2,300 5,930
Alkaline Battery		164	<u>0</u>
Lithium Battery		329	
Zinc-Air Battery		460	
Direct Methanol Fuel Cell (35% efficient)		1,680	ner
Gas Burning Microgenerator (20% efficient)		2,300	y S
100% Efficient Combustion of Pure Methanol		5,930	ourc
100% Efficient Combustion of Pure Gasoline		11,500	es
LENRs (based on an assumption of an average of 0.5 MeV per nuclear reaction in an LENR system)		0,000 (maximum theoretical energy – only a fraction would be achievable in practice)	LENRs

# Basic reactions in Widom-Larsen theory are simple Protons or deuterons react directly with electrons to make neutrons Neutrons are then captured by other atoms → catalyze nuclear transmutations

Collective many-body quantum effects: many electrons each donate little bits of energy to a much smaller number of electrons that are also embedded in same high electric field to reflect the detail of electrons that are also embedded in same high electric field to reflect the point where they can react directly with protons (or deuterons) to make neutrons and neutrinos  $e^{-*} p + p^+ \rightarrow n^0 + v_e$ 

 $v_e$  neutrinos: ghostly unreactive photons that fly-off into space;  $n^0$  neutrons: capture on nearby atoms

Neutron-capture-catalyzed transmutations release energy stored in atoms:

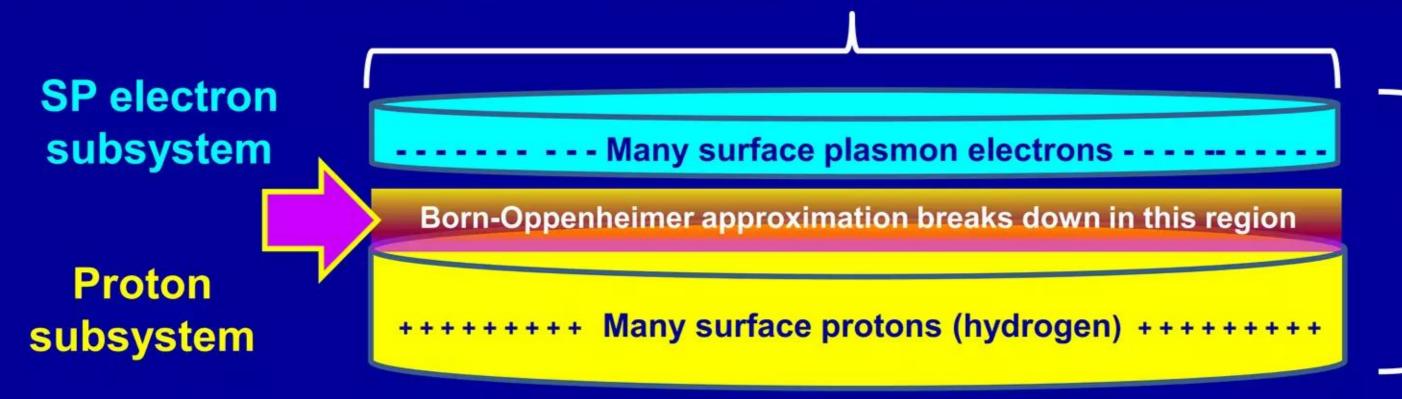
Neutrons + atomic nuclei ————— heavier elements + decay products

Releases vast amounts of stored nuclear binding energy as energetic particles/photons that create heat

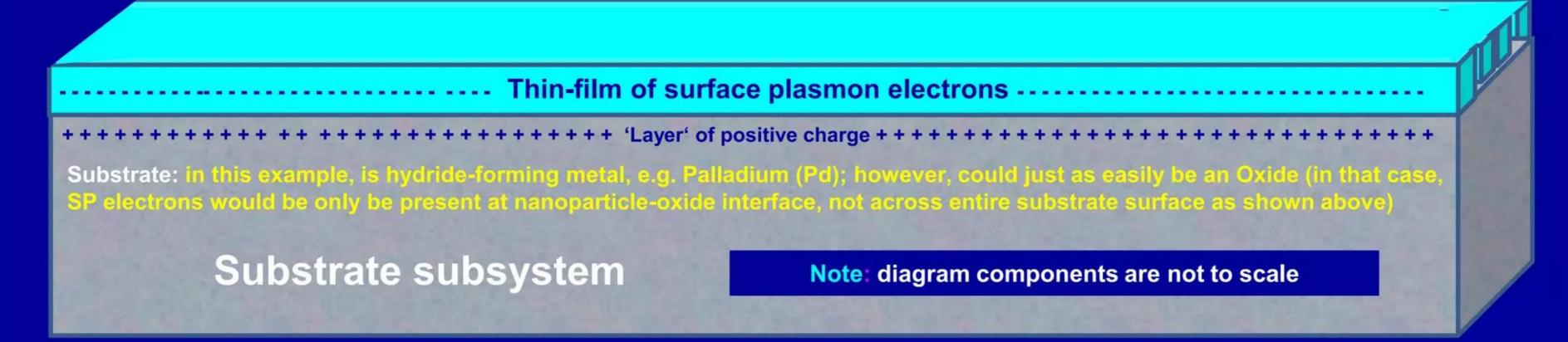
# Anatomy of a micron-scale LENR-active surface site Conceptual overview of many-body patches that form on surfaces

SP electrons and protons all oscillate collectively and mutually Q-M entangled

Diameters of many-body patches randomly range from several nm up to perhaps ~100+ microns



SP electron and proton subsystems form a many-body WLT patch; it can also reside on nanoparticles attached to surface



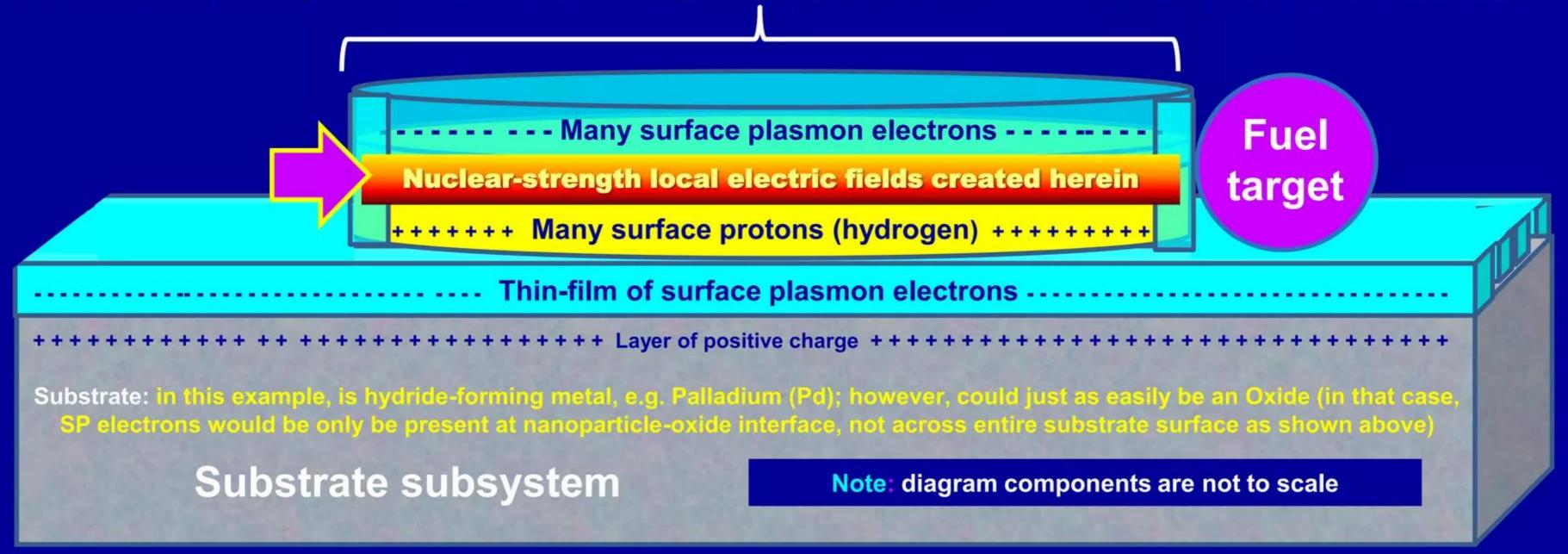
# Input energy creates very high electric fields in surface sites Born-Oppenheimer breakdown creates nuclear-strength electric fields

High electric fields increase effective masses of some patch SP electrons

Sufficient input energy will create local E-fields > 10<sup>11</sup> V/m within patch which permits:

Input energy<sub>E-field</sub> + 
$$e^-_{sp} \rightarrow e^{-*}_{sp} + p^+ \rightarrow n + v_e$$
 [condensed matter surfaces]

Diameters of many-body patches randomly range from several nm up to perhaps ~100+ microns



# LENRs occur in microscopic active sites found on surfaces Many-body collections of protons and electrons form spontaneously

Comprised of many-body collections of protons and electrons

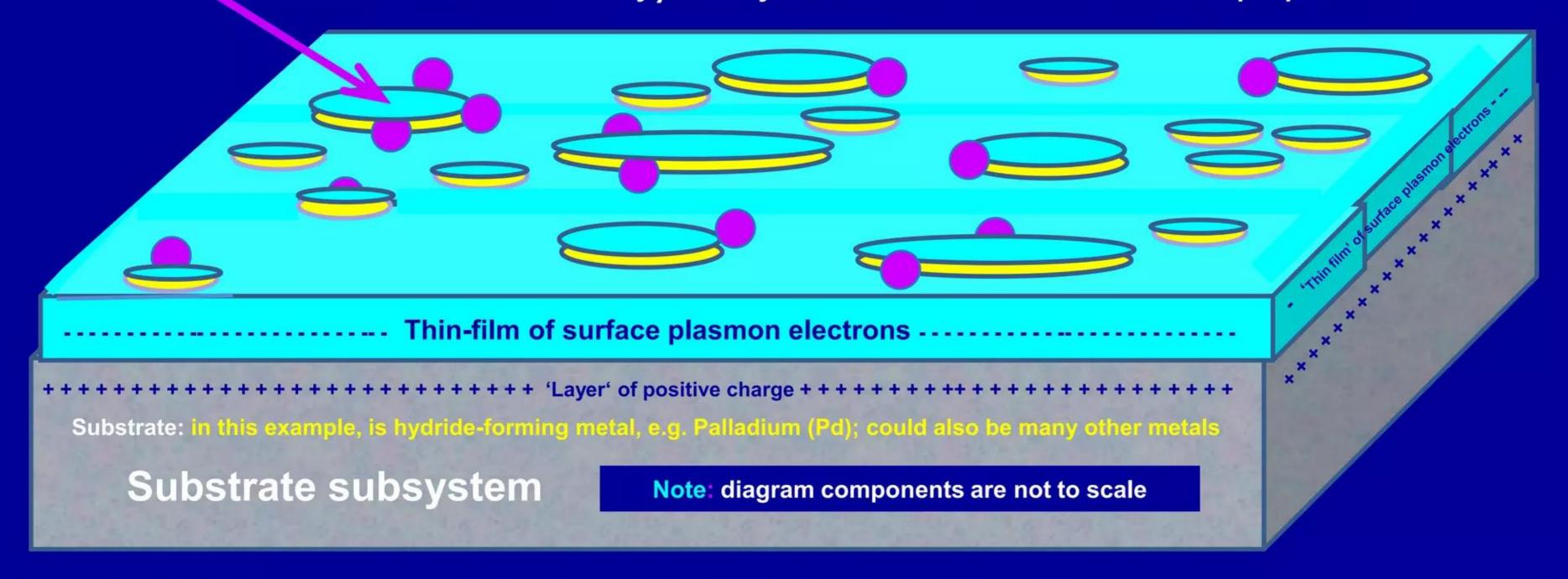
Intense heating in LENR-active sites will form  $\mu$ -scale event craters on substrate surfaces

After being produced, neutrons will capture on fuel targets:

 $n + (Z, A) \rightarrow (Z, A+1)$  [neutron capture on targets]

 $(Z, A+1) \rightarrow (Z+1, A+1) + e_{\beta}^- + v_e$  [beta decay] = Target fuel nanoparticle

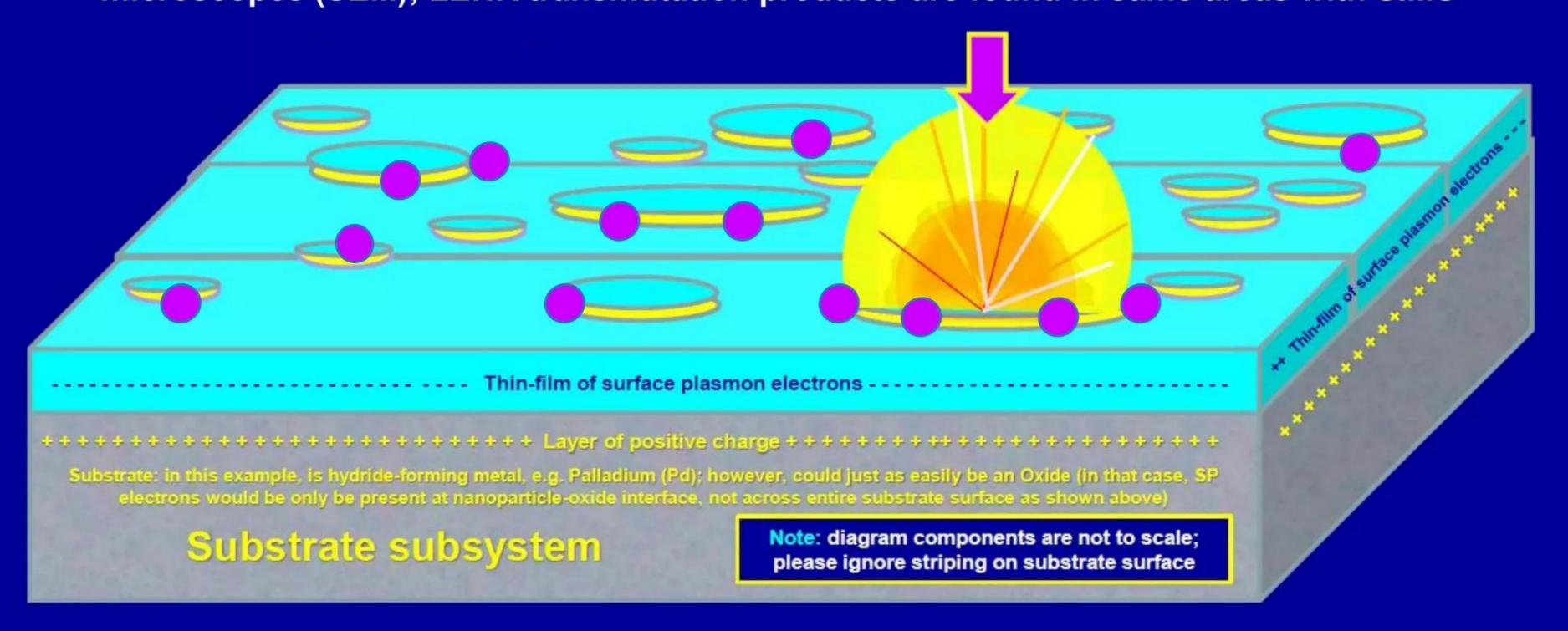
Often followed by  $\beta$  - decays of neutron-rich intermediate isotopic products



# LENR sites are analogous to transistors in computer chips Nanotechnology used to fabricate fuel targets emplaced on surfaces

Releases nuclear binding energy stored in fuels and transmutes elements

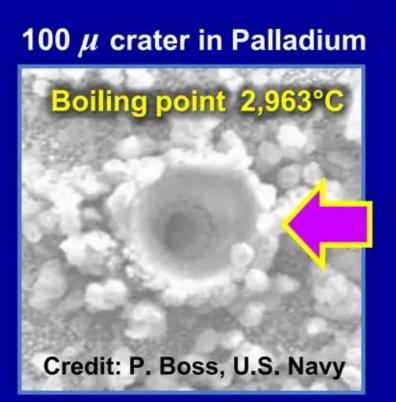
Explosive LENR 'hotspots' create distinctive surface craters ~2 - 100 microns in diameter Observed on LENR-active substrates post-experiment with scanning electron microscopes (SEM); LENR transmutation products are found in same areas with SIMS



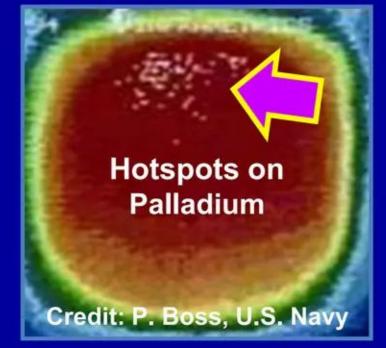
# LENRs could power Rankine and Brayton cycle engines Ideal for use in thermal-to-electric systems for CHP applications

LENRs produce very high temperatures well-suited to Brayton cycle

- ✓ LENRs intrinsically occur in localized micron-scale LENR-active sites on ~planar surfaces or curved surfaces of nanoparticles
- ▼ Tiny LENR-active sites live for less than ~300 400 nanoseconds before being destroyed by intense heat; local peak temps range from 4,000 - 6,000° C; LENR-active sites will spontaneously reform under right conditions in properly engineered devices
- ✓ Microscopic 100-micron LENR hotspot release up to 5<sup>+</sup> Watts of heat in less than 400 nanoseconds; create crater-like features on surfaces that are visible in SEM images and showing clear evidence for flash-boiling of precious and refractory metals
- **V** Peak local LENR power density can hit > 1.0 x 10<sup>21</sup> Joules/sec⋅m<sup>3</sup>
- ✓ Control macroscopic-scale temperatures in LENR systems by tightly regulating total input energy and/or total area/volumetric densities of LENR-active sites present in a reaction chamber



IR video of LENR hotspots



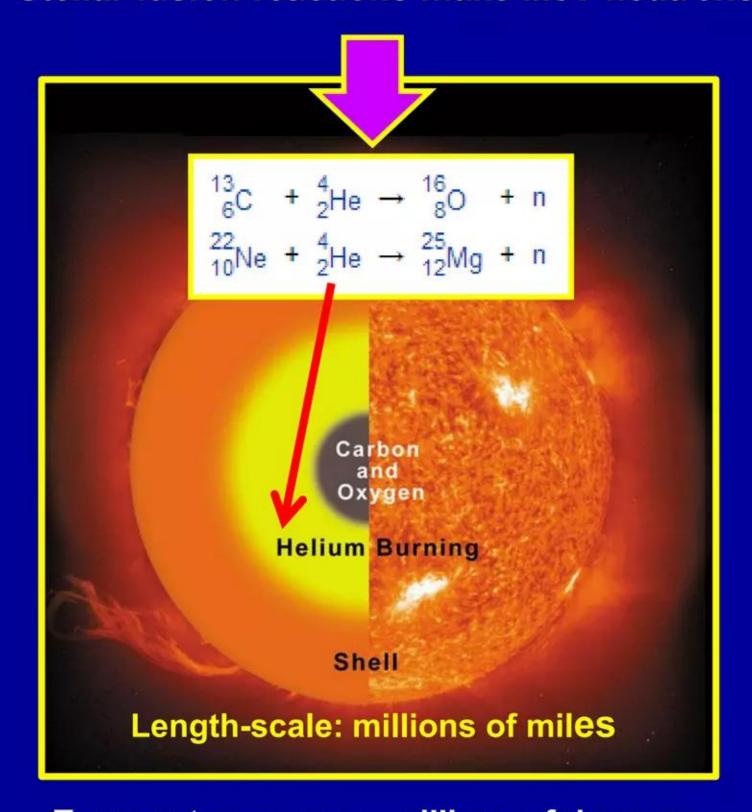
http://www.youtube.com/watch?v=OUVmOQXBS68

# LENR ultra low-energy neutrons are extremely safe

Fission and fusion neutrons are energetic, deadly and need shielding

All of the nuclear reactions shown below create neutrons: only LENRs are safe

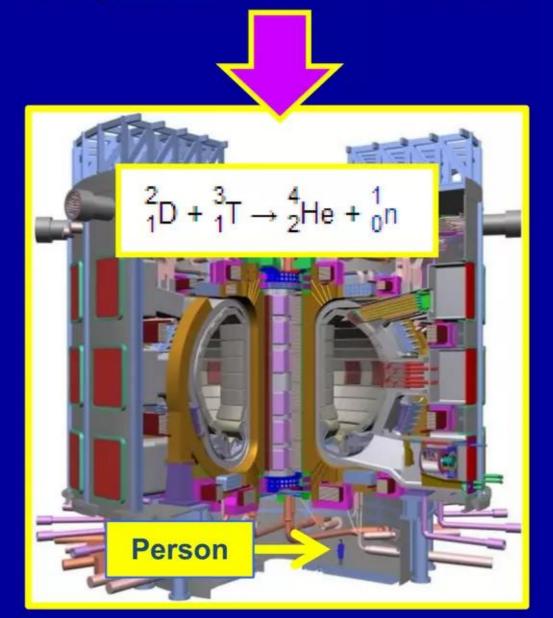
Stellar fusion reactions make MeV neutrons



Temperatures: many millions of degrees

ITER: D+T fusion reactor

**Dangerous 14.1 MeV neutrons** 



Length-scale: hundreds of feet

Temperatures: millions of degrees

Safe LENRs
Ultra low-energy





Length-scale: inches



Temperatures: only thousands of degrees

# Catalytic ultra low energy neutrons trigger heat production Release of nuclear binding energy creates vast amounts of usable heat

**Neutron 'match'** 



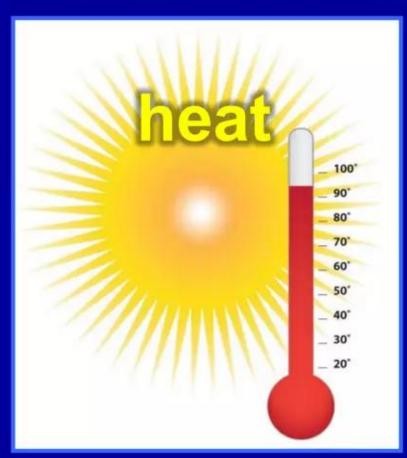
capture

Neutrons are readily absorbed by LENR fuels such as inexpensive Nickel, Titanium, Lithium, or Carbon atoms

Direct conversion of neutron capture and decay-related gammas to IR and beta/alpha particles create heat



produces



Neutrons + target fuel atoms ————> heavier elements + decay products

### LENR technology can transform today's fossil fuels

Breakthroughs in physics and nanotechnology make this possible Bitumen, heavy oil, and coal may be much more valuable as green LENR fuels

All of these natural hydrocarbons contain aromatic molecules that can be stripped-out



Canadian bitumen

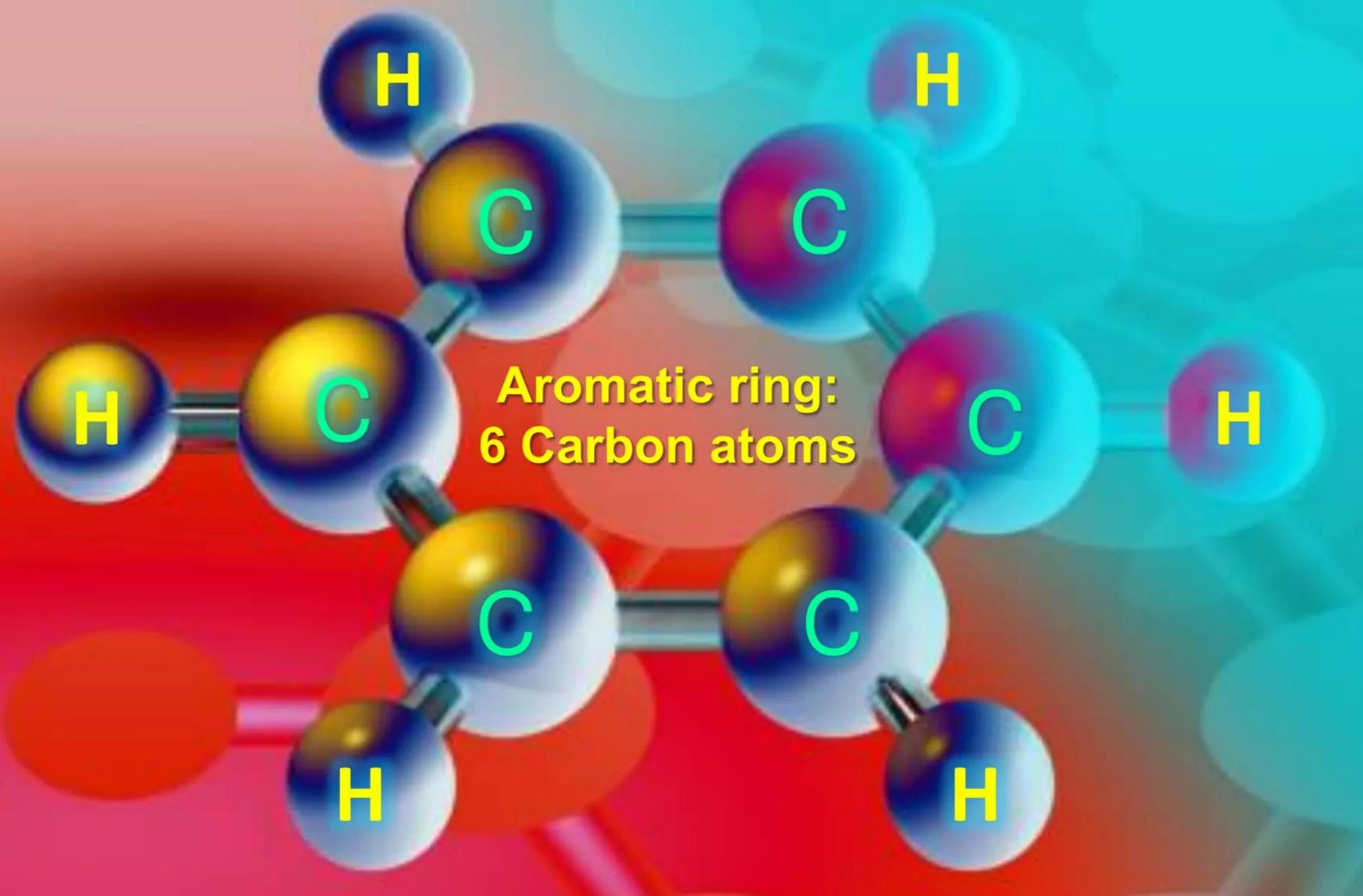


Heavy viscous oil



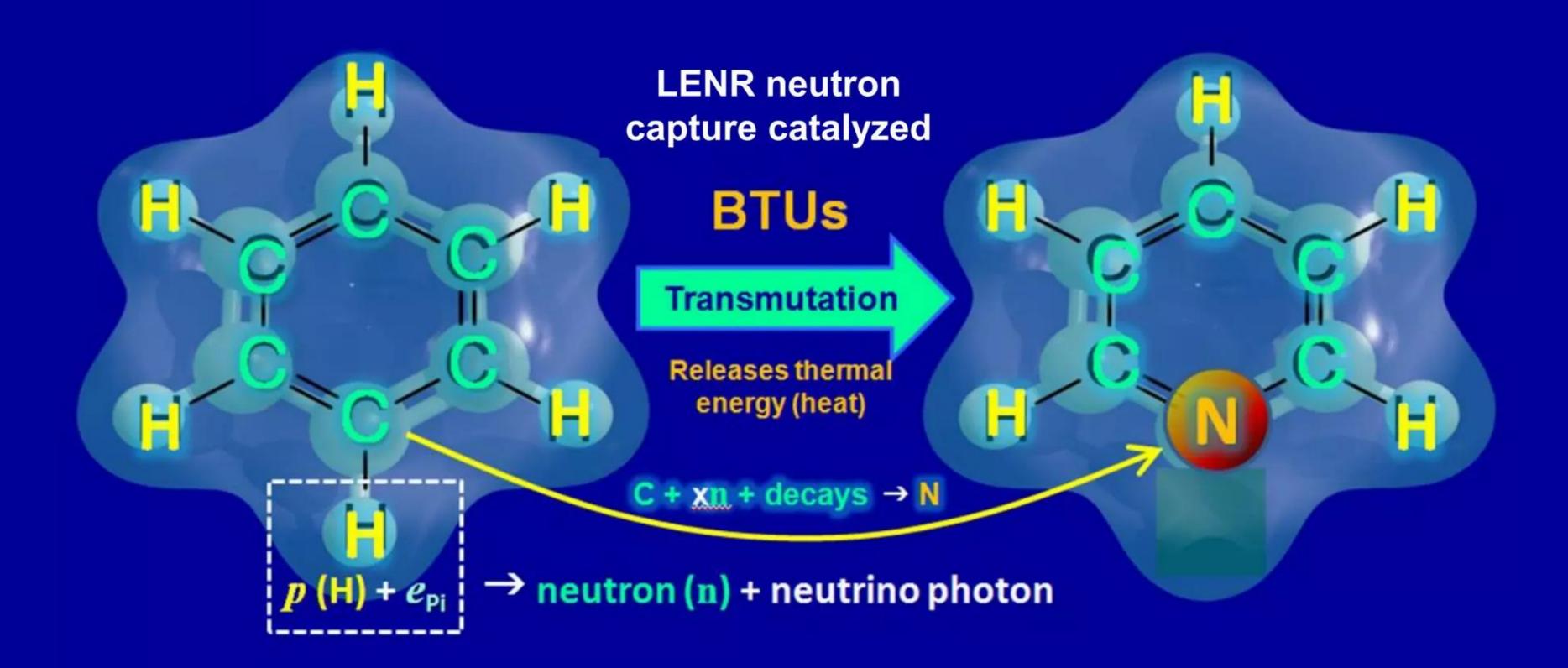
**Anthracite coal** 

Lattice has discovered that aromatic molecules can potentially be stripped-put and specially processed to be converted into green LENR fuels: no hard radiation emissions, no production of long-lived radioactive wastes or emission of gaseous CO<sub>2</sub> into the atmosphere but instead release > 5,000 times more thermal energy vs. combustion of Carbon-based molecules with Oxygen



Six Carbon atoms are arranged in hexagonal ring bonded to six Hydrogen atoms

Convert ring Hydrogen atoms (protons) into safe neutrons Neutrons are captured by ring Carbon atoms that are then transmuted



In this example Carbon is transmuted into Nitrogen by LENR processes

## Carbon transmutation releases > 5,000x more system BTUs

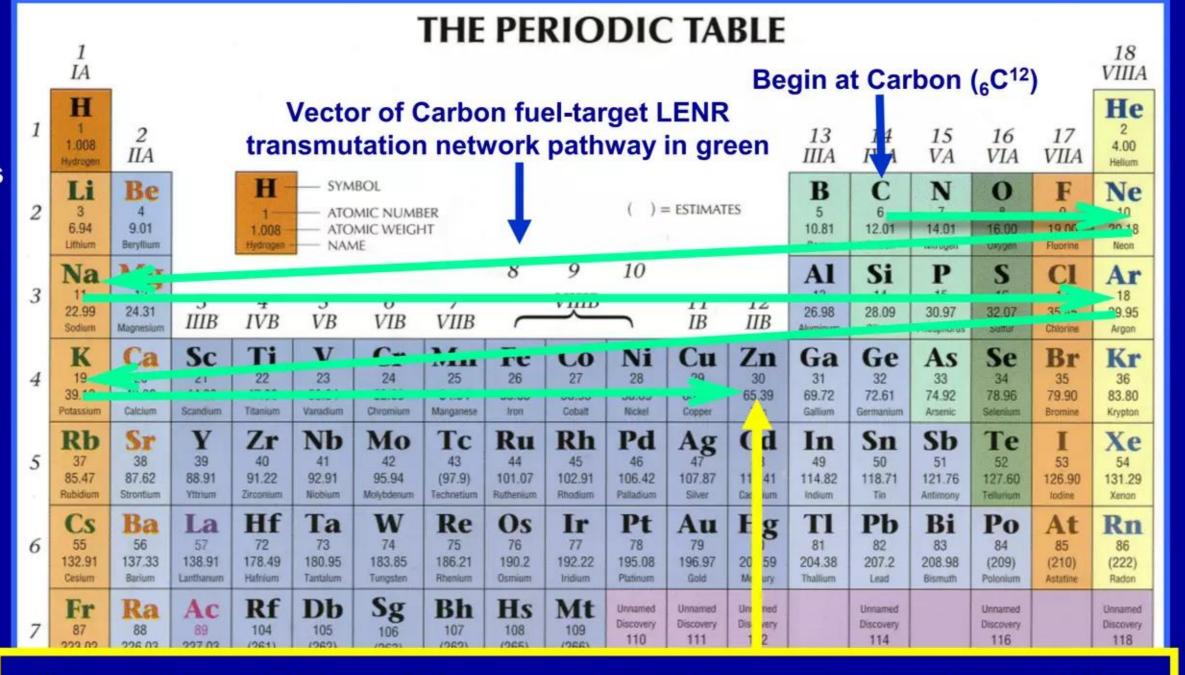
### LENR transmutation pathways tend to follow rows of Periodic Table

Stable elements produced by LENR network can be stopped at Oxygen

Carbon atoms in fossil fuels with Oxygen O<sub>2</sub> produces CO<sub>2</sub> and H<sub>2</sub>O; CO<sub>2</sub> gas emissions are a problem, which has led to schemes like Carbon capture and sequestration (CCS)

Additional issues with coal's varied trace elements

Scale of energy release from chemical reaction combustion processes are on the order of eVs



Can probably ~control where LENR process ends: could stop anywhere from Nitrogen to Zinc

METALS.														
AYDEN	Ce 58 140.12 Cerlum	Pr 59 140.91 Praeseodymium	60 144.24	Pm 61 (145) Promethism	62 150.36 Samarium	63 152.97 Europium	<b>Gd</b> 64 157.25 Gadolinium	65 158.93 Terbium	<b>Dy</b> 66 162.50 Dysprosium	67 164.93 Holmlum	68 167.26 Erbium	<b>T</b> m 69 168.93 Thulum	70 173.04 Ytterbium	71 71
CNEIL	Th	Pa 91	U	Np	Pu 94	Am 95	<b>Cm</b>	Bk 97	Cf	Es 99	Fm 100	<b>Md</b>	No 102	103
vw.hmpublishing.com	232.04 Thorium	231.04 Protacinium	238.03 Uranium	237.05 Neptunium	(240) Plutonium	243.06 Americium	(247) Curium	(248) Berkelium	(251) Californium	252.08 Einsteinium	257.10 Fermium	(257) Mendelevium	259.10 Nobelium	262.1 Lawrence

Depending on where nuclear process was stopped, LENR transmutation of Carbon atoms in oil and coal could produce a wide variety of stable elements up through Zinc; gaseous emissions might be limited to Neon, Argon, Nitrogen and/or preferably Oxygen

Scale of energy release is in MeV; or >10<sup>6</sup> larger than chemical reactions

### Transformation of oil and coal into CO<sub>2</sub>-free energy sources

Coal and oil crucial to the Industrial Revolution and modern society

LENRs enable oil and coal to become 21st century green energy sources



**Today** 



Early 1800s in England



**Today** 

"Clean coal is an attempt by the coal industry to try and make itself relevant in the age of renewables. Existing CCTs do nothing to mitigate the environmental effects of coal mining or the devastating effects of global warming. Coal is the dirtiest fuel there is and belongs in the past."

**Greenpeace policy statement (2009)** 

# Lattice's commercialization strategy akin to computer chips Scale-up LENR system power outputs and integrate energy conversion

- ✓ LENRs can presently reach temperatures of 4,000 6,000° K and boil refractory metals in limited numbers of microscopic LENR-active hot spot sites on laboratory device surfaces. Lattice plans to use its unique proprietary knowledge of LENR engineering physics and key operating parameters (e.g., achieving and maintaining very high local surface electric fields) to first get heat production working well microscopically. That is: reproducibly trigger LENRs on specific, purpose-designed nanoparticulate structures with dimensions ranging from nanometers to microns that are fabricated using existing, off-the-shelf nanotech processes and then deliberately emplaced at what will become LENR-active sites located on Hydrogen-loaded substrate surfaces
- In principle, output of such LENR heat sources could be readily scaled-up: either by fabricating larger area-densities of affixed nanostructures that facilitate formation of LENR hot spot sites on device surfaces, or by injecting larger quantities of specially designed fuel nanoparticles into volumetrically larger reaction chambers containing turbulent dusty plasmas, with or without spatially organized magnetic fields present
- ✓ A variety of off-the-shelf energy conversion subsystems could potentially be integrated with commercial versions of LENR-based heat sources. These include: thermoelectrics or thermionics; steam engines; Rankine cycle steam turbines; Brayton cycle gas turbines, boilers, etc. Other more speculative possibilities involve new types of direct energy conversion technologies that are still under development

### Lattice's commercialization strategy akin to computer chips

### Maximize unit volumes and ride experience curve to attack markets

- ✓ Over time, plan to ride down manufacturing experience cost curve; similar to build-cost reduction and market penetration strategies used by electronics manufacturers; e.g., microprocessors, memory chips, PCs, and smartphones
- As product manufacturing experience accumulates and internal build costs are progressively reduced, leverage enormous energy density/longevity advantages of LENRs (>million times larger than chemical); price LENR-based systems to drastically undercut price/performance provided by competing thermal sources and chemically-based power generation systems --- this strategy can be applied to portable, distributed stationary, mobile, and central station power markets
- ✓ Small-scale LENR systems might seem to be light years away from being able to compete with huge 500 1,500 MW coal-fired and Uranium-fission power plant behemoths; however, please recall history of personal computers versus mainframes. When PCs were first introduced 35 years ago, mainframe computer manufacturers regarded them as just toys, information processing jokes of no consequence. Less than 10 years later, mainframe companies weren't laughing any more. Today, except for just a handful of survivors like IBM, mainframe and minicomputer dinosaurs have disappeared, replaced by microprocessor arrays

### Commercializing LENRs enables a Moore's Law for energy

### Sustainable economic growth could be achieved by doing so

- ✓ While solar PV and wind are CO₂-free and extremely biosafe, their intrinsic energy densities are much lower than today's fossil fuels and inherently intermittent not continuous sources of electrical and thermal power
- ✓ Nuclear fission power has high energy densities, does not produce CO₂ and operates continuously; but it emits huge quantities of deadly neutron and gamma radiation during operation and produces many long-lived radwastes
- ✓ D-T nuclear fusion, while better than fission in terms of producing much less radwaste, still emits very dangerous neutron and gamma radiation during operation; also, there is still no sign of it being commercialized after 60 years of huge effort and hundreds of billions of R&D \$ spent worldwide. See July 31, 2014 *Nature* story on ITER by Elizabeth Gibney: <a href="http://tinyurl.com/mlk5d5k">http://tinyurl.com/mlk5d5k</a>
- ✓ Low energy neutron reactions (LENRs) are only primary energy technology on foreseeable horizon that can provide world with affordable dense green energy, connect the unconnected, and empower billions of powerless people

### **Working with Lattice**

### Partnering on commercialization and consulting on certain topics

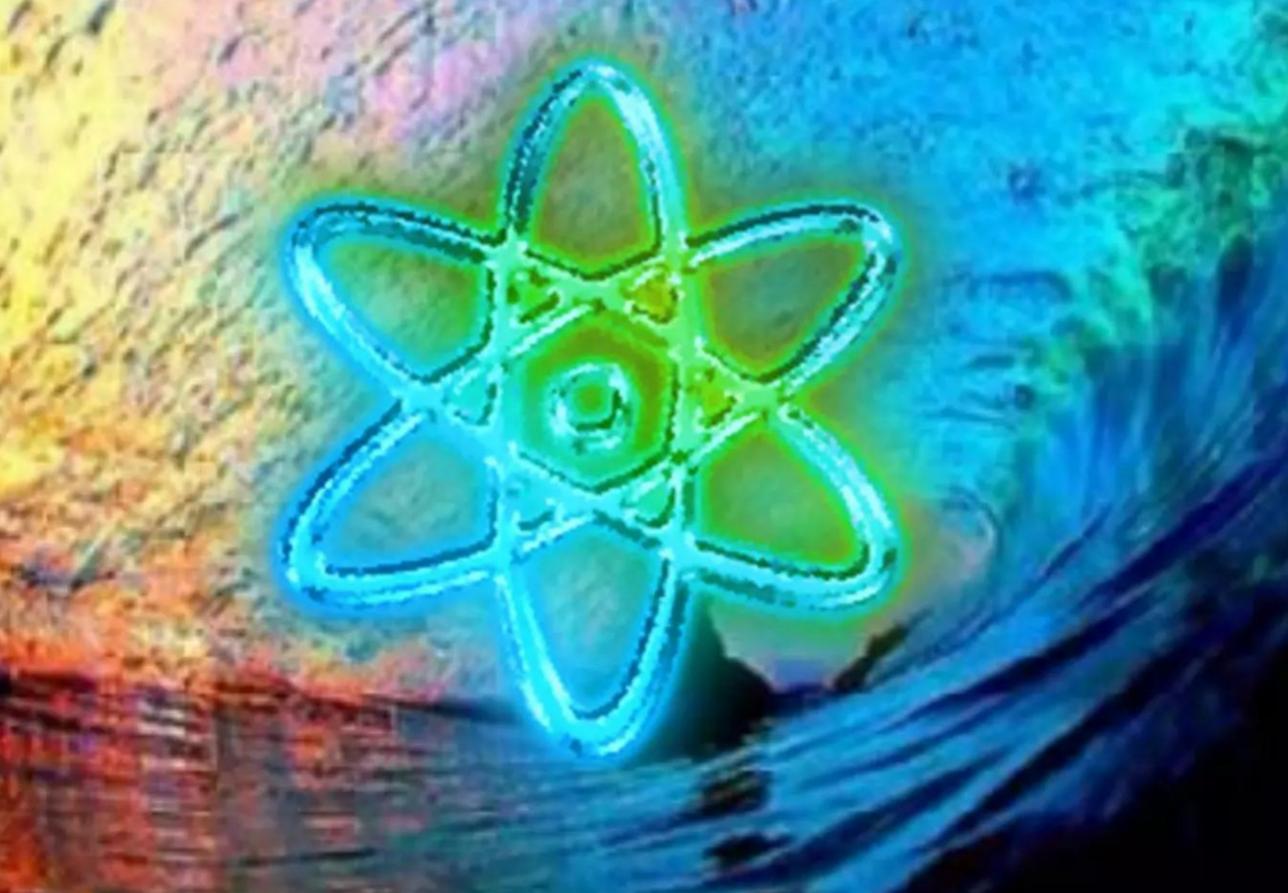
1-312-861-0115 lewisglarsen@gmail.com

L. Larsen c.v.: http://www.slideshare.net/lewisglarsen/lewis-g-larsen-cv-june-2013

- Lattice welcomes inquiries from large, established organizations that have an interest in seriously discussing the possibility of becoming a strategic capital and/or technology development partner in the near- or long-term time frames
- Lewis Larsen also selectively engages in fee-based third-party consulting. This work covers topics in the context of micron-scale, many-body collective quantum effects in condensed matter systems (including photosynthesis), safety issues arising from field failures causing Li-ion battery thermal runaways, nuclear waste remediation, and ultra-high-temperature superconductors, among others. Additional areas of expertise include long-term strategic implications of LENRs on high cap-ex long term investments in power generation and petroleum-related assets, as well as long-term price outlooks for and investments in precious metals and real price of energy. Will consult on such subjects as long as it does not involve my disclosing any proprietary engineering details applicable to LENR power generation systems

# Lattice Energy LLC

Commercializing a next-generation source of green CO<sub>2</sub>-free nuclear energy



LENRs enable society to "shoot the curl" and enter a New World of energy

### Additional reading for the technically inclined

Lattice document that provides a broad-based overview about LENR technology and its potential:

"Truly green nuclear energy exists – an overview for everybody: no deadly gammas ... no energetic neutrons ... and no radioactive waste"

L. Larsen, Lattice Energy LLC, v. 5 updated and revised through March 5, 2014 [108 slides]

http://www.slideshare.net/lewisglarsen/powering-the-world-to-a-green-lenr-future-lattice-energy-llcapril-11-2013

Index to large collection of online documents re LENR theory, experimental data, and the technology:

"Index to key concepts and documents" v. #19

\*\*\*\*\*\*\* RECENTLY UPDATED \*\*\*\*\*\*\*

L. Larsen, Lattice Energy LLC, May 28, 2013 [119 slides] Updated and revised through August 19, 2014

http://www.slideshare.net/lewisglarsen/lattice-energy-llc-index-to-documents-re-widomlarsen-theory-of-lenrsmay-28-2013

Review paper that covers all theoretical aspects of basic Widom-Larsen theory published to date:

"A primer for electro-weak induced low energy nuclear reactions"

Y. Srivastava, A. Widom, and L. Larsen, Pramana - Journal of Physics 75 pp. 617 - 637 (2010)

Abstract: "Under special circumstances, electromagnetic and weak interactions can induce low-energy nuclear reactions to occur with observable rates for a variety of processes. A common element in all these applications is that the electromagnetic energy stored in many relatively slow-moving electrons can (under appropriate circumstances) be collectively transferred into fewer, much faster electrons with energies sufficient for the latter to combine with protons (or deuterons, if present) to produce neutrons via weak interactions. The produced neutrons can then initiate low-energy nuclear reactions through further nuclear transmutations. The aim of this paper is to extend and enlarge upon various examples analyzed previously, present order of magnitude estimates for each and to illuminate a common unifying theme amongst all of them."

http://www.ias.ac.in/pramana/v75/p617/fulltext.pdf