Powering the world to a green future

Green nuclear and central station grid power

Speculative analysis of economics: LENRs vs. gas, coal, and fission

Commercializing LENRs could substantially reduce real price of electricity

Grid-scale LENR plants could potentially be ~ 54 - 74% less costly than natural gas

Analysis

Future economic potential

Lewis Larsen

President and CEO
Lattice Energy LLC

July 22, 2013

"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 ad (February 4, 1954)

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Key take-aways from this presentation

Commercializing LENRs could substantially reduce real price of electricity

- ✓ LENRs are a green, extremely energy-dense technology; strongly complements lower-density renewable sources such as wind and solar power
- ✓ Enable revolutionary portable nuclear power sources
- ✓ Are surprisingly synergistic with and useful to the oil and coal industries over the immediate future
- ✓ Could potentially enable cost-effective small-scale distributed generation worldwide; enhance stability of existing grids and help bring electricity to 1.6 billion people now living in rural areas without any power
- ✓ Number of large Japanese companies now involved in LENR R&D --- Mitsubishi Heavy Industries, Toyota Central Research, and Toyota Motors, among others --- somebody, somewhere will eventually succeed
- ✓ <u>Conclusions</u>: if commercialized, LENRs could be an extremely disruptive technology and affect many markets; grid-level LENR-based power plants could potentially be ~ 54 - 74% less costly vs. natural gas; possibility of retrofitting fossil plants with LENRs

Source: Sierra Club

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Contents

Commercializing LENRs could substantially reduce real price of electricity

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Relevant documents

White paper:

"Will low natural gas prices eliminate the nuclear option in the US?"
R. Graber and T. Retson (released July 2013)

Abstract: "A probabilistic comparison of the investment risks of nuclear power and natural gas-based electricity generating plants has been carried out using a total life cycle power plant model. Although the cost of the gas plant (with carbon tax) is found to be slightly cheaper, that choice of fuel carries a far greater cost uncertainty, suggesting a greater long-term investment risk than nuclear power." [10 pages]

http://www.nuclearenergyinsider.com/nuclear-construction-summit/content-neireport.php

This white paper was produced by EnergyPath Corporation who will be revealing further findings at the 5th Annual Nuclear Construction Summit (22-23 October, Charlotte, NC) – for further information on this event please see: www: www.nuclearenergyinsider.com | 7-9 Fashion Street I London E1 6PX

Lattice document concerning LENR-based power generation systems vs. fission and fusion:

"Truly green nuclear energy exists – an overview for everybody: no deadly gammas … no energetic neutrons … and no radioactive waste"
L. Larsen, Lattice Energy LLC, updated and revised through June 23, 2013 [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 documents re LENR theory, experimental data, and the technology:

"Index to key concepts and documents" v. #11
L. Larsen, Lattice Energy LLC, May 28, 2013 [82 slides]

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

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Edison's bold prophecy in 1880 was right

Huge drop in real price of electricity since 1880

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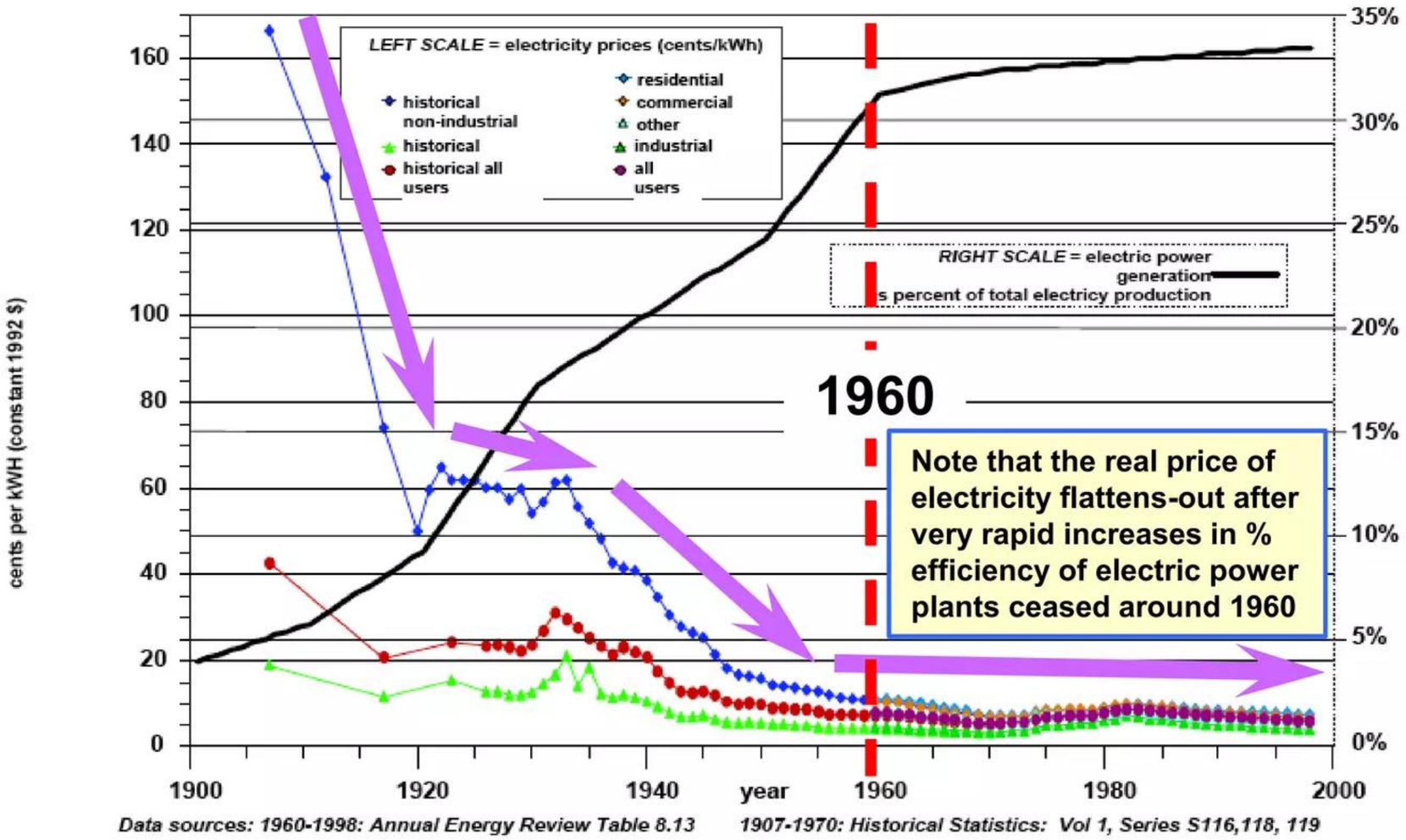
Edison's bold prophecy in 1880 was right

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

Average efficiency of coal-fired power plants has remained at ~32 - 34% since 1960

Electrical efficiency and the price of electricity: USA 1900-1998 (1990 dollars)



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

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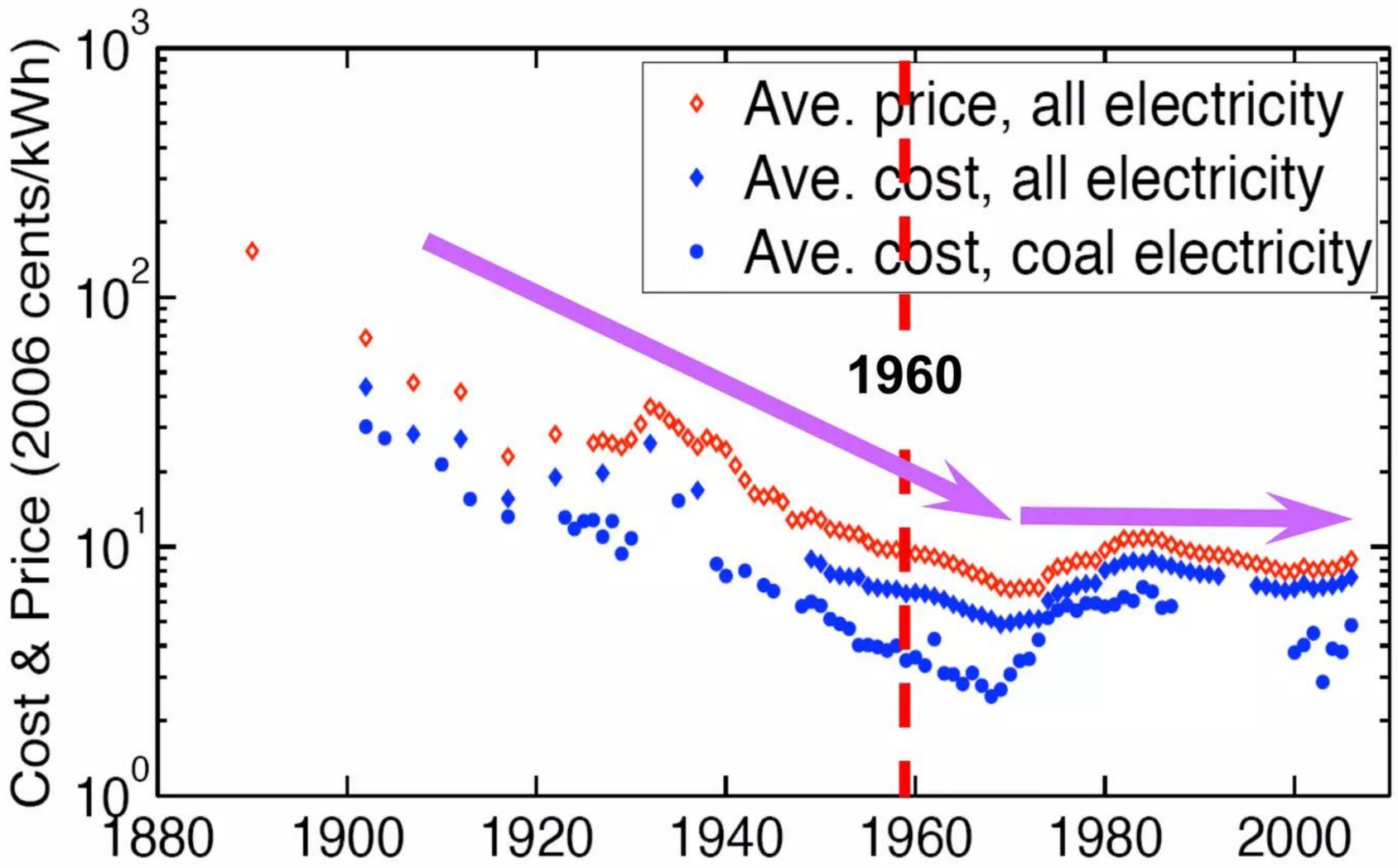
Edison's bold prophecy in 1880 was right

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)

Total cost of coal-fired electricity: comparison to ave. electricity cost



Source: Santa Fe Institute - working papers http://www.santafe.edu/media/workingpapers/09-12-047.pdf

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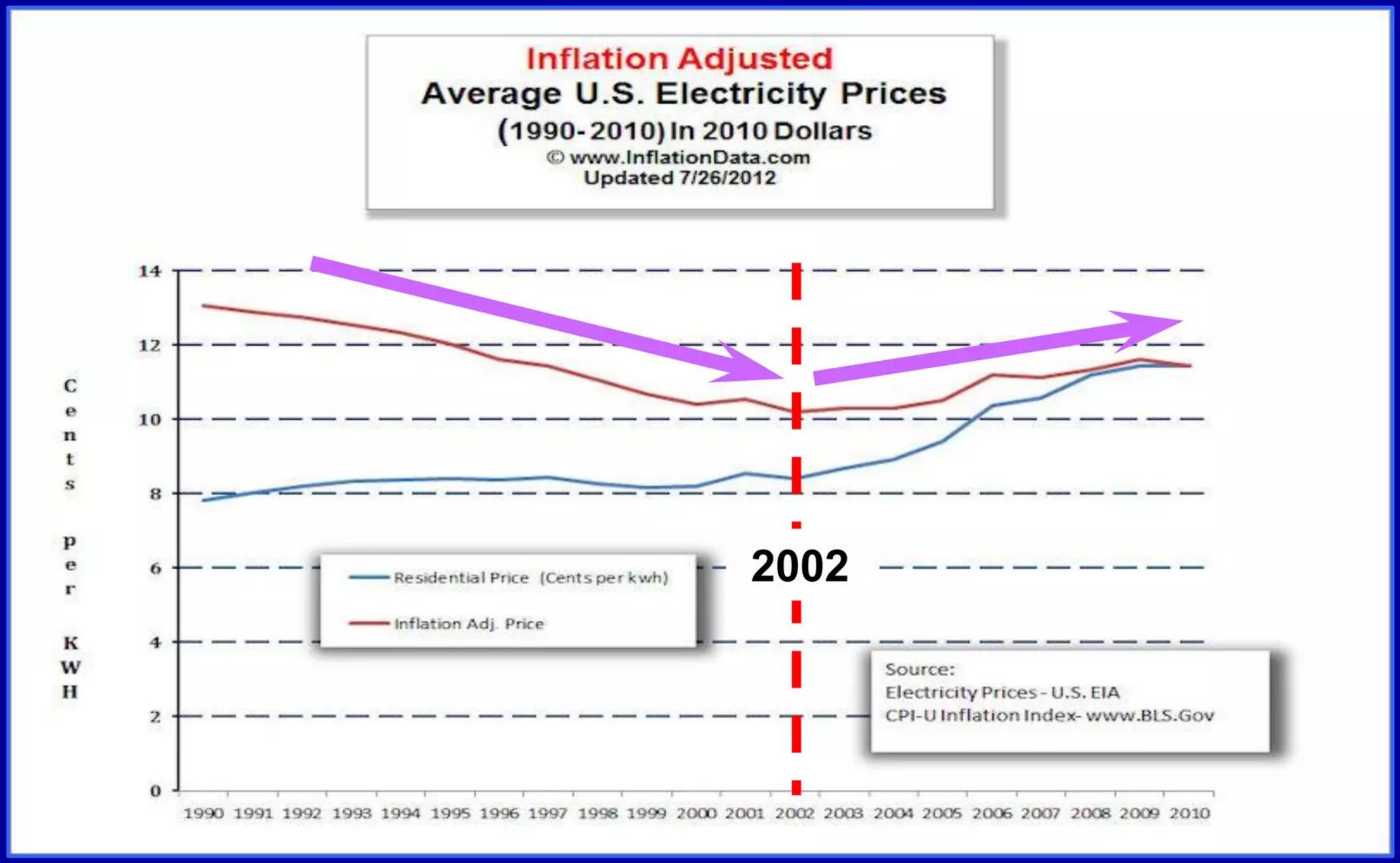
Edison's bold prophecy in 1880 was right

After 122 years of more-or-less steady declines since Thomas Edison made his prescient prophecy about future cheap electricity back in 1880, real prices in US may have finally bottomed-out



Source: http://inflationdata.com/articles/inflation-adjusted-prices/electricity-price-inflation-rate/

Experience curve effect can reduce real price

As more units are made get cheaper to produce

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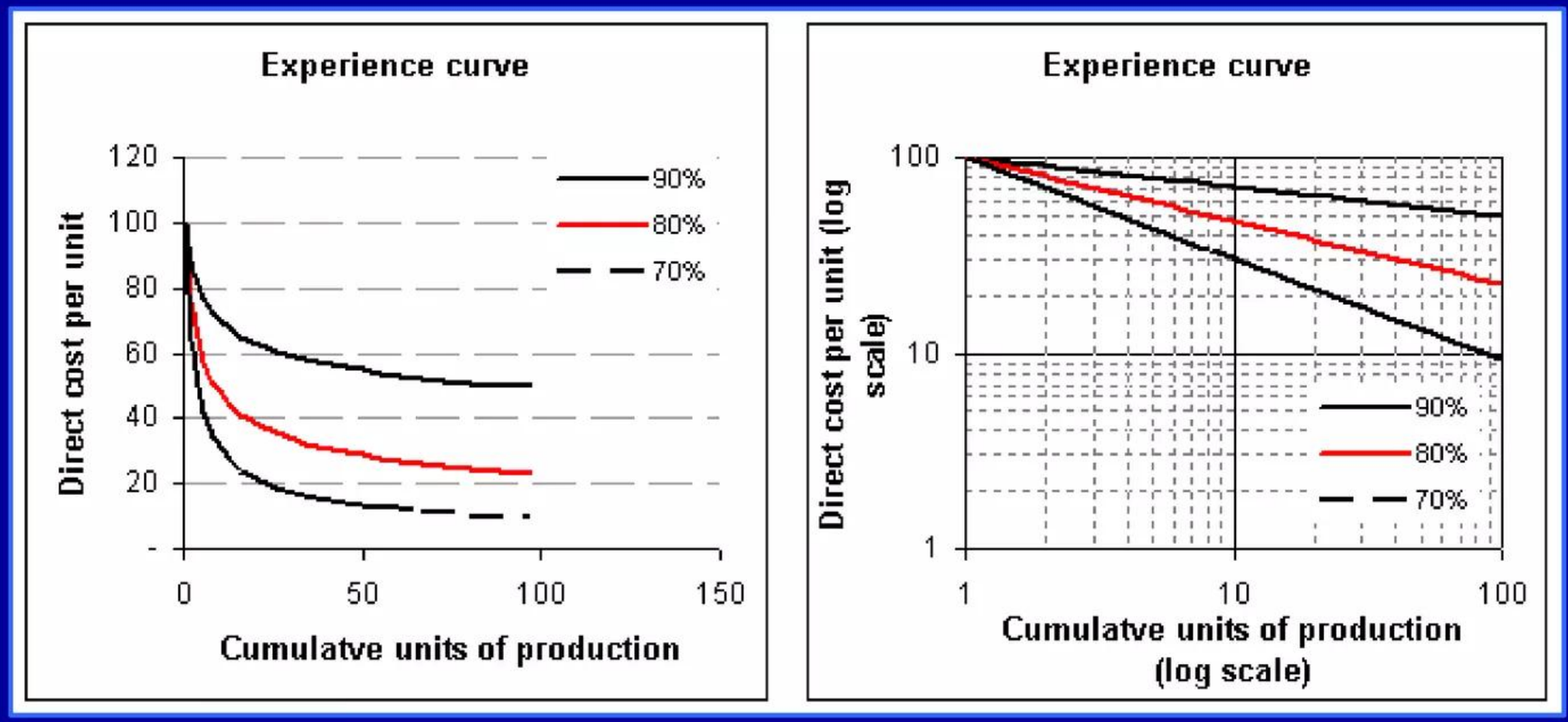
Experience curve effect can reduce real price

Idea developed and publicized by the Boston Consulting Group in 1960s

Edison intuitively understood experience curves when he made his prophecy in 1880

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 - http://en.wikipedia.org/wiki/Experience_curve_effects

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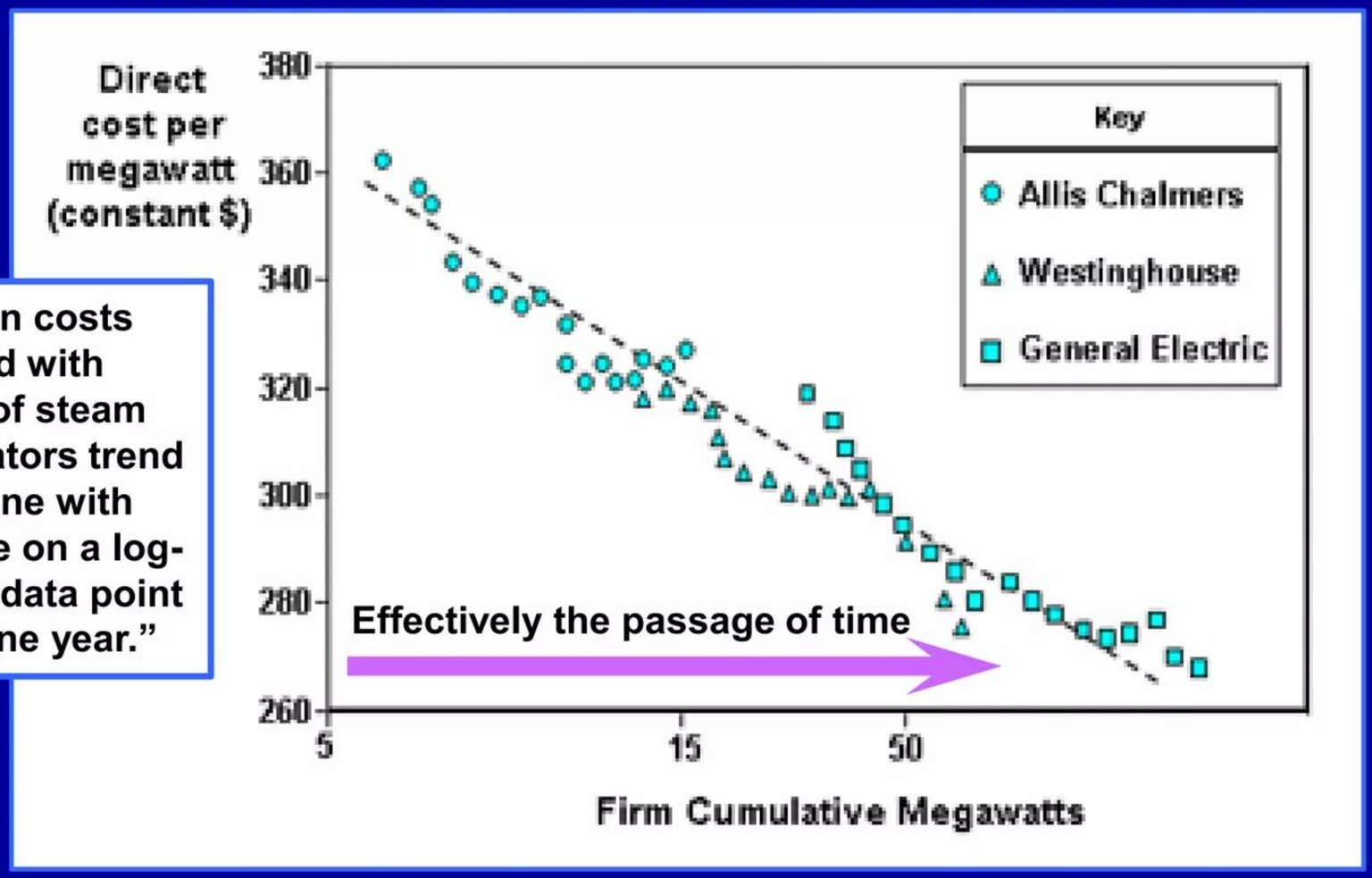
Experience curve effect can reduce real price

Found to apply to many very different types of manufactured products

Increase in steam turbines' % efficiency was increasing in parallel with decreases in cost

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



"Decrease in costs associated with production of steam turbine generators trend towards a line with constant slope on a log-log plot; each data point represents one year."

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

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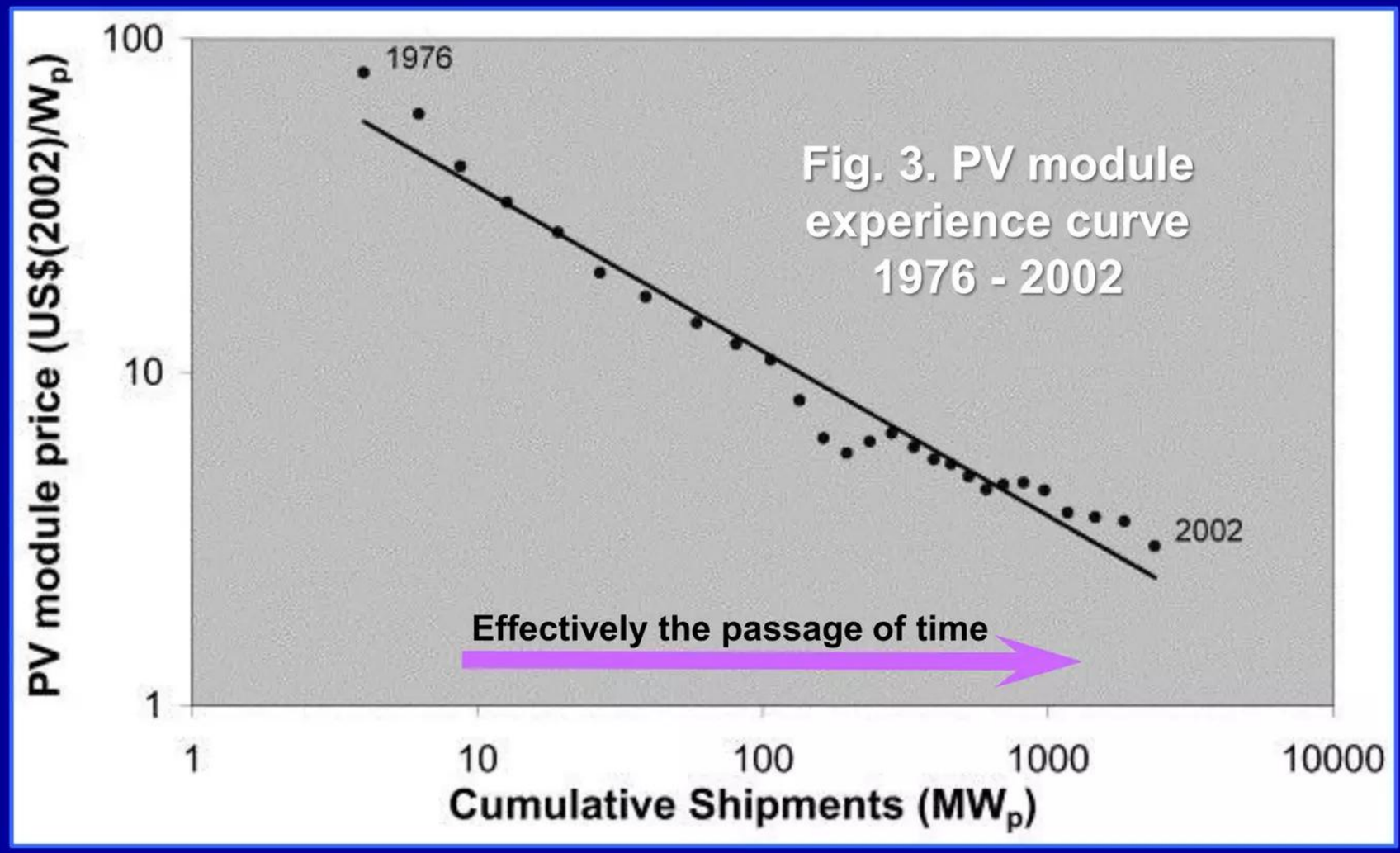
Experience curve effect can reduce real price

Real prices of microprocessor chips and hard disk storage are also examples

Solar photovoltaic (PV) modules' real prices are also decreasing - just like steam turbines

"Analysis of diffusion paths for photovoltaic technology based on experience curves"
D. Poponi, *Solar Energy* 74 pp. 331 - 340 (2003)



Source: http://www.sciencedirect.com/science/article/pii/S0038092X03001518

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Experience curve effect can reduce real price

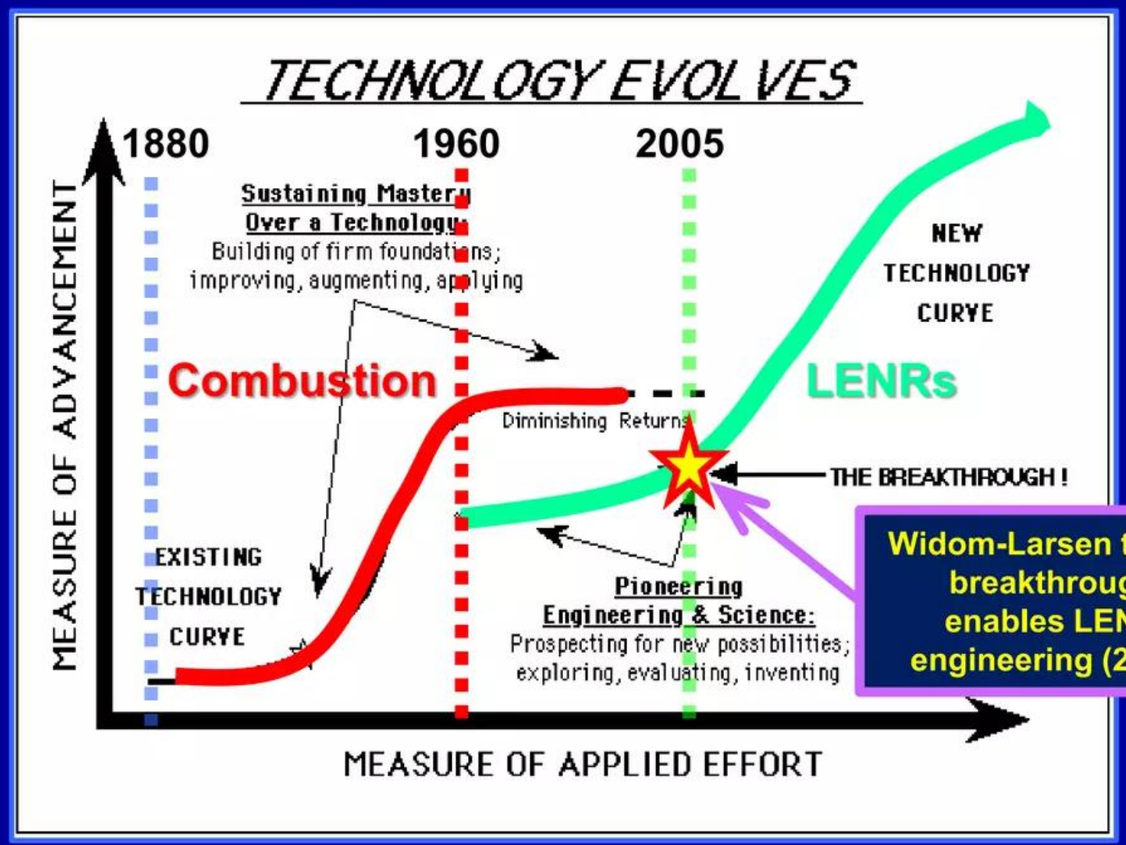
S-curve of product performance may also improve with cumulative R&D $

Similar to the experience curve concept but not as rigorously delineated or measured

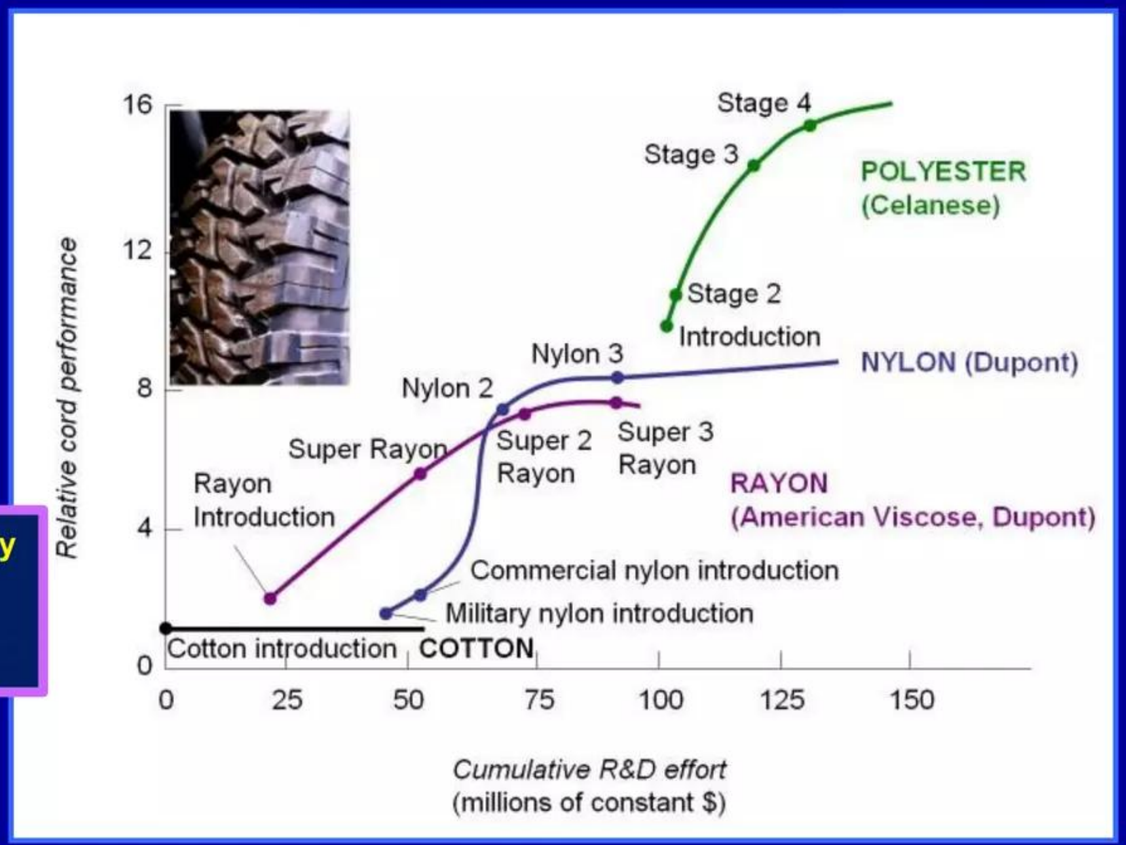
Slide #6 herein: data suggests combustion power plant technologies are mature

To further reduce electricity's price need a new breakthrough technology: LENRs

Technology S-curve for combustion vs. LENRs:



S-curve concept and tire cord technology:



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Future global energy demand will be very strong

Need new very energy-dense power sources that will complement wind and solar renewables

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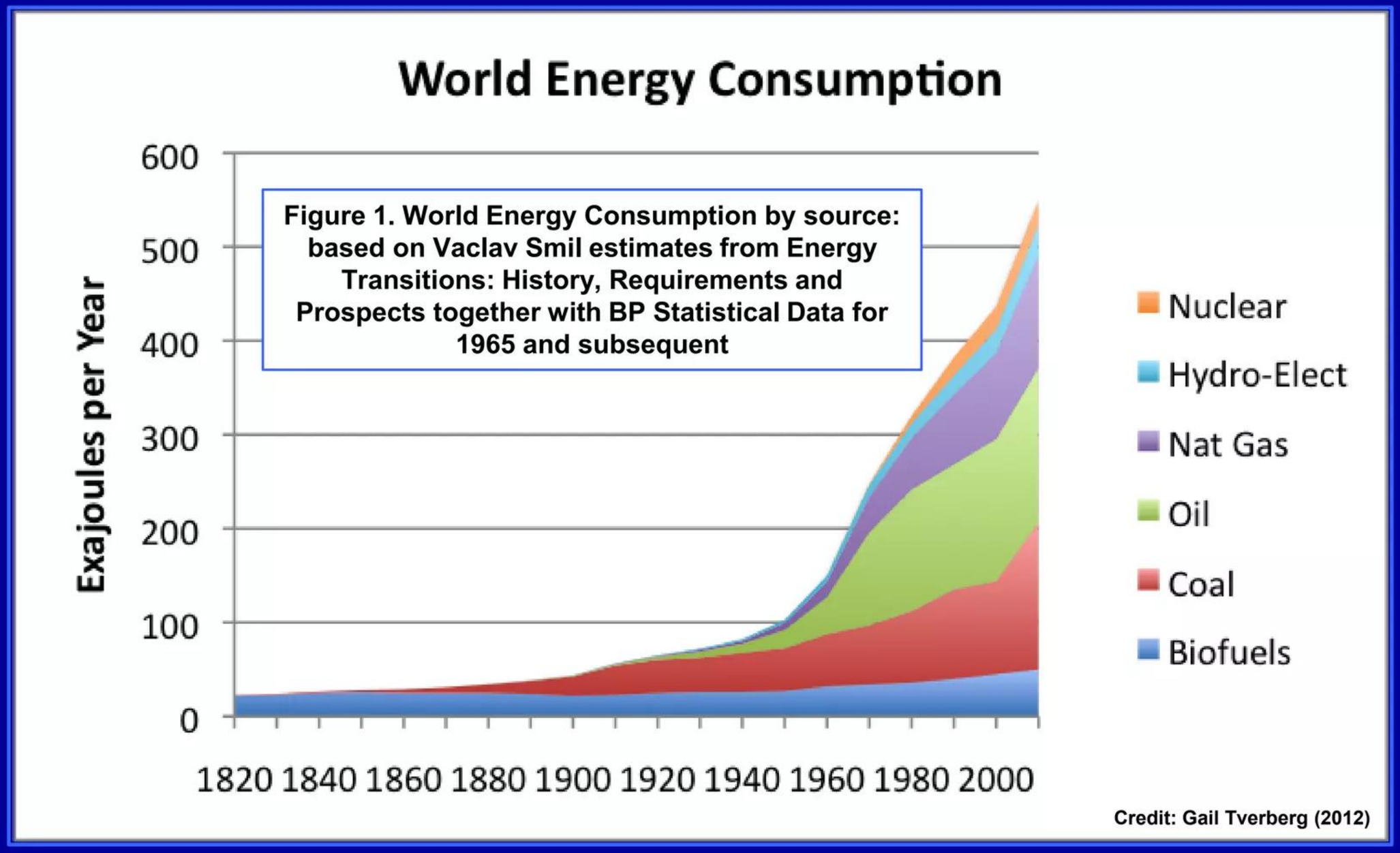
Future global energy demand will be very strong

Natural gas, oil, and coal still greatly dominate world energy consumption



Source: http://ourfiniteworld.com/2012/03/12/world-energy-consumption-since-1820-in-charts/

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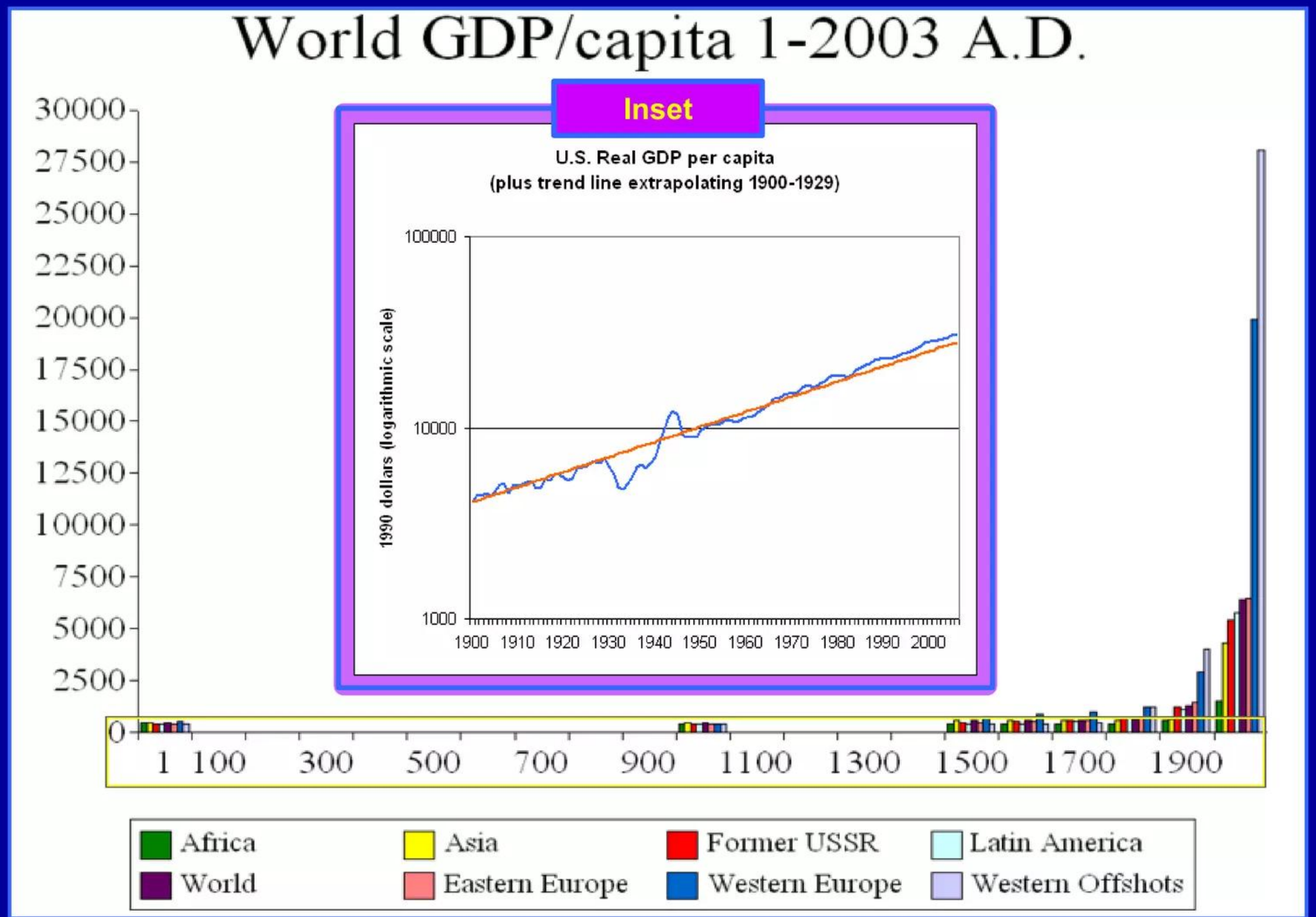
Future global energy demand will be very strong

World and U.S. GDP/capita have had strong growth for an extremely long time



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Future global energy demand will be very strong

Real GDP growth and increased demand for energy are highly correlated

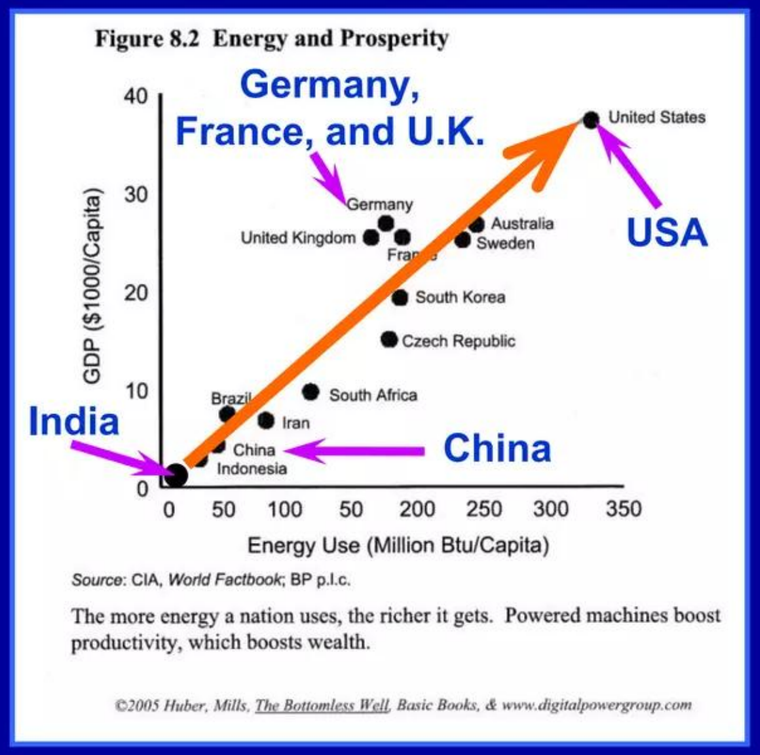
If vastly improved energy technologies are not developed, future demand cannot be met

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.



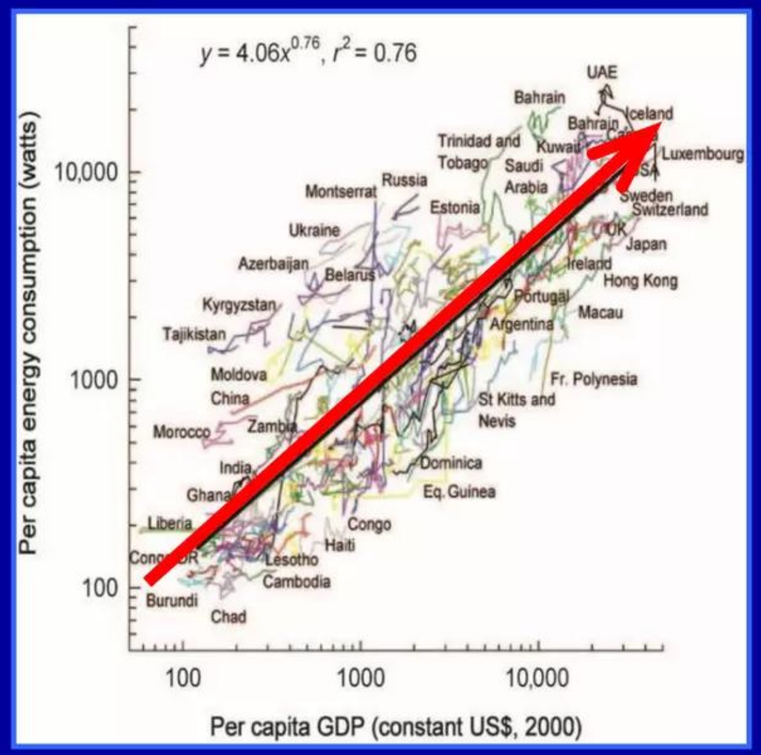


Fig. 1, pp. 20, Brown *et al.*, "The relationship between per capita energy use and per capita gross domestic product (GDP; in US dollars), plotted on logarithmic axes, from 1980 to 2003."

From: "Energetic Limits to Economic Growth" J. Brown *et al.* *BioScience* 61 pp. 19 - 26 (2011)

http://www.aibs.org/bioscience-press-releases/resources/Davidson.pdf

Powering the world to a green future

Future global energy demand will be very strong

Per capita consumption ~flat since 1960s: need lower-cost energy sources

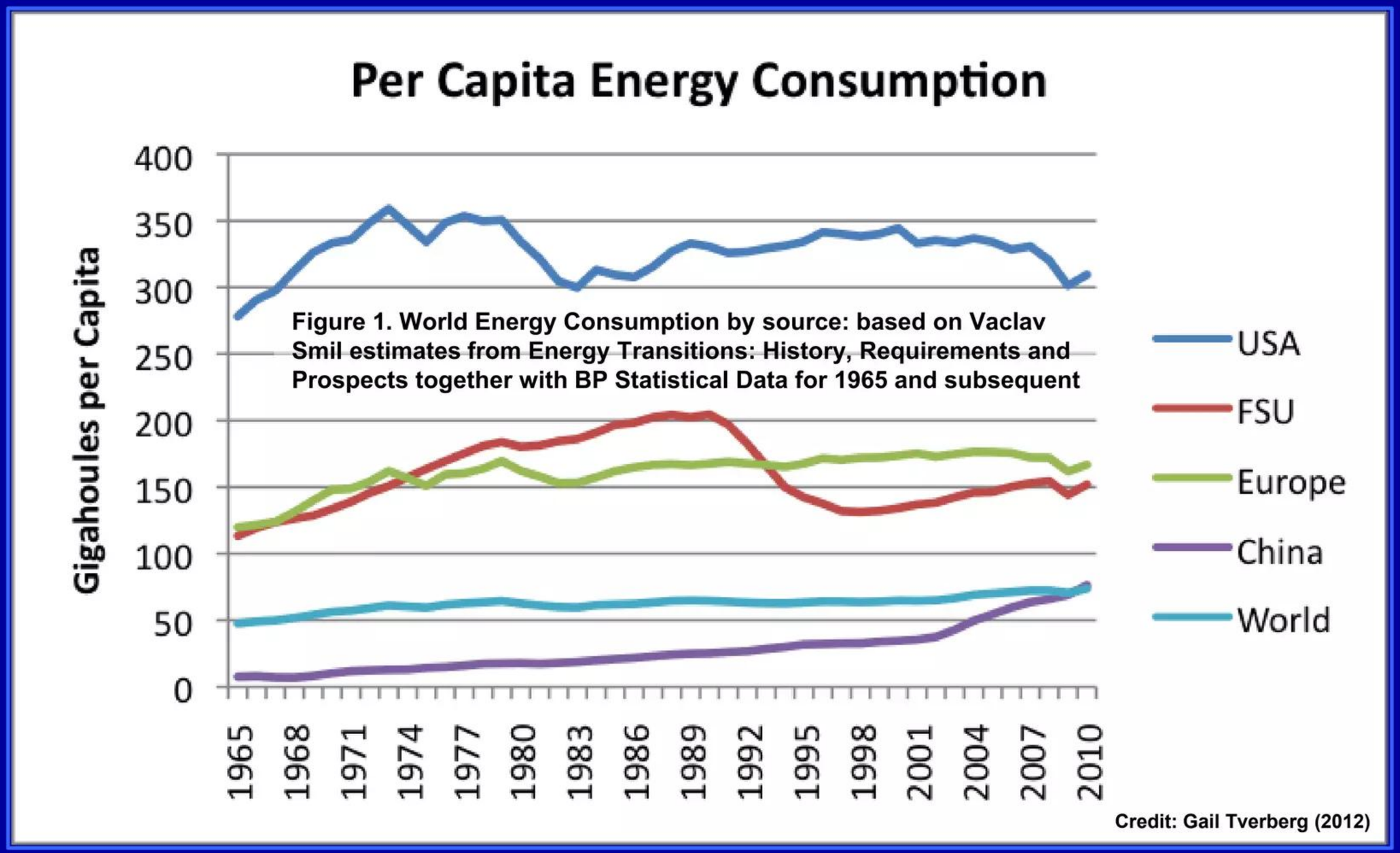


Figure 1. World Energy Consumption by source: based on Vaclav Smil estimates from Energy Transitions: History, Requirements and Prospects together with BP Statistical Data for 1965 and subsequent

Source: http://ourfiniteworld.com/2012/03/12/world-energy-consumption-since-1820-in-charts/

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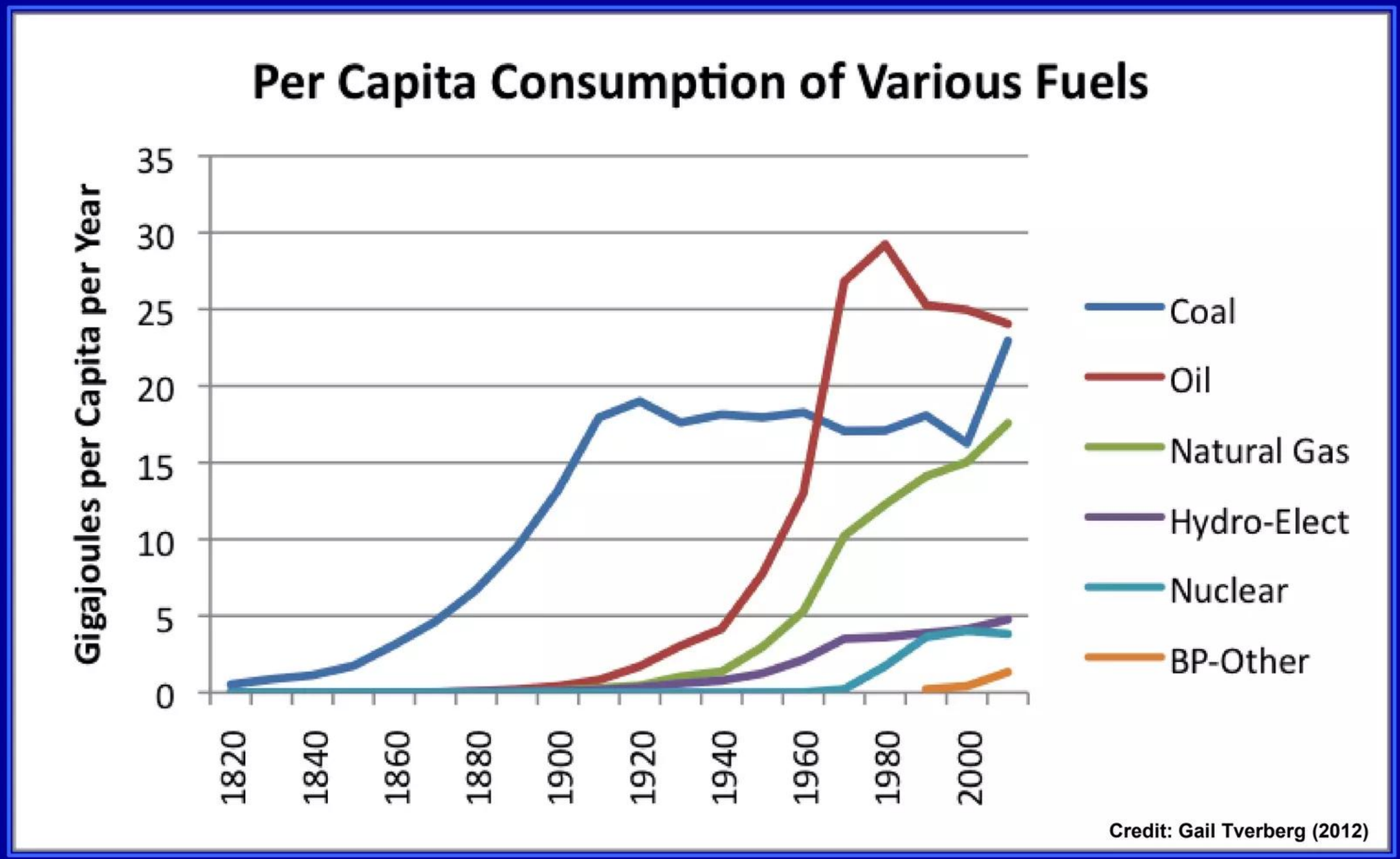
Future global energy demand will be very strong

Existing nuclear technology minor player due to safety and other issues



Source: http://ourfiniteworld.com/2012/03/12/world-energy-consumption-since-1820-in-charts/

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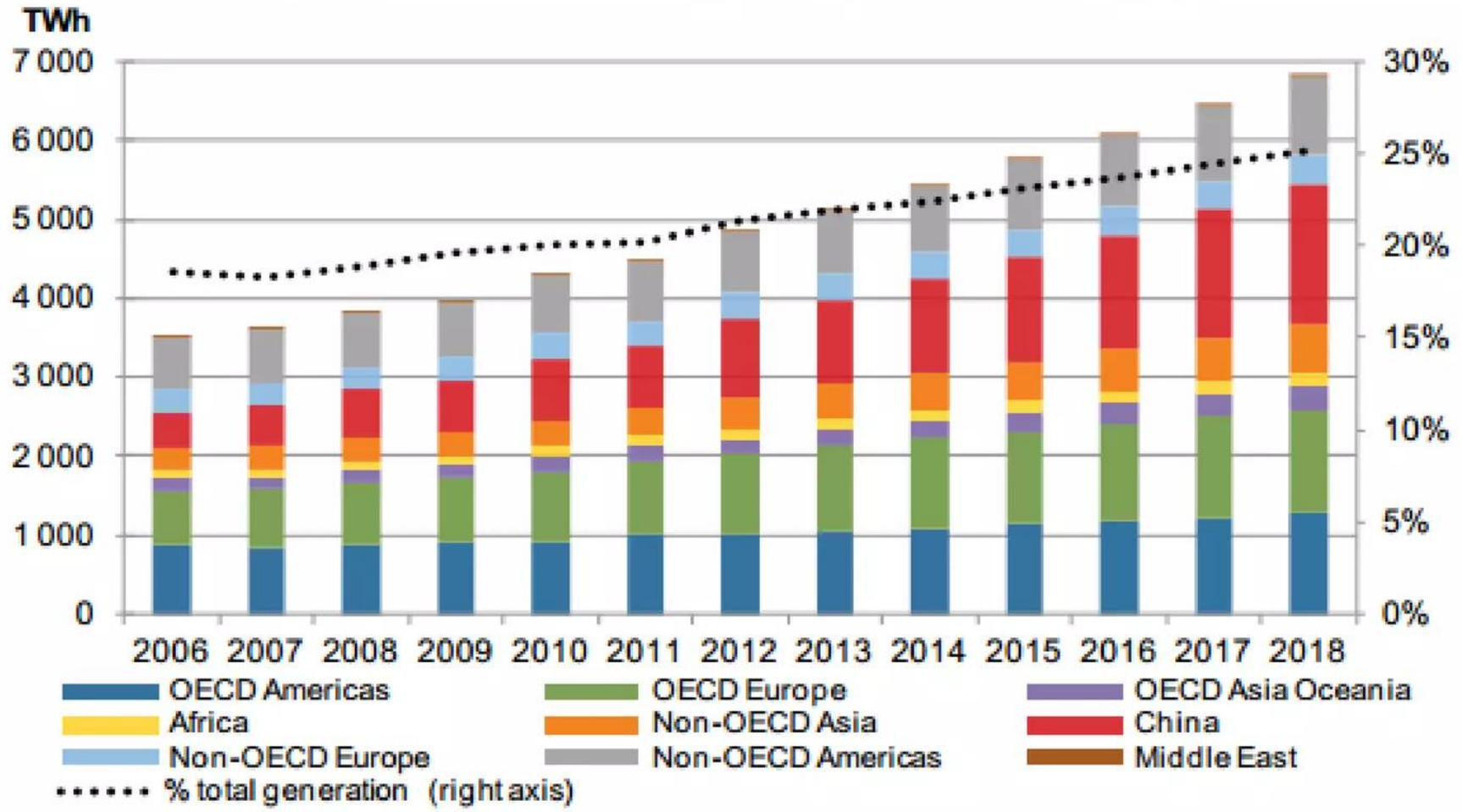
Future global energy demand will be very strong

Renewable sources of energy are growing at a reasonable pace worldwide

Figure 1 Global renewable electricity production by region



Notes: TWh ■ terawatt hours. Unless otherwise indicated, all materials in figures and tables in this chapter derive from International Energy Agency (IEA) data and analysis.

Source: International Energy Agency (IEA) http://www.iea.org/Textbase/npsum/MTrenew2013SUM.pdf

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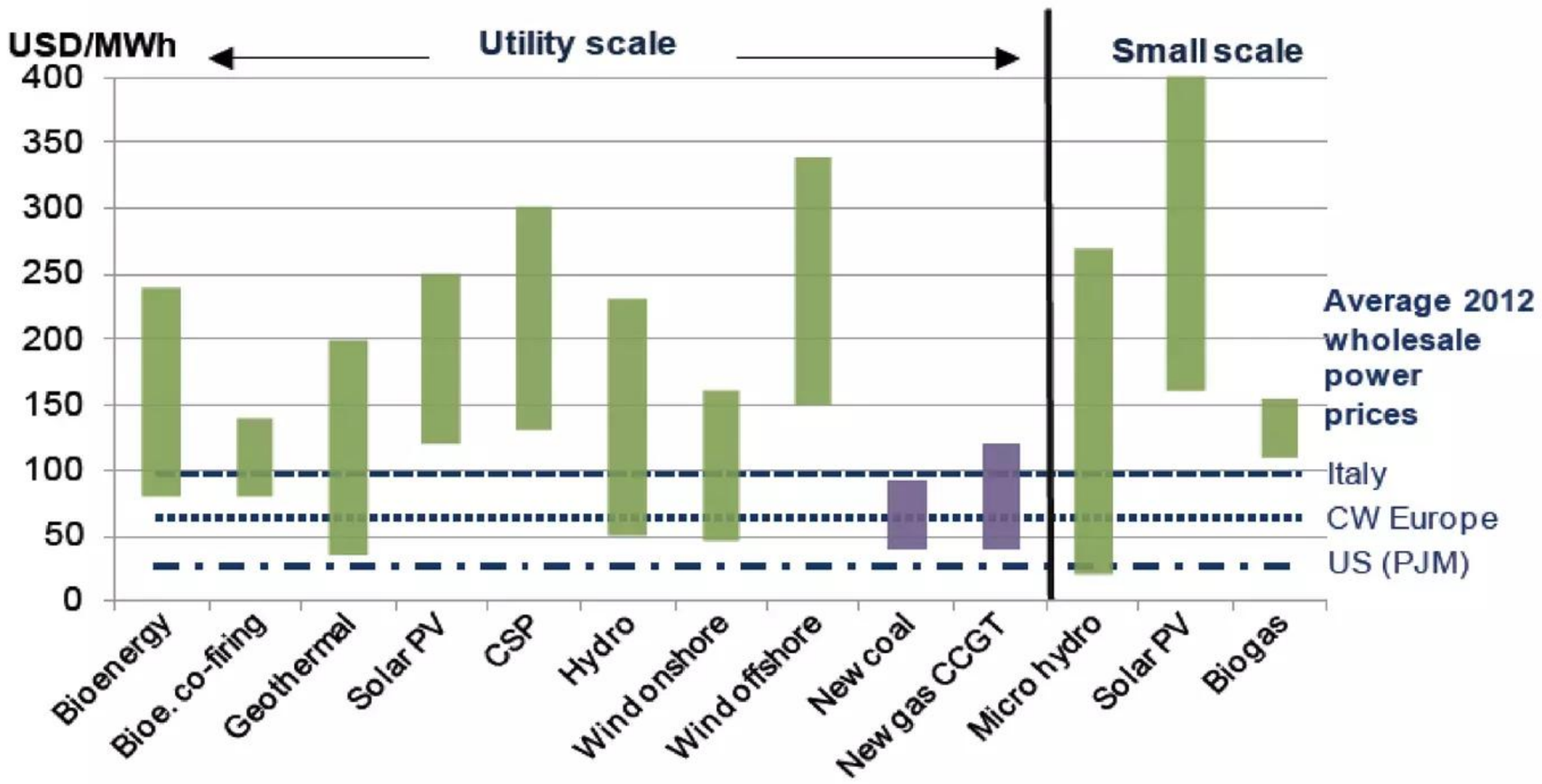
Future global energy demand will be very strong

Need new clean energy technology that makes small scale <<< less expensive

Figure 3 Global levelised costs of power generation ranges, first quarter of 2013



Notes: costs are indicative and ranges reflect differences in resources, local conditions and the choice of sub-technology. CCGT = combined-cycle gas turbine. Central-Western (CW) Europe = Austria, France, Germany, Switzerland. United States (US). PJM = regional transmission organisation covering 13 states and the District of Columbia (DC).

Source: IEA analysis with power price data from Bloomberg LP, 2013.

Source: International Energy Agency (IEA) http://www.iea.org/Textbase/npsum/MTrenew2013SUM.pdf

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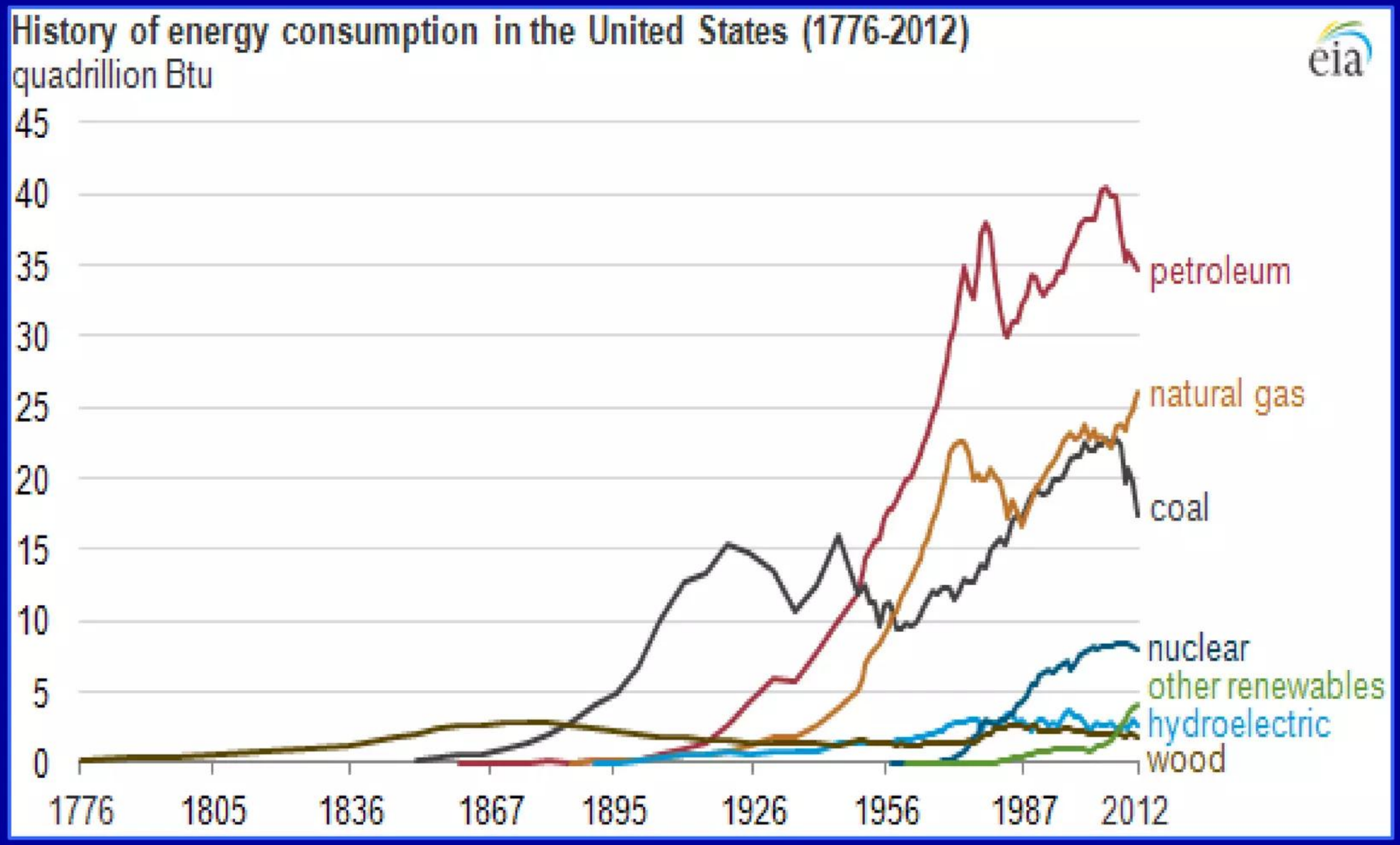
Future global energy demand will be very strong

Could next age of energy consumption be clean renewables and LENRs?



Source: U.S. Energy Information Administration (EIA)

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LENR systems: energy-dense and readily scale-up

Energy densities > million x higher than chemical

Powering the world to a green future

LENR systems: energy-dense and readily scale-up

Green: no deadly energetic neutrons or gamma emissions and no radwastes

Unique features eliminate need for any heavy, expensive containment and shielding

- ✓ **LENRs are revolutionary green nuclear technology; fully explained by Widom-Larsen theory breakthrough published in peer-reviewed journals**
- ✓ **Have none of the safety and environmental problems or proliferation issues associated with fission and fusion power generation technologies**
- ✓ **Absence of any requirements for shielding and containment subsystems opens-up the possibility of developing revolutionary battery-like portable nuclear power sources that are safe and low-cost; no onerous clean-up $**
- ✓ **Commercial LENR systems would incorporate substantial amounts of nanotechnology; manufacturing techniques would resemble computer chips much more than internal combustion engines or wind turbines**
- ✓ **Output of LENR power sources would be inherently upwardly scalable, either by increasing active working surface area and/or volumetrically**
- ✓ **Could be vastly less expensive than fission or fusion for power generation**

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LENR systems: energy-dense and readily scale-up

Energy density: key advantage in portable, small-scale, and mobile power

Solar and wind have innately low energy densities - need to collect and concentrate it

- ✓ **Vast majority of vehicles are now powered by internal combustion engines burning gasoline or diesel fuels with O_2 because effective energy densities are much higher than all-electric vehicles powered by advanced chemical batteries**
- ✓ **At the present time, vehicles with internal combustion engines have substantially lower total lifetime $ costs than all-electric vehicles**
- ✓ **LENRs are at least 5,000 times more energy-dense than gasoline**
- ✓ **If LENRs can be scaled-up to power vehicles, have opportunity to displace internal combustion**

Petroleum energy density: "A single gallon of gasoline contains approximately forty 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."

Table 1 Energy density — Source: B.E. Layton, *International Journal of Green Energy* 5 pp. 438 - 455 (2008)

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

Renewables

Fossil fuels

Source: http://www.drexel.edu/~/media/Files/greatworks/pdf_sum10/WK8_Layton_EnergyDensities.ash

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LENR systems: energy-dense and readily scale-up

Battery-like portable LENR devices could out-compete batteries and fuel cells

LENRs Versus Chemical Energy Sources: Batteries, Fuel Cells, and Microgenerators		
Source of Energy	**Approximate Energy Density (Watt*hours/kg)**	
Alkaline Battery	**164**	Chemical
Lithium Battery	**329**	Chemical
Zinc-Air Battery	**460**	Chemical
Direct Methanol Fuel Cell (35% efficient)	**1,680**	Chemical
Gas Burning Microgenerator (20% efficient)	**2,300**	Chemical
100% Efficient Combustion of Pure Methanol	**5,930**	Chemical
100% Efficient Combustion of Pure Gasoline	**11,500**	Chemical
LENRs (based on an assumption of an average of 0.5 MeV per nuclear reaction in an LENR system)	**57,500,000** (maximum theoretical energy density – only a fraction would be achievable in practice)	Nuclear

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LENR systems: energy-dense and readily scale-up

Simple calculations illustrate potential for use in compact power sources

- ✓ To simplify calculations, we will assume that conversion of input energy (in this case, an electric current) into energy available to produce LENR ULM neutrons is 100 percent efficient in order to estimate a *theoretical upper bound* on potential energy releases from a compact LENR heat source; will also assume that 100 percent of the ULM neutrons produced in the hypothetical device are absorbed locally (a pretty safe bet that is supported by 20+ years of experiments) and that they are *only* absorbed by a target fuel comprising isotopically pure Lithium-6, resulting in a series of nuclear reactions beginning with Lithium-6 and ending with Helium-4 (please see discussion on Slide #92). Lastly, we will assume that the base fuel used to produce LENR ULM neutrons in our hypothetical device is *deuterium* and that it has an LENR-active working surface area of 1 cm^2

- ✓ Input energy required to produce 1 neutron/cm^2/sec from deuterium base fuel to react with the Lithium-6 target fuel is 0.39 MeV per neutron. However, we need two ULM neutrons to complete the entire series of reactions, so the required total input energy to the device is 0.78 MeV/cm^2/sec. The net energy release from that particular series of LENR reactions starting with Lithium-6 is 26.9 MeV/cm2/sec = 4.28 x 10^{-12} J/cm^2/sec (1 eV = 1.602 x 10^{-19} J); 26.9 MeV thus represents a theoretical upper bound of ~ 34x total input power

- ✓ As there are ~ 10^{14} of these 26.9 MeV energy releases taking place per second on the 1 cm^2 LENR device, the total energy release is 4.28 x 10^{-12} J/cm^2/sec x 10^{14} = 428 J/cm^2/sec. This represents 428 W/cm^2, a large device-level power density. At a lesser ULM neutron production rate of 1 x 10^{12} cm^2/sec, the overall energy production rate would drop down to 4.28 J/cm^2/sec or 4.28 W/cm^2. At a ULM neutron production rate of 1 x 10^{11} cm^2/sec, the energy production rate would drop down to 0.428 J/cm^2/sec or 0.428 W/cm^2, which is close to levels of excess heat output that are often observed in the *limited subset* of electrolytic LENR experiments that researchers deem successful at making excess heat

- ✓ In this particular example, a heat generating rate of 428 W/cm^2 means 0.428 kWh/cm^2 produced in an hour for a Lithium-6-fueled 1 cm^2 LENR device, without releasing any CO_2. In comparison to minuscule nanogram (10^{-9} g) quantities of LENR reactants consumed, the complete combustion of 1 US gallon of gasoline (weighing 2.7 kg) with O_2 generates ~33.56 kWh of heat energy and releases ~8.8 kg of CO_2 into the atmosphere. Scaling up surface area of the idealized LENR device 1,000 fold could generate 428 kWh, while a 1 m^2 device would create a 4.28 Megawatt eco-green nuclear power source

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LENR systems: energy-dense and readily scale-up

LENRs potentially enable revolutionary safe portable nuclear power sources

- ✓ Advanced batteries are just beginning to approach their technological limits in terms of achievable energy densities; >100x increase in energy density is not possible chemically
- ✓ Lithium-based batteries could unknowingly be encountering LENRs already; subset of "field failure" thermal runaways could potentially be triggered by rare LENR 'hotspots' inside batteries
- ✓ Lithium-based batteries effectively store electrical energy in electrons in ions at only eV energies; a LENR Lithium fuel cycle releases ~27 MeV per nuclear reaction cycle (~27 million x more)
- ✓ Since they are radiation-free and do not produce long-lived radioactive isotopes, battery-like LENR power generation devices would not require any radiation shielding or containment subsystems, dramatically reducing their weight, size, and cost; enable development of revolutionary portable, battery-like nuclear power systems for compact electronics
- ✓ With energy densities >1 million x those of chemical systems, compact, portable LENR-based generators could eventually compete directly with batteries and fuel cells in key applications

? perhaps in some thermal runaways

Powering the world to a green future

LENR systems: energy-dense and readily scale-up

Sweet spot market-entry point may be systems with 1 - 10 kWh electrical output

Modular systems could be sold in customer-configurable arrays with varied total output

- ✓ **Select market-entry points to maximize unit production volumes of LENR-based power generation devices and systems to ride down the experience curve in terms of manufacturing cost/unit over time; this is same build-cost reduction and market penetration strategy used very successfully by manufacturers of microprocessors (e.g., Intel), memory chips (Samsung), PCs (Dell, HP), and portable communication devices (Apple, Nokia, Blackberry)**
- ✓ **As product manufacturing experience accumulates and internal build costs are progressively reduced, leverage enormous energy density and longevity advantages of LENRs (million times larger than chemical) to successfully penetrate additional market niches involving high-unit-volume applications**
- ✓ **LENR-based systems could be priced to drastically undercut price/performance provided by competing thermal sources and chemically-based power generation systems such as batteries and fuel cells --- this strategy for market penetration and eventual domination could potentially be applied to portable, distributed stationary, mobile vehicular, and central station power markets**

Powering the world to a green future

Fossil fuels still dominate grid power generation

While use of renewables is increasing steadily, it will take a very long time to replace fossil fuels

Powering the world to a green future

Fossil fuels still dominate grid power generation

Wide-area electric grids now dominate electricity production and distribution

Limited numbers of large central station power plants generate 90+% of grids' electricity

- ✓ In 2012: United States generated about 4,054 billion kilowatt hours of electricity; about 68% of the electricity generated was from fossil fuels (coal, natural gas, and petroleum). Detailed breakdown is: coal 37%; natural gas 30%; nuclear (Uranium-235 fission) 19%, hydropower 7%, other renewables 5%; biomass 1.42%; geothermal 0.41%; solar 0.11%; wind 3.46%; petroleum 1%; and "other gases" < 1% (source: EIA, May 2013)
- ✓ Centralized grid system architecture was well-established by 1900 in US, Europe, and Japan; has since spread worldwide
- ✓ In recent years, coal and nuclear fission have come under increasing attack by green activists and governments worldwide; changes in regulatory environments are causing accelerated retirement of many older coal plants and making financing of new, modern coal-fired power plants much more problematic – same issues for fission plants, especially in U.S.
- ✓ While use of renewable energy sources is increasing, in absence of carbon taxes, they are still more expensive than fossil fuels; don't fit as easily in a centralized grid architecture

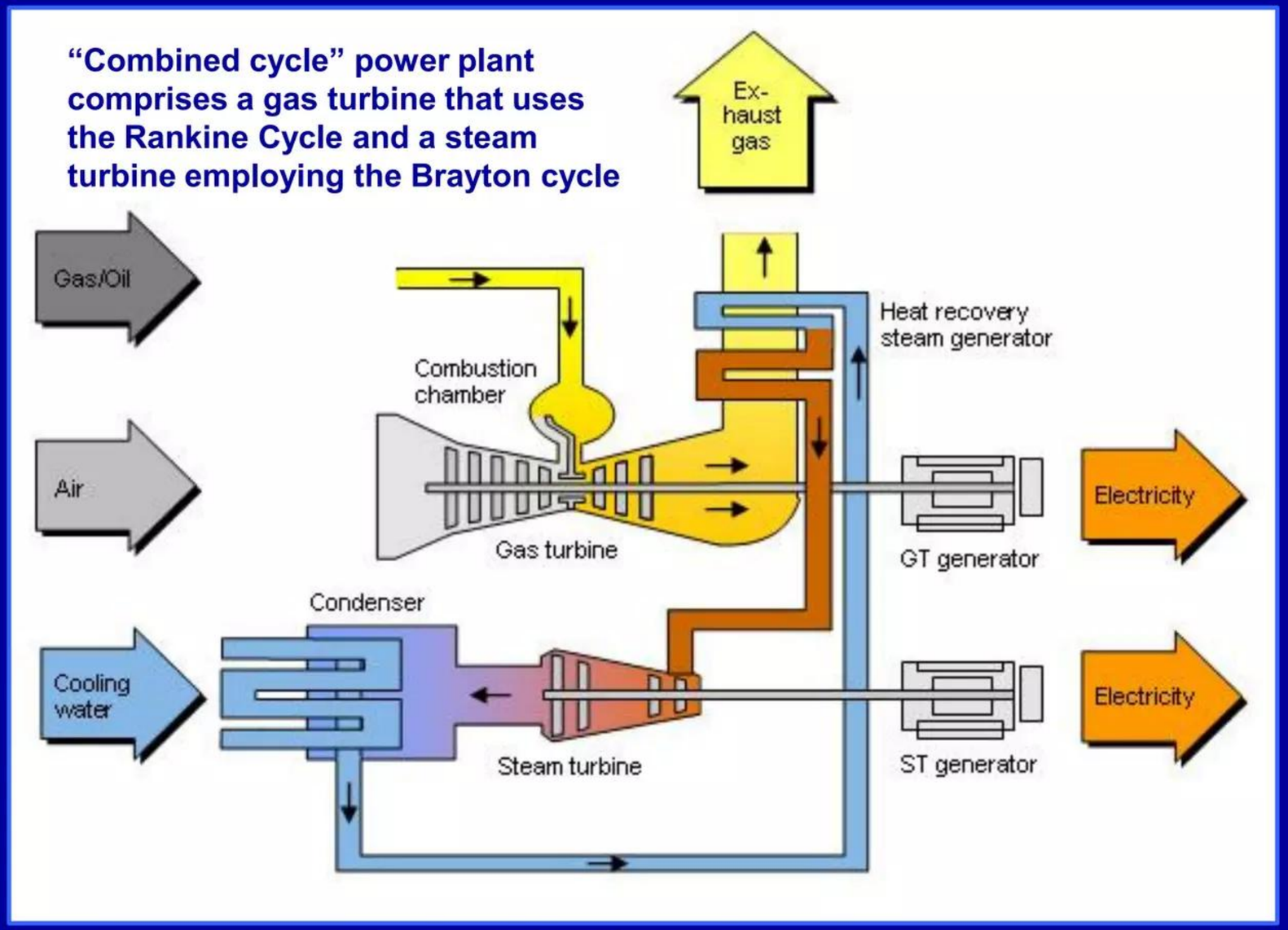
Source: http://www.ucsusa.org/assets/documents/clean_energy/Water-Smart-Power-Executive-Summary.pdf

Powering the world to a green future

Fossil fuels still dominate grid power generation

Fracking boom has made natural gas power plants $$$ attractive in U.S.

Modern combined-cycle system is cleaner, more efficient than single-cycle coal plants



Schematic representation of a combined cycle power plant
Source: Siemens

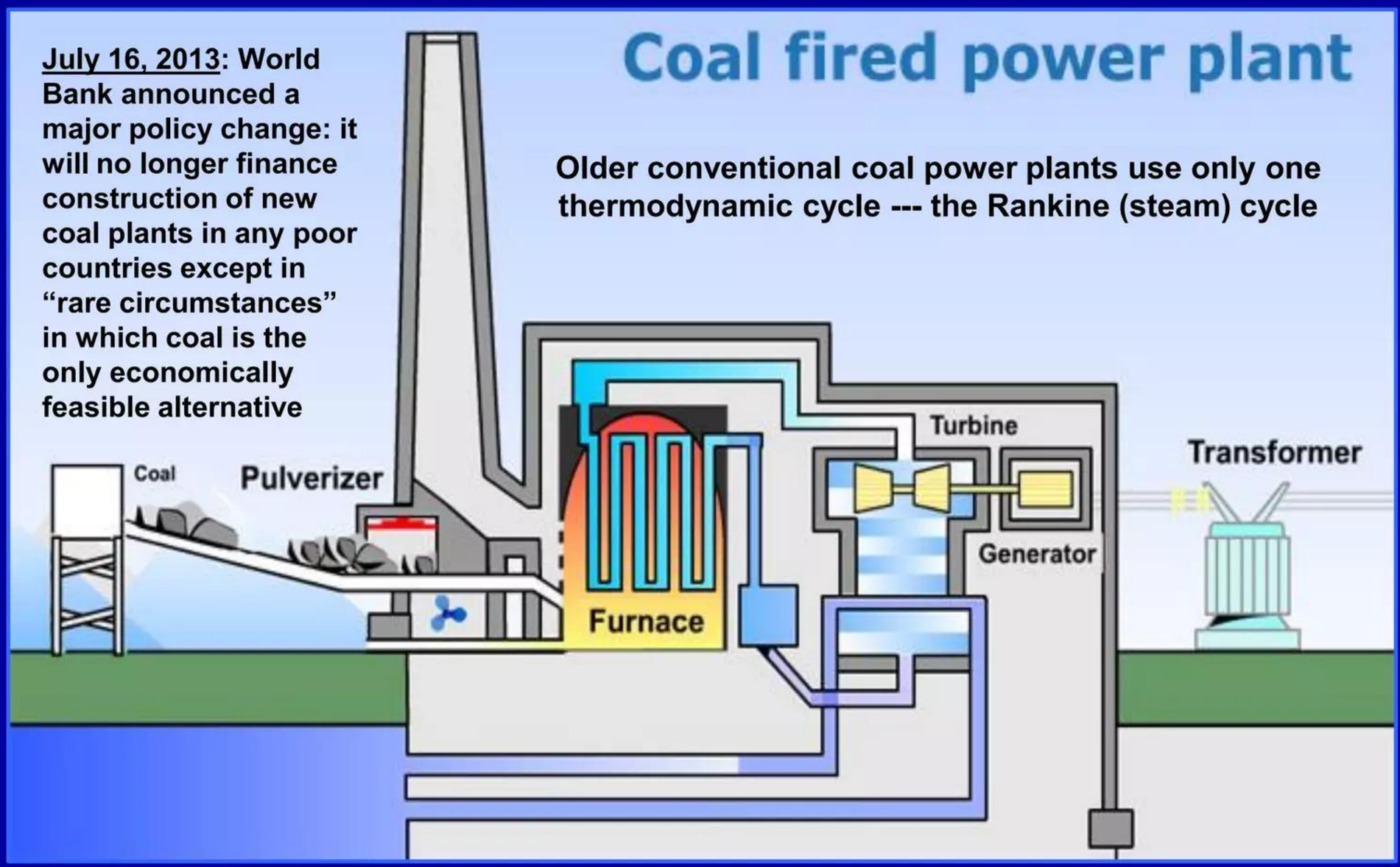
Powering the world to a green future

Fossil fuels still dominate grid power generation

Coal-fired plants have been a mainstay in many countries since 1900

Combustion of coal emits significantly more CO_2 and other pollutants than natural gas

<u>July 16, 2013</u>: World Bank announced a major policy change: it will no longer finance construction of new coal plants in any poor countries except in "rare circumstances" in which coal is the only economically feasible alternative



Powering the world to a green future

LENRs enable small-scale distributed generation

Improves stability of existing grids and permits cost-effective rural electrification worldwide

Powering the world to a green future

LENRs enable small-scale distributed generation

Cost-effective, small-scale LENR-based systems could change the world

- ✓ At system power outputs of just 5 - 10 kW, cost-effective green LENR-based distributed power generation systems could provide enough heat and electricity to potentially satisfy the stationary energy requirements of a majority of urban and rural households and smaller businesses worldwide
- ✓ At system power outputs of just 50 - 200 kW, LENR-based systems could begin to power steam or all-electric vehicles, breaking oil's stranglehold on transportation; could also provide high-quality heat for industrial processes
- ✓ Although they could very likely be designed and built, megawatt LENR systems are not mandatory to change the world of energy for the better
- ✓ If widespread deployment of small-scale distributed generation could be achieved, nowhere near as many new, large fossil-fired and/or fission power generation systems would have to be built to supply competitively priced electricity to regional grids serving urban and many rural areas. In that case, grid-based centralized power generation would be gradually displaced by vast numbers of smaller, lower-cost distributed systems in smarter grids

Powering the world to a green future

LENRs enable small-scale distributed generation

Distributed generation could bring electric power to the presently powerless

- ✓ **Development of low cost LENR-based portable and small-scale stationary systems could revolutionize green CO_2-free distributed power generation worldwide; it could potentially enable nearly ubiquitous LENR system deployment, and eventually permit universal global electrification at readily affordable societal costs**

- ✓ **Achievement of that goal would end energy poverty for ~1.6 billion people presently living in rural areas of our world that do not have any non-battery sources of local electric power generation --- grid-based, distributed stationary, mobile fossil-fueled gensets, or otherwise**

- ✓ **Use of a distributed LENR power generation strategy to provide full rural electrification could save countries like China and India many hundreds of billions if not trillions of yuan and rupees in investments that would otherwise have to be made to expand geographic coverage of presently limited-area electrical grids. The same is true for rural Africa, as well as hinterlands of the Middle East and South America**

Powering the world to a green future

LENRs enable small-scale distributed generation

Smaller LENR mammals could someday displace fossil-fueled dinosaurs

- ✓ **Small-scale LENR systems might seem to be light years away from being able to compete head-on with enormous 500 - 1,000 MW coal-fired and Uranium-fission power plant dinosaurs. But please recall the history of personal computers versus mainframes. When PCs were first introduced 35 years ago, mainframe computer manufacturers regarded them as little toys; information processing jokes of no consequence. Less than 10 years later, mainframe companies weren't laughing any more. Today, except for a small handful of survivor companies like IBM, most mainframe and minicomputer dinosaurs have disappeared. In fact, most of today's so-called mainframes contain internal arrays of commodity PC microprocessors**

- ✓ **Using a similar market penetration and expansion strategy that combines high-volume manufacturing, aggressive pricing and distributed generation, relative costs of electric power generation with coal vs. LENRs could potentially converge in not-too-distant future. Commercial versions of LENR technologies could someday begin competing directly with "king coal," oil, and natural gas as yet another cost-effective primary energy source**

Powering the world to a green future

LENRs enable small-scale distributed generation

Strategy is advantageous in industrialized countries and grid-less rural areas

Increases stability and robustness of existing grids and brings power to the powerless

- ✓ **A bold vision of the future of distributed power generation, "Micropower: the next electrical era," by Seth Dunn was published by the Worldwatch Institute (2000)**
  http://www.worldwatch.org/system/files/EWP151.pdf

- ✓ **"Perfect power: how the microgrid revolution will unleash cleaner, greener, and more abundant energy," Bob Galvin and Kurt Yeager (2008)**

- ✓ **In Lattice's opinion, paradigm-shifting LENRs are vastly bigger than any one company, however large, and bigger than any one country, however powerful ---- if there is such a thing, LENRs are truly a world technology**

Oil and coal fractions could become LENR fuels

Aromatic fractions might be processed to be able to transmute Carbon instead of burning it with O_2

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Oil and coal fractions could become LENR fuels

In theory, heavy oil and coal might be processed to also yield green LENR fuel

- ✓ As Lattice has shown in other published technical documents, it is possible that polycyclic aromatic hydrocarbon (PAH) aromatic fractions in bitumen and other heavy oils could someday be chemically extracted and specially processed to be transmuted as green nuclear fuels to release 5 million x more green energy
- ✓ Presently troublesome PAHs could potentially be worth perhaps greater than a million times more $$$ in BTU equivalents when utilized as anLENR fuel, as compared to alternatively being ring-cracked and combusted with oxygen in motor vehicle engines or simply used as a chemical process feedstock
- ✓ Similarly, coal of all kinds is innately chock-full of aromatic carbon rings of one kind or another; in the below-noted Lattice document, we discuss exactly how $_{6}C^{12}$ Carbon-seed LENR transmutation networks exist and have been observed in laboratory experiments. That being the case, the presence of aromatic rings in complex molecular structure of coal implies that there may well be a potential commercial opportunity for coal to be specially processed to yield LENR fuels
- ✓ See Lattice document dated March 15, 2012: http://www.slideshare.net/lewisglarsen/lattice-energy-llccoal-as-a-clenr-co2-emissionless-fuelmarch-15-2012-12109180

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Oil and coal fractions could become LENR fuels

In theory heavy oil and coal might be processed to also yield green LENR fuel

Instead of burning Carbon with Oxygen, simply transmute it into other elements

- ✓ **What we will refer to as seed or target nuclei are simply natural elements (which are themselves initially comprised of some number of stable natural isotopes) that serve as initial starting points for complex, dynamic neutron-capture-driven LENR transmutation reaction networks that can release very large amounts of clean heat**

- ✓ **What engineers call a "fuel cycle" in the nuclear power industry is essentially the same as what we call an LENR network. Major difference is that there are only very limited number of fuel cycles used in today's commercial fission reactors and they are based on Uranium isotopes (less problematic Thorium fuels are still under development). By contrast, the possibilities for LENR fuel cycles are almost limitless --- literally *any* seed element that will capture neutrons might be used (but some are much better than others; see Lithium example in other documents)**

- ✓ **Will now show a hypothetical Carbon-seed LENR network transmutation path that might be commercially usable at some point in the future if presently troublesome aromatics found naturally in oil and coal can be processed into nanoparticulate forms in which LENRs can be triggered. In Lattice's new scheme, carbon atoms present in oil or coal would instead be transmuted rather than chemically oxidized**

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Oil and coal fractions could become LENR fuels

In theory, heavy oil and coal might be processed to also yield green LENR fuel

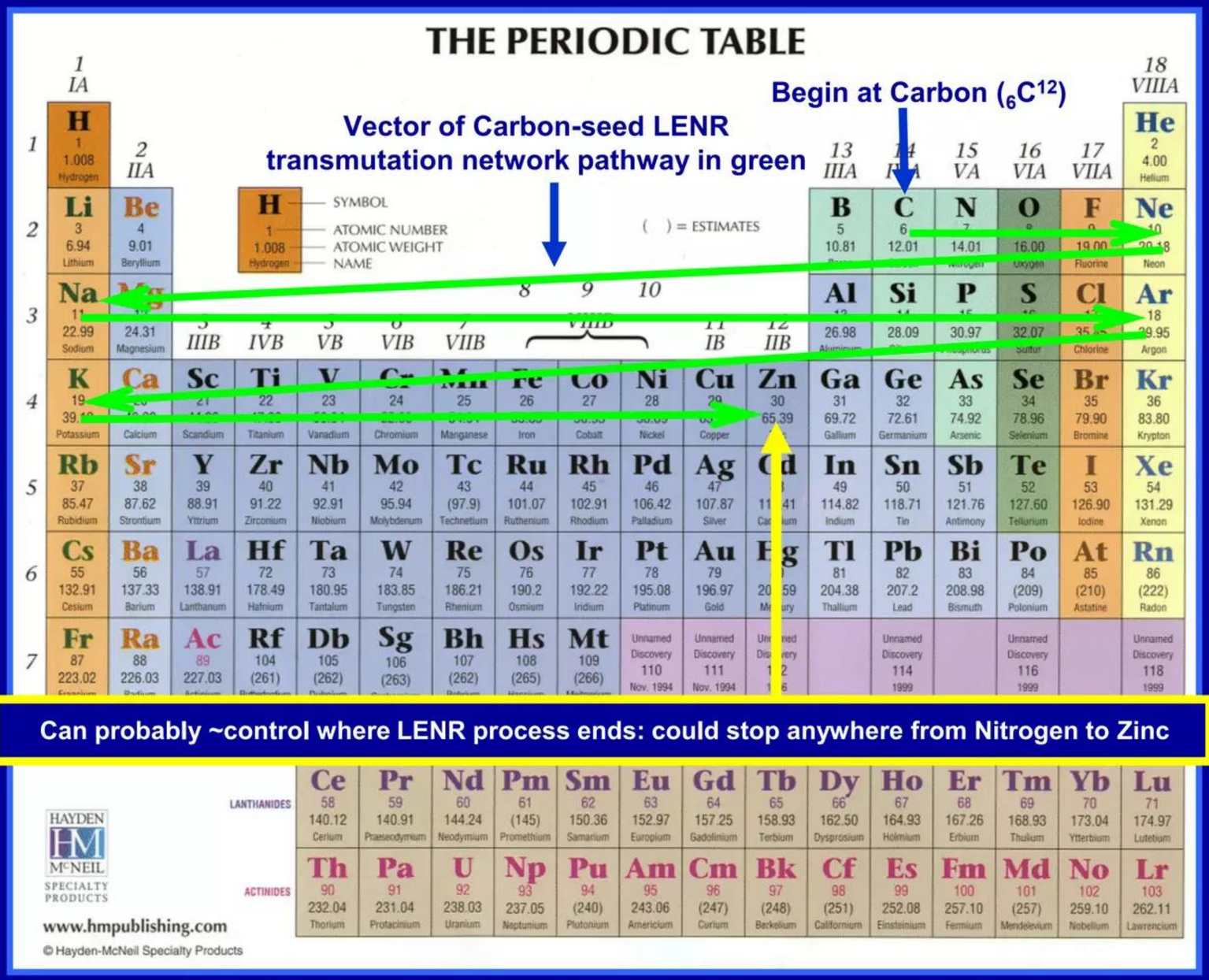
Carbon atoms in aromatic rings provide starting point for green transmutation process

Combustion:

Combustion of Carbon atoms in fossil fuels with Oxygen O_2 produces CO_2 and H_2O; CO_2 gas emissions are a problem, which has led to schemes like Carbon capture and sequestration (CCT)

Additional issues with coal's varied trace elements

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



Transmutation:

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 >10^6 larger than chemical reactions

Powering the world to a green future

Economics of LENR plants and retrofitting boilers

Retrofit fossil plants with LENR-based boilers + small-scale distributed generation = game changer

Powering the world to a green future

Economics of LENR plants and retrofitting boilers

Transmutation of coal-based LENR fuels >>> greener than combustion with O_2

Complete combustion of coal: $CH_4 + 2\ O_2 \longrightarrow CO_2 + 2\ H_2O$ + energy

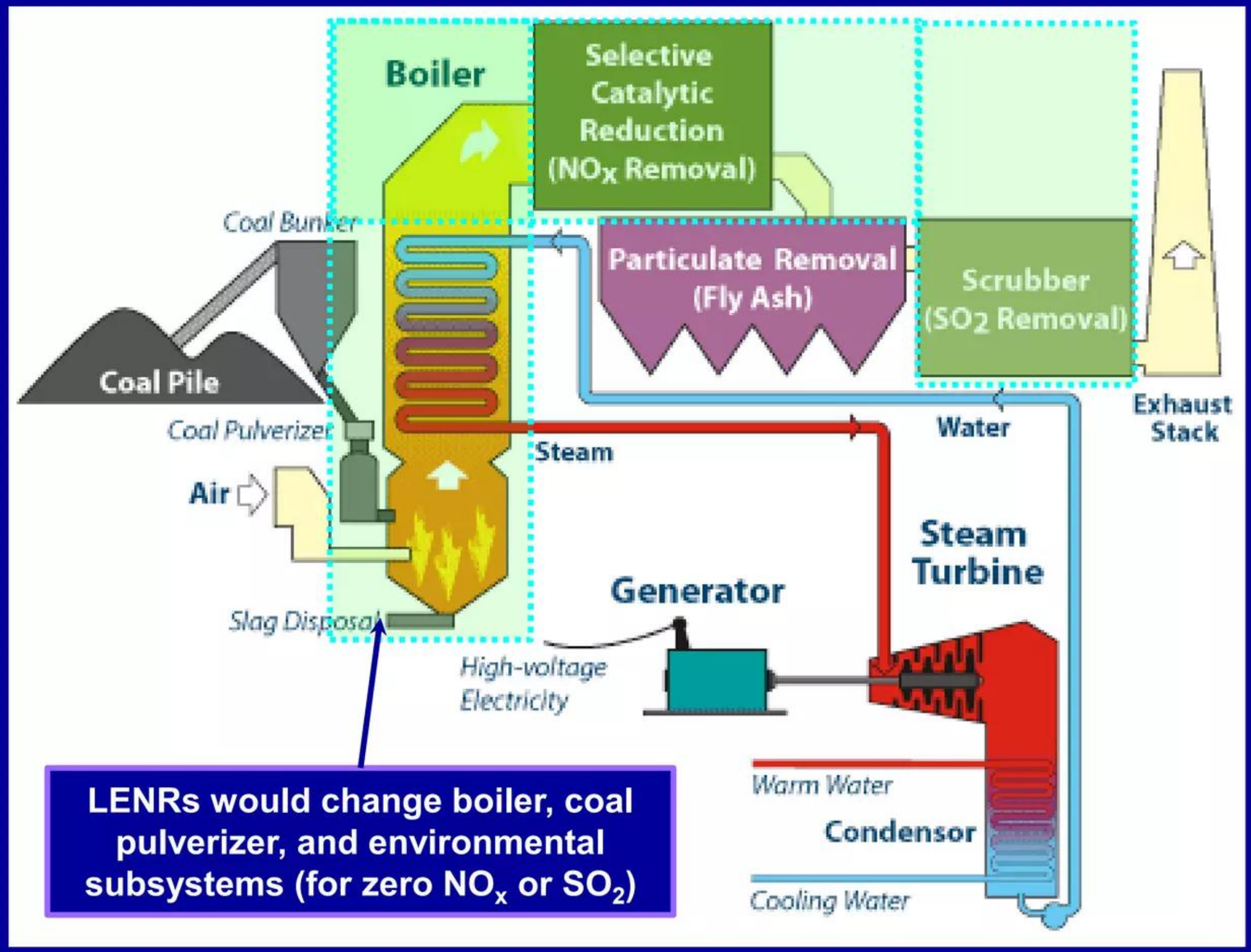
Today's inputs:

Capital $
bulk coal
air (O_2)

vs.

LENR inputs:

Capital $
bulk coal
electricity
base metals



Today's outputs:

Heat
electricity
CO_2
NO_x and SO_2
slag, particulates

vs.

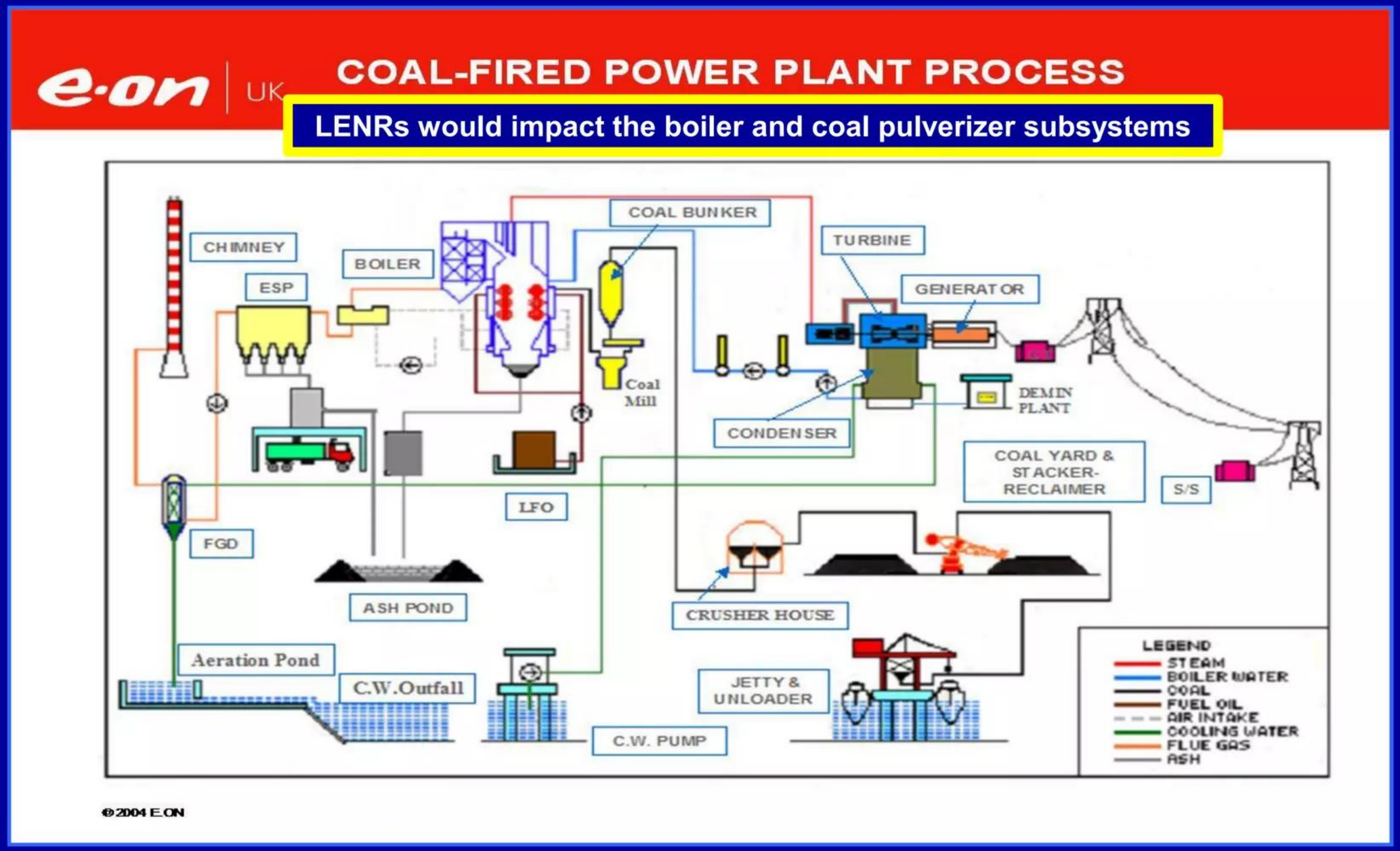
LENR outputs:

Heat
>> electricity
O_2 or N_2
'slag' (incl. $$$ elements)
particulates

Powering the world to a green future

Economics of LENR plants and retrofitting boilers

Coal-fired power plant system diagram: boiler is small part of total $ investment



Powering the world to a green future

Economics of LENR plants and retrofitting boilers

Adoption could be relatively painless and not prohibitively expensive

- ✓ **Limited changes to basic configurations of existing coal-fired power generation systems:** amazingly, an engineer working at a typical electric utility coal-fired power plant in 2013 would probably still feel quite familiar and 'at home' in a LENR-based $_{6}C^{12}$ seed plant of the future. Although boilers would look very different and there would likely be an additional onsite facility where green LENR fuels are made by chemically processing pulverized coal, appearance wise it would nevertheless look very similar to today's modern coal and gas-fired plants
- ✓ **Capital-efficient path toward adoption of new technology:** to minimize economic costs of adopting new LENR-based heat generation technology in the power generation business, it would seem likely that existing coal-fired power plants in reasonable condition could readily be retrofitted with physically compatible LENR-based boilers that would make hot steam to turn a plant's existing steam turbine generators. Not very much else in a retrofitted coal-fired power plant would have to be changed, other than the addition of a processing facility that would convert raw *μm*-sized coal particles produced by existing types of in-plant pulverizers into specially processed nanoparticulates, i.e., $_{6}C^{12}$ seed LENR fuels, which are then 'burned' in new types of high technology LENR-fired boilers

Powering the world to a green future

Economics of LENR plants and retrofitting boilers

Retrofitting fossil-fueled power plants is capital-efficient adoption strategy

- ✓ **To recoup part of the front-end investment:** involved in retrofitting LENR technology and further help-out the global environment, a retrofitted coal-fired power plant's existing pollution abatement equipment for removing NO_x and SO_2 from emitted smokestack gases could perhaps be dismantled and then sold/shipped used, as-is to commercial operators in third world countries who are still running environmentally dirty older coal-fired power plants that do not use pollution control equipment
- ✓ By retrofitting existing (otherwise very usable) licensed and operating plants, the vast majority of the substantial billion $ front-end capital investment in a utility's coal-fired power generation facility could be conserved and protected. Upgrading existing coal-fired power plants with LENR boiler technology could thus potentially be much less expensive over the long-run than the other alternatives of either building brand new, purpose-built LENR-based plants, or equipping conventional coal-fired plants with expensive carbon capture and sequestration technology (CCT) that might ultimately have untoward environmental consequences, e.g., CO_2 leaking out of gigantic underground reservoirs into the earth's atmosphere
- ✓ If this proved to be an economically attractive market penetration strategy, worldwide adoption and widespread deployment could potentially be surprisingly rapid process

Powering the world to a green future

Economics of LENR plants and retrofitting boilers

Admittedly speculative future cost scenarios; underlying assumptions noted

See white paper cited on slide #4: "Will low natural gas prices eliminate the nuclear option in the US?", R. Graber and T. Retson (released July 2013)

Discussion of Lattice's assumptions regarding different cost parameters:

Parameter	Assumptions made about each parameter and comments thereon
Capital	Capital costs substantially lower than fission plants since no radiation shielding or containment subsystems are required; > gas-fired; so assume 33% > gas = $16.92; retrofit is 20% of gas = $2.54
O&M	Operation and maintenance costs would likely be higher than combustion-based natural gas plants but substantially less expensive than fission power plants; thus assume O&M is 50% of nuclear = $5.02
Fuel	LENRs have vastly lower fuel costs (can use almost any target nano-fuel that can capture neutrons) compared to either fission or natural gas; in 2012, Uranium price averaged $54.99/lb; 2013 nickel price = $6/lb; titanium = $10/lb; avg. of Ni/Ti = $8.00/lb + $2/lb (processing) = $10/lb = 18% of nuclear = $1.00
Taxes	Taxes for LENR power plants would be exactly = natural gas, which is > nuclear; so assume = $10.39
Decommissioning	Unlike fission and hoped-for D-T fusion power plants, LENRs do not induce any appreciable amounts of radioactivity in reactor components; decommissioning costs should thus be ~same as gas = $0.00
Waste disposal	Unlike fission plants, LENRs do not produce any long-lived radioactive wastes. However, depending on target fuels used (e.g. nickel, titanium) can create stable heavy metals: assume 10% of nuclear = $0.10
Environmental compliance	Cost for compliance is = $0.00, since LENRs do not emit gaseous CO_2 into atmosphere; carbon taxes would not be applicable to LENR systems (presumably they would only apply to fossil-fueled plants)
Summary remarks	Using simple, relatively conservative assumptions about parameters, and based on Graber & Retson's model, purpose-built or retrofitted LENR plants could perhaps be 54 - 75% less costly than natural gas

Powering the world to a green future

Economics of LENR plants and retrofitting boilers

Future scenario compares nuclear and natural gas vs. retrofitted fossil plants

Purpose-built LENR plant cost might be ~54% less than natural gas with no Carbon tax

Table 2: Cost Components of Levelized Costs ($/MWh) ($2012)				Lattice estimates
Cost Component ($/MWh)	Nuclear	Natural Gas (No Environmental cost)	Natural Gas (With $25/Ton CO_2)	Purpose-built LENR plants
Capital	$ 57.78	$ 12.72	$ 12.72	**$ 16.92**
O&M	$ 10.03	$ 3.46	$ 3.46	**$ 5.02**
Fuel	$ 5.55	$ 46.99	$ 46.99	**$ 1.00**
Taxes[1]	$ 9.79	$ 10.39	$ 10.39	**$ 10.39**
Decommissioning	$ 1.46	-	-	**-0-**
Waste Disposal	$ 1.00	-	-	**$ .10**
Environmental Compliance	-	-	$ 9.80	**-0-**
TOTAL	**$ 85.61**	**$ 73.55**	**$ 82.35**	**$ 33.43**

Source: http://www.nuclearenergyinsider.com/nuclear-construction-summit/content-neireport.php

Powering the world to a green future

Economics of LENR plants and retrofitting boilers

Future scenario compares nuclear and natural gas vs. retrofitted fossil plants

Retrofitted plant cost might be ~74% less than natural gas plant with no Carbon tax

Table 2: Cost Components of Levelized Costs ($/MWh) ($2012)				Lattice estimates
Cost Component ($/MWh)	Nuclear	Natural Gas (No Environmental cost)	Natural Gas (With $25/Ton CO_2)	Retrofit nat. gas or coal plants
Capital	$ 57.78	$ 12.72	$ 12.72	**$ 2.54**
O&M	$ 10.03	$ 3.46	$ 3.46	**$ 5.02**
Fuel	$ 5.55	$ 46.99	$ 46.99	**$ 1.00**
Taxes[1]	$ 9.79	$ 10.39	$ 10.39	**$ 10.39**
Decommissioning	$ 1.46	-	-	**-0-**
Waste Disposal	$ 1.00	-	-	**$ .10**
Environmental Compliance	-	-	$ 9.80	**-0-**
TOTAL	**$ 85.61**	**$ 73.55**	**$ 82.35**	**$ 19.05**

Source: http://www.nuclearenergyinsider.com/nuclear-construction-summit/content-neireport.php

Powering the world to a green future

LENRs could greatly reduce real price of electricity

From the Old World of CO_2-producing fossil fuels to a New Green World of LENRs + renewables

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LENRs could greatly reduce real price of electricity

Substantial competitive advantages in certain large target market applications

Applications	Description	Target Markets
LENRs enable safe, green carbon-free nuclear energy production and power generation at reasonable cost - Vastly greater energy densities and longevity at a lower price per kWh compared to chemical power sources	**Scale-up and integrate LENR heat sources w. different energy conversion technologies:** e.g., develop portable battery-like devices using thermoelectrics that can convert raw heat directly to DC electricity; or, use heat to rotate a shaft for propulsion (e.g., Stirling or modern steam engines in motor vehicles)	**SAFE -** no radiation shielding or nuclear waste issues; could also eventually enter portable power markets and compete directly against chemical batteries, small fuel cells, and microgenerators
Bitumen extraction, heavy oil recovery, and/or oil shale processing According to Prof. K. Deffeyes of Princeton University, about 2/3 of oil remaining in the ground worldwide is classified as "heavy"	**Use well-hole LENR thermal sources to heat-up bitumen or heavy oil underground:** reduce production costs, enhance recovery; could **use LENR heaters for *in-situ* underground upgrading and downstream process heat**	**Major benefit to large oil producers –** can help increase long-term supplies of oil and reduce total production costs as well as CO_2 'footprint'
Develop much cleaner fission power generation technologies Use LENRs and ultra low momentum neutrons (ULMs) for triggering fission	**Design new types of LENR-based subcritical fission reactors** that can burn existing fissionable fuels down to stable isotopes – little or no long-lived radioactive wastes	**Retrofit new ULM-neutron reactors into existing nuclear fission power systems;** much better safety and lower costs
Nuclear waste treatment Transmute dangerous radioactive nuclear waste using LENRs; generate additional power from waste burn-up	**Develop turnkey systems for on-site nuclear waste clean-up** of existing worldwide inventories of stored fission wastes from nuclear power plants	**Nuclear waste remediation and clean-up –** opportunities in many countries, e.g., US, France, Japan, China, etc.
Transmutation of stable elements Produce almost any very valuable element or isotope in the periodic table at competitive costs compared to present mining and refining operations	**Use LENRs to transmute less expensive elements into much more valuable ones –** first do it abiologically; later migrate to methods using various species of genetically engineered bacteria	**Mostly target precious and rare metals production,** e.g., platinum, gold, rhodium, rare earth elements, etc

Time

First targets

Potential long-term opportunities

Powering the world to a green future

LENRs could greatly reduce real price of electricity

Working with Lattice

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

- ✓ **Lattice welcomes inquiries from large, established companies and financial principals that have an interest in seriously discussing the possibility of becoming a strategic capital and/or LENR technology development partner in the near- or long-term time frames**
- ✓ **To augment working capital and promote further development of LENR technology, Lattice also selectively engages in some fee-based third-party consulting. This work covers various topics in the context of micron-scale, many-body collective quantum effects in condensed matter systems (including photosynthesis), field failures involved in Li-based battery thermal runaways, nuclear fission waste remediation, and ultra-high-temperature superconductors, among others. Additional areas of expertise include long-term strategic implications of LENRs on high cap-ex investments in power generation and petroleum-related assets, as well as long-term price outlooks for precious metals and crude oil. We consult on any of these subjects as long as it does not involve disclosing proprietary engineering details applicable to Lattice's planned LENR power generation systems. Consulting is subservient to company's main goal: commercializing LENRs for applications in ultra-high energy density portable, mobile, and stationary power generation systems**
- ✓ **Larsen c.v.: http://www.slideshare.net/lewisglarsen/lewis-g-larsen-cv-june-2013**

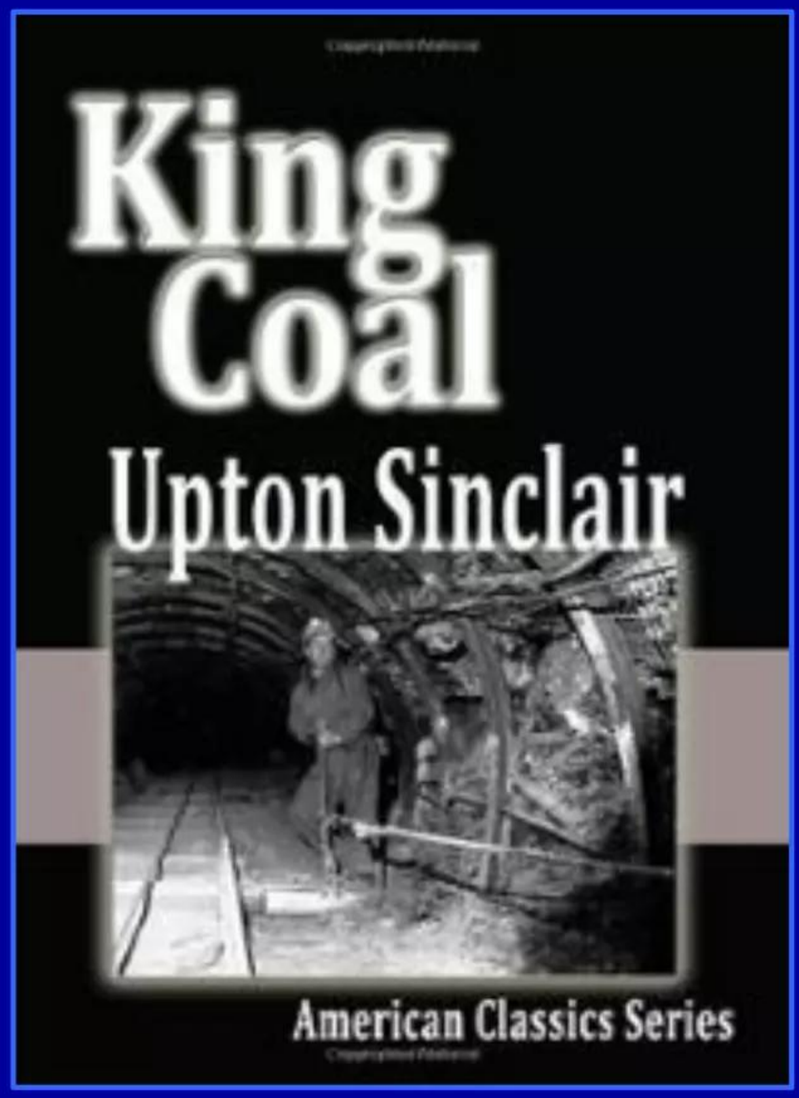
Credit: National Geographic

Powering the world to a green future

LENRs could greatly reduce real price of electricity

If commercialized, LENR power generation technology could change the world

- ✓ Potentially very disruptive to portable power markets
- ✓ Synergistic with oil and coal industries in the near-future
- ✓ Assuming that they can be successfully built, multi-megawatt output, grid-scale LENR power plants could potentially be 54 - 74% less costly vs. natural gas plants
- ✓ Potential to gradually replace internal combustion engines over the next 30 - 60 years; enable substantial reduction of man-made CO_2 emissions and someday energy independence from petroleum in transportation
- ✓ Widespread global deployment of LENR technologies, together with synergistic large- and small-scale photovoltaic and wind-power systems, could create a less expensive, greener energy future for humanity
- ✓ LENRs and portfolio of other types of carbon-free renewable energy technologies together have the potential to substantially reduce the real price of electricity and thus democratize access to affordable energy for every inhabitant of the planet



"King Coal" by Upton Sinclair (1878 - 1968)
First self-published in Pasadena, CA (1917)
http://www2.hn.psu.edu/faculty/jmanis/u-sinclair/KingCoal.pdf

Powering the world to a green future

LENRs could greatly reduce real price of electricity

Welcome to the New World of the future

From older problematic energy sources

To a greener less expensive tomorrow

Evolution of nuclear technology

Fossil fuels + fission + fusion → LENRs + renewables

"The Stone Age came to an end,
but not for a lack of stones,
and the oil age will end,
but not for a lack of oil."

H.E. Sheikh Ahmed Zaki Yamani
أحمد زكي يماني ;formerly
Oil Minister of Saudi Arabia

Stated during a media interview (2000)

Modern natural gas fired power station – Minsk, Belarus
Picture taken November 27, 2006
Credit: Reuters/Vasily Fedosenko (Belarus)