Adequate reasonably priced dispatchable power generation is critical for every country's energy security

Renewable energy sources sometimes unable to fill total national demand for power because they are intermittent

Unusual European weather in December 2016 demonstrated that Germany's Energiewende (energy transition) as idealistically envisioned by its many supporters may be impractical

Lewis Larsen
President and CEO
February 10, 2017

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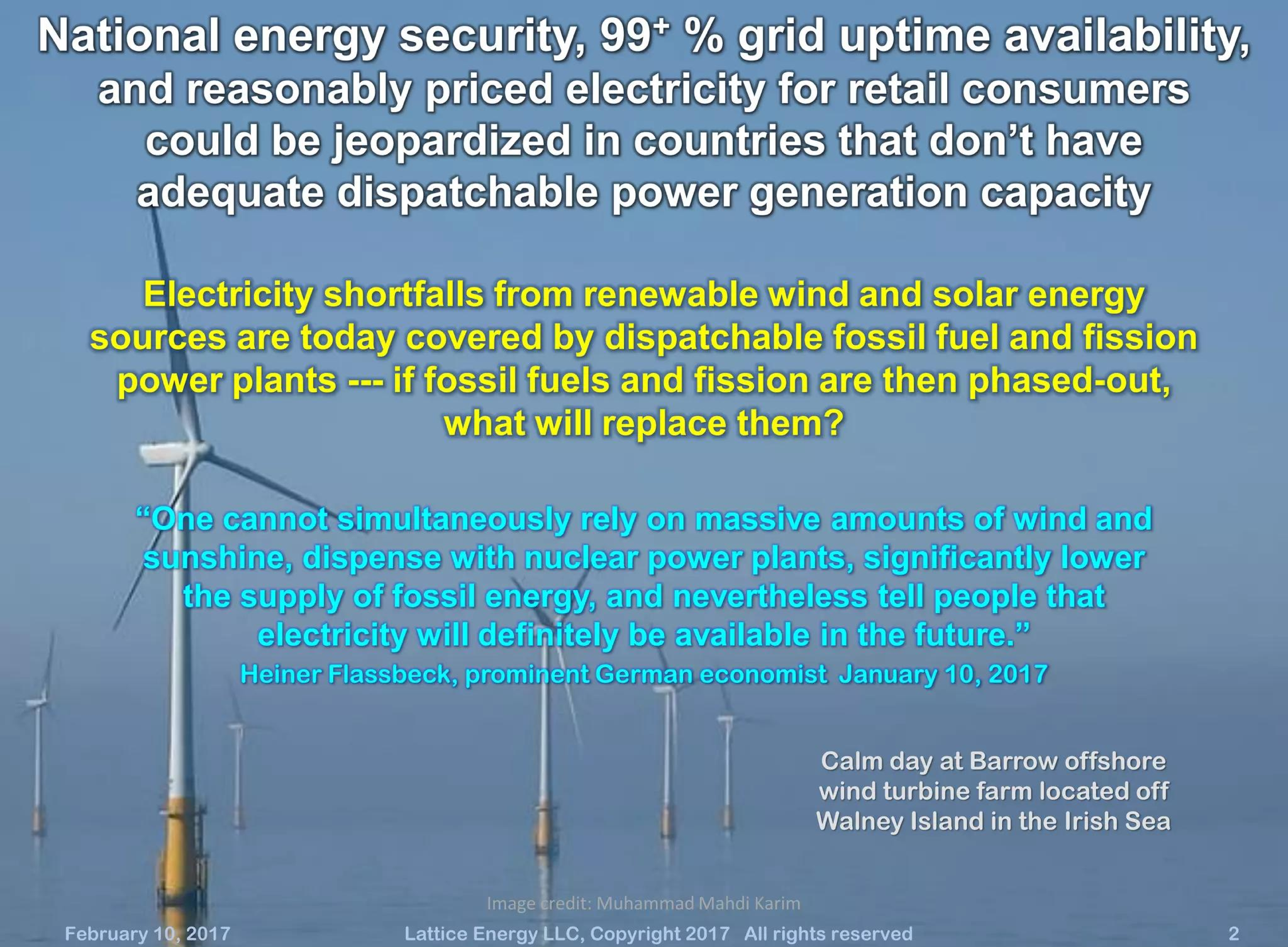
National energy security, 99^{+} % grid uptime availability, and reasonably priced electricity for retail consumers could be jeopardized in countries that don't have adequate dispatchable power generation capacity

Electricity shortfalls from renewable wind and solar energy sources are today covered by dispatchable fossil fuel and fission power plants --- if fossil fuels and fission are then phased-out, what will replace them?

"One cannot simultaneously rely on massive amounts of wind and sunshine, dispense with nuclear power plants, significantly lower the supply of fossil energy, and nevertheless tell people that electricity will definitely be available in the future."

Heiner Flassbeck, prominent German economist January 10, 2017



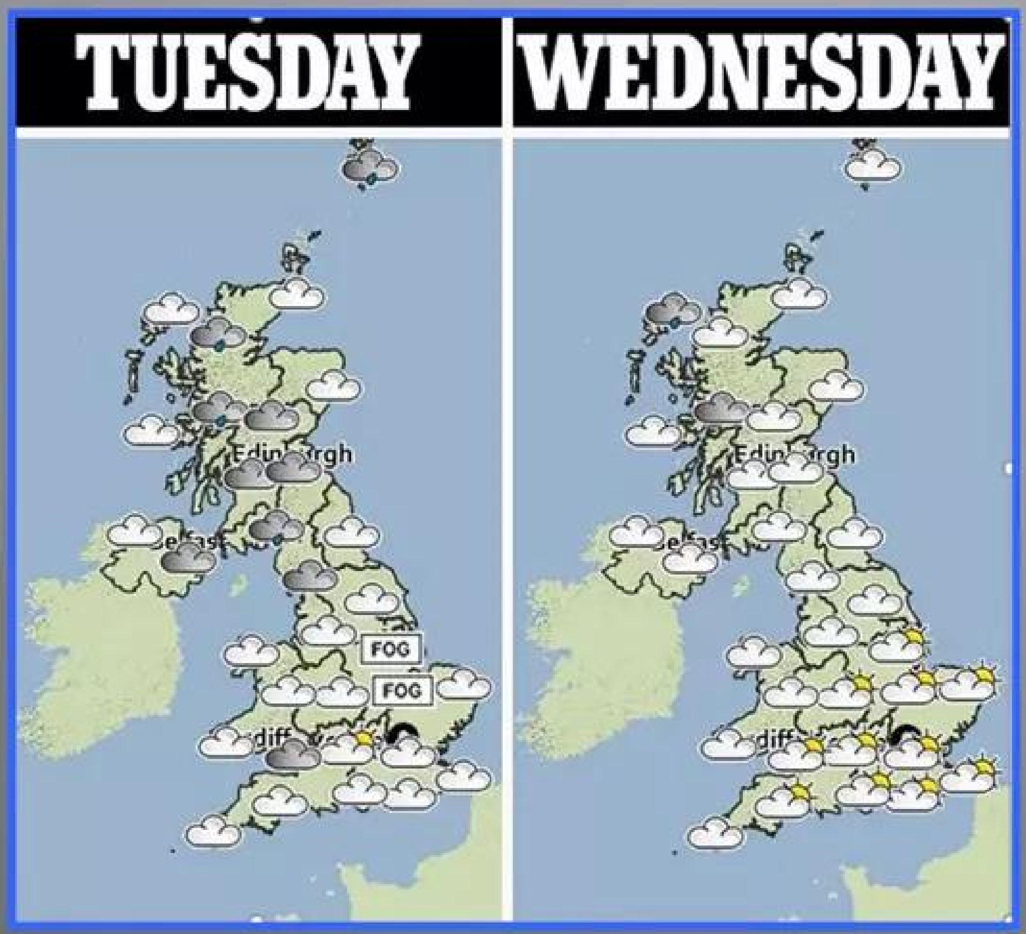
Calm day at Barrow offshore wind turbine farm located off Walney Island in the Irish Sea

Image credit: Muhammad Mahdi Karim

January 2017: days of fog and no wind caused London smog

Weather events like this reduce both solar and wind power generation

https://www.theguardian.com/environment/2017/jan/29/pollution-air-quality-london-environment



"A look at last week's pollution provides some clues – other factors were involved in London's atmospheric woes this winter. One couldn't be more simple: the weather. 'Meteorological conditions have been stagnant for several weeks,' said Martyn Chipperfield, professor of atmospheric chemistry at Leeds University. 'There has been a stable, blocking anticyclone resting over Britain and that has trapped air over the country. There has been nothing to blow the pollution away. Worse, any winds that we have had have come from the south east, from Europe where the air is already polluted. Our prevailing winds usually blow in from the Atlantic bringing in fairly fresh air. Instead, all we have had is the odd puff of already polluted air'."

The Guardian on January 29, 2017

"The Great Smog of 1952. Sorry, 2017"
Credit: Toby Melville/Reuters

Contents

Energiewende is German word for "energy transition"

Shift German energy system from fossil fuels and fission to renewbles

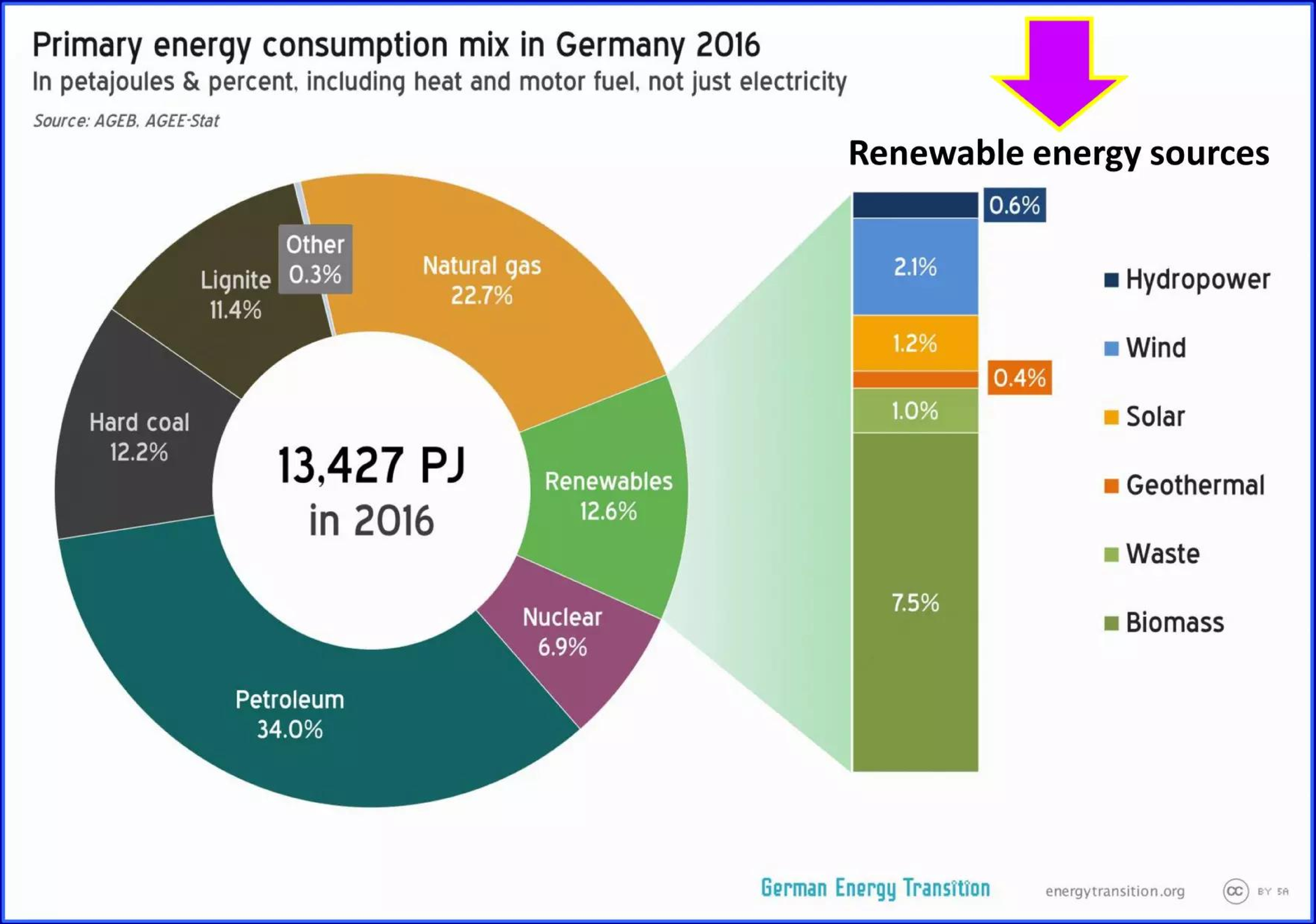
All coal-fired & fission power plants will close by 2040; 60% renewables by 2050

https://www.agora-energiewende.de/en/

Agora Energiewende

- ✓ Ambitious program aims to shift into renewable energy sources in Germany's electricity sector
- ✓ Heavy emphasis on solar photovoltaic (PV) and wind power for renewable energy technologies
- ✓ Support for program was legislated back in 2010
- ✓ After 2011 disaster with Fukushima reactors in Japan, German government eliminated fission as bridging technology in path to 80+% renewables
- ✓ Plan to shut-down all fission power plants by 2022; phase-out all coal powered plants by 2040
- ✓ Ultimate goal is 60% of electricity production via renewables by 2050 and, in parallel, reduce total greenhouse gas emissions from electricity sector by 80 - 95% relative to earlier levels back in 1990

German primary energy consumption mix in calendar 2016



German economist questions Energiewende assumptions

Dec. 2016: weather caused huge drop in wind & solar energy production

Flassbeck argues event shows that Energiewende won't provide energy security

"The end of Energiewende"
Heiner Flassbeck
Energy Post on January 10, 2017 translated by Jeffrey Michel"
http://energypost.eu/end-energiewende/

"Stable high-pressure winter weather has resulted in a confrontation. An Energiewende that relies mainly on wind and solar energy will not work in the long run. One cannot forgo nuclear power, eliminate fossil fuels, and tell people that electricity supplies will remain secure all the same."

"This winter could go down in history as the event that proved the German energy transition to be unsubstantiated and incapable of becoming a success story. Electricity from wind and solar generation has been catastrophically low for several weeks. December brought new declines. A persistent winter high-pressure system with dense fog throughout Central Europe has been sufficient to unmask the fairy tale of a successful energy transition, even for me as a lay person."

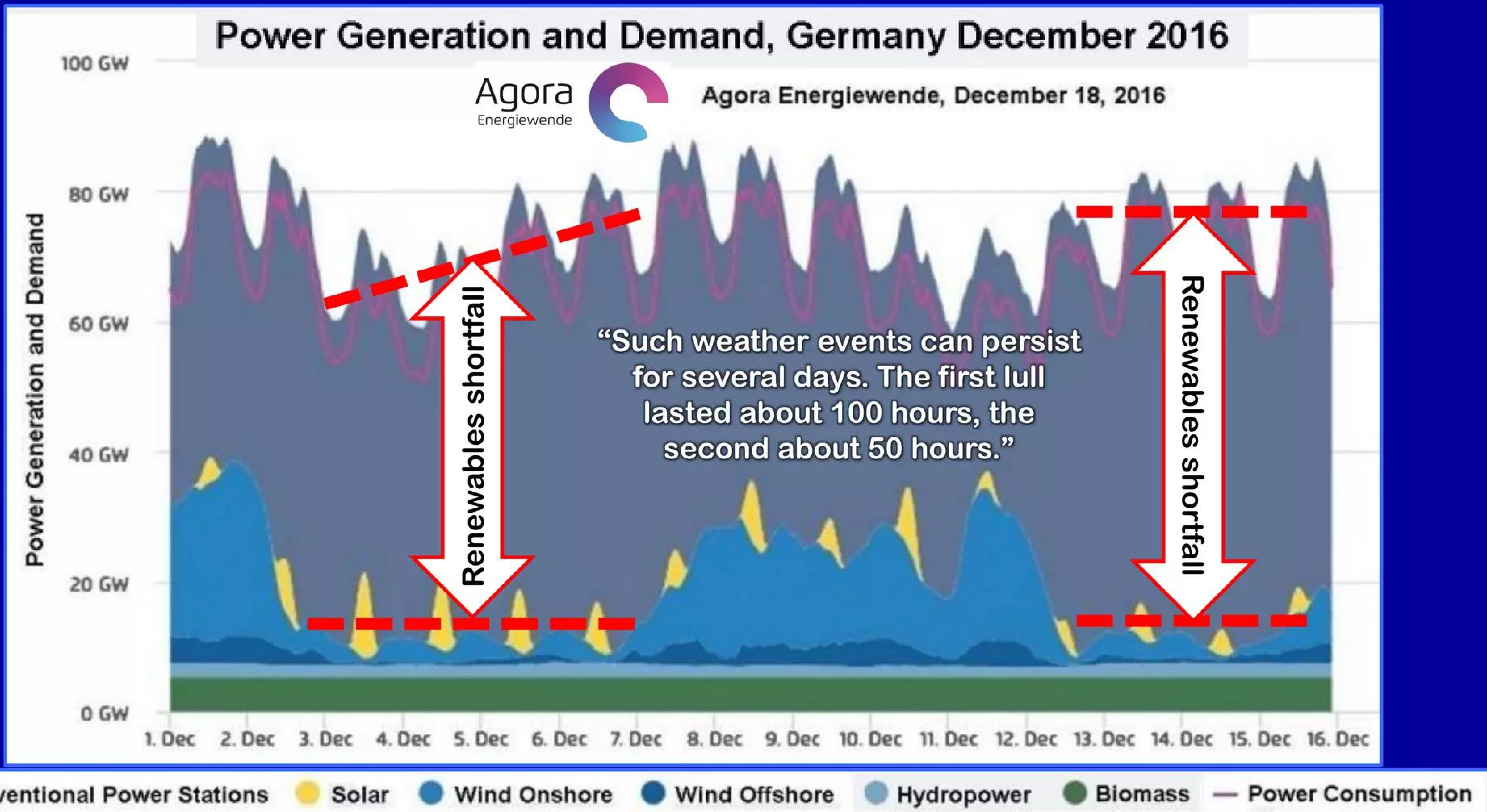
"I … never expected to see large-scale solar arrays and wind turbines, including those offshore, motionless for days on end … data compiled by Agora Energiewende … have recorded the appalling results for sun and wind at the beginning of December … from the 12th to 14th."

German economist questions Energiewende assumptions

Dec. 2016: weather caused huge drop in wind & solar energy production

Flassbeck argues events show that Energiewende won't provide energy security

Two large shortfalls in renewables electricity production in one month



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Dec. 2016: weather caused huge drop in wind & solar energy production

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Quoting from Heiner Flassbeck's article:

"Of power demand totaling 69.0 gigawatts (GW) at 3 pm on the 12th, for instance, just 0.7 GW was provided by solar energy, 1.0 by onshore wind power and 0.4 offshore. At noontime on the 14th of December, 70 GW were consumed, with 4 GW solar, 1 GW onshore and somewhat over 0.3 offshore wind. The Agora graphs make apparent that such wide-ranging doldrums may persist for several days."

"Let us suppose that today's wind and solar potential could be tripled by 2030, allowing almost all of the required energy to be obtained from these two sources under normal weather conditions. This is an extremely optimistic scenario and certainly not to be expected, because current policy is slowing down the expansion of renewable energy sources rather than accelerating it."

"If a comparable lull occurred in 2030 (stable winter high systems that recur every few years), then three times the number of solar panels and wind turbines (assuming current technologies) could logically produce only three times the amount of electricity. The deficiency of prevailing winds and sunshine will affect all of these installations, no matter how many there are. Even threefold wind and solar generation would then fulfill just 20% of requirements – again very optimistically – assuming that demand had not increased by 2030."

German economist questions Energiewende assumptions

Dec. 2016: weather caused huge drop in wind & solar energy production

Flassbeck argues event shows that Energiewende won't provide energy security

Quoting from Heiner Flassbeck's article:

"However, precisely the opposite can be expected, namely a massive increase in [electricity] consumption due to the substitution of fossil fuels by electrically powered automobiles that require increased generation. The possibility of saving so much energy in this short time, enabling overall consumption to be decreased despite abandoning fossil fuels, can be confidently ignored."

"Accordingly, Germany would end up with a catastrophic result 30 years after the start of the Energiewende. With nuclear power no longer available, a capacity of at least 50 gigawatts is required by other means, despite an enormously expanded network of wind turbines and solar systems under comparable weather conditions. Those other means according to current knowledge will be provided by coal, oil and gas."

"In other words, one cannot simultaneously rely on massive amounts of wind and sunshine, dispense with nuclear power plants (for very good reasons), significantly lower the supply of fossil energy, and nevertheless tell people that electricity will definitely be available in the future. Exactly that, however, is what politics largely does almost every day. It is quite irresponsible to persuade citizens that from 2030 onwards only electrically-powered new cars may be allowed, as has recently been propagated in the highest political circles."

Energiewende 2050 scenarios: with/without nuclear power

Post explores investment costs needed to handle renewables shortfalls

the energycollective — The world's best thinkers on energy & climate

"Wind and solar energy lulls: energy storage in Germany"
Willem Post in *The Energy Collective* Jan. 24, 2017

the energycollective — The world's best thinkers on energy & climate

http://www.theenergycollective.com/willem-post/2396941/wind-and-solar-energy-lulls-and-energy-storage-in-germany

- ✓ If Germany's Energiewende proceeds as presently planned, by 2050 present coal-fired and nuclear fission power plants will all have been eliminated
- ✓ To avoid blackouts in event of weather-related renewable electricity production shortfalls, grid deficits relative to demand for power will have to come from combination of electrical storage (batteries), dispatchable power generation assets, and/or imports from other countries via grid interconnects
- ✓ In thought provoking article, Willem Post explores future scenarios in 2050 concerning German capacity planning to handle weather-caused renewable electricity production shortfalls very much like what happened in Dec. 2016
- ✓ Using plausible set of assumptions and extrapolations, Post estimates capital investment requirements for two cases: (1) shortfalls will be covered by much greater amounts of storage and renewable power generation capacity; (2) shortfalls covered by judicious combination of lesser amounts of renewable sources and storage plus new 1,100 MW dispatchable nuclear power plants

Energiewende 2050 scenarios: with/without nuclear power

Post explores investment costs needed to handle renewables shortfalls

Finds utilization of nuclear power would reduce Germany's cost by $ 4 trillion

http://www.theenergycollective.com/willem-post/2396941/wind-and-solar-energy-lulls-and-energy-storage-in-germany

Quoting from Willem Post's article:

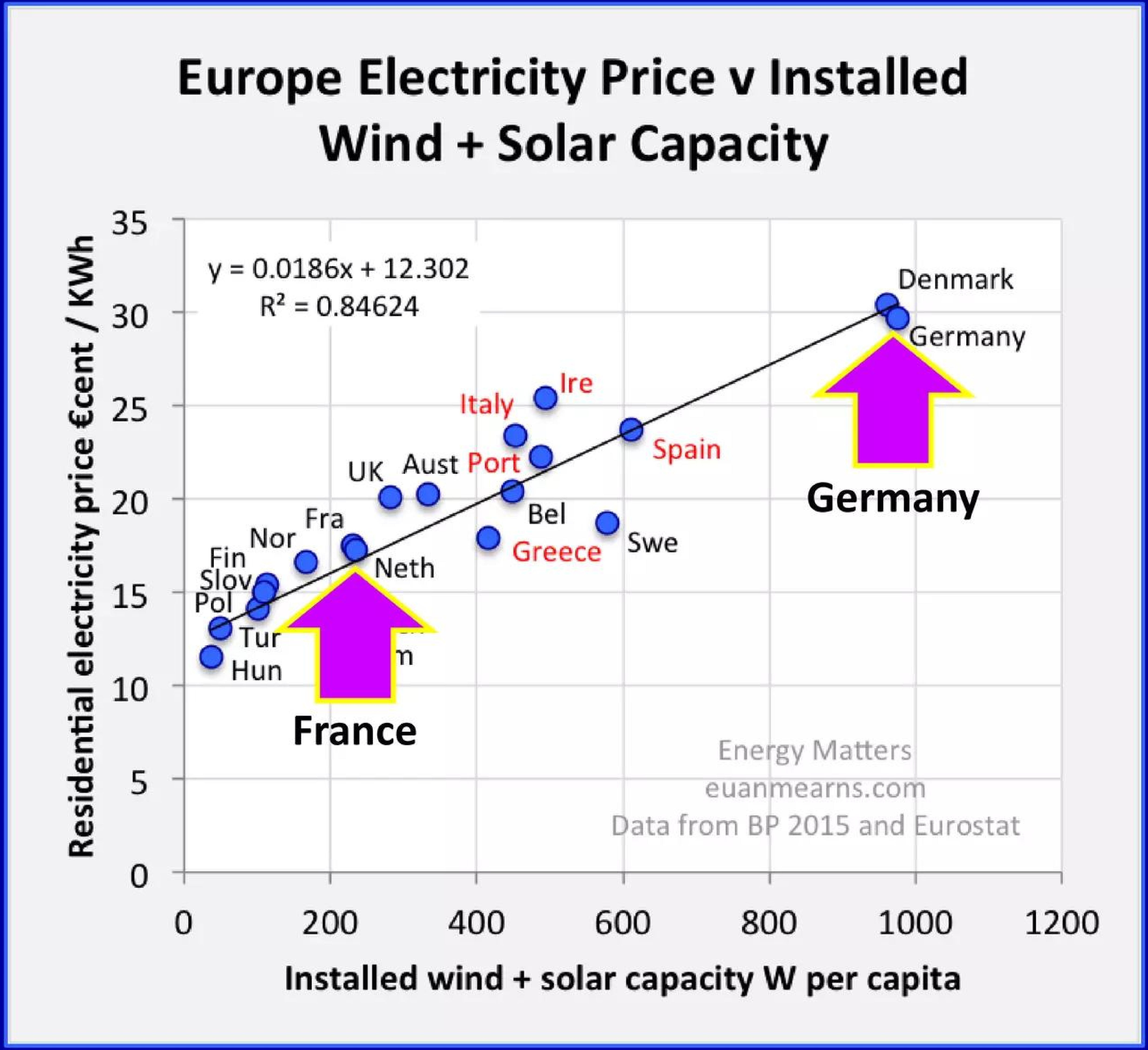
"Germany aims to have almost all of its domestic electricity consumption from renewable sources by 2050. The Energiewende targets are 35% RE by 2020, 50% by 2030, 65% by 2040, and 80% by 2050. Thus, about 20% of domestic electricity consumption could continue to be from fossil fuels, such as natural gas, in 2050 … In 2016, gross electricity generation was 652 TWh, of which 456 TWh was from conventional generators and 196 TWh was from renewables, i.e., about 30% of gross electricity generation was from renewable sources, such as wind, solar, hydro, bio, etc. … On an annual basis, wind and solar (stochastic sources) was 126/652 = 19.3% of electricity generation."

"German household electric rates are the SECOND highest in Europe, about 28.69 eurocent/kWh in 2015; Denmark is the leader with about 30 eurocent/kWh. Both are RE mavens. France, about 80% nuclear generation, has one of the lowest."

Lattice comment: depending on state, U.S. retail electricity rates in cents/kWh (1 Eurocent $\simeq$ 1 U.S. cent) range from 9.5 to 28.5 (Hawaii); national avg. = 12.75

German retail electricity price is second highest in Europe

France uses ~75% nuclear power: retail price is ~40% less than Germany



Post extrapolates Dec. 2016 renewable shortfalls to 2050

Major assumptions are below; see *Energy Collective* article for details

http://www.theenergycollective.com/willem-post/2396941/wind-and-solar-energy-lulls-and-energy-storage-in-germany

Quoting from Willem Post's article:

"Alt. No. 1, Wind and Solar Lulls in December 2050: RE proponents claim wind, solar, hydro, bio, etc., generate almost all electricity, and fossil fuel and nuclear generators are not needed. However, if fossil fuel and nuclear generators were closed down and wind and solar were minimal, hydro, bio, etc., whether in Germany or abroad, would not be able to meet Germany's electrical demand without massive, bulk energy storage systems."

"For this alternative, we assume Germany would:

- Consume the same quantity of energy in 2050, as in 2016, i.e., increased due to population and gross product growth, but reduced due to energy efficiency.
- Increase its electricity generation from 35% of all energy to 60% of all energy.
- Have 8 times the installed capacity, MW, of wind and solar systems and associated transmission, in 2050.
- Experience the same wind and solar lulls in December 2050, as in December 2016."

Post: nuclear power reduces Germany's cost by ~$4 trillion

Use of dispatchable nuclear power generation much lower-cost strategy

Reduced cost is from smaller investments in renewables and storage capacity

http://www.theenergycollective.com/willem-post/2396941/wind-and-solar-energy-lulls-and-energy-storage-in-germany

"Summary of capital costs of alternatives [in 2050]: below is a summary of the capital costs of the two alternatives. The capital cost of the nuclear alternative is less costly by about 6.71 - 2.68 = $4.03 trillion."

Alternative No. 1, without nuclear

2050	Times	GW in 2050	$trillion
Solar	8	328.0	0.82
Onshore wind	8	355.8	0.78
Offshore wind	8	26.3	0.11
Storage, distributed			5.00
Total			**6.71**

Alternative No. 2, with nuclear

2050	Times	GW in 2050	$trillion
New Nuclear		75.0	0.45
Solar	4	164.0	0.41
Onshore wind	4	177.9	0.39
Offshore wind	4	13.1	0.06
Storage, distributed			1.38
Total			**2.68**

Lattice comment: cost saving of $4 trillion is ~ 10x cost of new nuclear power plants

Utilization of nuclear power cuts total capital requirements

Dispatchable nuclear power would also much improve grid resiliency

Can't achieve Energiewende's 2050 Carbon emissions cuts without nuclear

http://www.theenergycollective.com/willem-post/2396941/wind-and-solar-energy-lulls-and-energy-storage-in-germany

Quoting from Willem Post's article:

"Germany may change its collective mind regarding nuclear energy, once the people realize the cost and environmental impacts of the required wind, solar and transmissions system build-outs by 2050, as shown in Alternative No. 1."

"Germany policymakers are beginning to realize expensive, bulk energy storage systems are not an economically viable option in the near future."

"At a cost of about $0.45 trillion for nuclear plants (with almost no CO_2 emissions), implementing the Energiewende would be about $4.03 trillion less costly, plus the environmental adversities of wind turbines, solar panels and associated transmission lines would be significantly less intrusive."

[Under the nuclear power scenario] "German electricity generation would be about 90% without CO_2 emissions by 2050; bio-electricity has CO_2 emissions). There can be no hope of achieving that without nuclear plants, and with continued operation of coal, oil and gas plants."

Ongoing climate change disrupts prior weather patterns

Mystery wind drought hit the western U.S. during first half of 2015

Total wind-powered electrical output down 6% while capacity went up 9%

Renewable decreases akin to Germany's in December 2016 have already occurred elsewhere in the world: far-western U.S. experienced serious wind drought in first-half 2015

"2015 turned out to be a terrible year for wind power"

Total wind-powered electrical output down 6% while capacity went up 9%

THE DAILY CALLER NEWS FOUNDATION

Andrew Follett, energy and environmental reporter
Feb. 24, 2016

http://dailycaller.com/2016/02/24/2015-turned-out-to-be-a-terrible-year-for-wind-power/#ixzz41bsV92Ev

"Wind turbines are pretty useless when there's not much wind. That's what the wind power industry learned in 2015 when lots of subsidized turbines were installed, but there was less wind to generate electricity. Average wind speeds were 20 percent below those of the previous year, and the trend appears set to continue in 2016, according to a Monday report by *New Scientist*. As a result, the amount of electricity produced by wind turbines dropped 6 percent even though lots of new turbines were built, according to Energy Information Administration (EIA) … Electricity from new wind farms is still three times more expensive than power generated from existing conventional power plants and four times more expensive than power from nuclear reactors. Wind power has been heavily subsidized since the 1980s and still gets 69 times more in subsidies than coal, oil, and natural gas per watt. Wind power still isn't capable of providing electricity at predictable times. The output of a wind power plant is quite variable over time, but the times when wind power generates the most electricity don't coincide with the times when power is most needed. Peak power demand also occurs in the evenings, when solar power is going offline."

Major wind drought occurred in U.S. during first half 2015

DNV-GL operates in over 100 countries and employs 16,000 professionals

DNV·GL

"Whither the winds in 2015? Analysis of the anomalously low winds in the U.S." Doc. #108917-RT-01-A Feb. 12, 2016

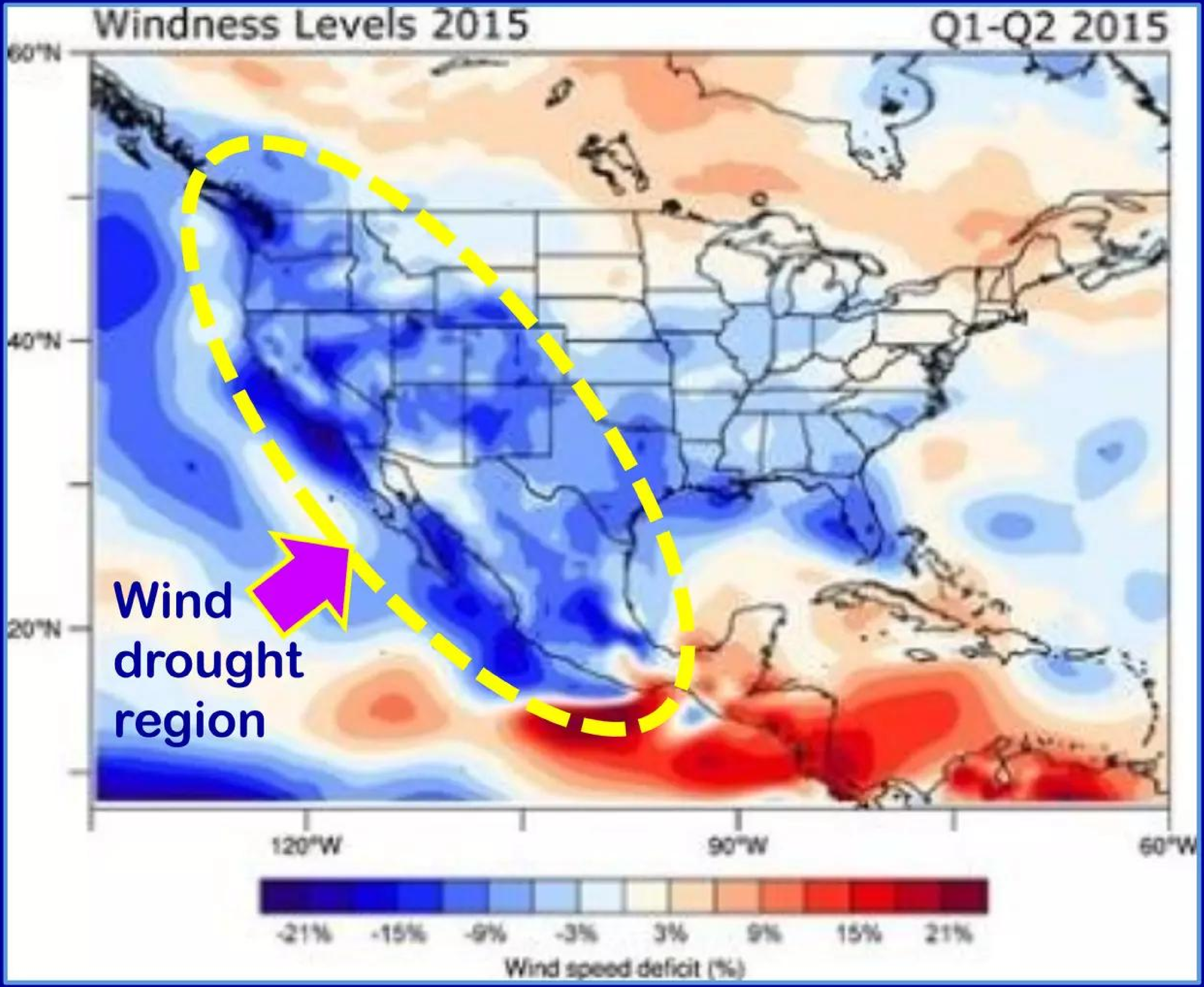
https://www.dnvgl.com/news/dnv-gl-study-el-nino-not-cause-of-2015-wind-drought--57798

"During the first half of 2015, large swaths of the United States (U.S.) experienced anomalously low winds, whose geographic extent and longevity eclipses any similar event in recent history. Ebbs in windiness are of course commonplace, driven by the passage of weather systems - some fair, some stormy - but rarely do so such lulls last beyond a few days. A number of claims and hypotheses have been made about the connection between the low winds and various climatic drivers - some are highly speculative. Unfortunately, such claims greatly outnumber established results. To help remedy this situation, this note attempts to illuminate the characteristics of the anomalous winds and, through careful quantitative analysis, offers one plausible explanation for their origin … wind speeds over much of the U.S. ranged from 6% below the long term mean to a deficit as high as 20%. Over California, Oregon, Washington, Nevada, Arizona, southeast Texas, and Florida, these are the lowest observed wind speeds within the entire 1979-present record. However, other regions were not nearly as affected, particularly the Great Plains which has a large installed capacity of operating wind farms. By mid-year, the winds returned to their more normal patterns of variability. It is natural to seek the root causes of this event, and to determine whether we will ever witness a so long-lived and so significant event in the future."

Fig. 2-1 in DNV-GL report "Whither the winds in 2015?"

Image shows departure from mean wind speeds for first half of 2015

Darkest shade of blue indicates greatest value for deviation from mean = ~21%



Data source: NASA (generated from MERRA)

Wind power fluctuations spatially correlated over kilometers

Violates present industry assumptions: Bandi et al. publish key analysis

OIST

"Re-thinking renewable energy predictions"
By Rebecca Hofland, March 3, 2016 [excerpts are below]
Okinawa Institute of Science and Technology news center

http://www.oist.jp/news-center/news/2016/3/3/re-thinking-renewable-energy-predictions

OIST Prof. Mahesh M. Bandi, whose team conducted the research, said, "A fluctuating power source threatens the even distribution of power in the electrical grid. That makes it difficult to balance the fluctuating power output with the fluctuating consumer demand." They " … analysed data from the Irish grid wind farms and saw that power outputs from the farms on the grid fluctuate in similar ways. This is different than previously thought. "It's generally assumed that geographically distributed wind farms are independent. In other words, the fluctuations in power output from one wind farm are different from that of another wind farm, say 50 km away," Bandi said. Instead, the data that Bandi and his team analysed showed that the wind farms on a grid no longer function independently of one another in response to local wind speed conditions, but instead become part of a larger geographic weather system that forces all the wind farms to have similar or correlated outputs for a time span of up to one day … The unpredictability of wind power supply, as well as working with a larger geographic weather system can then create errors in forecasting power output … "This technique or tool is not limited to wind power," Bandi said. This means it can also be used across other renewable energy sources to predict error, so long as they possess time-related corresponding changes that have a statistical structure.

Wide-area wind droughts & spatially-correlated power output

"Variability adds a cost to renewable power … absent in conventional …"

IOP Institute of Physics

"Grid-scale fluctuations and forecast error in wind power" G. Bel, C. Connaighton, M. Toots, and M. Bandi *New Journal of Physics* 18 pp. 023015 (2016)

http://iopscience.iop.org/article/10.1088/1367-2630/18/2/023015/pdf

"One normally assumes that geographically distant wind farms are independent and that temporal correlations in the fluctuating wind power for each farm do not translate into long-range spatial correlations … Using data from the Irish grid operator EIRGRID as a representative example, we studied the temporal correlations in the aggregate wind power entering the Irish grid. The Irish grid is fed by 224 wind farms spread across the Republic of Ireland, a much larger number of farms than the number in the aggregate power previously considered in Texas. We found that the aggregate wind power entering the Irish grid exhibits temporally correlated fluctuations with a self-similar structure. The persistence of correlations, despite an order of magnitude increase in the number of wind farms (and their spatial distribution), strongly points to the presence of long-range spatial correlations in the atmospheric turbulence, which couples geographically distributed wind farms, thereby rendering them non-independent … forecast models constitute essential tools in estimating the magnitude of fluctuations beforehand and in planning for the optimal operating reserves required on call. Yet, no standards for forecast accuracy currently exist … Here, we suggest that the performance of wind power forecast models (as well as the performance of any model for non-stationary processes) should also account for the quality of the prediction against temporal correlations."

Volcanic eruptions can reduce sunlight at Earth's surface

Increases amount of sunlight reflected (albedo) - can affect large regions

Solar power production can also be greatly reduced for long times in desert areas

Copper Mountain solar farm in Boulder City, Nevada, produces 458 MW/yr. of electricity for ~18,000 homes; uses ~1 million PV solar panels and covers land area of 1.8 sq. km

Volcanic eruptions can reduce sunlight at Earth's surface

Increases amount of sunlight reflected (albedo) - can affect large regions

Ability to generate solar power can be substantially reduced for long time periods

Mount St. Helens (Oregon, USA) eruption on May 18, 1980 - photo taken from a small aircraft


Photo credit: Richard Bowen (1980)

Series of minor volcanic eruptions can reduce sunlight

Reduction can cause measurable decreases in solar power generation

nature geoscience
LETTERS
PUBLISHED ONLINE: 23 FEBRUARY 2014 | DOI: 10.1038/NGEO2098

"Volcanic contribution to decadal changes in tropospheric temperatures"
B. Santer *et al.*, *Nature Geoscience* 7 pp. 185 - 189 (2014)

https://dspace.mit.edu/openaccess-disseminate/1721.1/89054

"We were able to show that part of the cause of the recent lack of temperature increase is the large number of minor volcanic eruptions during the last 15 years. The ash and chemicals from these eruptions caused less sunlight than usual to arrive at the Earth's surface, temporarily reducing the amount of temperature increase we measured at the surface and in the lower troposphere. The most recent round of climate models studied for the IPCC report did not adequately include the effects of these volcanoes, making their predictions show too much warming. For climate models to make accurate predictions, it is necessary that the input data that is fed into the model is accurate. Examples of input data include information about changes in greenhouse gases, atmospheric particles and solar output."

http://www.theguardian.com/environment/climate-consensus-97-per-cent/2014/feb/25/global-warming-slowdown-volcanoes-contribute

Huge volcanic eruptions drastically impact Earth's climate

Toba eruption 74,000 years ago reduced sunlight at surface for 10 years

National Aeronautics and Space Administration
Goddard Institute for Space Studies

Goddard Space Flight Center
Sciences and Exploration Directorate
Earth Sciences Division

Science Briefs

Super-Eruptions, Climate and Human Survival

By Drew Shindell — July 2009

http://www.giss.nasa.gov/research/briefs/shindell_12/

"Roughly 74,000 years ago, a 'super-eruption' took place in Indonesia, the largest known eruption in the past 100,000 years. The Toba eruption was enormous, throwing out roughly 1,000 times as much rock as the 1980 eruption of Mt. St. Helens. Dust trapped in polar ice cores shows that ejected material spread around the globe, indicating that the eruption injected substantial material into the stratosphere, where it can strongly affect climate … Recently we used state-of-the-art climate models to examine this question … Among the most interesting findings was that in response to the reduced sunlight able to penetrate the think blanket of ash and particles in the atmosphere, broadleaf evergreen trees and tropical deciduous trees virtually disappeared for several years. However, the Earth's climate returned to near-normal conditions within a decade in most simulations."

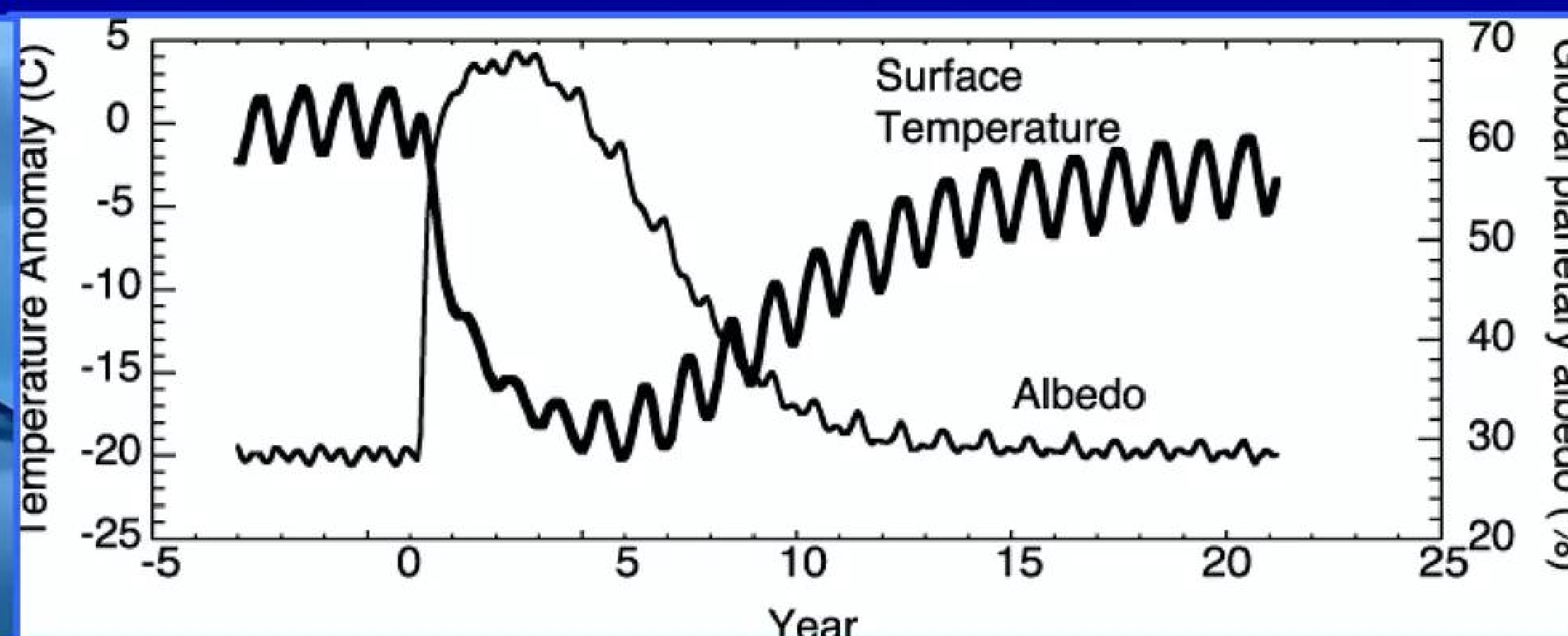
Toba eruption 74,000 years ago hugely impacted climate

Researchers used climate models to simulate effects of this eruption

"Did the Toba eruption of ~ 74 ka B.P. produce widespread glaciation?"
A. Robock *et al.*, *Journal of Geophysical Research* 114 pp. D10107 (2009)

http://pubs.giss.nasa.gov/docs/2009/2009_Robock_etal_1.pdf

Fig. 2: response of global mean surface air temperature and albedo (reflectivity) following the eruption of Toba (at year 0)



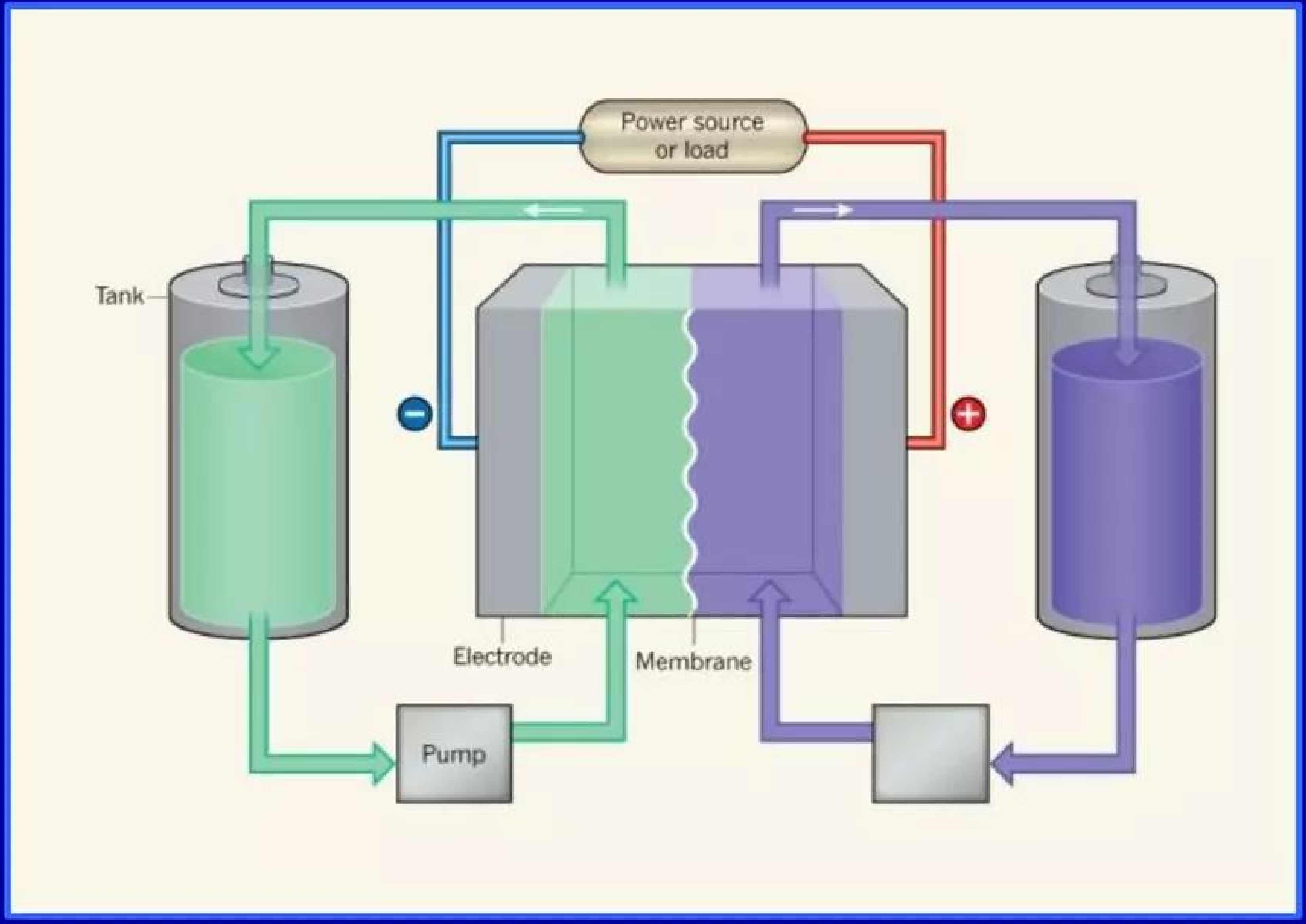
" … a Toba-like eruption could certainly produce a decade-long volcanic winter, with serious effects on plant and animal life … While our results show that indeed the eruption could have produced great stress on humans and their environment, it would have been quite concentrated in the few very dark, cold, and dry years immediately following the eruption … it is probable that the sudden dark, cold, and dry conditions that followed the super-eruption of Toba about 74,000 years ago could have largely destroyed the food supplies of humans and therefore caused a significant reduction in population sizes."

Grid-level storage for wind/solar intermittency and shortfalls

Extremely large flow batteries touted as effective technological solution

- ✓ Large present-era 'dumb' power grids require continuous production of electricity that ideally matches demand on a second-by-second basis as well as large standby power generation facilities that can be dispatched on very short temporal notice
- ✓ Wind and solar power sources are inherently intermittent in their output of electricity; modern wide-area grids could not function at 99^{+}% availability if power generation was only provided by renewables
- ✓ Enter the possibility of flow batteries that are low-cost vs. Li-ion and can be scaled-up volumetrically to gigantic storage capacities
- ✓ Good technology within certain limitations, largest being their intrinsically low energy density: newly discovered quinone-based chemistry only achieves ~50 Wh/kg versus 150 - 200 Wh/kg for commercial Lithium-ion

Conceptual schematic of a flow battery



Membrane separates charge-carrier liquids

Flow batteries can buffer wind or solar generation shortfalls

Concept: huge battery farms store electricity produced by wind or solar

Issue: flow batteries have fraction of Lithium-ion chemistry's energy density

Comparison: energy densities of flow batteries vs. other battery types

Batteries	Energy Density (Wh/L)	Power Density (W/L)
Bromine-polysulfide	20-35	60
Vanadium-vanadium	20-35	60-100
Vanadium-bromine	20-35	50
Zinc-bromine	20-35	40
Zinc-cerium	20-35	50
Lead-acid	60-80	230
Lithium-ion	150-200	275
Nickel metal hydride	100-150	330

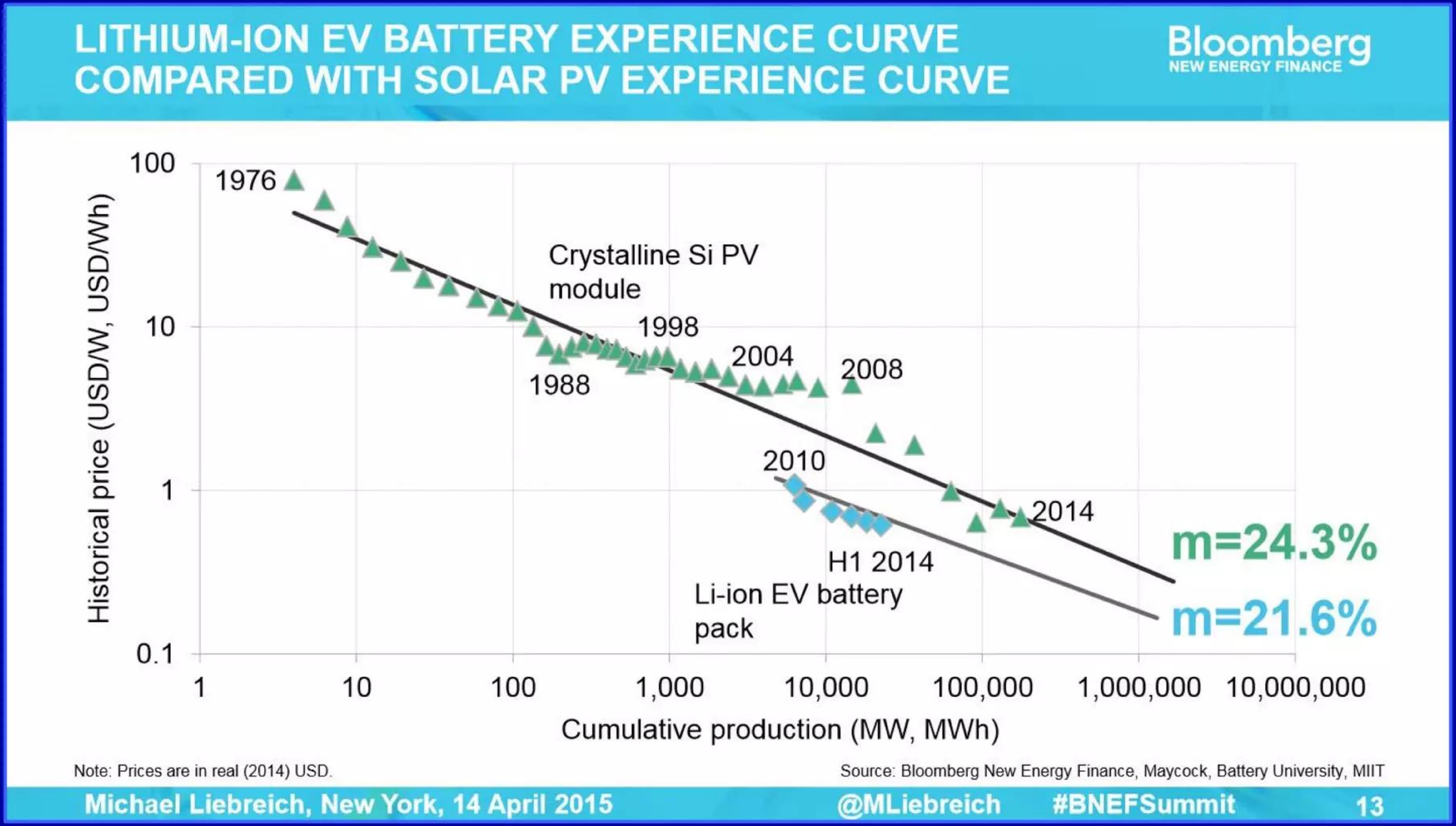
Table 1: Battery Comparison (based on data from [4]). The first five are flow batteries.

Source of Table 1: "Introduction to Flow Batteries: Theory and Applications," Bhaskar Garg, Stanford University, March 22, 2012

Solar PV and Li-battery costs have been falling over time

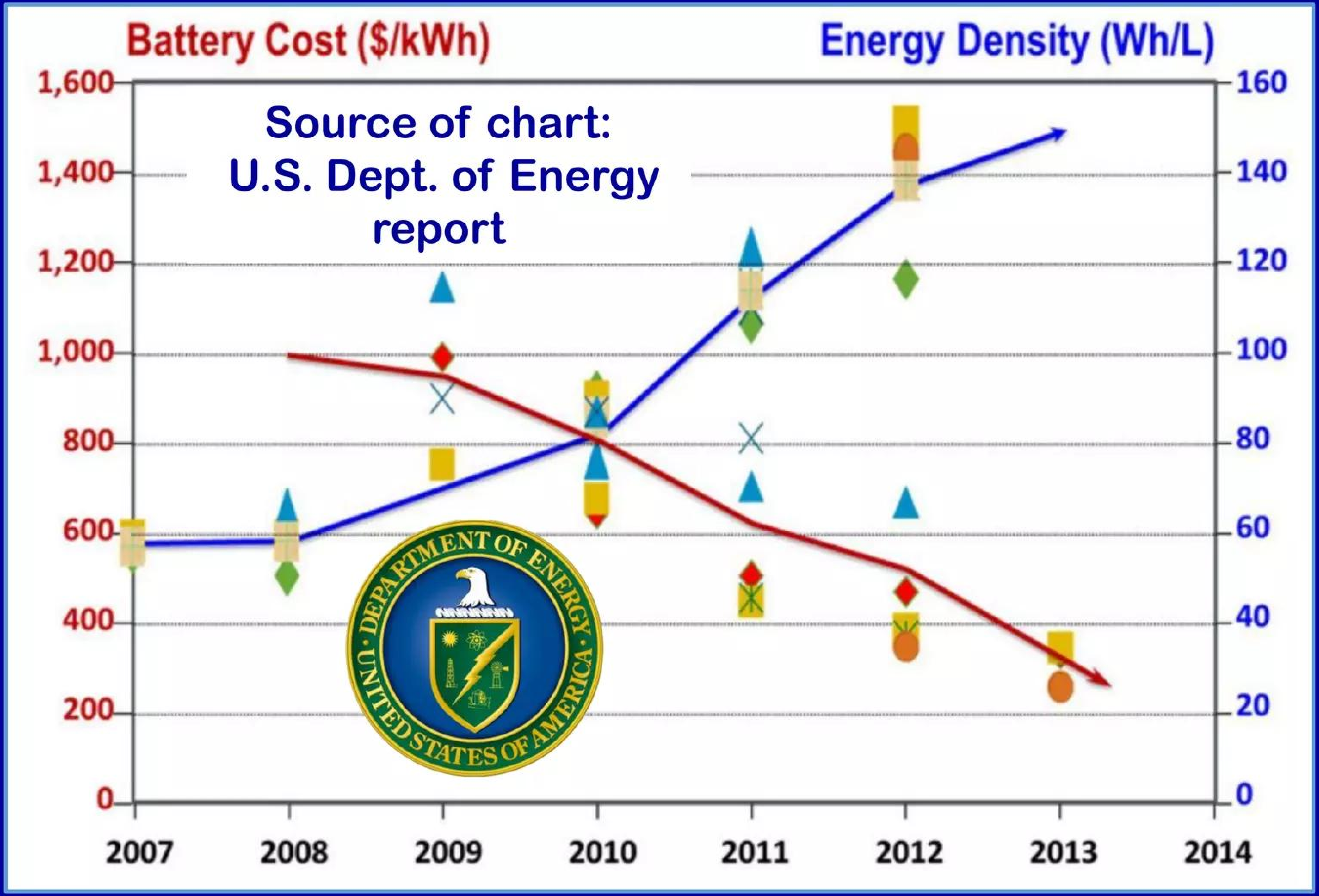
Chart shows how experience curve effect cut costs from 1976 to 2014

Cost reductions eventually flatten-out for all technologies as they hit their limits



Battery cost reduction tied to increases in energy density

If energy density increases slow down then cost reductions will stagnate

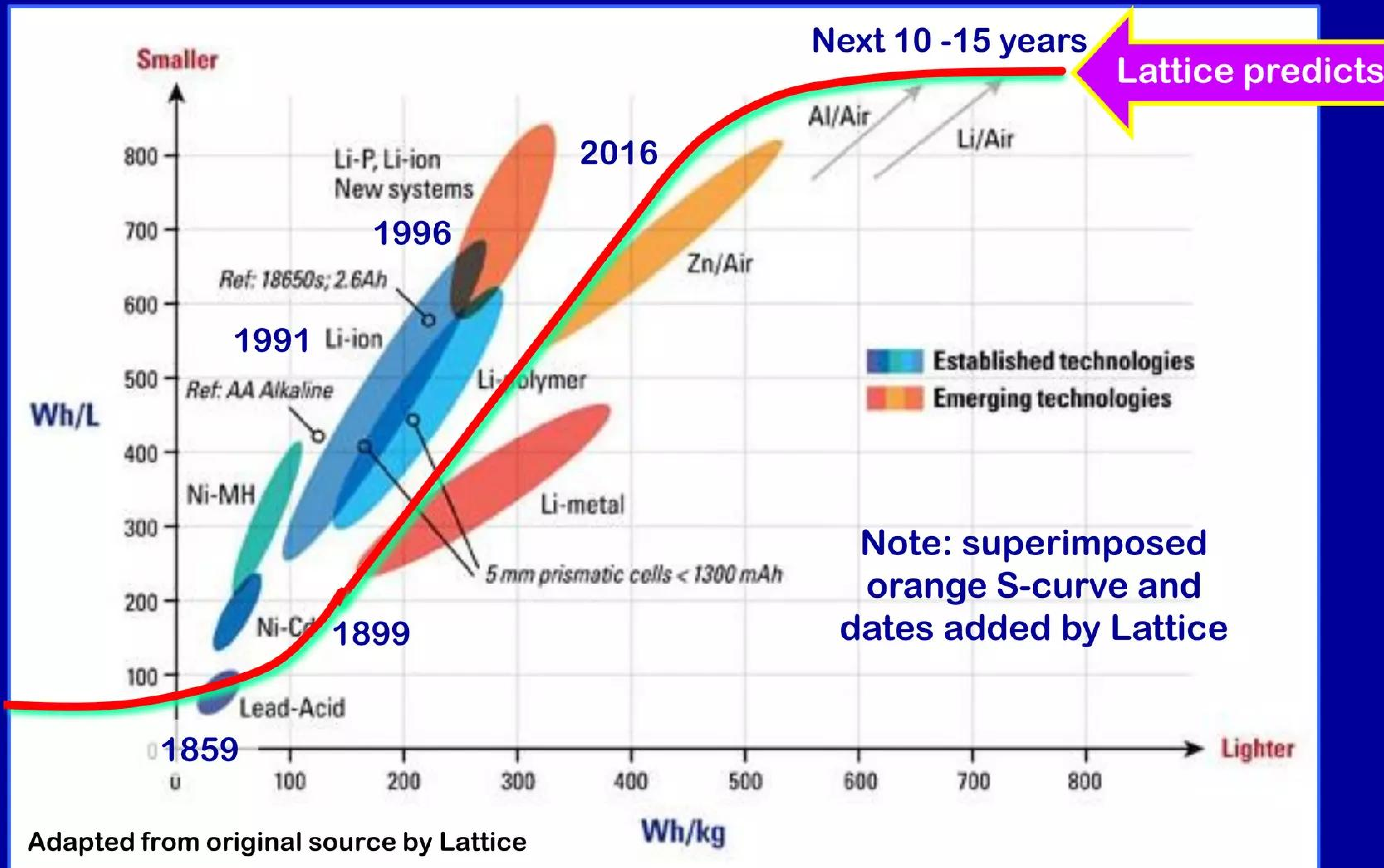


http://theenergycollective.com/onclimatechangepolicy/347491/making-low-carbon-future-better-well-cheaper

Batteries are maturing and approaching technological limits

Energy density increases and related cost reductions will slow down

Battery costs will likely not drop low-enough to replace dispatchable power



http://www.estquality.com/technology

Fossil fuels exhausted within ~ 150 - 200 years from today

Over 80% of total global energy demand now satisfied by fossil fuels

Fossil fuel reserves exhausted within < 200 years per BP

Solar PV/wind: energy density insufficient to 100% replace fossil fuels

World will always need dense energy sources for transportation & portable power

Batteries for energy storage: flow batteries + solar/wind cannot rival fossil energy densities

Comparison of intrinsic energy densities

Table 1 Energy density

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

Gasoline vastly more energy-dense

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)

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

See: "BP Statistical Review of World Energy June 2016" this 65th edition was released in June 2016

https://www.bp.com/content/dam/bp/pdf/energy-economics/statistical-review-2016/bp-statistical-review-of-world-energy-2016-full-report.pdf

World should reduce CO_2 emissions from power generation

Dispatchable power generation is synergistic with renewable energy

- ✓ While some harbor doubts about degree to which human activities contribute to or exacerbate climate change, published data suggests that increases in atmospheric CO_2 levels are reasonably well-correlated with increases in mean global temperatures. Consequently, attempting to combat climate change by decreasing CO_2 emissions from power generation is a desirable technological goal as long as the long-term economic costs for society can be reasonable
- ✓ Solar photovoltaic (PV), concentrated solar power (CSP), and wind generation are CO_{2-}–free; their output can be substituted for fossil-fueled dispatchable power plants to cut CO_2 emissions. However, renewable energy sources are intermittent. This intrinsic vulnerability to vagaries of Nature was underscored by an unexpected and mysterious U.S. wind drought in early 2015 which lasted for 6 months before vanishing, as well as two large shortfalls in German wind and solar power production that occurred in December 2016. During 6-month U.S. wind drought, total electricity produced by wind in U.S. dropped over 15%
- ✓ It would be uneconomic to build a sufficient excess of wind power generation capacity and/or enormous amounts of grid battery storage capacity to handle multi-month episodes of substantially reduced wind velocity that could slash electricity production by wind turbines. Fortunately, short-notice dispatchable power generation capacity can readily provide low-cost electricity to fill such supply gaps and thereby function as an essential component of modern grids

Dispatchable power generation will always be needed

Nuclear power could be key component in long-term future of energy

- ✓ Given innate variability in power output of renewable green energy sources, substantial amounts of short-notice dispatchable generation capacity are an unavoidable necessity and key asset for maintaining modern high-availability electricity grids that ideally provide customers with 99^{+} % uptime. This crucial requirement would continue to exist even if --- sometime in the near future --- distributed wind and/or solar renewables happened to become substantially *less* expensive than large dispatchable fossil-fueled or nuclear fission power plants
- ✓ From just a risk management perspective, maintaining adequate dispatchable generation capacity would be a cost-effective investment that could also help prevent an unimaginable societal catastrophe in unlikely event of a very rare, enormous “Black Swan” volcanic dust eruption that would sharply reduce both sunlight and wind speeds on Earth’s surface for months or even several years
- ✓ Having adequate dispatchable power generation capacity is thus an invaluable asset in maintaining 99^{+}% reliable electricity grids and national energy security. It would also be prudent to reduce future CO_2 emissions from power generation. This will eventually happen anyway because at current rates of consumption, BP estimates that global fossil fuel resources will be totally exhausted in < 200 years
- ✓ Nuclear power plants are dispatchable and do not emit any CO_2. Like it or not, major worldwide expansion of nuclear power generation is probably inevitable and could be a key strategic component in the long-term future of green energy

Nuclear power is CO_2-free could help reduce emissions

NEA/IEA report: nuclear should double by 2050 to curb global warming

CLIMATE CENTRAL

NEA Nuclear Energy Agency

iea International Energy Agency Secure • Sustainable • Together

"Nuclear power needs to double to meet warming goal"

By Bobbie Magill, Climate Central, January 29, 2015

"International Energy Agency and the Nuclear Energy Agency suggest in a report released Thursday that nuclear will have such a significant role to play in climate strategy that nuclear power generation capacity will have to double by 2050 in order for the world to meet the international 2°C (3.6°F) warming goal … To accomplish the needed CO_2 emissions cuts to keep warming no greater than 2°C, the IEA says global nuclear power generation capacity needs to increase to 930 gigawatts from 396 gigawatts by 2050."

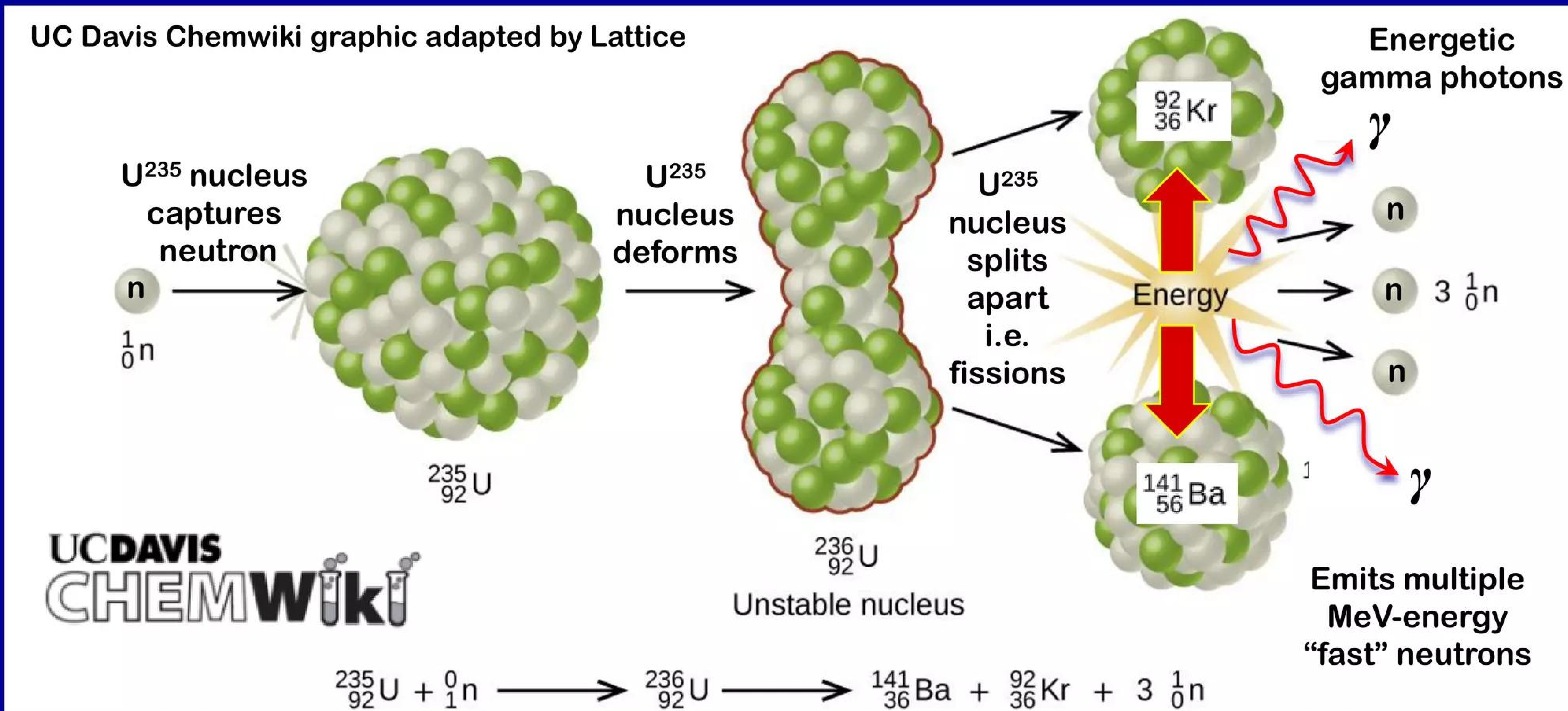
http://www.climatecentral.org/news/nuclear-power-needs-to-double-to-meet-warming-goal-18610

http://www.iea.org/publications/freepublications/publication/TechnologyRoadmapNuclearEnergy.pdf

Nuclear fission uses neutrons to explode heavy atoms

Uranium fission emits deadly energetic gamma and neutron radiation

Process also produces copious amounts of long-lived radioactive waste isotopes



Japanese and German public are opposed to fission power

Germany’s Energiewende plans to phase-out fission reactors by 2022

Japan now imports ~84% of its energy needs; if no fission what will they do?

“Scientists measure highest radiation levels yet inside Fukushima's damaged reactors”
“The latest measurements are over seven times the previously measured high --- enough to fry a robot in two hours”
Jason Daley in *Smithsonian.com* on February 6, 2017

http://www.smithsonianmag.com/smart-news/fukushima-reactor-shows-highest-radiation-level-initial-meltdown-180962050/

http://www.dw.com/en/opposition-to-nuclear-energy-grows-in-japan/a-36110302

Image credit: Reuters
Credit: Reuters

Latest estimates are that clean-up of the Fukushima site will cost US$190 billion and require up to 40 years to complete

Could nuclear fusion potentially replace fission someday?

Fusion still not commercialized after 60 years with large R&D funding

Many scientists blithely assume success with fusion technology inevitable

ITER D+T fusion reactor is now being built in Cadarache, France

Achieving controlled nuclear fusion
became the Holy Grail of energy science
because it could potentially provide mankind with a
cleaner, less expensive form of CO_2-free nuclear power
compared to much less technically difficult but vastly more
problematic (accidents, proliferation) Uranium fission technology.

Many think that energy's future will be renewables and fusion.
What happens if this common presumption turns-out to be wrong?

Credit: SOHO -ESA & NASA

Recent picture of ITER worksite in Cadarache, France

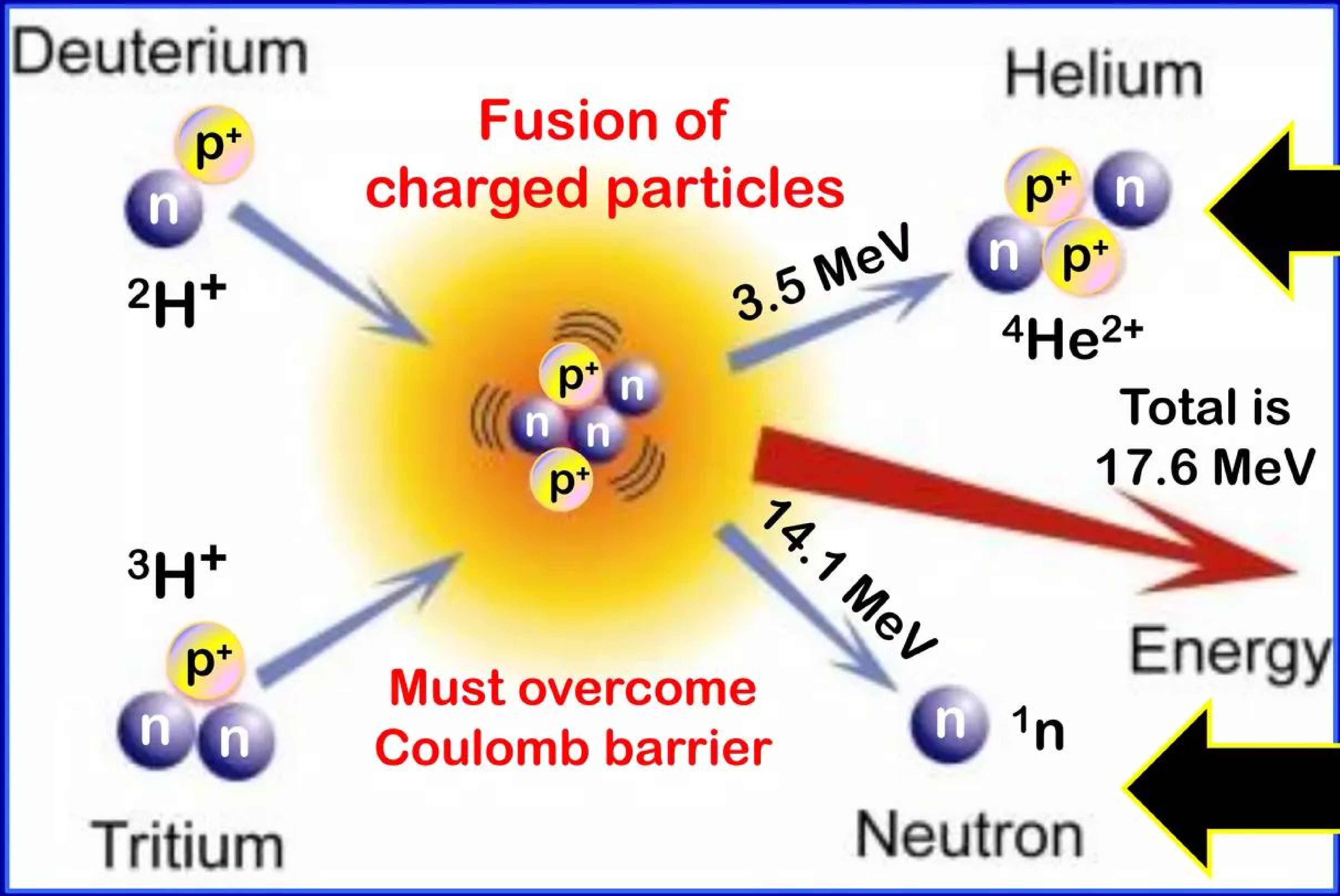
Deuterium + Tritium (D+T) fusion reaction is utilized in ITER

D+T fusion reactor needs 100^+ million degree star-like temperatures

Long-sought Holy Grail of government fusion research since mid-1950s

Produces dangerous energetic neutrons and high-energy gamma radiation

D+T fusion reaction: $^2H^+ + ^3H^+ \rightarrow ^4He^{2+} + ^1n + 17.6$ MeV



20% of D+T reaction's energy

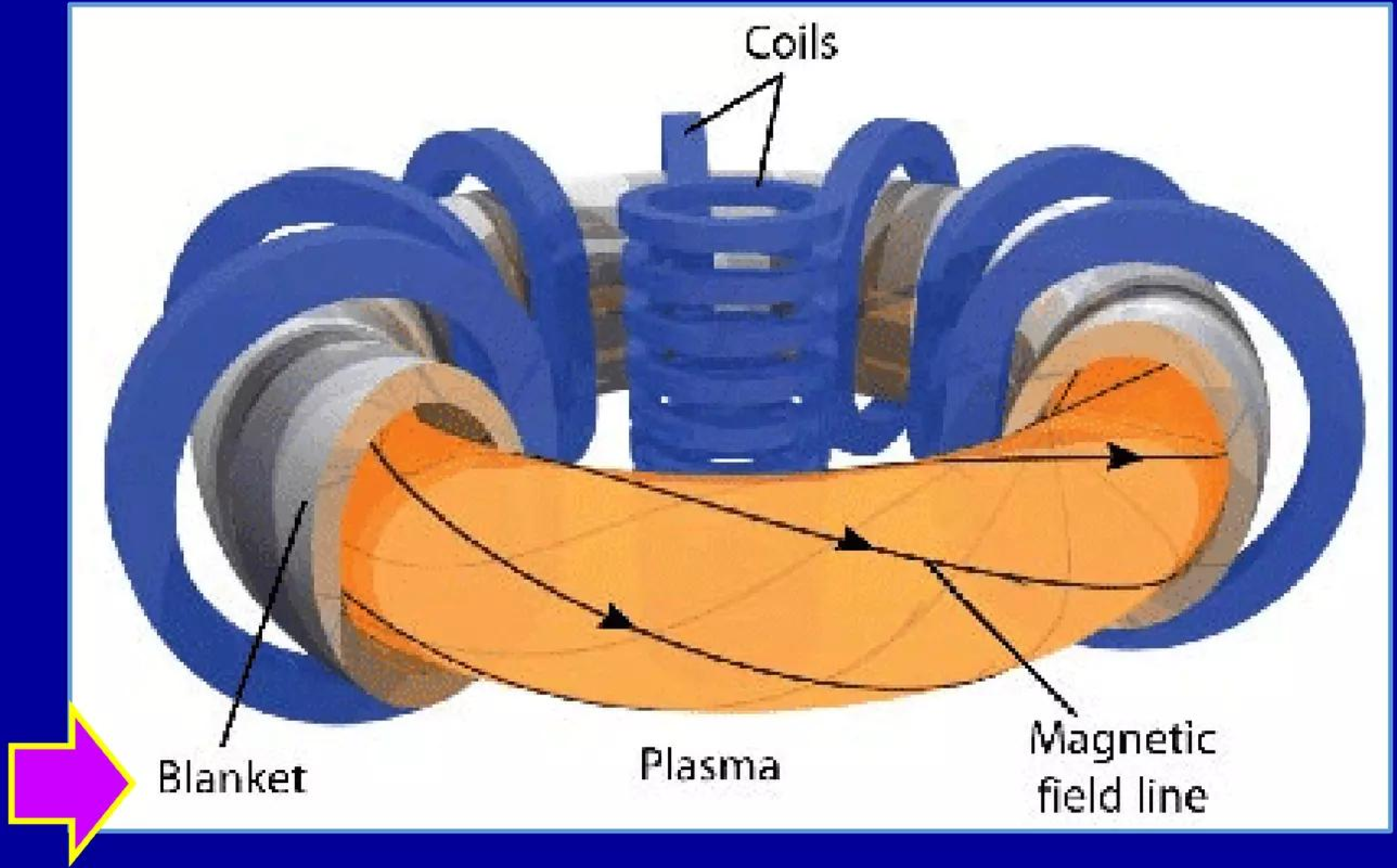
80% of D+T reaction's energy

Conceptual graphic of D+T tokamak fusion reactor like ITER

D+T reactor needs 100^+ million degree temperatures in fusion plasma

Commercial economics dictate that Tritium fuel must be produced in blanket

Price of Tritium fuel for D+T fusion reactors is presently at ~$30,000 per gram.
Current world production from CANDU fission reactors only ~ 20 kilograms/year.
Future D+T fusion reactors would *each* consume an estimated 100 - 200 kg/yr.
Viable D+T fusion reactors thus probably must produce more Tritium than they consume as fuel to be cost-competitive for use in commercial power generation



Deuterium + Tritium (D+T) tokamak fusion reactors like ITER

Tritium is $30,000/gram; fusion reactors must be able to self-produce fuel

- ✓ ~80% of D+T reactor's energy output comprises energetic (14 MeV) neutrons that escape magnetic fields; other ~20% ionized $^{4}He^{2+}$ stays in plasma & helps heat it
- ✓ Being uncharged energetic neutral particles unaffected by magnetic fields, 14 MeV neutrons are very damaging form of deeply penetrating nuclear radiation. Consequently, D+T fusion reactors have mandatory requirements for ultra high performance radiation shielding and materials. Some radiation shields must face directly toward 100+ million degree fusion plasma; are designed to intercept and fully absorb particle and photon radiation emitted by super-hot ionized plasma
- ✓ Innermost shielding subsystems used in D+T fusion reactors called "blankets." Functionally designed and engineered to: (1) absorb and harvest energy from large fluxes of high-energy neutrons emitted by fusion plasma; and (2) protect reactor's physical supporting structures from exposure to damaging neutrons that could reduce mechanical strength of reactor structural materials over time
- ✓ Blankets would have an additional functional requirements in commercial fusion power reactors: (3) they must be able to produce ("breed") more Tritium (^{3}H) than quantity of Tritium 'burned' during reactor operation; need minimum ratio of ~1.04x ^{3}H fuel consumed. Blanket produces excess ^{3}H by neutron captures on Lithium (Li) isotopes embedded in Lithium (15%)/Lead (Pb) alloy material in liquid phase above 325º C melting point of Li/Pb alloy; also spallation neutrons from Pb. If self-producing Tritium is impossible, commercial reactors may be uneconomic

Selective overview of nuclear fusion research

- ✓ Funded mostly by governments, research on fusion for use in nuclear weapons and commercial power generation began in early 1950s and continues today
- ✓ Over period of ~60 years, likely that $200 - 250 billion (constant $) was spent worldwide to develop what many believe is ultimate energy source: controlled use of nuclear fusion reactions similar to those that power stars out in Nature
- ✓ Unfortunately, researchers have been forced to make technical compromises to have any chance of achieving substantial rates of fusion for prolonged times in experiments that can be practically conducted in terrestrial laboratories
- ✓ Stars are physically large, heavy objects that readily use their extremely strong gravitational fields to contain and confine super-hot ionized Hydrogen plasmas. By contrast, out of necessity, vastly smaller Earthbound fusion machines are compelled to use organized, very high local magnetic fields to achieve stable, long duration confinement of their plasmas --- this is much trickier proposition
- ✓ Plasma densities in stellar cores where fusion naturally occurs always greater than 2 x 10^{11} atmospheres (atm.). In 2016 experiments, MIT's Alcator C-Mod fusion reactor achieved record-breaking plasma densities of only 2.05 atm.; this is vastly lower than in stars. This causes a technical compromise in which experimental fusion reactors must operate at significantly higher temperatures than stars in order to achieve useful rates of fusion. This mandates injection of greater initial input energy to heat plasmas to temperatures that support fusion

Selective overview of nuclear fusion research

- ✓ Anxious to minimize reactor engineering challenges, fusion researchers have focused on Deuterium + Tritium (D+T) reaction because it offers the highest reaction rates (cross-section) at lowest-possible temperatures and pressures
- ✓ 60 years of R&D by many thousands of scientists and enormous amounts of $ in funding have culminated in ITER fusion reactor now under construction. At an estimated final cost of ~$24 billion, ITER is ~3 times its initial program budget and nearly 10 years behind original schedule. Number of immense D+T reactor engineering obstacles were successfully overcome along the way. ITER's first experiments presently scheduled to begin in 2025 and be completed by 2035
- ✓ If ITER's present experimental program is successful as planned, all it will have accomplished by 2035 is demonstrate that scientists can create fusion plasmas in which total thermal energy released by D+T reactions in confined plasma exceed input energy (externally supplied to plasma proper) that is used for heating-up the plasma to temperatures that can support D+T fusion. "Fusion power" is ratio of plasma heating power output to plasma heating power input
- ✓ Note that "fusion power" by definition does not include any accounting for certain additional input energy that is required for ITER to operate as fully functional reactor system. Input energy that is omitted from this performance metric includes what is used for energizing powerful magnetic fields that confine its fusion plasma as well as power-hungry cooling systems associated with operation of ITER's array of immense superconducting magnets

Selective overview of nuclear fusion research

- ✓ Testing of various alternative designs for Tritium-breeding blankets one of a number of crucial to-do items in ITER's research program. Purpose of blanket testing is to determine: (1) best design; (2) whether enough Tritium can be produced in blankets to cover Tritium that is consumed as fuel in ITER reactor
- ✓ Next technological step after ITER program has completed would be design and construction of demonstration reactors (DEMO). Unlike ITER, these future experimental systems would be designed to operate at large multiples of true net "breakeven" at reactor system-level (total energy output)/(total energy input). DEMOs would also include energy conversion subsystems capable of generating electricity; they would thus begin to resemble commercial reactors. While DEMO reactor programs are still in embryonic phase, current thinking is that individual countries would build these reactors, unlike ITER consortium
- ✓ In series of articles published in *New Energy Times*, investigative science journalist Steven Krivit revealed that ITER personnel and their supporters have engaged in misleading characterization of reactor performance progress; see:

"The Selling of ITER" Jan. 12, 2017

http://news.newenergytimes.net/2017/01/12/the-selling-of-iter/

"Former ITER Spokesman Confirms Accuracy of New Energy Times Story" Jan. 19, 2017

http://news.newenergytimes.net/2017/01/19/former-iter-spokesman-confirms-accuracy-of-new-energy-times-story/

Technology readiness levels (TRL) show state of progress

Description below is used by European Commission to evaluate projects

European Commission

Technology Readiness Levels

TRL 0: **Idea**. Unproven concept, no testing has been performed.

TRL 1: **Basic research.** Principles postulated and observed but no experimental proof available.

TRL 2: **Technology formulation**. Concept and application have been formulated.

TRL 3: **Applied research**. First laboratory tests completed; proof of concept.

TRL 4: **Small scale prototype** built in a laboratory environment ("ugly" prototype).

TRL 5: **Large scale prototype** tested in intended environment.

TRL 6: **Prototype system** tested in intended environment close to expected performance.

TRL 7: **Demonstration system** operating in operational environment at pre-commercial scale.

TRL 8: **First of a kind commercial system**. Manufacturing issues solved.

TRL 9: **Full commercial application**, technology available for consumers.

Sagara et al. estimate TRLs of ITER and DEMO reactors

Presented at 2015 IAEA workshop; good discussion of technical issues

http://www-naweb.iaea.org/napc/physics/meetings/TM49530/website/talks/May%2012%20Sessions/Sagara_A.pdf

3rd IAEA DEMO Programme Workshop
11-14, May 2015 , Hefei
@University of Science and Technology of China

Special Session 2
Topics 1 : Contribution of integrated devices to closing the gaps (1)

Technological readiness comparison for Helical and Tokamak DEMO

A. Sagara[1], R. Wolf[2] and H. Neilson[3]

1) National Institute for Fusion Science, Japan
2) Max-Planck-Institut fur Plasmaphysik, Germany
3) Princeton Plasma Physics Laboratory, USA

Sagara et al. estimate that ITER program spans TRL 5 - 6

Lattice: ITER would be TRL-5 based on European Commission's criteria

TRL for fusion reactor realization

TRL	Definition	State for magnetic confinement fusion (incl. R&D in DEMO)	State for inertial fusion
TRL1	Basic principles observed and reported	Proof of concept	Proof of concept
TRL2	Technology concepts and/or applications formulated		
TRL3	Analytical and experimental demonstration of critical function and/or proof of concept	Component validation	Component validation (including validation of reactor-core physics and fusion burning)
TRL4	Component and/or bench-scale validation in a laboratory environment		
TRL5	Component and/or breadboard validation in a relevant environment	ITER (Exp. Reactor)	
TRL6	System/subsystem model or prototype demonstration in relevant environment		Demonstration reactor
TRL7	System prototype demonstration in prototypic environment	DEMO reactor	
TRL8	Actual system completed and qualified through test and demonstration		Prototype reactor
TRL9	Actual system proven through successful operations		
Remarks	After GNEP's definition	Main machines: ITER & DEMO	Main machines: (NIF, LMJ, FIREX etc), DEMO, Prototype

GNEP: Global Nuclear Energy Partnership

3rd IAEA DEMO Pro. WS, May 12, 2015,

Sagara 10 / 34

Unclear when commercial fusion plants might be available

Hedge bets on availability of fusion with parallel investments in LENRs

- ✓ Built on 60 years of prior R&D and $200 - 250 billion in worldwide government funding, if ITER program successful then Technology Readiness Level of D+T fusion reactors will only have advanced to TRL-5 (use EC criteria). Successful completion and extended operation of later DEMO reactors after 2035 would advance readiness to ~TRL 6-7 (per European Commission's EC TRL criteria)
- ✓ As noted earlier, ITER was not designed to achieve system-level breakeven. Considering ~10 year time-delay relative to ITER's original development plan, daunting array of still-unsolved technical obstacles, and lingering questions about economic viability of fusion for power generation, it seems unlikely that deployment of single bona fide fusion reactor could occur before 2050 at the earliest. Unfortunately, given the prior 60-year history and apart from undying optimism of fusion scientists, there are no guarantees that worldwide quest to commercialize fusion will be successful within *any* reasonable time-frame
- ✓ Consequently, and given that national body politics may not be willing to tolerate vast expansion in use of fission reactors, prudence and sensible national risk management would argue that fusion should not be any nation's sole bet on future dispatchable nuclear power systems. Countries' present bets on D+T fusion technology could be hedged with parallel investments in what could potentially be a newer, even better type of future CO_2-free nuclear energy source: radiation-free ultralow energy neutron reactions (LENRs)

Comparison of LENRs to fission and fusion

Fission, fusion, and LENRs all involve controlled release of nuclear binding energy (heat) for power generation: no CO_2 emissions; scale of energy release is MeVs (nuclear regime) > 1,000,000x energy density of chemical energy power sources

Heavy element fission: involves shattering heavy nuclei to release stored nuclear binding energy; requires massive shielding and containment structures to handle radiation; major radioactive waste clean-up issues and costs; limited sources of fuel: today, almost entirely Uranium; Thorium-based fuel cycles now under development; heavy element U-235 (fissile isotope fuel) + neutrons → complex array of lower-mass fission products (some are very long-lived radioisotopes) + energetic gamma radiation + energetic neutron radiation + heat

Fusion of light nuclei: involves smashing light nuclei together to release stored nuclear binding energy; present multi-billion $ development efforts (e.g., ITER, NIF, other Tokamaks) focusing mainly on D+T fusion reaction; requires massive shielding/containment structures to handle 14 MeV neutron radiation; minor radioactive waste clean-up $ costs vs. fission

Two key sources of fuel: Deuterium and Tritium (both are heavy isotopes of Hydrogen)

Most likely to be developed commercial fusion reaction involves the following:

D + T → He-4 (helium) + neutron + heat (total energy yield 17.6 MeV; ~14.1 MeV in neutron)

Ultralow energy neutron reactions (LENRs): distinguishing feature is neutron production via electroweak reaction; neutron capture on fuel + gamma conversion to IR + decays [β^-, α] releases nuclear binding energy; early-stage technology; no emission of energetic neutron or gamma radiation and no long-lived radioactive waste products; LENR systems would not require massive, expensive radiation shielding or containment structures → much lower $$$ cost; many possible fuels --- any element/isotope that can capture LENR neutrons; involves neutron-catalyzed transmutation of fuels into heavier stable elements; process creates heat

LENRs are superior to fission and fusion technologies

Why build huge D-T fusion reactors if LENRs can be commercialized?

Greenness of LENRs could enable revolutionary portable nuclear power sources

- ✓ While LENRs do use safe ultralow energy neutrons to trigger release of nuclear binding energy (heat) from an enormous array of stable element target fuels, they are radically different from U and Th fission reactors that require criticality to operate properly. Unlike fission, LENRs don't involve multiplicative chain reactions with fuels that in turn release multiple neutrons which then explosively accelerate neutron production --- nuclear runaways are not a risk with LENRs
- ✓ D-T fusion reactors like ITER and other similar Tokamaks mainly create heat by harvesting the kinetic energy of deadly 14.1 MeV neutrons. Consequently, they require massive shielding and containment systems for safe operation and unsurprisingly have enormous costs and unavoidably huge physical size. Given that the Lithium LENR fuel cycle releases nearly 27 MeV versus a total Q-value of 17.6 MeV for the D-T fusion reaction, it is hard to imagine a sound economic argument for spending 100s of billions on commercial fusion reactors if LENR technology is successfully developed and scaled-up as we have outlined herein
- ✓ Lack of hard radiation and radioactive wastes permit *downward* scalability that could enable future development of revolutionary, compact battery-like portable LENR power sources that can compete directly on $ price/kwh with chemical batteries in many applications including power tools, tablets, and smartphones

Major Japanese companies are now developing LENRs

Mitsubishi Heavy Industries, Toyota, and Nissan have R&D programs

Won't admit it publicly but their goal is to replace the internal combustion engine

- ✓ Mitsubishi Heavy Industries and Toyota have been quietly funding R&D in LENRs out of their own budgets since 1989 with minimal funding from their government
- ✓ Keiretsu - Japanese term that describes a loose association of different companies that share one or more common interests and work closely together to achieve mutually agreed-upon key business and technological objectives. They may or may not have some degree of mutual ownership and are tied to banks. Mitsubishi and Toyota are members of respective keiretsu; Toyota is presently considered the largest vertical conglomeration in today's Japan
- ✓ Mitsubishi Heavy Industries and Toyota have been conducting and reporting important experimental basic science results on LENR transmutation measurements for many years. Heretofore, they did not focus on trying to produce substantial amounts of excess heat to generate power. Nissan Motor Company recently initiated a basic research program on LENRs without any public fanfare
- ✓ In 2013, Toyota published a paper in the peer-reviewed *Japanese Journal of Applied Physics* which confirmed important experimental results that Mitsubishi Heavy Industries had first published back in 2002. Mitsubishi's patented Hydrogen permeation method is capable of triggering clean, radiation-free LENR nuclear transmutation reactions under relatively modest temperatures and pressures

Mitsubishi pushing to increase LENR transmutation rates

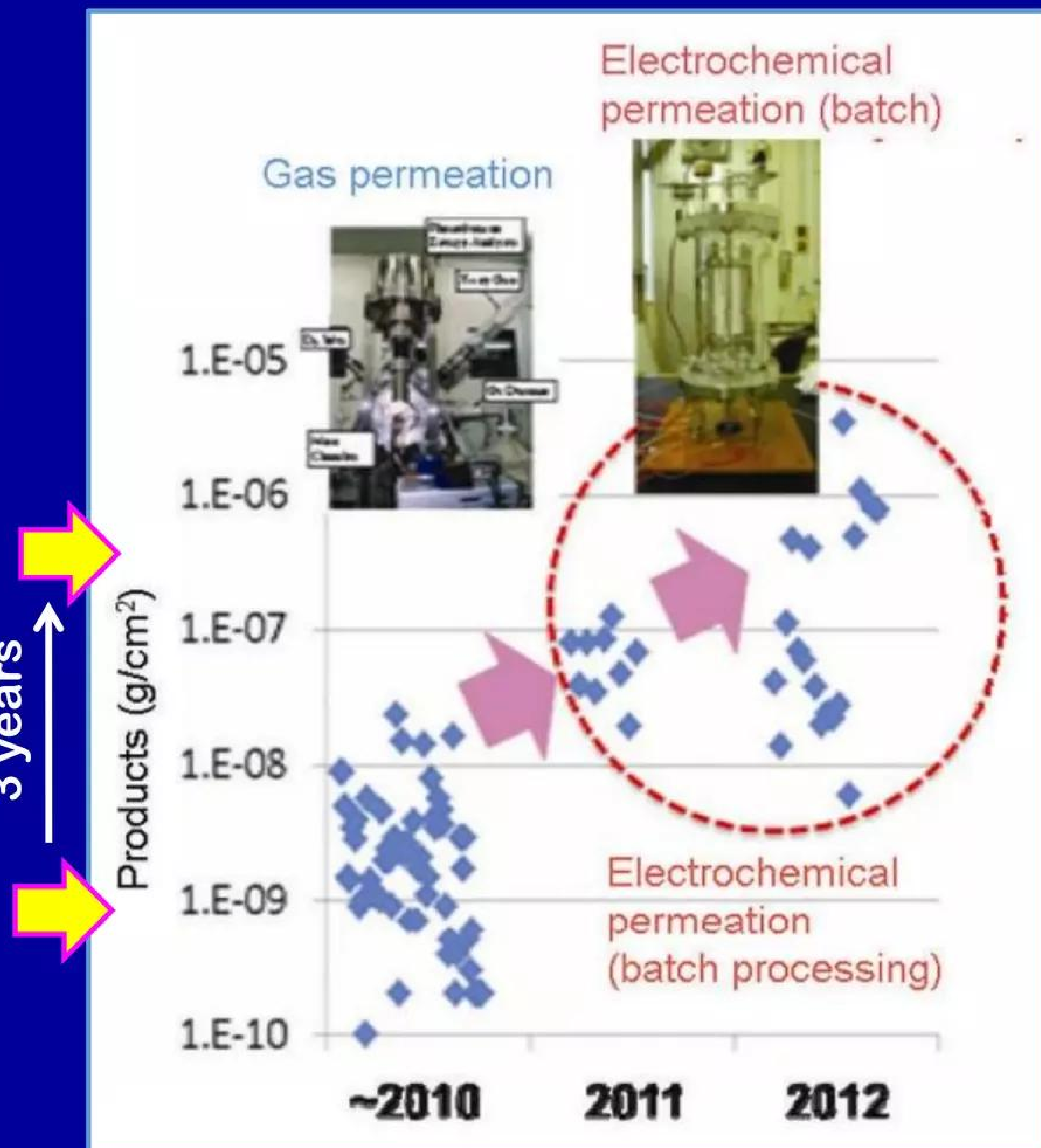
Unknowingly followed guidelines detailed in W-L rate theory paper (2007)

"Transmutation reaction induced by Deuterium permeation through nanostructured multi-layer thin film" reproduced Fig.6

Y. Iwamura *et al.*, *Current Science* 108 No. 4 pp. 628 - 632 (February 2015)

http://www.currentscience.ac.in/Volumes/108/04/0628.pdf

Changing MHI's older permeation method from 2002 that always used gaseous D_2 and a pressure gradient to current-driven electrochemical D_2O cells clearly increased LENR transmutation product yields by nearly 3 orders of magnitude in just about three years



Switching to a very different permeation method increased LENR transmutation product yields in MHI reactors because there are much higher densities of $e^{-}*d^{+}$ pairs on device's LENR-active working Palladium surface and the fact that a much larger quantity of input energy (in form of a several Volt DC electrical current) is being injected into experimental system

New Energy Times reported NEDO issued RFP on LENRs

NEDO: New Energy and Industrial Technology Development Association

Arm of Government of Japan - its mission is to develop new energy technologies

Japanese Government Will Fund LENR Research Again

http://news.newenergytimes.net/2015/08/24/japanese-government-will-fund-lenr-research-again/

Selected excerpts quoted directly from Steven Krivit's August 24, 2015 news story:

For the first time in two decades, the Japanese government has issued a request for proposals [RFP] for low-energy nuclear reaction (LENR) research, according to information recently obtained by *New Energy Times*.The request for proposals was published by the New Energy and Industrial Technology Development Organization (NEDO), a national research and development agency.

The request for proposals, "Energy and the Environment New Leading Technology Program," was released in July. The line item for the LENR research is on PDF Page 16, item D4. The item translates to "Metal which becomes new energy source and analysis and control of the technology of heat reactions between metals and hydrogen."

In a response to an e-mail from *New Energy Times*, long-time LENR researcher Tadahiko Mizuno confirmed that item D4 is for LENRs. Some Japanese LENR researchers, according to Mizuno, are filing a joint application to NEDO, with the assistance of Akito Takahashi, a former professor at Osaka University.

In 1994, the Japanese government, through the Ministry of Trade and Industry [MITI], sponsored an earlier research program called the New Hydrogen Energy Agency. It ran for several years at a cost of several million dollars. It terminated after researchers reported lackluster results.

Japan, Inc. hedges its bets on utilizing fission and fusion

Government of Japan has now resumed official funding of R&D in LENRs

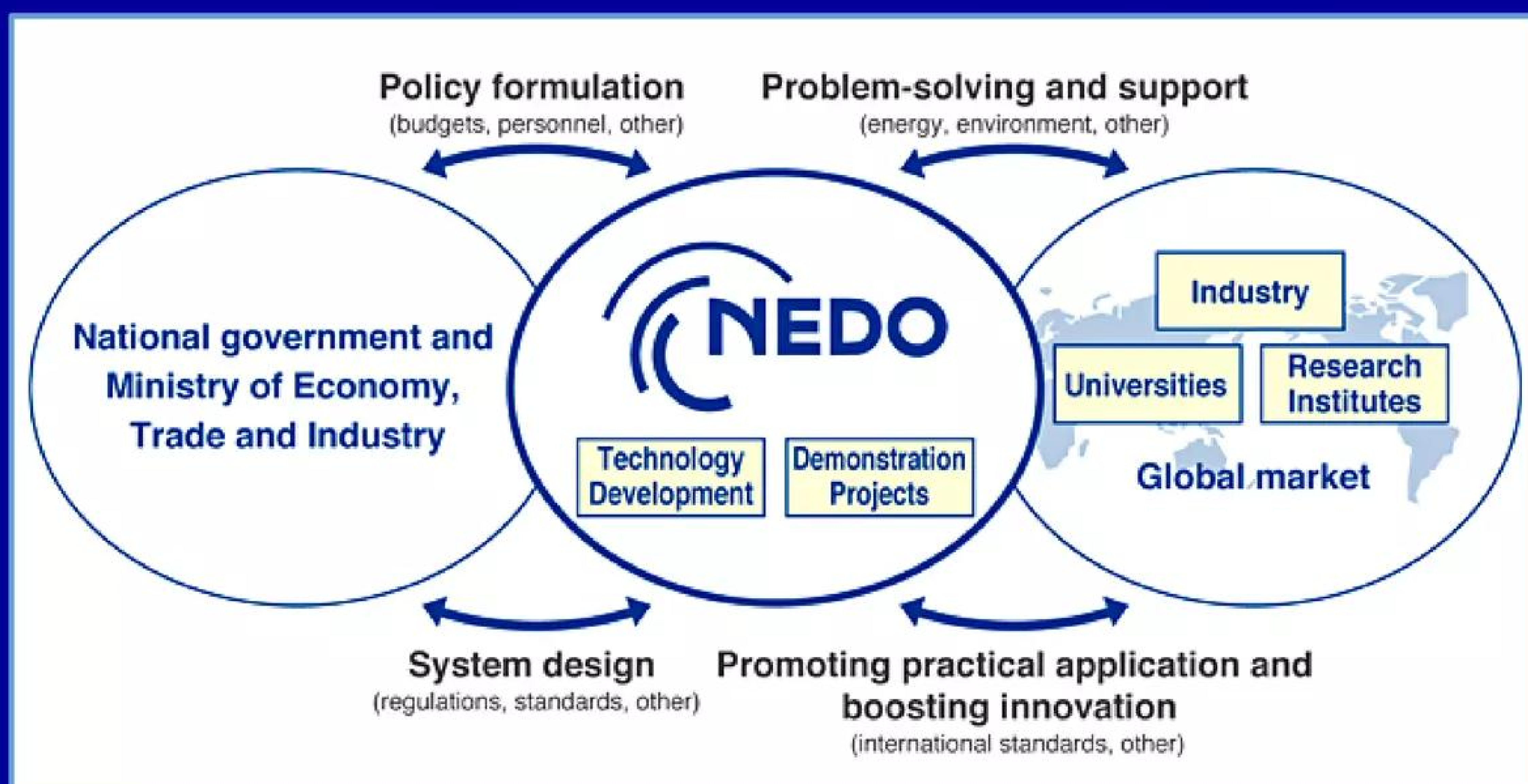
NEDO New Energy and Industrial Technology Development Organization

Combining the efforts of industry, government and academia and leveraging established international research networks, NEDO is committed to contributing to the resolution of energy and global environmental problems and further enhancing Japan's industrial competitiveness

http://www.nedo.go.jp/english/

Mode of operation – graphic is copied from home page of NEDO website

経済産業省 Ministry of Economy, Trade and Industry



MITSUBISHI

TOYOTA

NISSAN

Congressional committee requests briefing about LENRs

U.S. House Armed Services Committee requests briefing from the U.S. Department of Defense on national security implications of Ultralow energy neutron reactions (LENRs)

Congressional request appears on page #87 of the 707 page National Defense Authorization Act for Fiscal Year 2017 Report released on May 4, 2016

"The committee is aware of recent positive developments in developing low-energy nuclear reactions (LENR), which produce ultraclean, low-cost renewable energy that have strong national security implications. For example, according to the Defense Intelligence Agency (DIA), if LENR works it will be a 'disruptive technology that could revolutionize energy production and storage'."

Screenshot: U.S. Congressional request for LENR briefing

URL to pdf copy of Report is provided below

http://www.congress.gov/114/crpt/hrpt537/CRPT-114hrpt537.pdf

Low Energy Nuclear Reactions (LENR) Briefing

The committee is aware of recent positive developments in developing low-energy nuclear reactions (LENR), which produce ultra-clean, low-cost renewable energy that have strong national security implications. For example, according to the Defense Intelligence Agency (DIA), if LENR works it will be a "disruptive technology that could revolutionize energy production and storage." The committee is also aware of the Defense Advanced Research Project Agency's (DARPA) findings that other countries including China and India are moving forward with LENR programs of their own and that Japan has actually created its own investment fund to promote such technology. DIA has also assessed that Japan and Italy are leaders in the field and that Russia, China, Israel, and India are now devoting significant resources to LENR development. To better understand the national security implications of these developments, the committee directs the Secretary of Defense to provide a briefing on the military utility of recent U.S. industrial base LENR advancements to the House Committee on Armed Services by September 22, 2016. This briefing should examine the current state of research in the United States, how that compares to work being done internationally, and an assessment of the type of military applications where this technology could potentially be useful.

Screenshot: cover page of Armed Services Committee report

114TH CONGRESS *2d Session*	HOUSE OF REPRESENTATIVES	REPORT 114–537

NATIONAL DEFENSE AUTHORIZATION ACT
FOR FISCAL YEAR 2017

REPORT

OF THE

COMMITTEE ON ARMED SERVICES
HOUSE OF REPRESENTATIVES

ON

H.R. 4909

together with

ADDITIONAL VIEWS

[Including cost estimate of the Congressional Budget Office]

MAY 4, 2016.—Committed to the Committee of the Whole House on the State of the Union and ordered to be printed

NASA believes that LENRs are an "ideal energy solution"

2014 document revealed they are studying possible use of LENRs to power future advanced green subsonic aircraft

http://nari.arc.nasa.gov/sites/default/files/attachments/17WELLS_ABSTRACT.pdf

Two screenshots of 1-page pdf Abstract (continues on next slide)

Low Energy Nuclear Reaction Aircraft

Investigator(s): Doug Wells, NASA Langley Research Center

Purpose

The purpose of this research is to investigate the potential vehicle performance impact of applying the emergent Low Energy Nuclear Reaction (LENR) technology to aircraft propulsion systems. LENR potentially has over 4,000 times the density of chemical energy with zero greenhouse gas or hydrocarbon emissions. This technology could enable the use of an abundance of inexpensive energy to remove active design constraints, leading to new aircraft designs with very low fuel consumption, low noise, and no emissions. The objectives of this project are to: (1) gather as many perspectives as possible on how and where to use LENR for aircraft including the benefits arising from its application, (2) explore the performance, safety, and operational impacts to individual aircraft and the fleet, (3) evaluate potential propulsion system concepts, and (4) foster multi- disciplinary interaction within NASA.

NASA believes that LENRs are an "ideal energy solution"

Studying possible use of LENRs to power future green aircraft

Background

LENR is a type of nuclear energy and is expected to be clean, safe, portable, scalable, and abundant. The expected benefits make it an ideal energy solution. When it is applied to aircraft, LENR removes the environmental impacts of fuel burn and emission from combustion. Excess energy can be used to reduce noise so that all three of NASA's technology goals for future subsonic vehicles are either eliminated or addressed. Furthermore, aviation impacts almost every part of our daily lives, civilian and military. A revolutionary technology like LENR has the potential to completely change how businesses, military, and the country operate as a whole, giving a tremendous financial, tactical, and resource advantage to the country that utilizes it in the most effective way.

LENR creates some unique capabilities as well as challenges for integration into aircraft. The LENR concept that has reported most of the success generates heat in a catalyst process that combines nickel metal (Ni) with hydrogen gas (H). The initial testing and theory show that radiation and radioisotopes are extremely short lived and can be easily shielded. Although nuclear fission has been looked at for use in aircraft, LENR is different. LENR has a higher energy density and no radioactive by products.

Success of this research will provide a firm foundation for future research and investment for LENR technology integration into aircraft. Key research and development areas will be identified with any gaps in the current technology research. This research will guide NASA on the most effective way to invest in LENR to be the world leader in LENR aircraft research.

http://nari.arc.nasa.gov/sites/default/files/attachments/17WELLS_ABSTRACT.pdf

Revolutionary ultralow energy neutron reactions (LENRs)

Radiation-free LENRs transmute stable elements to other stable elements

Fission and fusion — Evolution of nuclear technology → Safe green LENRs

Laura 13

No deadly MeV-energy gamma radiation

No dangerous energetic neutron radiation

Insignificant production of radioactive waste

Vastly higher energies vs. chemical processes

Revolutionary, no CO_2 , and environmentally green

Is fully explained by physics of Widom-Larsen theory

Image credit: co-author Domenico Pacifici
From: “Nanoscale plasmonic interferometers for multispectral, high-throughput biochemical sensing”
J. Feng et al., *Nano Letters* pp. 602 - 609 (2012)

Ultralow energy neutron reactions (LENRs)

LENRs: alternative technology hedge for dispatchable nuclear power

Many-body collective LENRs are very different from few-body fusion and fission

LENRs involve production of neutrons from protons and electrons via an electroweak reaction followed by neutron capture on target fuels such as Carbon and Lithium. This releases nuclear binding energy from fuels which creates usable process heat in integrated energy conversion systems that can generate electrical or motive power

Electroweak reaction in Widom-Larsen theory is simple

Protons or deuterons react directly with electrons to make neutrons

Need input energy source such as electricity to drive LENR neutron production

electrons + protons (Hydrogen) → neutrons + neutrinos (benign particles, fly into space)

Require source(s) of input energy — Input energy creates electric fields > 2.5×10^{11} V/m

Many-body collective electroweak neutron production — Heavy-mass e^{-*} electrons react directly with protons

Collective many-body quantum effects: many electrons each transfer little bits of energy to a much smaller number of electrons also bathed in the very same extremely high local electric field

Quantum electrodynamics (QED): smaller number of electrons that absorb energy directly from local electric field will increase their effective masses ($m = E/c^2$) above key thresholds β_0 where they can react directly with a proton (or deuteron) → neutron and neutrino

$$\text{Energy}_{\text{E-field}} + e^{-}_{sp} \rightarrow e^{-*}_{sp} + p^{+} \rightarrow n^{0} + \nu_{e}$$

ν_e neutrinos: ghostly unreactive particles that fly-off into space; n^0 neutrons capture on nearby atoms

LENRs create ultralow energy neutrons in condensed matter

Production with weak $e + p$ reaction creates safe low energy neutrons

Ultralow energy LENR neutrons captured locally and will not escape reactors

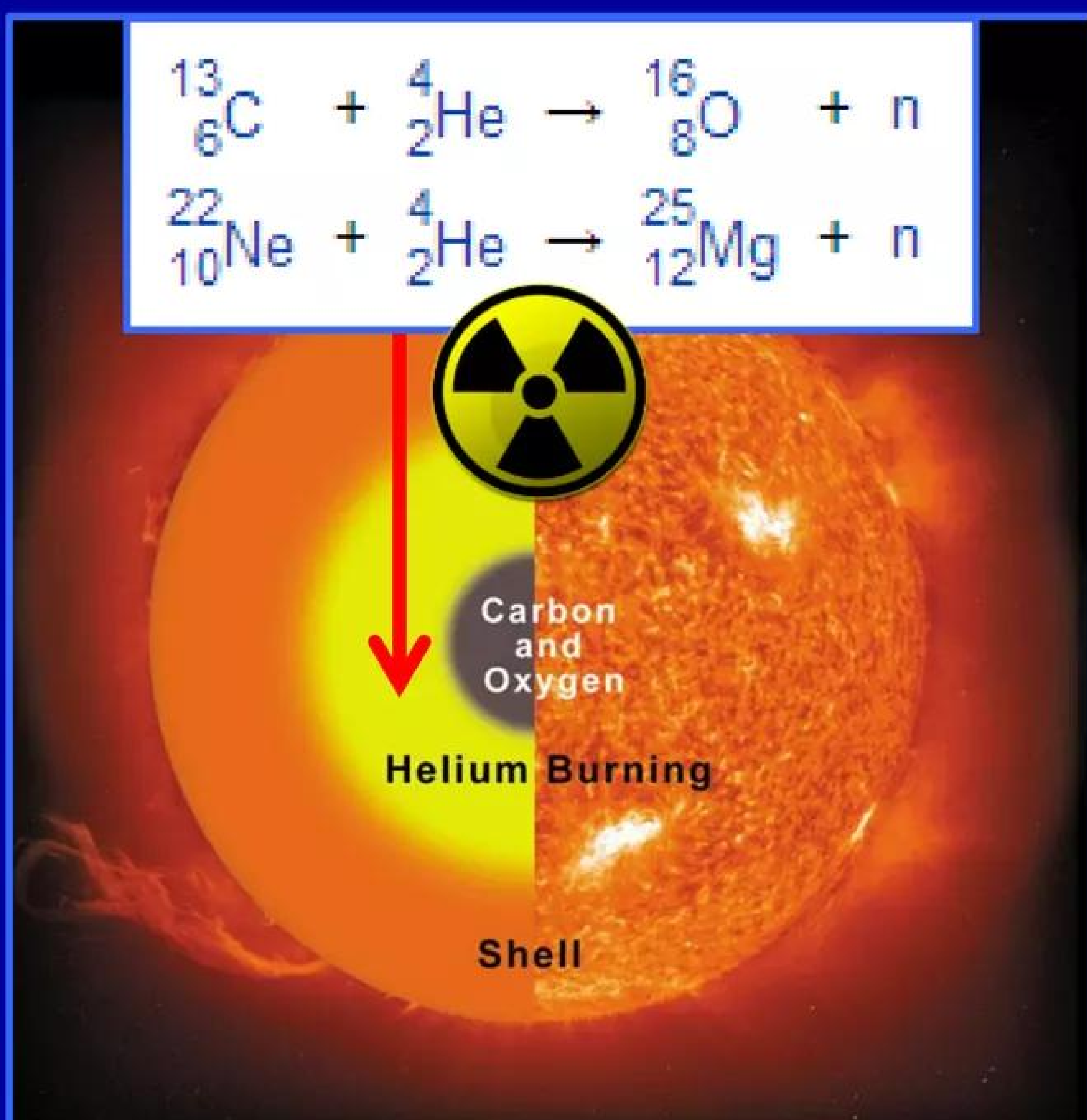
All these nuclear fusion and LENR reactions below create neutrons (n):

Fusion reactions in Red Giant star

Energetic MeV-energy neutrons

$$^{13}_{6}C + ^{4}_{2}He \rightarrow ^{16}_{8}O + n$$

$$^{22}_{10}Ne + ^{4}_{2}He \rightarrow ^{25}_{12}Mg + n$$



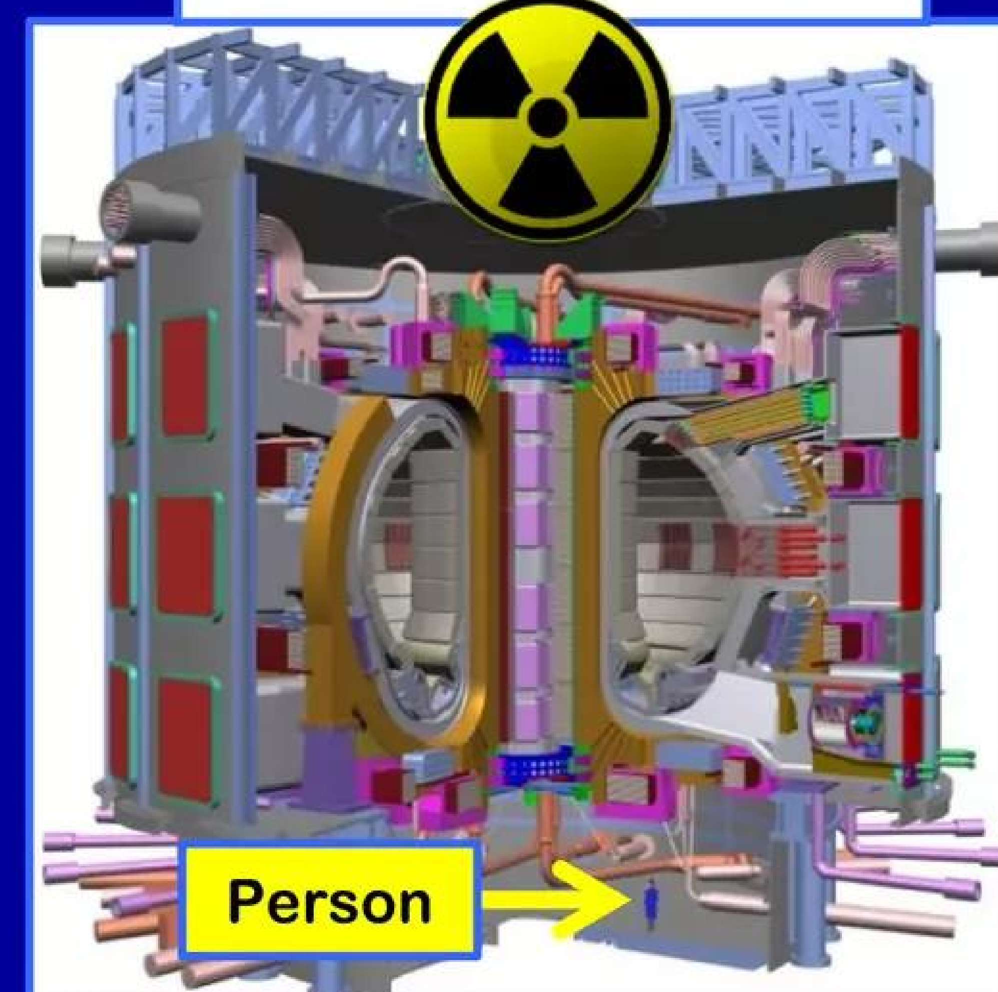
Length-scale: millions of miles

Temperatures: millions of degrees

ITER: D+T fusion reactor

Deadly energetic 14 MeV neutrons

$$^{2}_{1}D + ^{3}_{1}T \rightarrow ^{4}_{2}He + ^{1}_{0}n$$



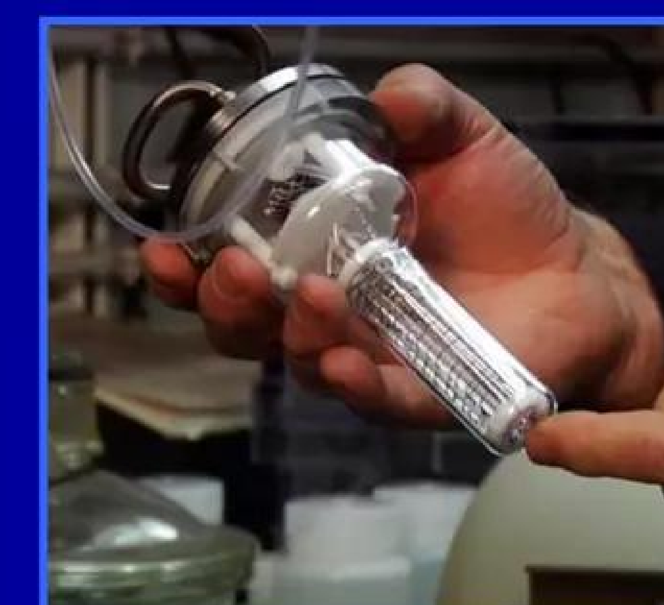
Length-scale: hundreds of feet

Temperatures: millions of degrees

LENR device

These are bio-safe

$$e + p \rightarrow \nu_e + n$$



Length-scale: inches

Temperatures: only thousands of degrees in tiny microscopic sites

LENRs are green: no energetic radiation or radwastes

Lack of hard radiation obviates need for shielding and containment

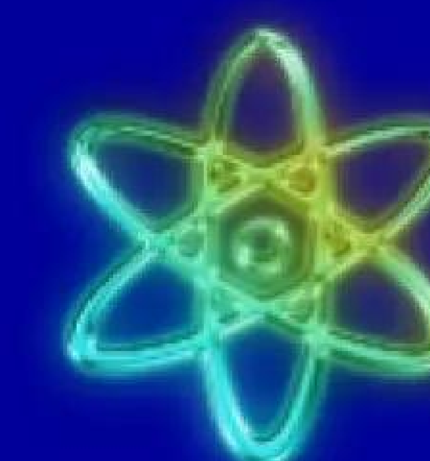
Major opportunity to develop safe, battery-like portable LENR power sources

Fission and fusion processes both emit deadly MeV-energy neutron and gamma radiation

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

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

Revolution in green nuclear technology



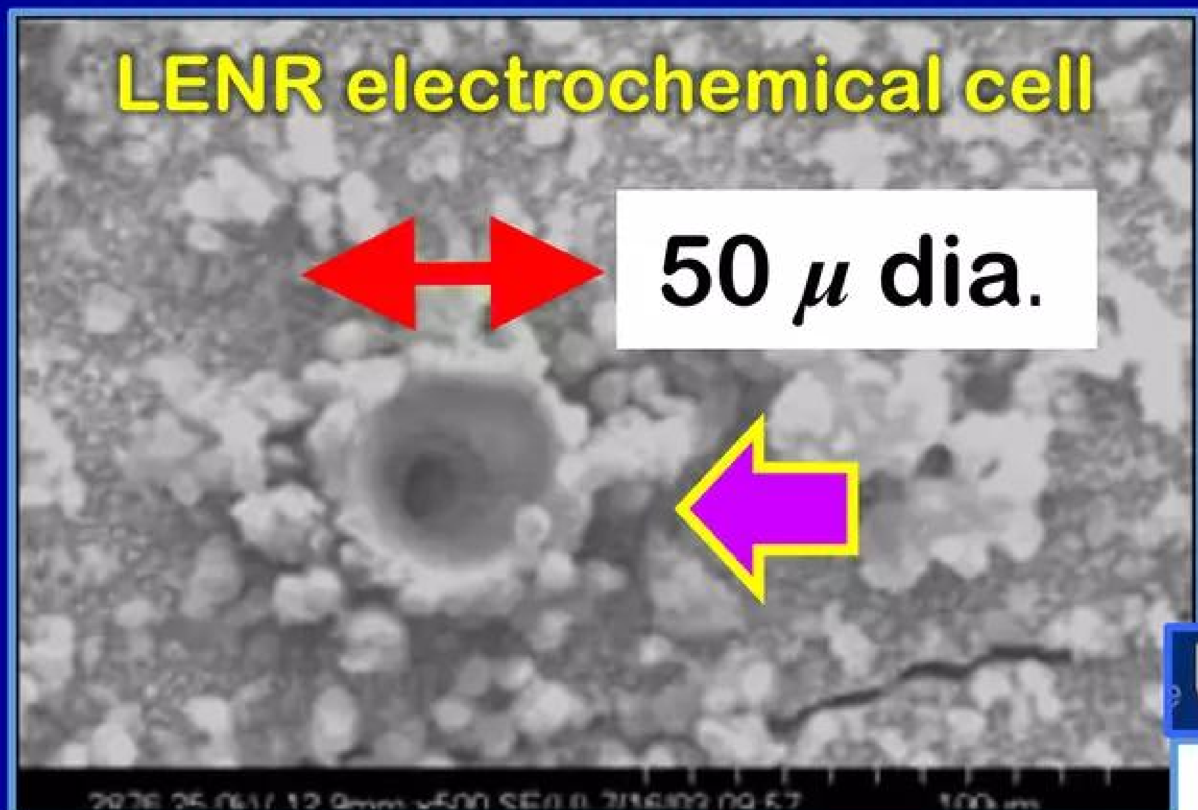
Much larger LENR devices based on dusty plasma embodiments can potentially scale-up to megawatts; akin to today's power plants

Widom-Larsen provides crucial model of LENR active sites

Size of such active sites ranges from 2 nanometers up to ~100^+ microns

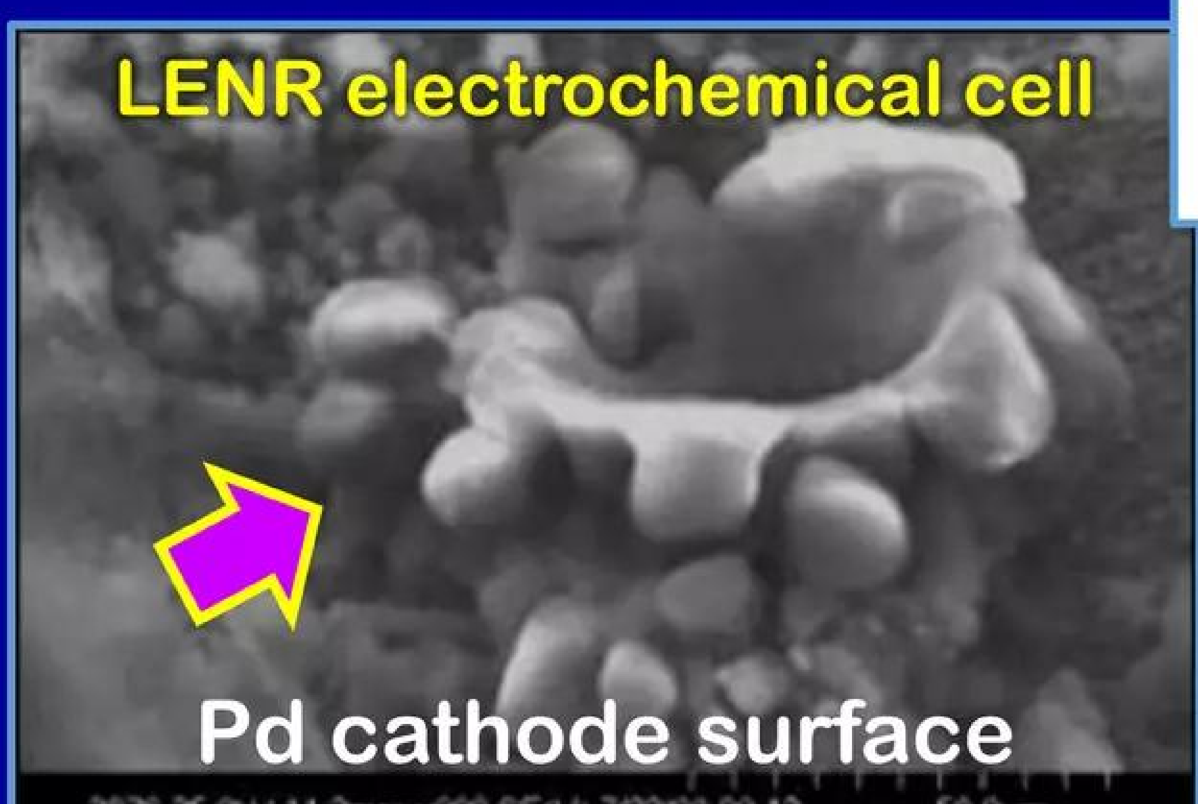
Active sites can be designed & fabricated by leveraging existing nanotechnology

50 μ LENR active site crater in Pd cathode



Credit: P. Boss, U.S. Navy SPAWAR

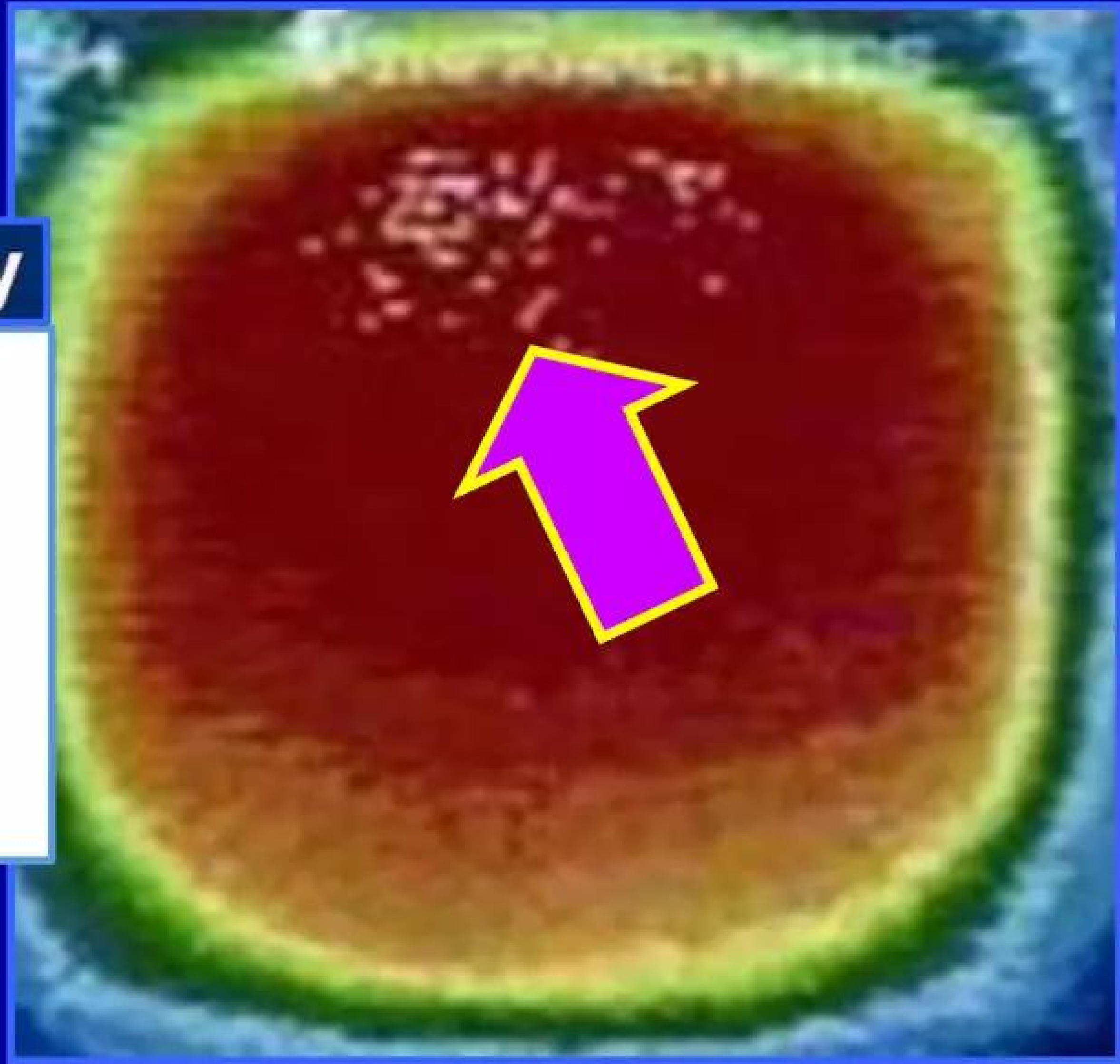
LENR active site crater



Credit: P. Boss, U.S. Navy SPAWAR

United States Navy
SPAWAR
Systems Center PACIFIC

Infrared video of tiny LENR hotspots that form spontaneously on Pd cathode surfaces in aqueous electrochemical cells



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

Credit: P. Boss, U.S. Navy SPAWAR (1994)

Incredible variety of LENR fuels for many applications

Lithium fuel can release more energy than ITER's D+T fusion reaction

Any element that captures neutrons could serve as LENR fuel; Carbon also good

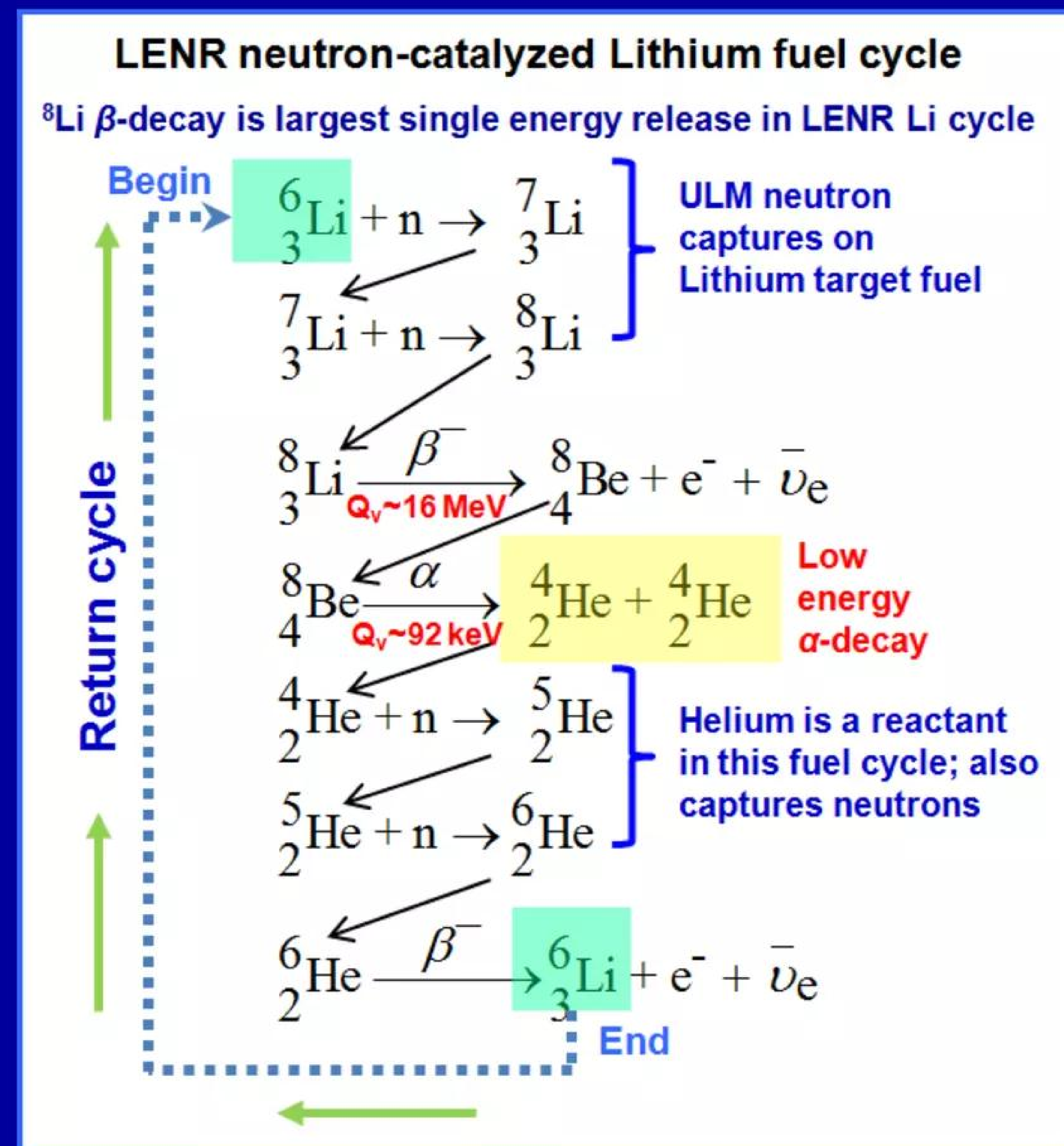
LENR heat production using Lithium fuel already demonstrated in laboratory

- ✓ Widom & Larsen's *European Physical Journal C* paper (2006) shows following LENR target fuel cycle using ordinary Lithium:

  Lithium-6 + 2 ULM neutrons → 2 Helium-4 + beta particle + 2 neutrinos + Q-value = 26.9 MeV

- ✓ Deuterium-Tritium (D-T) fusion reaction Q-value = 17.6 MeV creates dangerous high-energy neutrons

- ✓ **LENR Lithium fuel releases greater amounts of process heat and does not emit any deadly gamma radiation**



Lithium-fuel LENR thermal sources can scale to megawatts

Scale-up system power output by increasing total working surface area

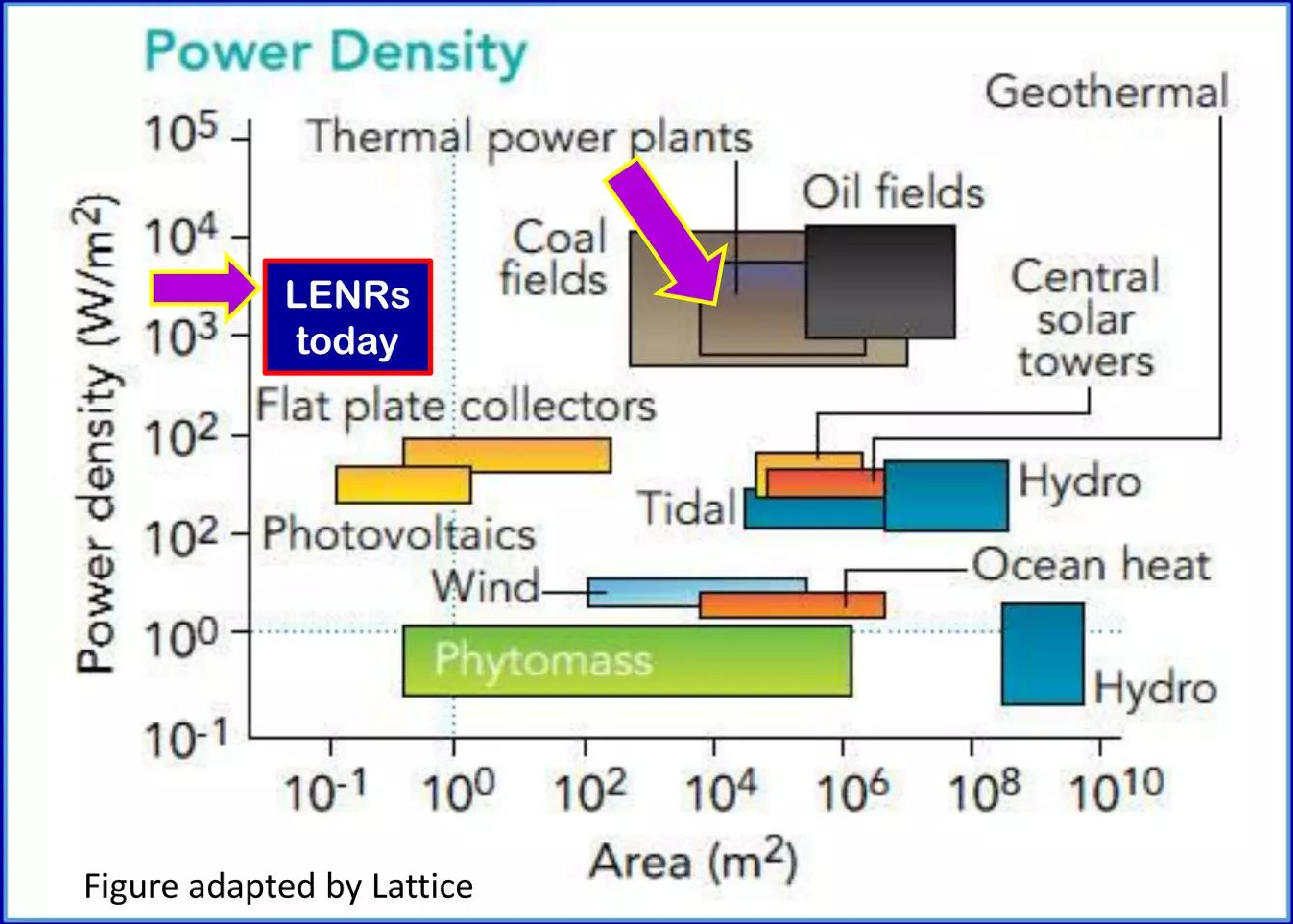
Neutron flux of ~1 x 10^{12} cm^2/sec matches heating observed in some lab devices

- ✓ As there are ~ 10^{14} of these 26.9 MeV energy releases taking place per second on the 1.0 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 ULE neutron production rate of 1 x 10^{12} cm^2/sec, overall energy production rate would drop down to 4.28 J/cm^2/sec or 4.28 W/cm^2. At ULE neutron production rate of 1 x 10^{11} cm^2/sec, rate of heat production would drop down to 0.428 J/cm^2/sec or 0.428 W/cm^2 (4.28 x 10^3 W/m^2): value ~same as excess heat outputs observed in a somewhat limited subset of electrolytic LENR experiments researchers have deemed 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

Power densities of primitive experimental LENR devices

Device power densities of 4.28 x 10^3 W/m^2 same as thermal power plants

LENR system areas small: no shielding and fuel energy density > 5,000x gasoline



Source: "Do We Have the Energy for the Next Transition?" R. A. Kerr in *Science* 329, pp. 781 (2010)

LENR dusty plasma systems should scale-up to MWs

Energiewende could integrate LENR systems for dispatchable power

Use solar/wind electricity as input power for LENR systems: power amplification

- ✓ LENRs can be triggered on target fuel nanoparticles injected into dusty plasmas; should readily scale-up volumetrically to megawatt (MW) total thermal outputs
- ✓ LENR thermal sources could likely produce neutron fluxes of 1×10^{14} cm^2/sec that can then create thermal power fluxes of ~428 W/cm^2 using Lithium fuel targets
- ✓ Total thermal fluxes created at focus receivers of concentrated solar power (CSP - see right) systems can reach values on the order of roughly 200 - 400 W/cm^2 ; this ~ matches LENR heat fluxes estimated above
- ✓ Could potentially adapt Brayton cycle CSP systems for use in large LENR-based dusty plasma reactors
- ✓ Could also develop hybrid wind or solar + LENR power generation systems; renewable electricity used as input power for LENRs → amplify input power by 5x to 10x

Dish CSP system

Tower CSP system

Ivanpah - California, USA

LENRs and future of CO_2-free global power generation

5 -10 kwh LENR-based power systems revolutionize energy production

Systems with total output measured in megawatts not needed to accomplish this

- ✓ At system power outputs of just 5 - 10 kwh, modular LENR-based distributed power generation systems providing combined heat and electricity (CHP) could potentially satisfy the requirements of a majority of urban and rural households and smaller businesses worldwide, including rural powerless
- ✓ At system power outputs of just 50 - 200 kwh, LENR-based systems could begin to power steam or electric vehicles, breaking oil's stranglehold on transportation; provide high-quality heat for many 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 very affordably priced electricity to regional grids serving urban and many rural areas. Under that scenario, grid-based centralized power generation would be gradually displaced by vast numbers of smaller, lower-cost distributed power systems

Applied nanotechnology required to commercialize LENRs

Large length scales

What was formerly thought impossible becomes possible by utilizing Widom-Larsen and applying nanotechnology

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

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

Widom-Larsen enables commercialization of LENRs

Applied nanotechnology and LENRs are mutually joined at the hip

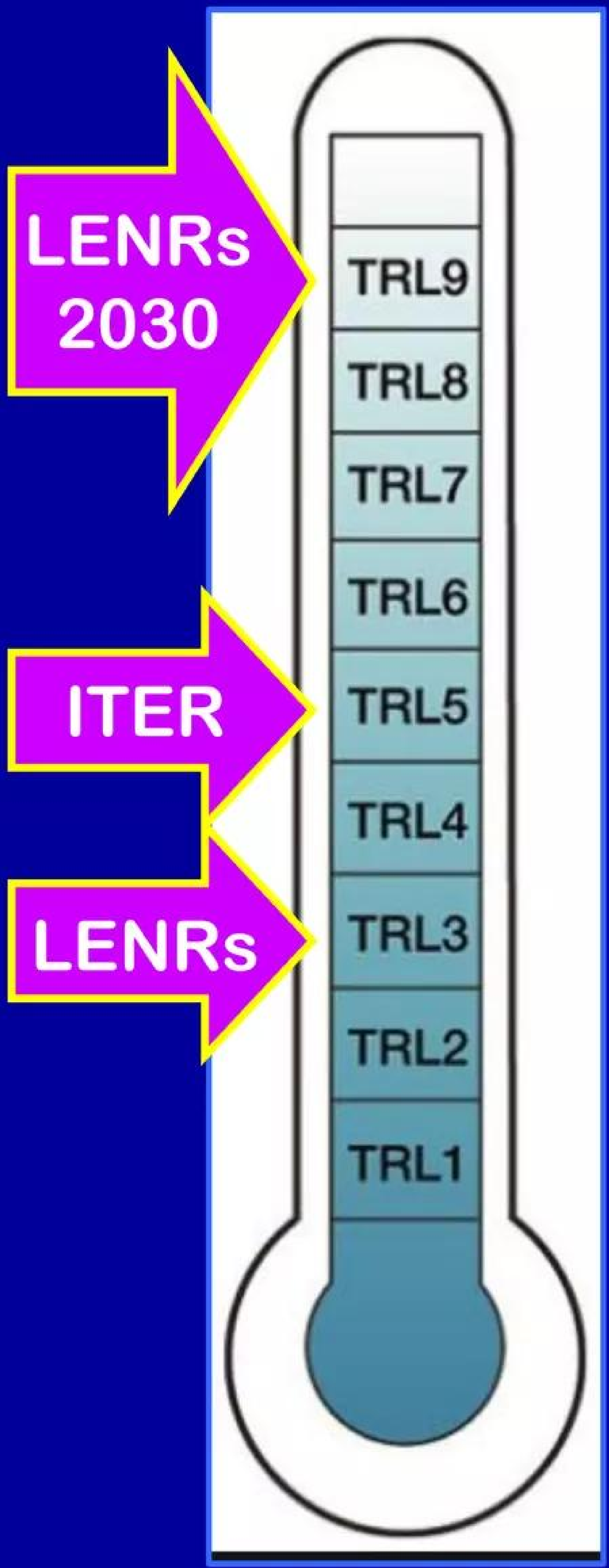
Development risks can be reasonable thanks to Widom-Larsen and nanotech

Guided by physics of the Widom-Larsen theory, an opportunity to commercialize LENRs as truly green CO_2-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.

Visualization of surface plasmon electric field strength (Volts/meter) - highest fields are dark red

Widom-Larsen theory enables commercialization of LENRs

D+T fusion technology at TRL-5 if ITER successful; LENRs now at TRL-3



- ✓ Over past 28 years, *cumulative* worldwide investment in R&D on LENRs was ~ US$200 - 250 million or ~1,000x *less* total funding than fusion; still, LENRs advanced to TRL-3
- ✓ Thanks to Widom-Larsen theory, LENR device physics are now well-understood. By leveraging nanotech, funding of US$100 - 150 million and 3 - 5 years of R&D should be able to advance LENRs to TRL-4 (European Commission). If on-schedule at that point, additional funding of US$150 - 200 million should advance LENR development to reach TRL-7. Unless totally unforeseen new technical obstacles are then encountered beyond TRL-7, likely that array of commercial LENR products could be introduced into the marketplace before year 2030 with cumulative funding of <US$2 billion
- ✓ In CY 2014 global oil & gas industry collectively spent US$ 670 billion in searching for and developing new fossil fuel resources. Investment risk capital that is required to fully commercialize LENR technology is well-within financing capabilities of major oil & gas producers; large funding by national governments along with private sector is optional

Widom-Larsen theory enables commercialization of LENRs

Microscopic reproducibility of active sites is key to commercialization

- ✓ In successfully fabricated primitive laboratory devices typical of today, LENRs can presently reach temperatures of 4,000 - 6,000^o K in relatively small numbers of microscopic LENR active sites located on device surfaces. Evidence for the existence of such extremely hot localized sites is provided in post-experiment SEM images of working surfaces wherein distinctive crater-like structures are visible; these features are produced by rapid heat releases in LENR active sites that briefly create local high temperature flash-boiling of metals like Palladium
- ✓ At present stage of LENR technology (TRL-3), trying to fabricate cm-scale and larger devices that can reliably and controllably produce macroscopically large fluxes of excess heat - "boiling a cup of tea" - is putting the cart before the horse
- ✓ Lattice plans to use proprietary knowledge of LENR devices and key operating parameters (e.g., achieving and maintaining very high local surface electric fields) to first get key LENR effects --- namely excess heat, transmutations --- working well microscopically. That is, to be able to reproducibly create rationally designed nanoparticulate structures with their dimensions ranging from nanometers to microns that are fabricated using certain existing, off-the-shelf nanotechnology techniques/methods and then emplaced, along with suitable target fuel nuclei (e.g., Lithium, Carbon, transition metals) in close proximity, at what will become LENR active sites on the surfaces of appropriate substrates

Lattice's LENR engineering plan has three key stages:

(1) Reproducible fabrication of well-performing LENR active sites

(2) Scale-up heat output by increasing # of active sites per unit area/volume

(3) Select and integrate energy conversion subsystems suitable for specific applications

- ✓ Once microscopic reproducibility of active sites is achieved, output of LENR heat sources could be readily scaled-up, either by (1) fabricating larger area-densities of affixed nanostructures that facilitate formation of LENR active hot spot sites on device surfaces, or by (2) injecting larger quantities of specially designed target fuel host nanoparticles into volumetrically larger reaction chambers containing turbulent dusty plasmas, with or without spatially organized magnetic fields present
- ✓ Variety of off-the-shelf energy conversion subsystems could potentially be integrated with commercial versions of LENR-based heat sources. These include: thermophotovoltaic; thermoelectric; steam engines; Rankine cycle steam turbines; Brayton cycle gas turbines, simple boilers, etc. Other more speculative possibilities involve new types of direct energy conversion technologies that are still in very early stages of development
- ✓ Lattice's nanocentric approach to R&D is unique by being interdisciplinary and directly guided by various proprietary insights enabled by Widom-Larsen theory of LENRs and related relevant knowledge borrowed from advanced materials science, plasmonics, nanotechnology, and chemistry

Fossil Carbon could be converted into green LENR fuels

New breakthroughs in physics and nanotechnology make this possible

Bitumen, heavy oil, and coal may be much more valuable as CO_2-free LENR fuels

Able to understand LENR experiments that were conducted at Hokkaido University (Japan, 2008), by 2009, Larsen had figured-out how aromatic molecules could potentially be extracted, processed, and converted into green LENR fuels from which there would be no hard radiation emissions, no production of hazardous long-lived radioactive wastes or emission of gaseous CO_2 into atmosphere. **Would be able to release > 5,000 times more thermal energy versus combustion of Carbon-based molecules with Oxygen**

These fossil hydrocarbons contain aromatic ring molecules on which LENRs can be triggered

Canadian natural bitumen

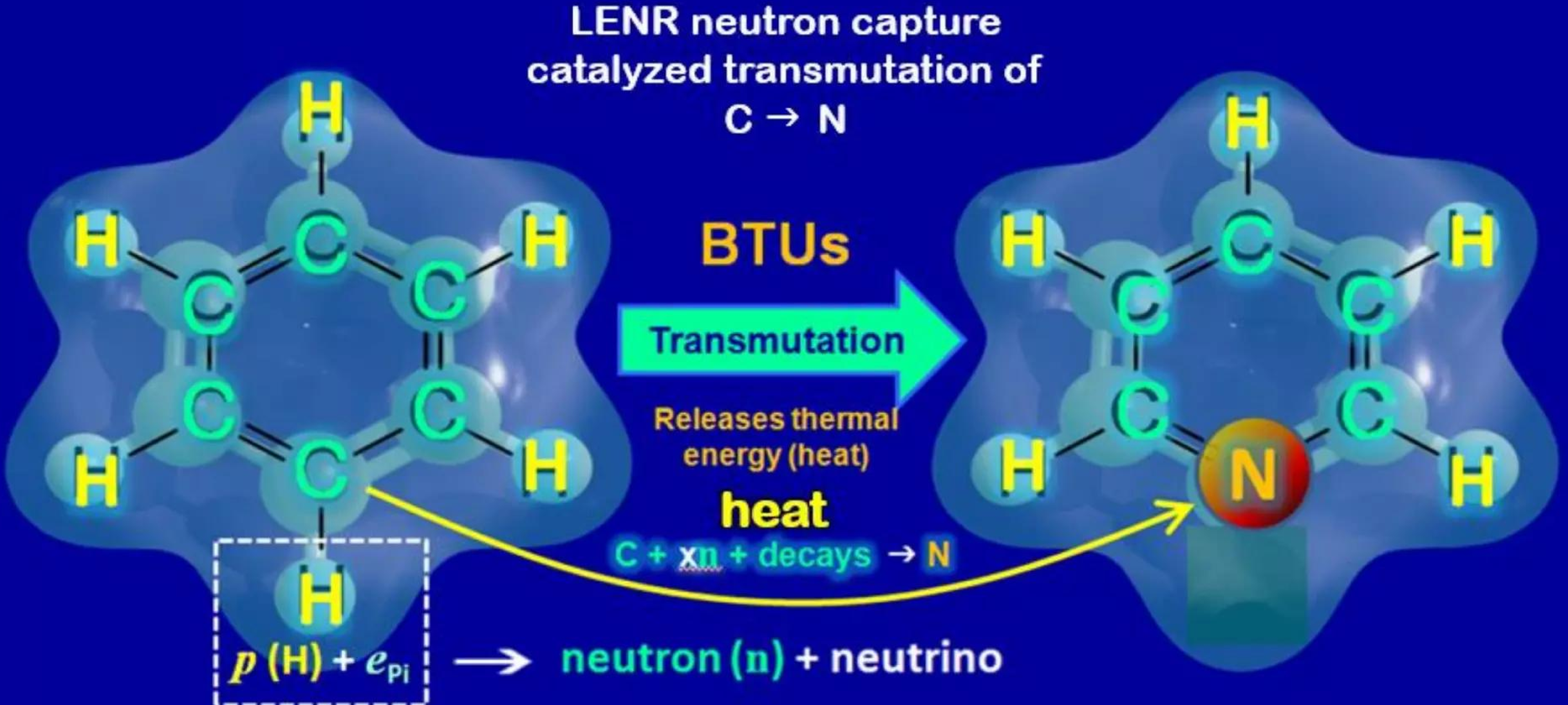
Heavy viscous oils found in many fields

Various grades of coal

Convert ring Hydrogen atoms (protons) into safe neutrons

Neutrons are captured by ring Carbon atoms that are then transmuted

Carbon atom is transmuted into Nitrogen by LENR process in this example



Process does not emit any deadly radiation or produce troublesome radwastes

Fossil Carbon can be transmuted rather than combusted

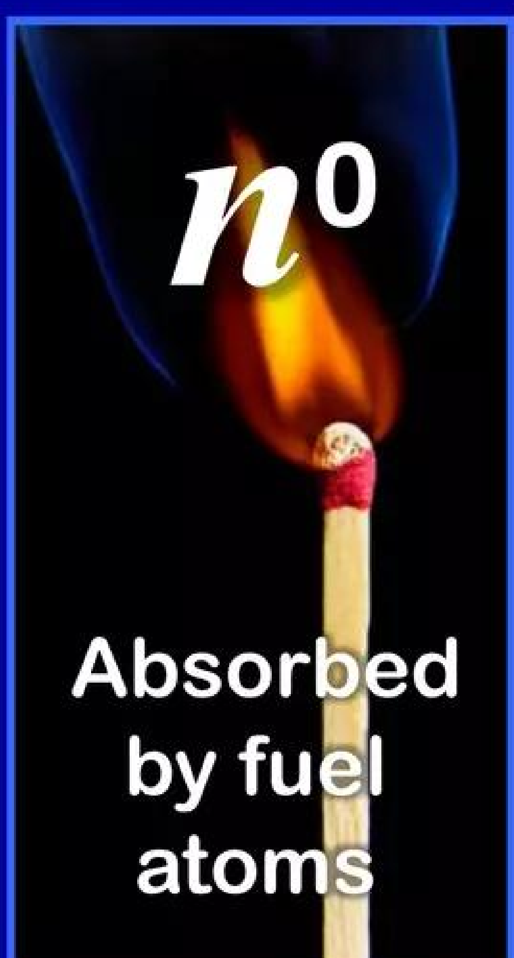
Heavy oil and coal could be processed to produce CO_2-free LENR fuels

Carbon atoms found on aromatic rings good fuel for radiation-free transmutation

Hard radiation-free LENR transmutation

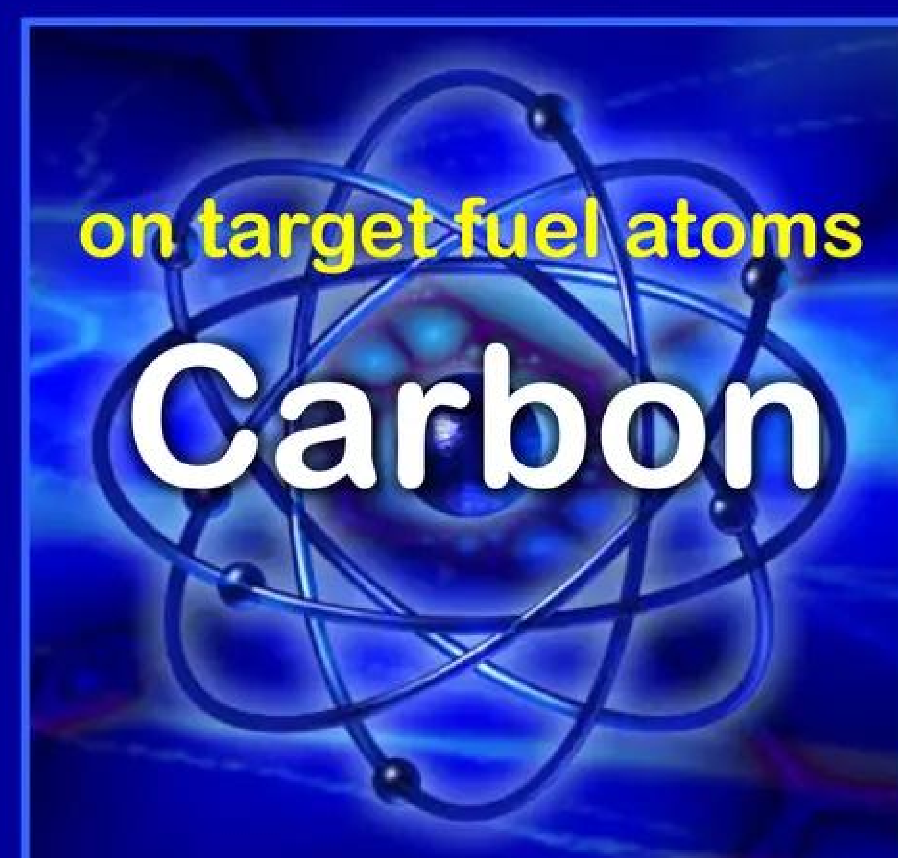
Neutrons + target fuel atoms → heavier elements + decay products + heat

Catalytic neutron 'match'



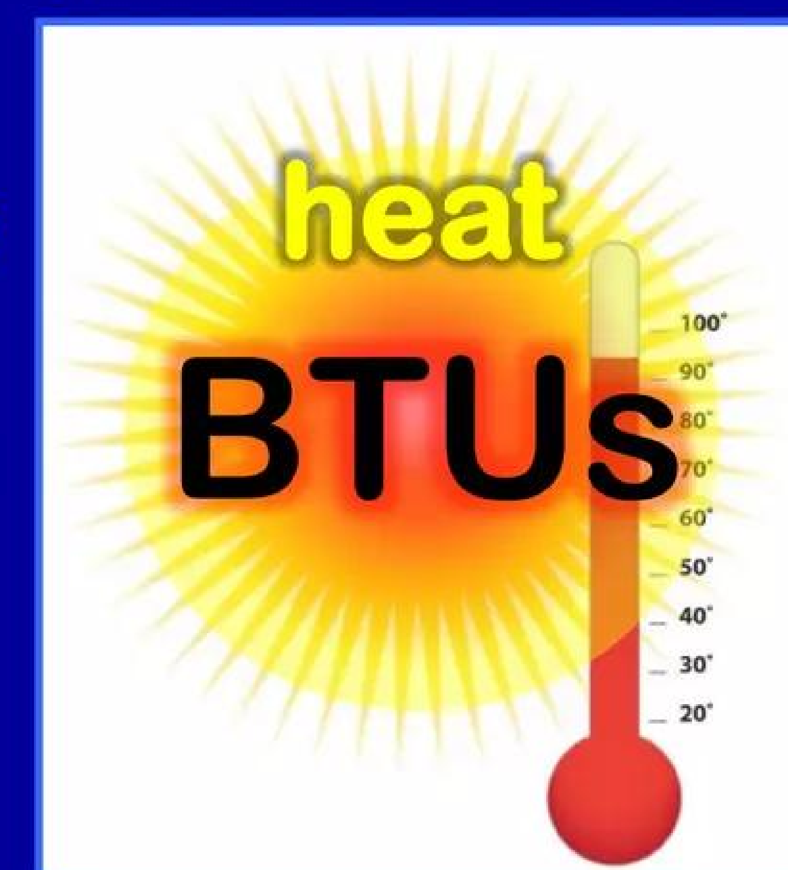
capture +

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



produces →

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

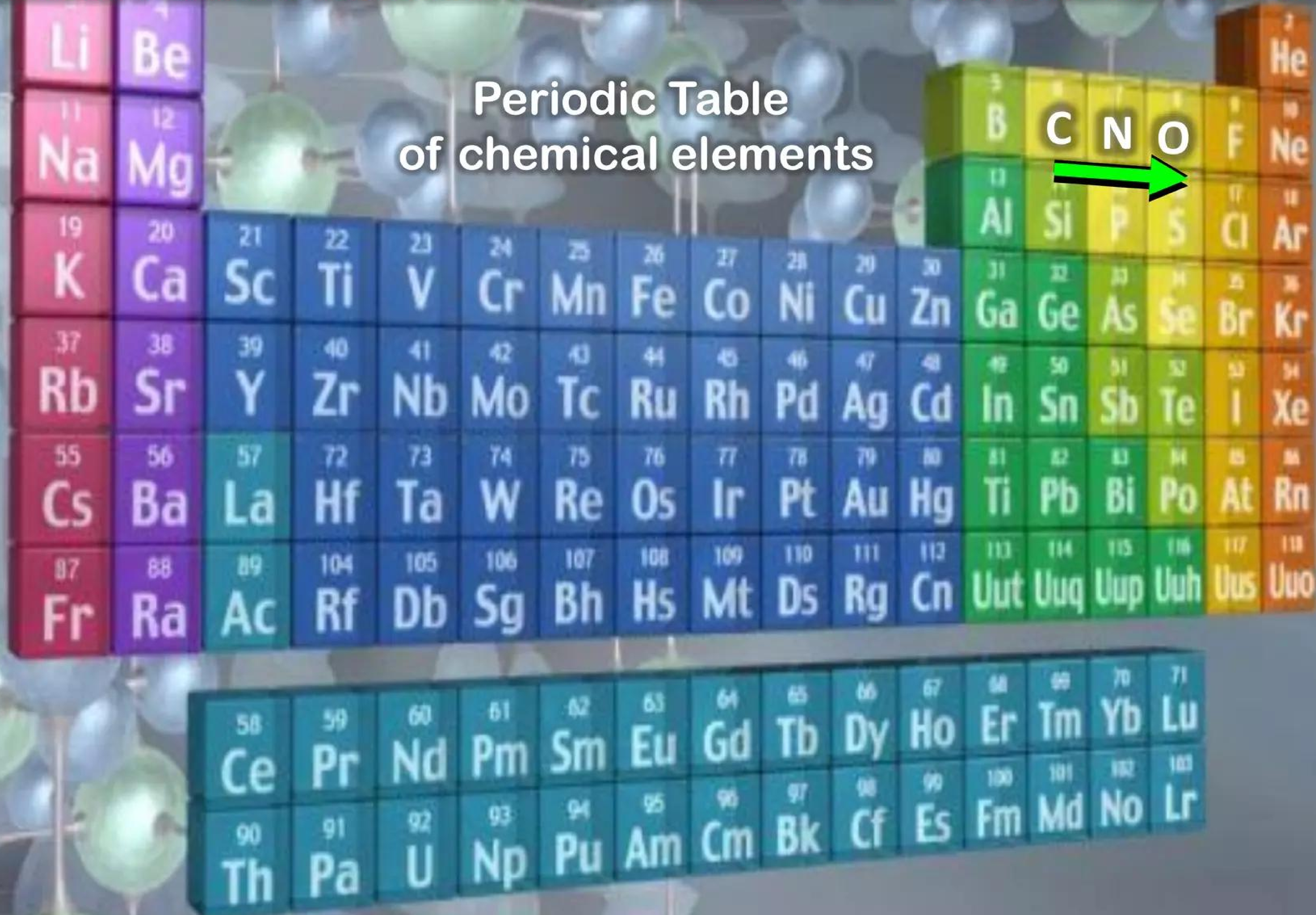


Process does not emit any deadly radiation or produce troublesome radwastes

LENR transmutations go left-to-right along rows of Table

Transmutation of Carbon to O_2 releases 5,000x > heat than combustion

Any element in Periodic Table can serve as LENR fuel - some better than others



Many moieties contain or are convertible into aromatics

LENR fuels can be created from many different types of Carbon sources

Base feedstock → Aromatic molecules → Nanoparticulate fuels

Contain aromatic molecules

Examples:

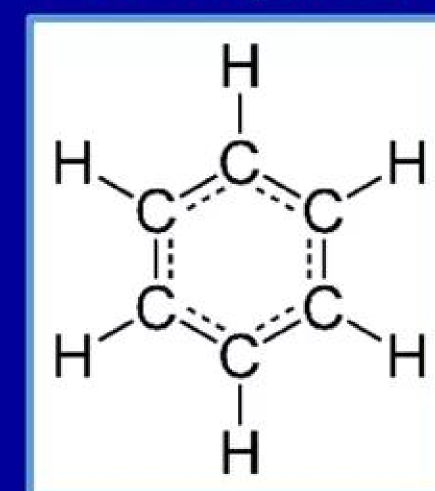
- Heavy oils and natural bitumen — Extract →
- Coal — Extract →
- Lignin from renewable biomass — Digest →

Chemical process

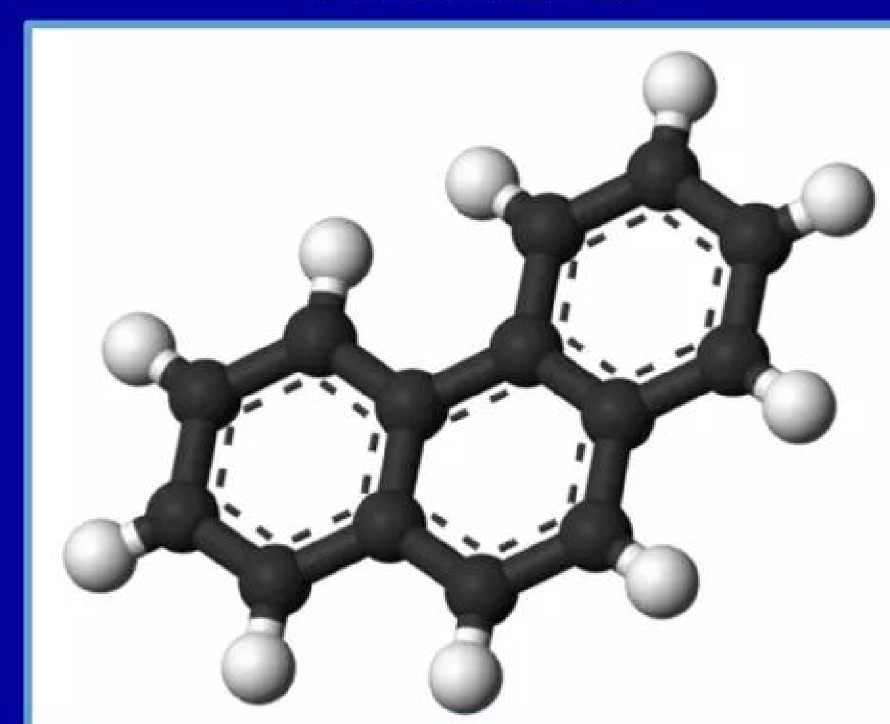
- CH_4 natural gas — Mo catalyst / LNG →
- CO_2 → C nanofibers — Processing →

Variety of simple and complex aromatic molecules

Examples:



Benzene



Phenanthrene

Enormous gain in energy density makes processing conversions $$$ economic

Chemical processing

Process into

plus nanotech

Green CO_2-free LENR fuels

5,000x greater energy density

Bottom line: just about any Carbon-based moiety can be converted into aromatic ring-structure molecules using a chemical process

From Carbon combustion to LENR Carbon transmutation

BTU values of LENR fuels derived from aromatics ~5,000x combustion

$$$ economic values of derived LENR fuels could increase to > 500x combustion

Value if combusted

Credit: Frank Boenigk (2009)

Adoption of LENR technology →

Value if transmuted

Today: barrel of crude oil priced at ~US$ 50 - 55

500x →

Future: LENR products made from same barrel of oil could be worth US$ 25,000

Transmutation of fossil Carbon much better than combustion

LENR technology could enable sustainable growth at reasonable cost

- ✓ Successful commercialization and broad deployment of green LENR Carbon transmutation in power generation applications could increase the effective economic BTU $$$ value of remaining in-ground fossil Carbon resources by at least 500x by releasing thermal energy from Carbon atoms via CO_2-emission-free nuclear transmutation process rather than by continuing to rely on today's age-old chemical combustion technology used by man for 350,000 years
- ✓ So-called "stranded asset" fossil Carbon financial risk issues would disappear
- ✓ Carbon transmutation could substantially extend the effective economic lifetime of present in-ground fossil fuel resources from an estimated <200 years per British Petroleum out to at least another 25,000 years further into the future
- ✓ LENRs are therefore truly synergistic rather than being directly competitive with fossil fuels: http://www.slideshare.net/lewisglarsen/lattice-energy-llc-compelling-economics-of-transmutation-vs-combustion-of-carbonaceous-energy-sources-jan-14-2015
- ✓ Rather than totally replacing fossil fuels with solar, wind, and renewable energy sources over time, LENR technology would instead allow oil, gas, and coal producers to convert fossil Carbon into vastly more valuable forms of green LENR fuels. Fossil fuel producers, energy consumers, and Earth would all win

LENRs are strategic opportunity for oil & gas producers

- ✓ **LENRs could enable 'green' dispatchable nuclear power generation that would be vastly safer and much less costly versus nuclear fission or fusion**
- ✓ **Development and utilization of LENR thermal sources for process heat could help reduce upstream and downstream costs for oil & gas producers and significantly decrease CO_2 emission footprints for entire oil & gas industry**
- ✓ **Should be possible to develop green LENR fuels derived from aromatic fractions present in oil, coal, and biomass as well as aromatics produced from natural gas; these would be suitable for use in many applications that include stationary/portable power generation and vehicular propulsion**
- ✓ **Oil & gas producers that successfully utilize this technology to produce LENR fuels for sale to customers will: (1) exploit a major strategic diversification opportunity to expand beyond their present product lines and (2) greatly enhance their capacity for RBL debt financing as a result of very substantial increases in net present economic value of their proven fossil fuel reserves**
- ✓ **Existing crude oil refineries could be modified to add capabilities for production of LENR fuels in parallel with traditional industry products**
- ✓ **Not competitive; LENRs are a strategic opportunity for oil & gas producers**

Nanoparticulate LENR fuels could be used in many systems

Huge energy density advantages vs. fossil fuels & chemical batteries

Energy densities of LENR fuels could be > 5,000x larger than gasoline

Consequence: an automobile powered by LENRs could travel around the entire world on a quantity of nanoparticulate fuel that fits into just a single FedEx box

LENR fuels would be inert and benign and could use existing package delivery systems for resupply; typical gasoline or diesel tanker truck carries ~5,000 - 12,000 US Gallons of liquid fuel; **LENR fuels producing same # of BTUs could be shipped in 1 - 2 FedEx boxes**

Paradigm-shifting new energy technology

Major increases in product performance with LENR fuels

Commercial LENR power systems could likely achieve 10x to 100x chemical

Enhancements in product range and endurance if LENR technology was commercialized

	Product Name	Present capabilities with today's power sources Range (endurance)	Vastly enhanced capabilities with future LENR-based power sources	
			10x chemical	100x chemical
Various aircraft	GreenWing e430	180 miles (~3 hours @ 60 mph)	1,800 (30)	18,000 (300)
Various aircraft	Airbus E-Fan 2.0	99 miles (1 hour @ 99 mph)	990 (10)	9,900 (100)
Various aircraft	Predator MQ-1	1,800 miles (24 hours @ 75 mph)	18,000 (240)	180,000 (2,400)
Various aircraft	Super Heron	est. ~ 4,000 miles (45 hours @ 89 mph?)	40,000 (450^+)	400,000 (4,500)
Various aircraft	Springtail	184 miles (2.2^+ hours @ 94 mph)	1,840 (200^+)	18,400 ($2{,}000^+$)
Various aircraft	Crazyflie	Speed not measured (3 - 10 minutes)	? (30 - 100 min.)	? (maybe 5 - 17 hrs.)
Various aircraft	InstantEye	est. ~ 8 miles (18 - 20 min @ 25 mph)	est. 80 (3.2 hrs.)	800 (32 hrs.)
	Tesla Model S car	~ 294 miles (4 - 5 hours @ 70 mph)	3,000 (40 - 50)	30,000 (400 - 500)
	Shkval Russian navy torpedo	6.8 - 9.3 miles (1.8 - 2.4 min @230 mph)	68 - 93 (18 - 24 min)	680 - 930 (3 - 4 hrs)
	Exoskeletons and autonomous robots	Require tether cables connected to some type of external power source	Duration of autonomous activity might be extended up to weeks or even months	

Note: roughly 730 hours in a month - 8,760 hours in year; average U.S. car's IC engine runs for ~5,000 hrs over lifetime

Key conclusion of theoretical paper published in Pramana

Journal is peer-reviewed publication of Indian Academy of Sciences

“A primer for electro-weak induced low energy nuclear reactions”

“The analysis presented in this paper leads us to conclude that realistic possibilities exist for designing LENR devices capable of producing ‘green energy’, that is, production of excess heat at low cost without lethal nuclear waste, dangerous γ-rays or unwanted neutrons. The necessary tools and the essential theoretical know-how to manufacture such devices appear to be well within the reach of the technology available now. Vigorous efforts must now be made to develop such devices whose functionality requires all three interactions of the Standard Model acting in concert.”

Publications about the Widom-Larsen theory of LENRs

Index provides comprehensive guide to available online information

"Ultra low momentum neutron catalyzed nuclear reactions on metallic hydride surfaces"
A. Widom and L. Larsen (author's copy)
European Physical Journal C - Particles and Fields 46 pp. 107 - 112 (2006)
http://www.slideshare.net/lewisglarsen/widom-and-larsen-ulm-neutron-catalyzed-lenrs-on-metallic-hydride-surfacesepjc-march-2006

"A primer for electro-weak induced low energy nuclear reactions"
Y. Srivastava, A. Widom, and L. Larsen (author's copy)
Pramana - Journal of Physics 75 pp. 617 - 637 (2010)
http://www.slideshare.net/lewisglarsen/srivastava-widom-and-larsenprimer-for-electroweak-induced-low-energy-nuclear-reactionspramana-oct-2010

"Theoretical Standard Model rates of proton to neutron conversions near metallic hydride surfaces"
A. Widom and L. Larsen
Cornell physics preprint arXiv:nucl-th/0608059v2 12 pages (2007)
http://arxiv.org/pdf/nucl-th/0608059v2.pdf

"Index to key concepts and documents" all hyperlinks in document are live
v. #21 updated and revised through Sept. 7, 2015
L. Larsen, Lattice Energy LLC, May 28, 2013 [133 slides] download is enabled
http://www.slideshare.net/lewisglarsen/lattice-energy-llc-hyperlinked-index-to-documents-re-widomlarsen-theory-and-lenrs-september-7-2015

Recent books about LENRs and the Widom-Larsen theory

Three volumes in series titled “Explorations in Nuclear Research”

Provides overview of entire field at level of *Scientific American* article

“Hacking the Atom” (Volume 1)
Steven B. Krivit
Pacific Oaks Press, San Rafael, CA, September 11, 2016 (484 pages)
Paperback US$16.00; hardcover US$48.00; Kindle US$3.99

https://www.amazon.com/dp/0996886451

“Fusion Fiasco” (Volume 2)
Steven B. Krivit
Pacific Oaks Press, San Rafael, CA, November 11, 2016 (531 pages)
Paperback US$16.00; hardcover US$48.00; Kindle US$3.99

https://www.amazon.com/dp/0976054523

PowerPoint synopsis of book with additional commentary:

http://tinyurl.com/z6fsbn2

“Lost History” (Volume 3)
Steven B. Krivit
Pacific Oaks Press, San Rafael, CA, November 11, 2016 (380 pages)
Paperback US$16.00; hardcover US$48.00; Kindle US$3.99

https://www.amazon.com/dp/0996886419

Working with Lattice Energy LLC

Partnering on commercialization and consulting on certain subjects

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

- ✓ We believe Lattice is the world-leader in proprietary knowledge about LENR device engineering required to develop high-performance, long lived, scalable power sources. Our published peer-reviewed theoretical papers rigorously explain the breakthrough device physics of LENR processes, including the absence of dangerous energetic neutron or gamma radiation and lack of long-lived radioactive waste production
- ✓ Lattice welcomes inquiries from large, established organizations that have an interest in discussing the possibility of becoming Lattice's strategic capital and/or technology development partner
- ✓ Lewis Larsen also independently engages in fee-based consulting on a variety of subject areas that include Lithium-ion battery safety issues and evaluating potential future impact of LENRs from a long-term investment risk perspective for pending large CAPEX projects in the oil & gas, petrochemicals, transportation, utility, and aerospace industries