Enormous potential future value for diversified portfolios of renewable, fossil-fueled, and nuclear power generation --- enable grids to have resilience against extreme weather events related to climate change and "Black Swan" volcanic eruptions

What may appear 'greener' and less $$$ in short-term decision making could end-up being extremely $$$ expensive or catastrophic in long-term

"In the first place … an ounce of prevention is worth a pound of cure." Benjamin Franklin (1735)

Extreme Weather

Black Swans

Benjamin Franklin – quoted from his anonymous letter to his own newspaper, *The Pennsylvania Gazette,* published on February 4, 1735 in which he was advocating formation of professional fire fighting companies and licensing of Philadelphia chimney sweeps to combat rash of deadly fires

Lewis Larsen, President and CEO, Lattice Energy LLC

Lattice Energy LLC, Copyright 2017 All rights reserved

Ongoing climate change: recent past not indicative of future

Many aspects of climate and weather now changing in unexpected ways

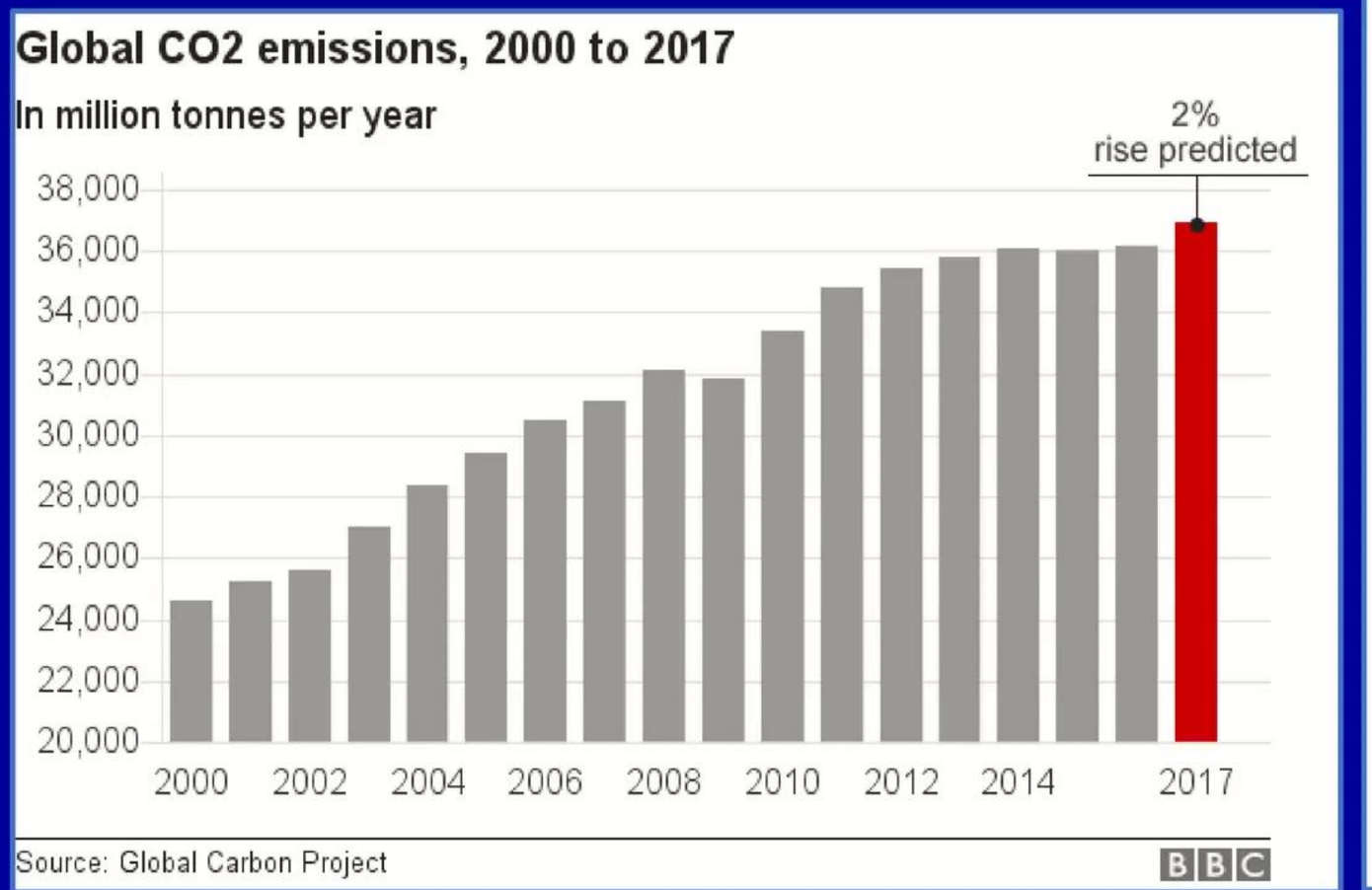
BBC NEWS Science & Environment

"First CO_2 rise in four years puts pressure on Paris targets"

By Matt McGrath, Environment correspondent, Bonn, Nov. 13, 2017

http://www.bbc.com/news/science-environment-41941265

"One common theme around the world is continued use of gas and oil", says Prof. Le Quéré.



"Latest figures indicate that in 2017, emissions of CO_2 from all human activities grew by about 2% globally. There is some uncertainty about the data but the researchers involved have concluded that emissions are on the rise again. 'Global CO_2 emissions appear to be going up strongly once again after a three-year stable period. This is very disappointing,' said the lead author of the study, Prof Corinne Le Quéré from the University of East Anglia."

Lattice Energy LLC, Copyright 2017 All rights reserved

Climate change increases number of extreme weather events

Trend since 1984 is clear: reliability of U.S. electricity grids being affected

CLIMATE CENTRAL

BLACKOUT: EXTREME WEATHER, CLIMATE CHANGE AND POWER OUTAGES

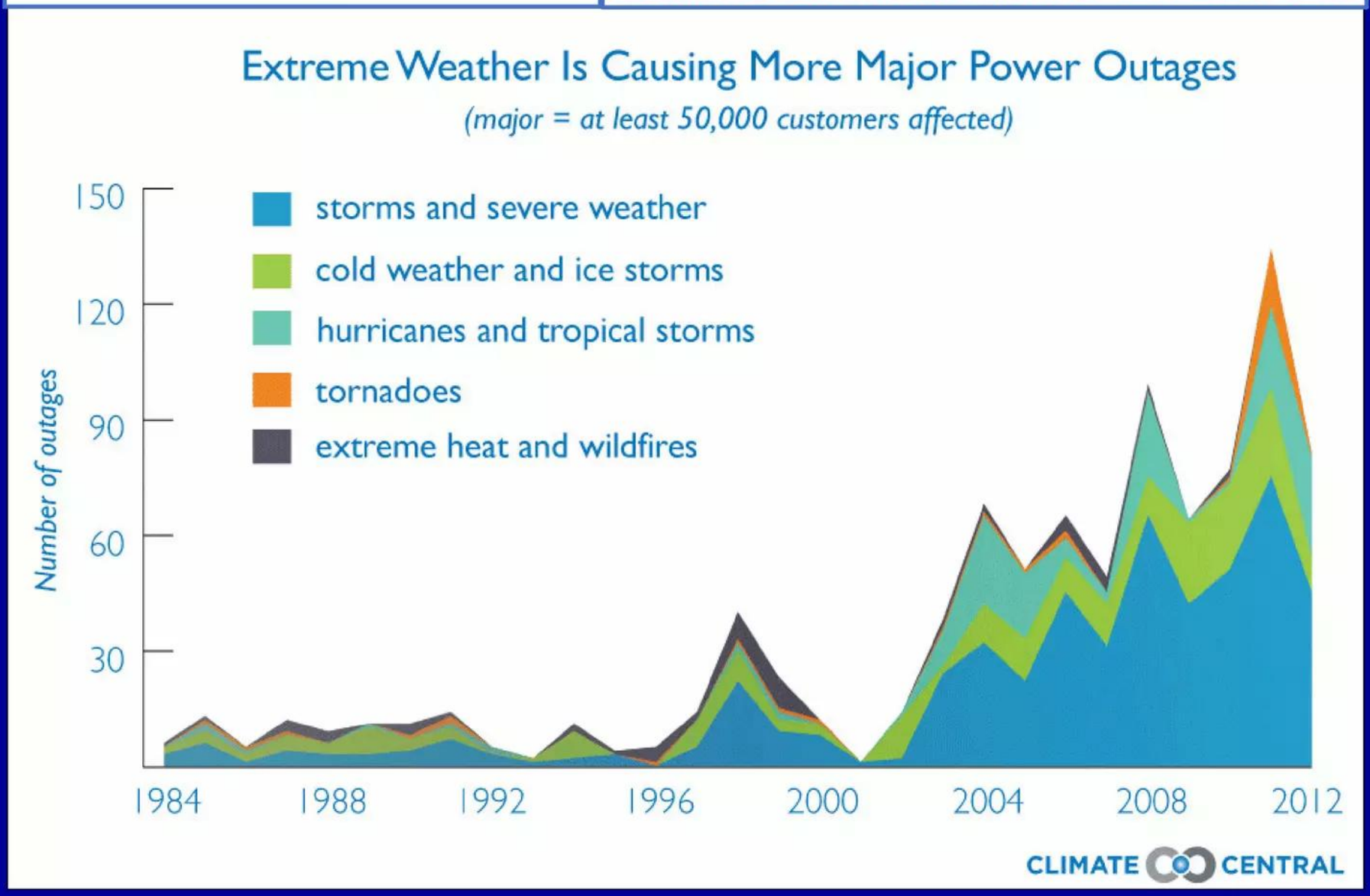


Figure in Summary on pp. 3 of report by A. Kenward and U. Raja, Climate Central (2014)

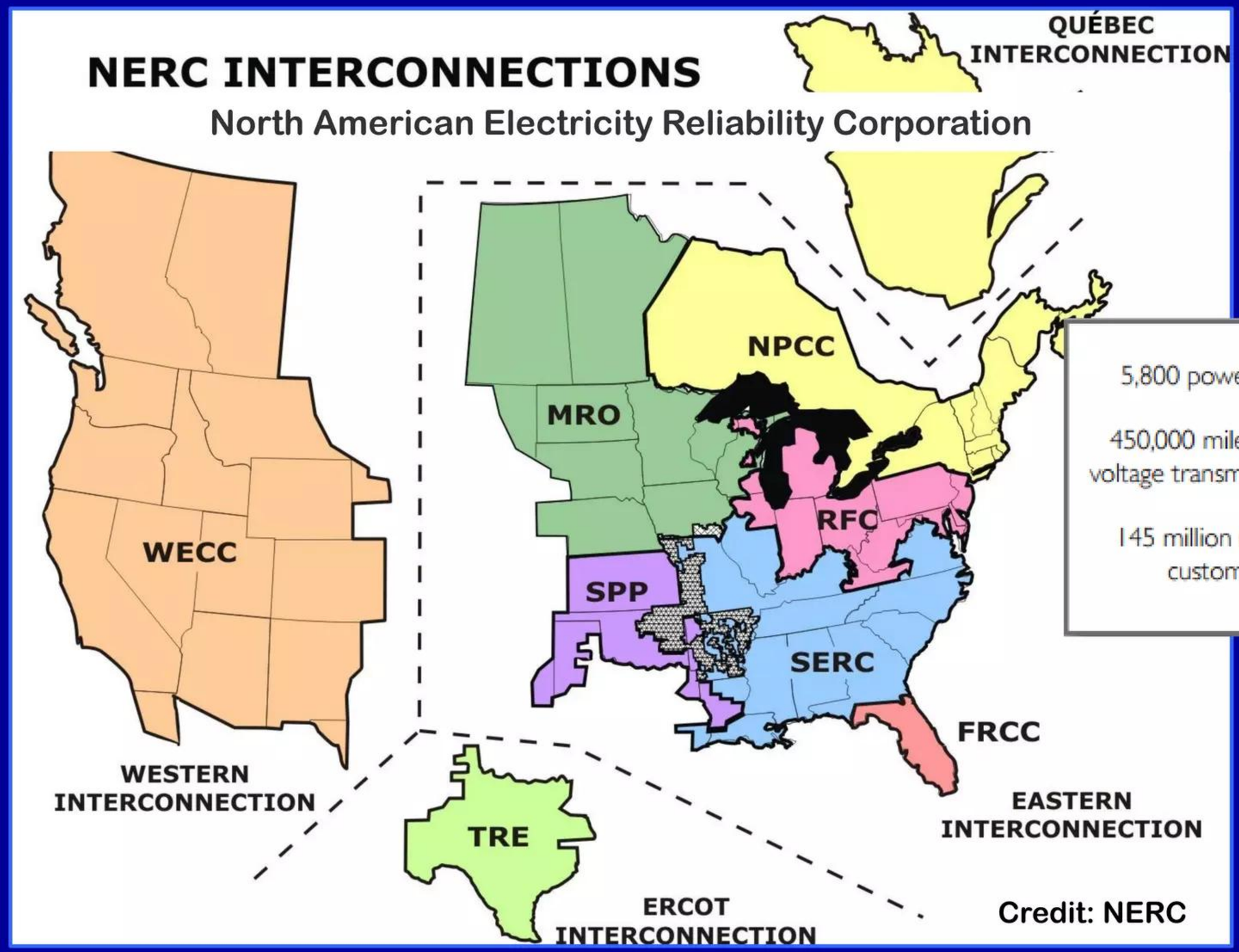
http://assets.climatecentral.org/pdfs/PowerOutages.pdf

Lattice Energy LLC, Copyright 2017 All rights reserved

United States electricity generation and transmission system

Key electricity grids (interconnections) in U.S. : Eastern, Western, ERCOT

Regional electric reliability councils: WECC,TRE, MRO, SPP, NPCC, RFC, SERC, FRCC



Lattice Energy LLC, Copyright 2017 All rights reserved

United States electricity generation and transmission system

Two-thirds of reported outages occurred in Eastern RFC & SERC regions

Regional electric reliability councils: WECC,TRE, MRO, SPP, NPCC, RFC, SERC, FRCC

CLIMATE CENTRAL

BLACKOUT: EXTREME WEATHER, CLIMATE CHANGE AND POWER OUTAGES

Two-Thirds of Reported Outages Occurred in the Eastern RFC and SERC Regions Between 2003-2012

Figure 5 on pp. 13 of report by A. Kenward and U. Raja, Climate Central (2014)

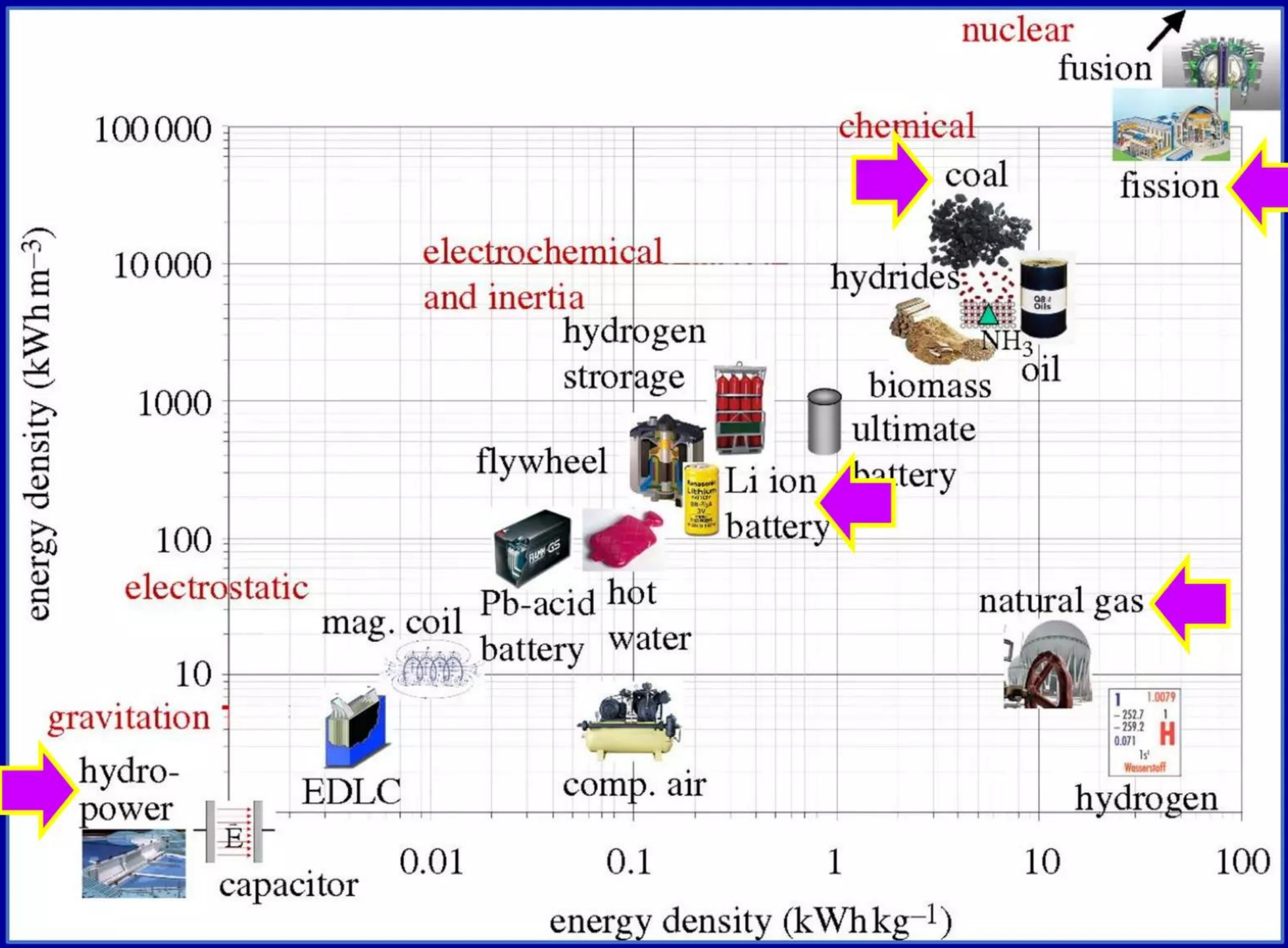
Credit: NERC

http://assets.climatecentral.org/pdfs/PowerOutages.pdf

Lattice Energy LLC, Copyright 2017 All rights reserved

Grid power sources have very wide range of energy densities

Fig. 7 in "Hydrogen: the future energy carrier" A. Zuttel et al.
***Phil. Trans. R. Soc. A* 368 pp. 3329 - 3342 (2010)**



Lattice Energy LLC, Copyright 2017 All rights reserved

Energy density of fuels key parameter among power sources

Nuclear, coal, and natural gas >>> higher energy densities vs. renewables

Pipeline natural gas: volumetric energy density <<< less versus nuclear and coal

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 2017" this 66th edition was released in June 2017

https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review-2017/bp-statistical-review-of-world-energy-2017-full-report.pdf

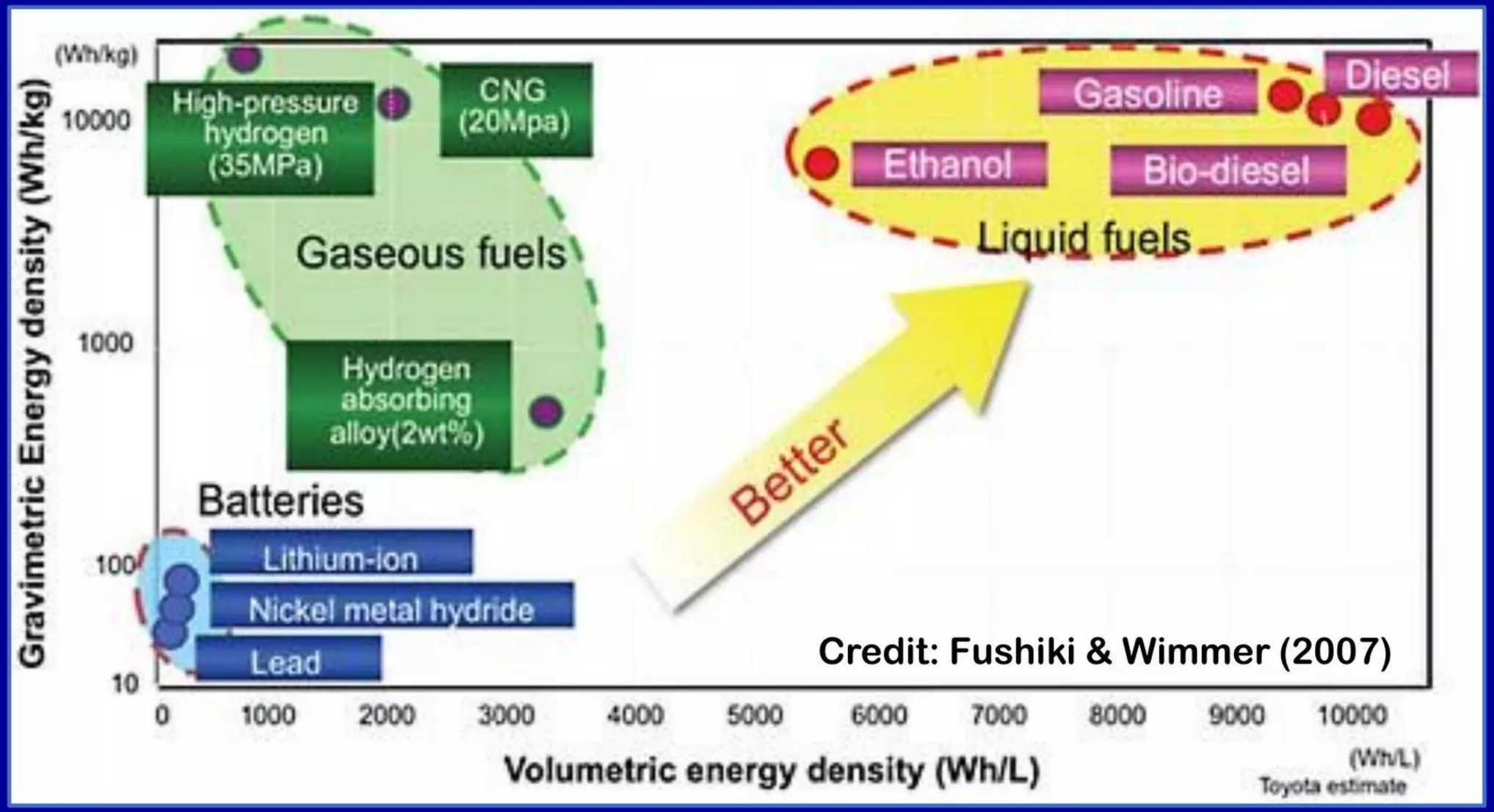
Lattice Energy LLC, Copyright 2017 All rights reserved

Energy density of fuels key parameter among power sources

Volumetric energy density of batteries much lower than liquid fossil fuels

Energy density of onsite battery storage <<< gas or liquid fuels, coal, nuclear

Volumetric and gravimetric energy densities amongst competing forms of energy storage



Credit: Fushiki & Wimmer (2007)

Lattice Energy LLC, Copyright 2017 All rights reserved

Fuel energy density controls how much can be stored onsite

Nuclear/coal volumetric energy density > vs. various forms of natural gas

Are We Toast?

OR, DO WE HAVE THE TIME AND WISDOM TO PROTECT OUR PLANET'S CLIMATE?

Selected Fuels	energy density	
	by mass	*by volume*
	MJ/kg	MJ/L
nuclear fission (of U-235) (Used in Nuclear Power Plants)	77,000,000	1,500,000,000
anthracite coal	32.5	72.4
diesel fuel/residential heating oil	45.8	38.7
gasoline	46.9	34.6
biodiesel oil (vegetable oil)	42.20	30.53
gasohol (10% ethanol 90% gasoline)	43.54	28.06
ethanol	30	24
liquid hydrogen	143	10.1
compressed natural gas at 200 bar	53.6	10
wood	6 - 17	1.8 - 3.2
natural gas		.038

Values abstracted from Wikipedia

Uranium-235

Anthracite coal

Energy value of LNG ranges from 24 MJ/L to 21 MJ/L. Energy density of LNG is 2.4 times greater vs. CNG and about 1/3 that of Coal

CNG

Natural gas

https://arewetoast.com/energy-content-of-selected-fuels.html

Lattice Energy LLC, Copyright 2017 All rights reserved

Nuclear reactors can store up to 18 months of fuel onsite

Enormous energy density of Uranium fuels enables huge onsite storage

Nuclear plants provide vital essentially uninterruptible baseload power generation

WORLD NUCLEAR ASSOCIATION | The Nuclear Fuel Cycle

"To maintain efficient reactor performance, about one-third of the spent fuel is removed every year or 18 months, to be replaced with fresh fuel. The length of fuel cycle is correlated with the use of burnable absorbers in the fuel, allowing higher burn-up."

"In the USA about 85% of reactors have an 18-month fuel cycle, a few have 24-month ones. In Asia, over 80% have 18-month cycles, the rest 12-month. In Europe, over 60% have 12-month cycles, the balance 18-month, and over one-quarter do not use burnable absorbers. All reactors in the USA and Asia use burnable absorbers. So, 18 months is a typical worldwide refueling interval."

"Typically, some 44 million kilowatt-hours of electricity are produced from one tonne of natural uranium. The production of this amount of electrical power from fossil fuels would require the burning of over 20,000 tonnes of black coal or 8.5 million cubic metres of gas."

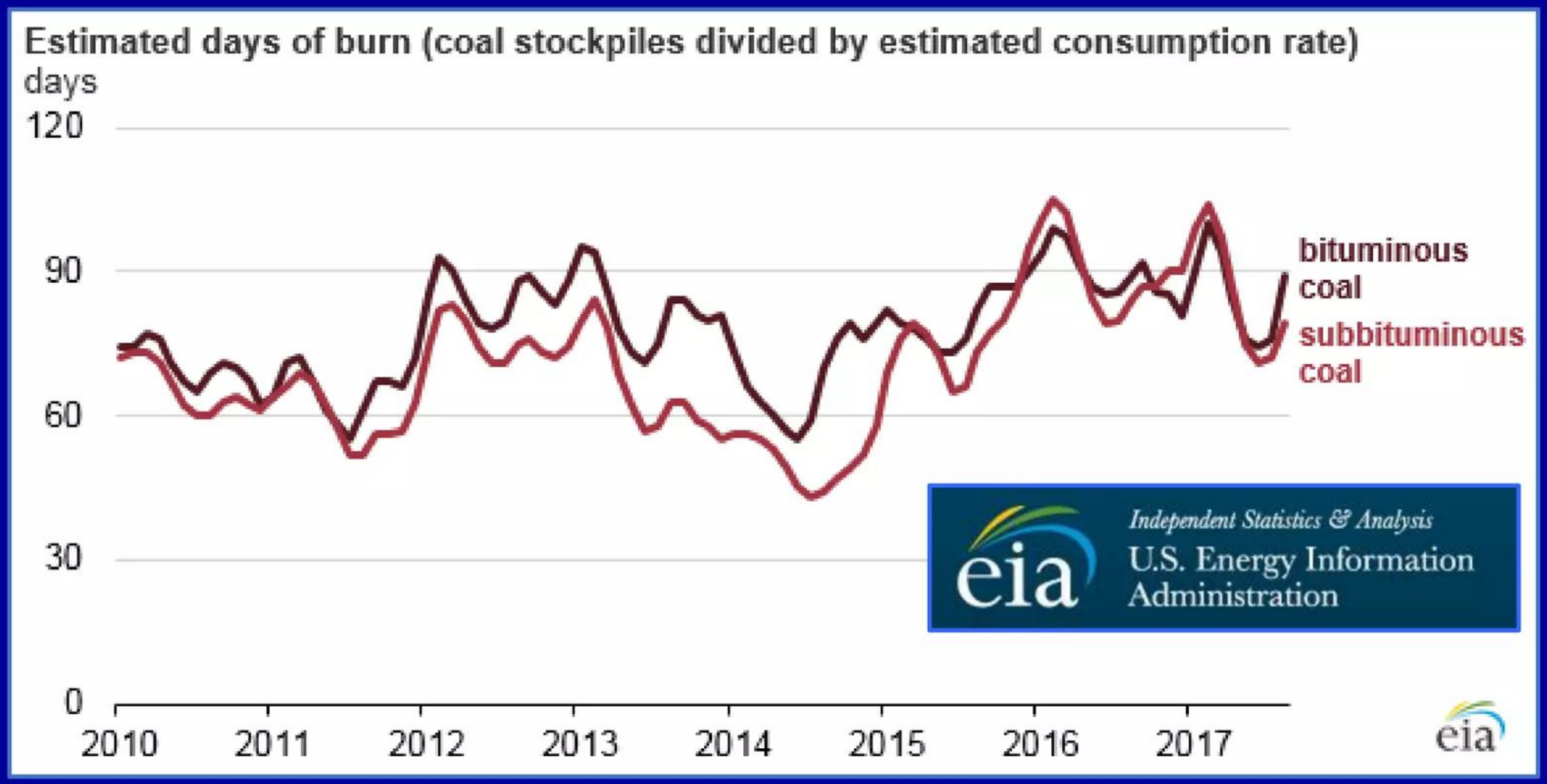
http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/introduction/nuclear-fuel-cycle-overview.aspx

Lattice Energy LLC, Copyright 2017 All rights reserved

U.S. coal-fired power plants store 2 - 3 months of fuel onsite

Vastly lower energy density of coal fuel permits much less onsite storage

Energy density of pipeline natural gas fuel <<< coal thus no onsite storage of gas



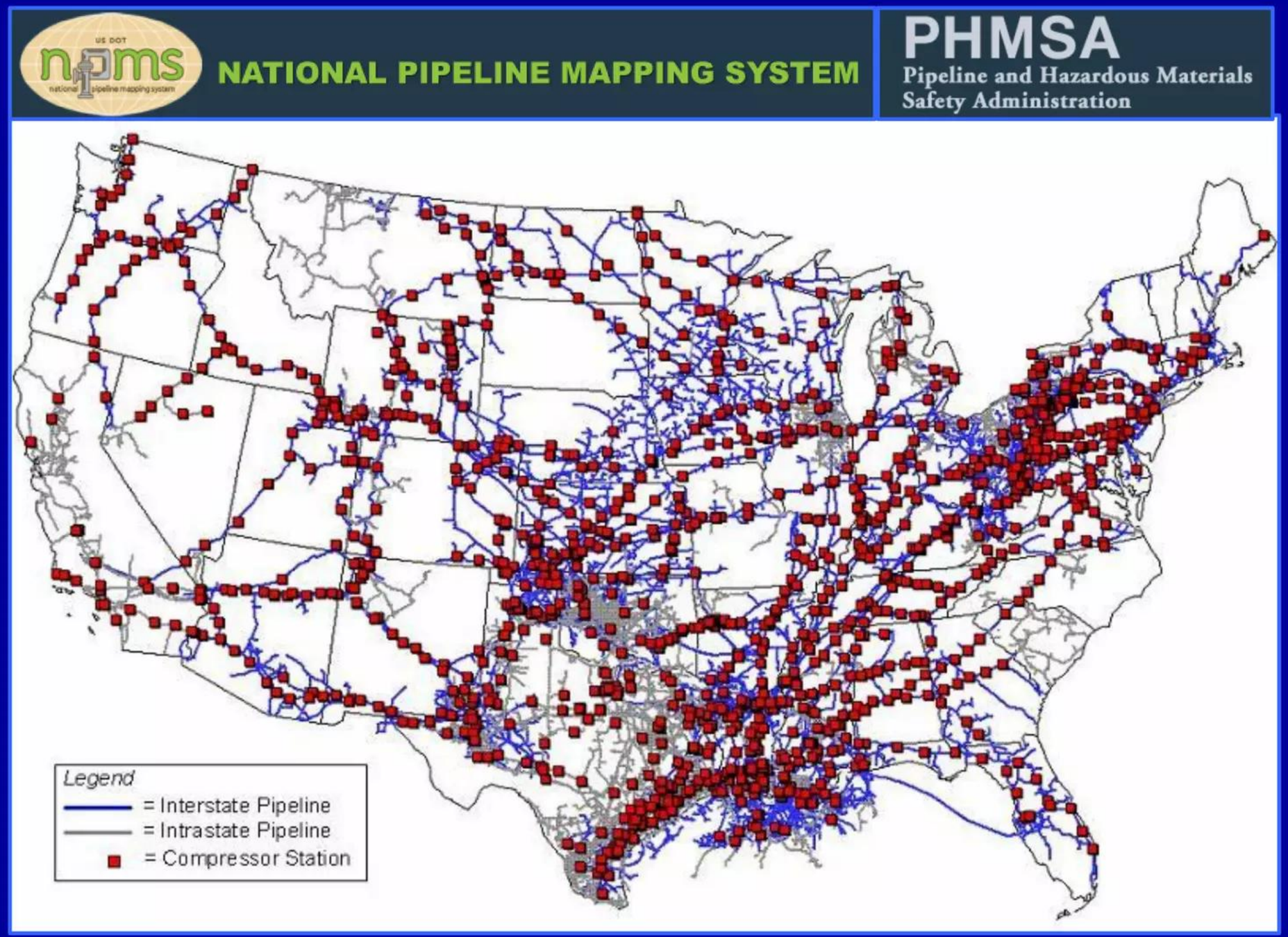
"In addition to surveying coal stockpile levels, EIA also calculates how long these stockpiles would last assuming no additional coal was received. This value, known as days of burn, considers each plant's current stockpile level and its estimated consumption rate in coming months. EIA estimates the historical burn rate by averaging the most recent three years of historical data and applying that to the upcoming months."

Lattice Energy LLC, Copyright 2017 All rights reserved

Natural gas power plants connect directly to pipeline system

Just-in-time delivery of fuel from pipeline; no natural gas is stored onsite

Technology exists to store LNG onsite but would increase capital costs of plants

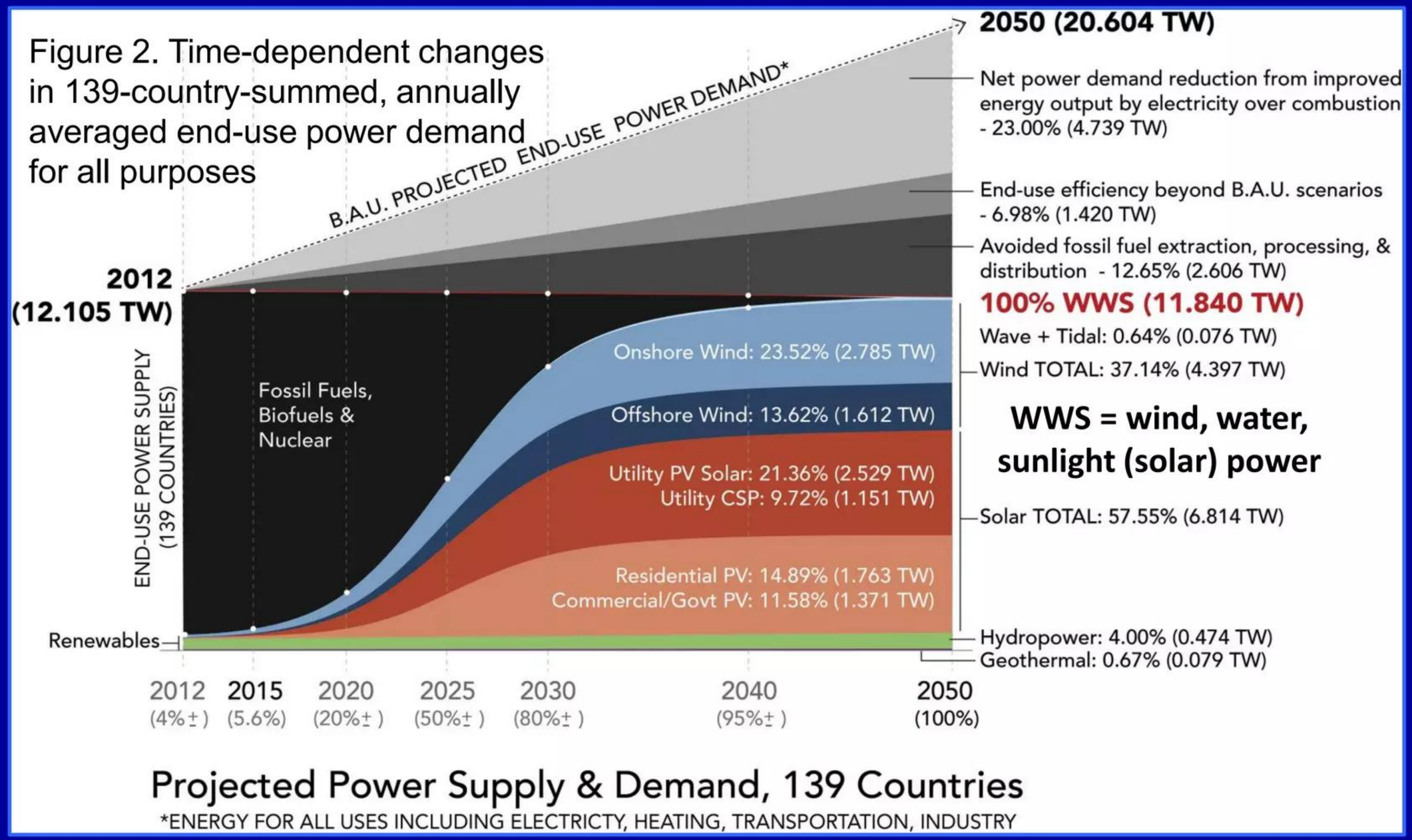


Lattice Energy LLC, Copyright 2017 All rights reserved

Green utopian vision of M. Jacobson et al. is very unrealistic

100% WWS 2050 scenario ignores weather, earthquake, Black Swan risks

"100% clean and renewable wind, water, and sunlight all-sector energy roadmaps for 139 countries of the world" M. Jacobson et al. *Joule* 1 pp. 107 - 121 (2017)



http://www.sciencedirect.com/science/article/pii/S2542435117300120?via%3Dihub

Lattice Energy LLC, Copyright 2017 All rights reserved

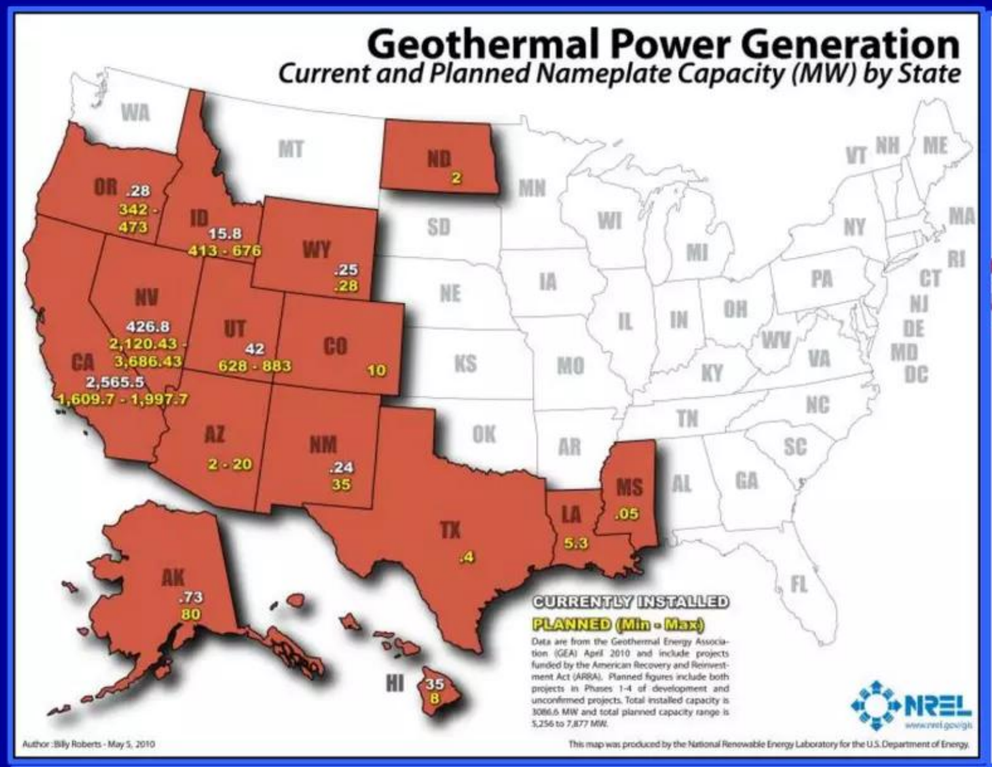
Green utopian vision of M. Jacobson et al. is very unrealistic

100% WWS 2050 scenario uses geothermal and hydro for baseload power

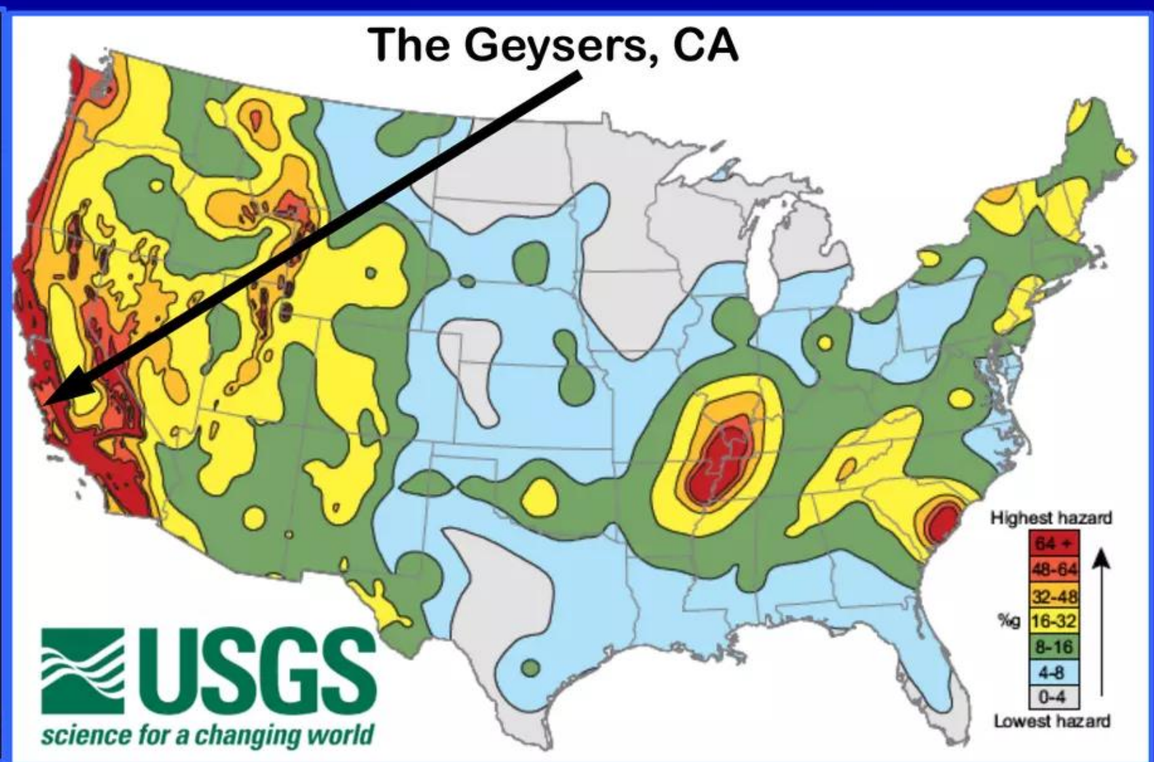
Problem with strategy: geothermal contiguous with >>> higher earthquake risks

Geothermal now 0.3% of U.S. power generation - what about rest of the U.S.?

Geothermal power plant locations



USGS earthquake hazard map for US



In 2015, United States was still world leader in producing geothermal electricity: 3.5 GW of installed capacity from 98 power stations; world's largest group of 18 geothermal power plants at The Geysers in California

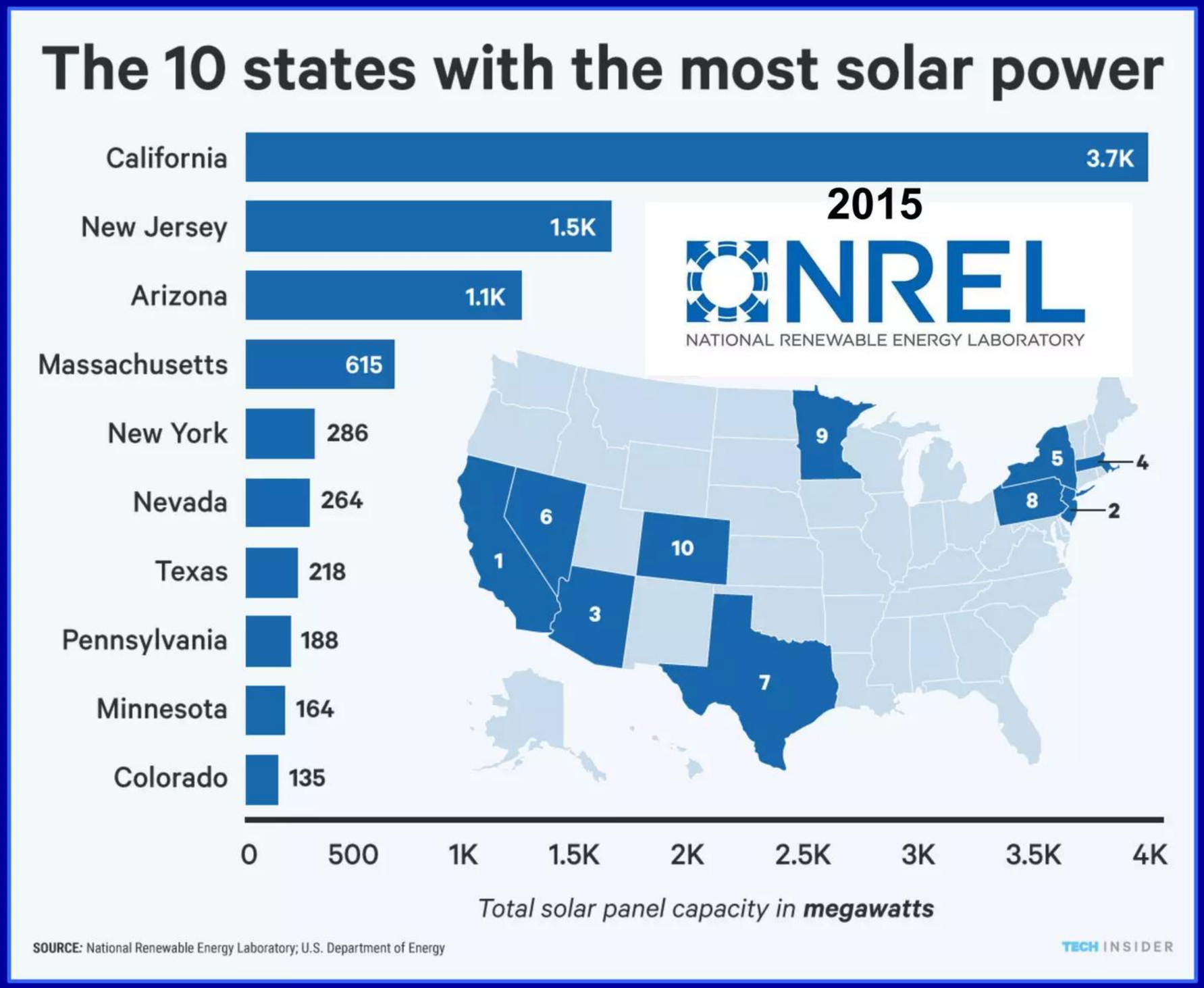
"A big chunk of … central Philippines was without electricity because a geothermal power plant in … town of Jaro sustained [earthquake] damage" - AP July 6, 2017

https://wtop.com/asia/2017/07/strong-shallow-earthquake-shakes-central-philippines-2/

Lattice Energy LLC, Copyright 2017 All rights reserved

Solar power varies by state & regional electric reliability council

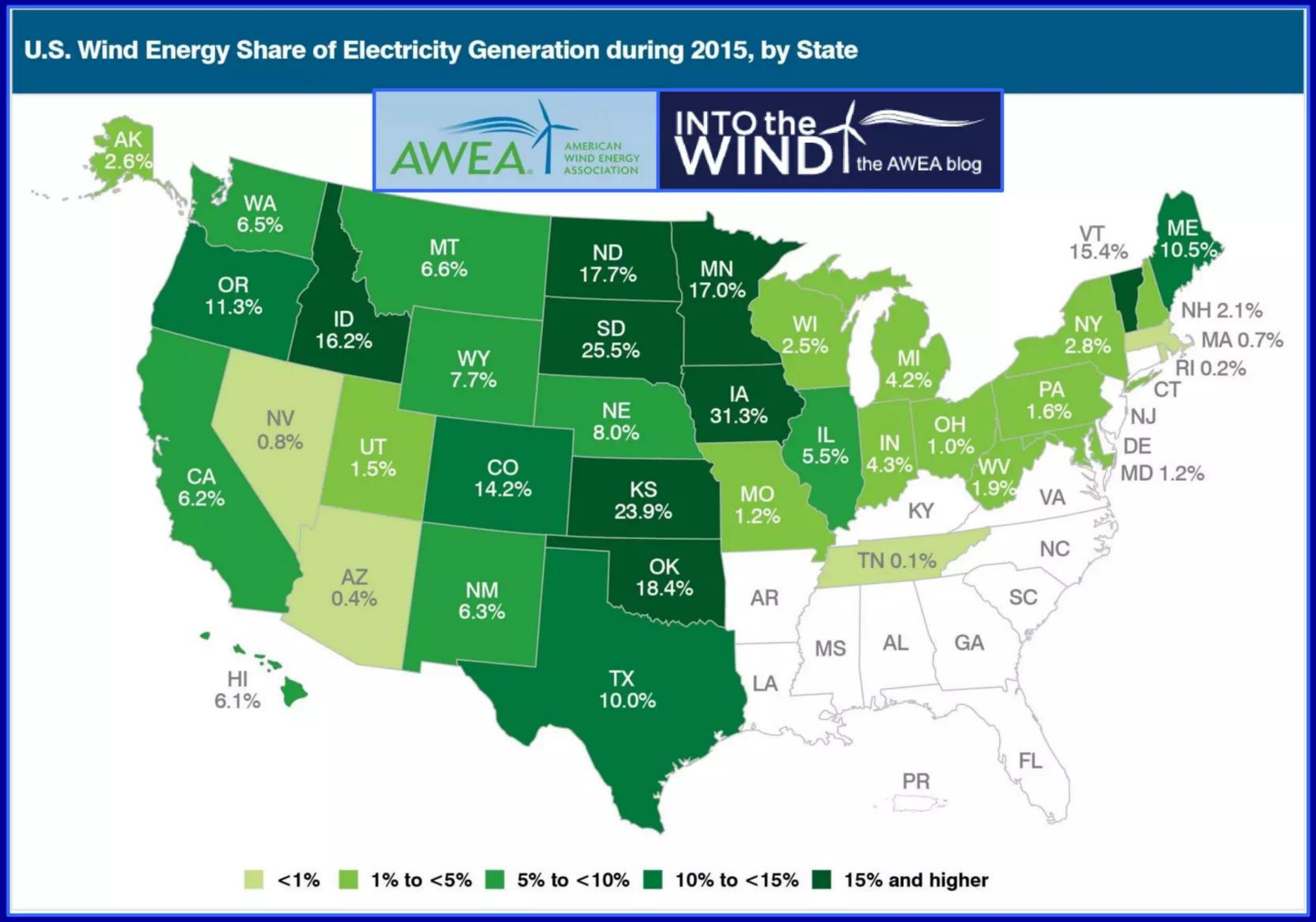
Some states have many more MWs of solar powergen capacity vs. others



Lattice Energy LLC, Copyright 2017 All rights reserved

Wind power varies by state & regional electric reliability council

Certain states have much higher % of wind power generation vs. others



Lattice Energy LLC, Copyright 2017 All rights reserved

Green utopian vision of M. Jacobson et al. is very unrealistic

Reliability, resilience, and fragility risks with 100% WWS not addressed

"100% clean and renewable wind, water, and sunlight all-sector energy roadmaps for 139 countries of the world" M. Jacobson et al. *Joule* 1 pp. 107 - 121 (2017)

Assert: grid stability "is evaluated in separate work" – no, risks cursorily glossed over

"Roadmaps envision 80% conversion by 2030 and 100% by 2050 …
Seriousness of air-pollution, climate, and energy-security problems worldwide requires a massive, virtually immediate transformation of world's energy infrastructure to 100% clean, renewable energy producing zero emissions."

"Previous studies have established that it may be technically and economically feasible to transition the world as a whole and the 50 US states to 100% WWS for all purposes, and that the main barriers are social and political."

"Present study does not examine grid stability, since it is evaluated in separate work (see Matching Electric Power Supply with Demand and Section S7)."

"Roadmaps assume the adoption of new energy-efficiency measures but exclude the use of nuclear power, carbon capture, liquid and solid biofuels, and natural gas primarily because the latter sources all increase air pollution and climate-warming emissions more than do WWS technologies and because the use of nuclear power entails serious risks that WWS systems do not have."

http://www.sciencedirect.com/science/article/pii/S2542435117300120?via%3Dihub

Lattice Energy LLC, Copyright 2017 All rights reserved

Green utopian vision of M. Jacobson et al. is very unrealistic

Reliability, resilience, and fragility risks with 100% WWS not addressed

Jacobson et al. acknowledge intrinsic intermittency of solar and wind (~95% of total power generation in their 2050 scenario) and purport to 'solve' this huge problem via:

1. Renewables comprise 95% of total grid power generation capacity; are randomly distributed across a large geographic area comprising entire grid - authors assume that sun and wind conditions are uncorrelated between grid sub-regions; thus, local fluctuations in power output of grid-connected renewable electricity generation will effectively cancel-out when averaged across the whole grid
   - ❖ Assumption that local weather conditions are uncorrelated across large fraction of grid's total area was flatly refuted in two peer-reviewed academic papers published in 2016 (Slides #23 - 24 in March 2, 2016 Lattice PowerPoint)
   - ❖ Assumption of local uncorrelation also refuted by 6-month wind drought in FH 2015 that reduced total wind power output by 20% and involved entire U.S. West Coast (Slides #20 - 22 in March 2, 2016 Lattice PowerPoint). Also refuted by nearly 1 month of no sun and no wind that occurred in Europe during January-February 2017 (Slides #6 -14 in April 19, 2017 Lattice PowerPoint)
2. Hydro comprises only 4% of total generation capacity in 2050 scenario and their only grid power source dispatchable on short notice – to cover shortfalls when renewable power output cannot fulfil grid electricity demand, authors glibly say this problem will be 'solved' by using an unspecified combination of concentrating solar power (CSP) thermal storage systems plus grid-scale chemical flow batteries
   - ❖ Authors omit that capital cost for huge grid electrical storage capacity would be enormous and uneconomic (Slides #13 - 18 in Feb. 10, 2017 Lattice PowerPoint)

Lattice Energy LLC, Copyright 2017 All rights reserved

Higher % of renewable energy sources is a two-edged sword

Upside rewards versus downside risks

Upside rewards: greener (CO_2-free) and can be very cost-competitive during periods when sun is shining and/or the wind is blowing steadily

Downside risks: excessive % of renewable power sources can reduce resiliency/reliability and increase fragility of electricity grids to variety of extreme weather events

Lattice Energy LLC, Copyright 2017 All rights reserved

Climate change ups frequency & severity of extreme weather

Long periods of cloudy skies can be accompanied with low or no winds

If you believe that wind and solar will someday be able to 100% replace dispatchable, effectively uninterruptible sources of baseload power generation like U.S. grid's existing nuclear and coal plants then think again, because they simply can't --- ever

> **"Wind doesn't always blow, the sun doesn't always shine, and natural gas pipelines don't always have enough capacity to meet demand"**
>
> U.S. Energy Secretary Rick Perry testifying before Congress

Credit: Getty Images

Lattice Energy LLC, Copyright 2017 All rights reserved

Modern proverb: “Don’t put all your eggs in one basket”

“Venture not all in one bottom”
Giovanni Torriano (1666)

Torriano used term “bottom’ to mean ship. Based on much older Latin proverb about shipping

Painting by eyewitness William Bradford of the whaling ship Nantucket’s wreck off Nashawena Island on August 7, 1859

Lattice Energy LLC, Copyright 2017 All rights reserved

“Venture not all in one bottom” Giovanni Torriano (1666)

Chinese practiced this strategy for risk management in 2,000 - 3,000 BC

“The first methods of transferring or distributing risk in a monetary economy, were practised by Chinese and Babylonian traders in the 3rd and 2nd millennia BC, respectively. Chinese merchants travelling treacherous river rapids would redistribute their wares across many vessels to limit the loss due to any single vessel's capsizing. The Babylonians developed a system that was recorded in the famous Code of Hammurabi, c. 1750 BC, and practised by early Mediterranean sailing merchants. If a merchant received a loan to fund his shipment, he would pay the lender an additional sum in exchange for the lender's guarantee to cancel the loan should the shipment be stolen or lost at sea.”

“By the end of the seventeenth century, London's growing importance as a centre for trade was increasing demand for marine insurance. In 1686, Edward Lloyd opened a coffee house on Tower Street in London. It soon became a popular haunt for ship owners, merchants, and ships' captains, and thereby a reliable source of the latest shipping news. It became the meeting place for parties in the shipping industry wishing to insure cargoes and ships, and those willing to underwrite such ventures. These informal beginnings led to the establishment of the insurance market Lloyd's of London and several related shipping and insurance businesses.” Source: Wikipedia

https://en.wikipedia.org/wiki/History_of_insurance

Lattice Energy LLC, Copyright 2017 All rights reserved

Diversity is valuable in ecosystems & grid sources of energy

‘Laws’ of biological ecosystems have analogues in man’s electricity grids

Energy source diversity boosts resilience of grid power output to extreme events

https://conservationbytes.com/2014/01/08/more-species-more-resilience/

“Relationship between ‘diversity’ (simply put, ‘more species’) and ecosystem resilience (i.e., resisting extinction) has never been demonstrated so elegantly. Not only is study elegant … it demonstrates the biodiversity-stability hypothesis in a natural setting (not experimental) over a range of thousands of kilometers.” (2014)

“Biodiversity increases the resistance of ecosystem productivity to climate extremes”
F. Isbell et al. *Nature* 526 pp. 574 - 577 (2015)
https://www.nature.com/articles/nature15374

“We show that biodiversity increased ecosystem resistance for a broad range of climate events, including wet or dry, moderate or extreme, and brief or prolonged events. Across all studies and climate events, the productivity of low-diversity communities with one or two species changed by approximately 50% during climate events, whereas that of high diversity communities with 16 - 32 species was more resistant, changing by only approximately 25%.”

Lattice Energy LLC, Copyright 2017 All rights reserved

Europeans believed Black Swans were impossible until 1697

Assumed all swans must be white because no other color had been seen

Black Swan (*Cygnus atratus*) is a large waterbird, a species of swan which breeds mainly in the southeast and southwest regions of Australia. Within Australia they are nomadic, with erratic migration patterns dependent upon climatic conditions. Black swans are large birds with mostly black plumage and red bills. Black swans were first seen by Europeans in 1697, when Willem de Vlamingh's expedition explored the Swan River, Western Australia. Black swans were introduced to various countries as an ornamental bird in the 1800s, but have escaped and formed stable populations." Source: Wikipedia

Lattice Energy LLC, Copyright 2017 All rights reserved

Black Swan

Quoting directly from source at URL: "What are Black Swan events?"

"A Black Swan event is an event in human history that was unprecedented and unexpected at the point in time it occurred. However, after evaluating the surrounding context, domain experts (and in some cases even laymen) can usually conclude: 'it was bound to happen'. Even though some parameters may differ (such as the event's time, location, or specific type), it is likely that similar incidences have had similar effects in the past."

"Term Black Swan originates from the (Western) belief that all swans are white because these were the only ones accounted for. However, in 1697 the Dutch explorer Willem de Vlamingh discovered black swans in Australia. This was an unexpected event in (scientific) history and profoundly changed zoology. After the black swan were discovered, it seemed obvious that black swans had to exist just as other animals with varying colors were known to exist as well. In retrospect, the surrounding context (i.e., the observations about other animals) seemed to imply the Black Swan assumption – empirical evidence validated it. Theory around Black Swan events was introduced by Nassim Nicholas Taleb in 2007."

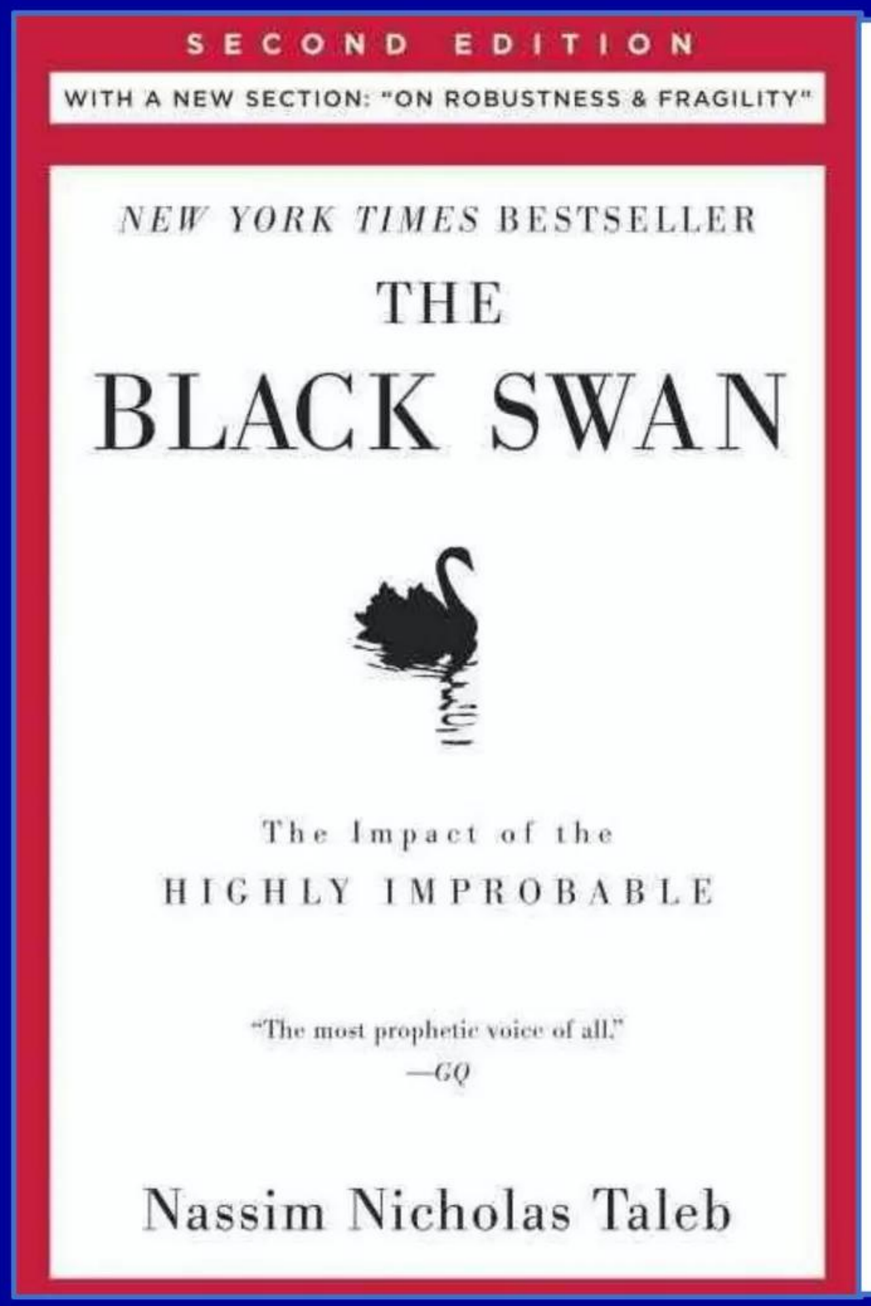
http://blackswanevents.org/?page_id=26

Lattice Energy LLC, Copyright 2017 All rights reserved

"The Black Swan: Second Edition" was published in 2010

Importance of unlikely events: new section: "On robustness and fragility"

N. Taleb "We always run the risk of experiencing the improbable, rare, and novel"



"Who gets rewarded, the central banker avoids a recession or the one who comes to 'correct' his predecessors' faults and happens to be there during some economic recovery? Who is more valuable, the politician who avoids a war or the one who starts a new one (and is lucky enough to win)?"

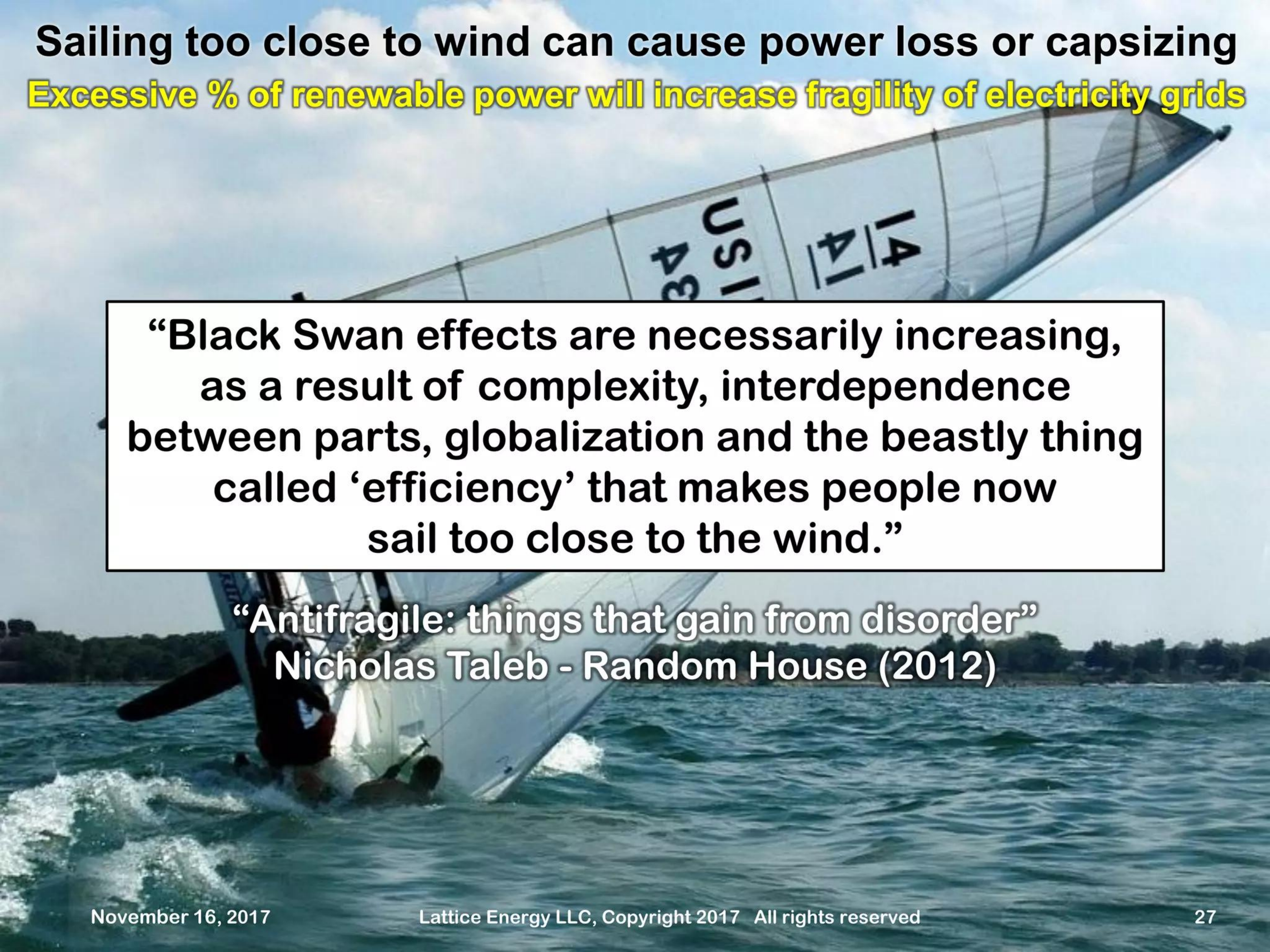
"It is the same logic reversal we saw earlier with the value of what we don't know; everybody knows that you need more prevention than treatment, but few reward acts of prevention. We glorify those who left their names in history books at the expense of those contributors about whom our books are silent. We humans are not just a superficial race (this may be curable to some extent); we are a very unfair one."

https://www.amazon.com/Black-Swan-Improbable-Robustness-Fragility/dp/081297381X

Lattice Energy LLC, Copyright 2017 All rights reserved

Sailing too close to wind can cause power loss or capsizing

Excessive % of renewable power will increase fragility of electricity grids



> **"Black Swan effects are necessarily increasing, as a result of complexity, interdependence between parts, globalization and the beastly thing called 'efficiency' that makes people now sail too close to the wind."**

"Antifragile: things that gain from disorder"
Nicholas Taleb - Random House (2012)

Lattice Energy LLC, Copyright 2017 All rights reserved

Power grids should be robust and antifragile to Black Swans

Japan 2011: nuclear plant backup generators fragile to effects of tsunami

Fukushima nuclear disaster might not have happened if generators had survived

“Not seeing a tsunami or an economic event coming is excusable; building something fragile to them is not.”

“Antifragile: things that gain from disorder”
Nicholas Taleb – Random House (2012)

Tsunami wave destroying everything in its path, Japan on March 11, 2011

Lattice Energy LLC, Copyright 2017 All rights reserved

March 11, 2011: magnitude 9.0 earthquake occurred off Japan

Most powerful earthquake ever-recorded in Japan; 4th in world since 1900

Created huge tsunami or tidal wave > 13 meters high when it hit reactor complex

Fukushima-Daiichi TEPCO electric power generation complex consisted of 6 commercial BWR nuclear fission reactors that were built on Pacific shoreline of 860-acre site from 1967 – 1973.
All 6 reactors are now decommissioned post-disaster.

Epicenter of earthquake

Credit: United States Geological Service

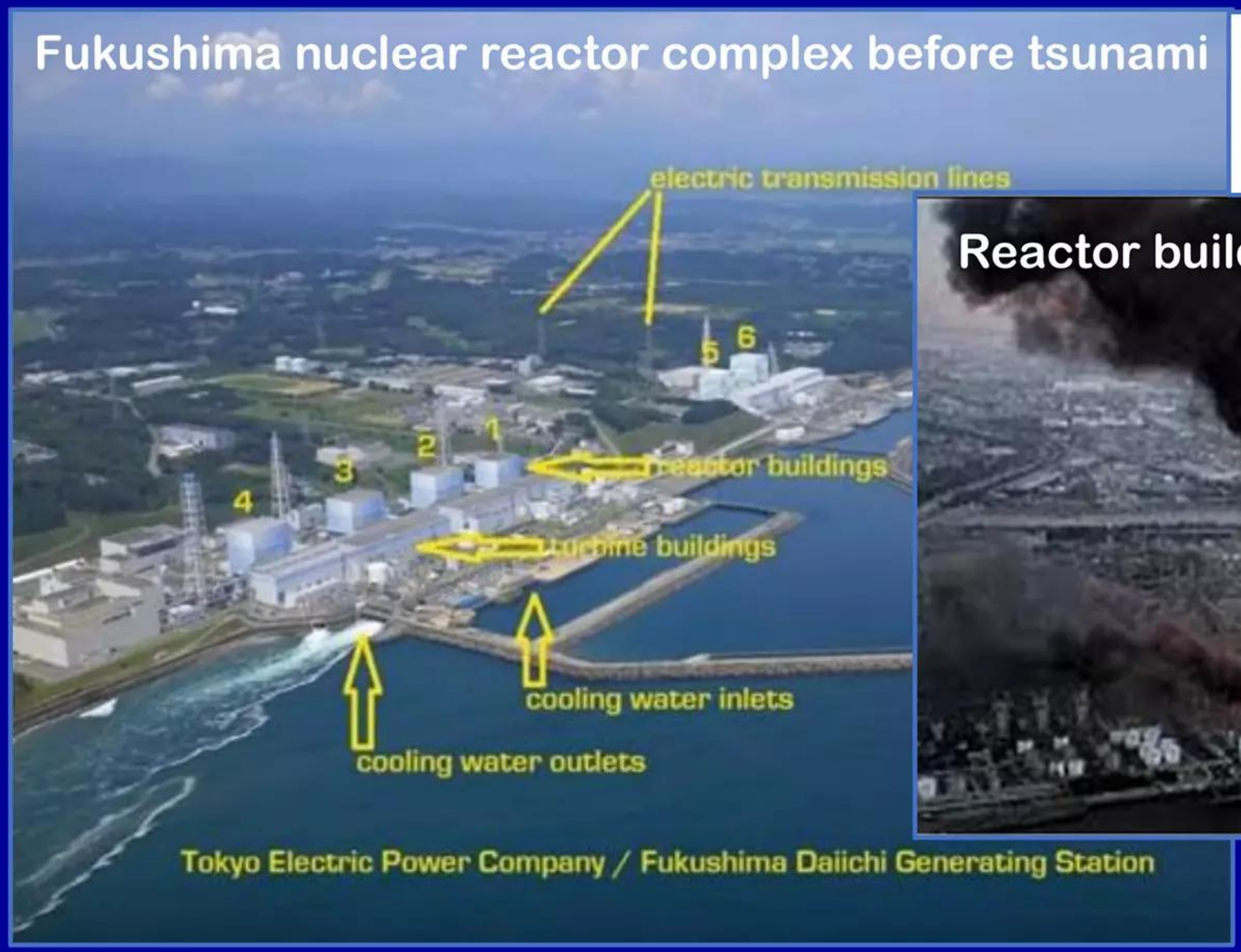
Lattice Energy LLC, Copyright 2017 All rights reserved

Nuclear reactor complex on shoreline in Fukushima, Japan

Latest cost estimate to clean-up complex: $189 billion and 30 - 40 years

Extra cost to properly relocate reactors' diesel backup generators < $200 million

Cost numbers affirm old proverb "An ounce of prevention is worth a pound of cure"



Backup generators located *underground*; flooded when a 13 m tsunami wave struck

Lattice Energy LLC, Copyright 2017 All rights reserved

Fukushima reactor owner TEPCO ignored Black Swan events

Warned in 2006: refurbish facility to boost its resilience to larger tsunamis

"The Fukushima disaster - systemic failures as the lack of resilience"

E. Hollnagel & Y. Fujita *Nuclear Engineering and Technology* 45 pp. 13 - 19 (2013)

http://www.sciencedirect.com/science/article/pii/S1738573315300024

"Unexampled events represent those occurrences that are virtually impossible to imagine, and which exceed the organisation's collective experience. What happened at Fukushima on March 11, 2011 clearly falls into that category. Design related anticipation should look at least to the irregular threats, but should also acknowledge the possibility of unexampled events."

"Scale of the March 2011 Tohoku earthquake was much larger than the design basis, and the height of the Tsunami was twice what had been assumed. The tsunami wall was designed to withstand a 5.7 meter wave, which was far too little in the actual case."

"After the Tsunami had happened, it became clear that a historical study had revealed that a much larger Tsunami occurred in the middle of the ninth century (estimated to be in AD 869), and that a researcher had made a strong recommendation for refurbishment of the plant in 2006 [reactors had operated without serious incidents since first of 6 was built in 1967]. But, recommendation was reportedly turned down for the reason that the tsunami was hypothetical, and because the claimed evidence was not accepted by specialists in the nuclear sector."

Lattice Energy LLC, Copyright 2017 All rights reserved

2006: TEPCO had a chance to reduce risk to backup gensets

Black Swan of losing all electricity deemed too improbable to worry about

"The Fukushima disaster - systemic failures as the lack of resilience"

E. Hollnagel & Y. Fujita – continued (2013)

"Complacency … came from a strong belief among experts that the plant design was perfect. It was therefore, in practice, unthinkable for them to imagine a situation where the plant would totally lose electricity, and consequently totally lose its cooling capability. In Westrum's terminology (op. cit.), this was not just an irregular threat, it was an unexampled event. We thus see that the neglect of scientific advice was most grave; scientists did point out that a much larger Tsunami might hit the nuclear power plant, and that the plant needed to be modified for it to be able to survive. But this was one of the conditions that were discarded, because they were seen as being too improbable … Low probability events [were] simply left out."

"One lesson learnt from the accident of the Fukushima nuclear power plant is that we need to think not only about how the plant should work and respond to regular threats, but also how it possibly could have or acquire the properties that would make it resilient. In the case of Fukushima, it appears that the assumed technical perfection was a hindrance to even thinking of acquiring these properties."

Lattice Energy LLC, Copyright 2017 All rights reserved

If it's not too expensive to mitigate a Black Swan, you do it !!!

"Resilience engineering advocates … we be mindful of overconfidence"

"The Fukushima disaster - systemic failures as the lack of resilience"

E. Hollnagel & Y. Fujita - continued (2013)

"It is hardly a surprise that people in the nuclear industry generally believe in the accuracy of technical analyses and expert judgements, at least until an accident actually happens. For this reason an accident is, for most of them, really a bolt out of the blue – an unexpected and unexampled event. It is all too easy to find statements from experts who once were full of confidence in the theoretical bases of the design, as well as the rationality of their practical assumptions, but who later regretted their short-sightedness. It has repeatedly been reported by the Japanese media that the commissioner of the Nuclear Safety Commission (NSC) of Japan apologetically admitted that their judgement to exclude the consideration of a Station Blackout (SBO) was a mistake. It is known that a working group of NSC in 1993 pointed out that an SBO was possible, but that the NSC and the government did not listen to the advice."

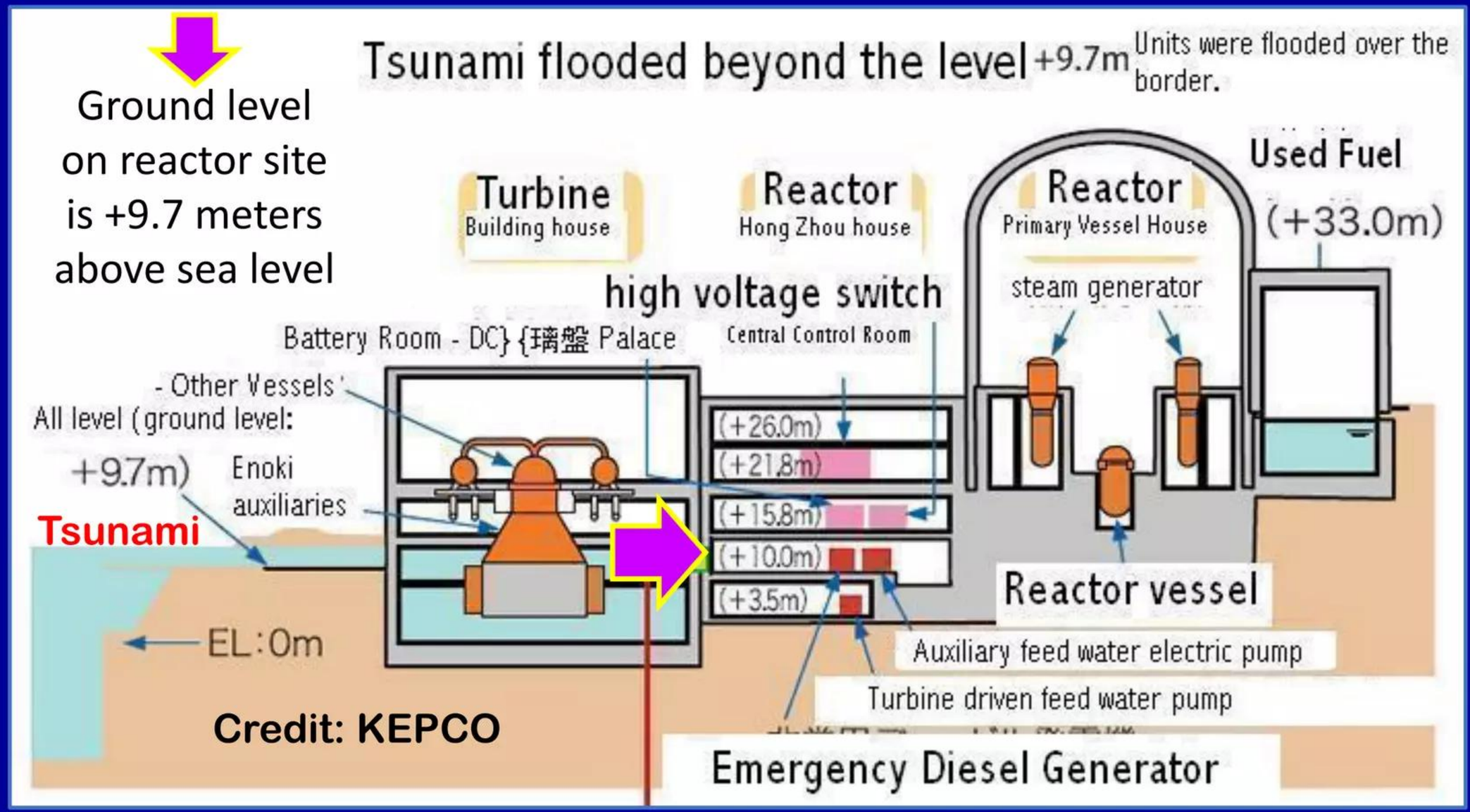
"Because severe accidents are very rare, we easily become overconfident in the analysis methods. The reasoning seems to go something like this: We have analysed the possible risks; we have built the installation following the recommendations; and we have operated safely for *n* years – whatever *n* is. This reasoning is, however, fallacious, because the absence of a failure does not prove that the precautions were correct, or even sufficient."

Lattice Energy LLC, Copyright 2017 All rights reserved

KEPCO graphic shows why backup generators were flooded

Diesel gensets only +10 meters above sea level (EL); tsunami +13 meters

"Main portion of plant sits between 9.7 and 15 meters above sea level with many key pieces of equipment below that level … equipment in pink and red in diagram below are key components such as important pumps, electrical panels, diesel generators and the control rooms …. it is easy to see potential risks at for many key systems."



http://www.fukuleaks.org/web/?p=6248

Lattice Energy LLC, Copyright 2017 All rights reserved

Japanese very aware of risks from earthquakes and tsunamis

Black Swan mitigation would have avoided fragility of backup generators

"Fukushima disaster was preventable, new study finds"

"Critical backup generators were built in low-lying areas at risk for tsunami damage - despite warnings from scientists"

USC News

By Robert Perkins, September 21, 2015

USC University of Southern California

https://news.usc.edu/86362/fukushima-disaster-was-preventable-new-study-finds/

"Worst nuclear disaster since the 1986 Chernobyl meltdown never should have happened, according to a new study. In the peer-reviewed *Philosophical Transactions A of the Royal Society*, researchers Costas Synolakis of the USC Viterbi School of Engineering and Utku Kânoğlu of the Middle East Technical University in Turkey distilled thousands of pages of government and industry reports and hundreds of news stories, focusing on the run-up to the Fukushima Daiichi disaster in 2011. They found that 'arrogance and ignorance,' design flaws, regulatory failures and improper hazard analyses doomed the coastal nuclear power plant even before the tsunami hit. 'While most studies have focused on the response to the accident, we've found that there were design problems that Synolakis, led to the disaster that should have been dealt with long before the earthquake hit,' said professor of civil and environmental engineering at USC Viterbi. 'Earlier government and industry studies focused on the mechanical failures and buried the lead. The pre-event tsunami hazards study, if done properly, would have identified the diesel generators as the linchpin of a future disaster. Fukushima Daiichi was a sitting duck waiting to be flooded'."

Lattice Energy LLC, Copyright 2017 All rights reserved

Japanese very aware of risks from earthquakes and tsunamis

Refurbishment could have mitigated risks of larger Black Swan tsunamis

"Fukushima disaster was preventable, new study finds"

USC News

By Robert Perkins – continued September 21, 2015

USC University of Southern California

"Synolakis and Kânoğlu report that the Tokyo Electric Power Co. (TEPCO), which ran the plant, first reduced the height of the coastal cliffs where the plant was built, underestimated potential tsunami heights, relied on its own internal faulty data and incomplete modeling and ignored warnings from Japanese scientists that larger tsunamis were possible."

"Prior to the disaster, TEPCO estimated that the maximum possible rise in water level at Fukushima Daiichi was 6.1 meters — a number that appears to have been based on low-resolution studies of earthquakes of magnitude 7.5, even though up to magnitude 8.6 quakes have been recorded along the same coast where the plant is located."

"This is also despite the fact that TEPCO did two sets of calculations in 2008 based on datasets from different sources, each of which suggested that tsunami heights could top 8.4 meters — possibly reaching above 10 meters. During the 2011 disaster, tsunami heights reached an estimated 13 meters at Fukushima Daiichi — high enough to flood all of the backup generators and wash away power lines."

Lattice Energy LLC, Copyright 2017 All rights reserved

Future impact of climate change on grids is *terra incognita*

Complex problem: insure future reliability and resiliency of electric power

Cost-effective use of electric grid's existing power generation assets

Remember very expensive lessons of Fukushima!

Ongoing climate change creates extreme weather events

Fragility vs. Resilience and Reliability

Weather events more frequent in near-term future

Rise of renewables: disruptive shift in power generation technology

Greener is better, right?
Caveat: could be much less reliable in future

Urgent need to reduce societal CO_2 emissions

Lattice Energy LLC, Copyright 2017 All rights reserved

Climate change creates new risks: some unknown unknowns

“There are known knowns; there are things we know that we know. There are known unknowns; that is to say, there are things that we now know we don't know. But there are also unknown unknowns - there are things we do not know we don't know.”

Donald Rumsfeld
U.S. Secretary of Defense
Press conference (2002)

Credit: AFP - Getty Images

Lattice Energy LLC, Copyright 2017 All rights reserved

Climate change boosts frequency of extreme weather events

Quoted from press release by Northeastern University on July 30, 2014

"By now, most scientists --- 97 percent of them, to be exact --- agree that the temperature of the planet is rising … until recently, the jury was still out regarding the variability surrounding that increase --- for example, how much difference there will be between the hottest hot days from one year to the next, as well as with each year's coldest cold days."

"Kodra and his adviser Auroop Ganguly, a climate change expert and associate professor in Northeastern's Department of Civil and Environmental Engineering, decided to take a different approach in their paper published … in *Scientific Reports*, published by *Nature*."

"They found that while global temperature is indeed increasing, so too is the variability in temperature extremes. For instance, while each year's average hottest and coldest temperatures will likely rise, those averages will also tend to fall within a wider range of potential high and low temperate extremes than are currently being observed."

"This means that even as overall temperatures rise, we may still continue to experience extreme cold snaps, said Kodra. 'Just because you have a year that's colder than the usual over the last decade isn't a rejection of the global warming hypothesis,' Kodra explained."

https://news.northeastern.edu/2014/07/climate-change-research-goes-to-the-extremes/

Lattice Energy LLC, Copyright 2017 All rights reserved

Climate change/global warming cause hot and cold extremes

Data indicates increased frequency of very hot and cold weather events

"Asymmetry of projected increases in extreme temperature distributions"
E. Kodra & E. Ganguly *Scientific Reports* 4 article #5884 (2014)

https://www.nature.com/articles/srep05884.pdf

"In general, there is consensus: asymmetry is greater than zero for more than 80% of the data points used in the analysis. The most dramatic asymmetry is found for winter minima events, especially those over ocean."

"Over land, the asymmetry is particularly pronounced for summer maxima and winter minima. From an impacts perspective, these are important to note since they suggest a wider range of temperature extremes within each season. Over land, summer maxima events show more asymmetry than summer minima. Dichotomously, winter minima events exhibit larger asymmetry than winter maxima over land."

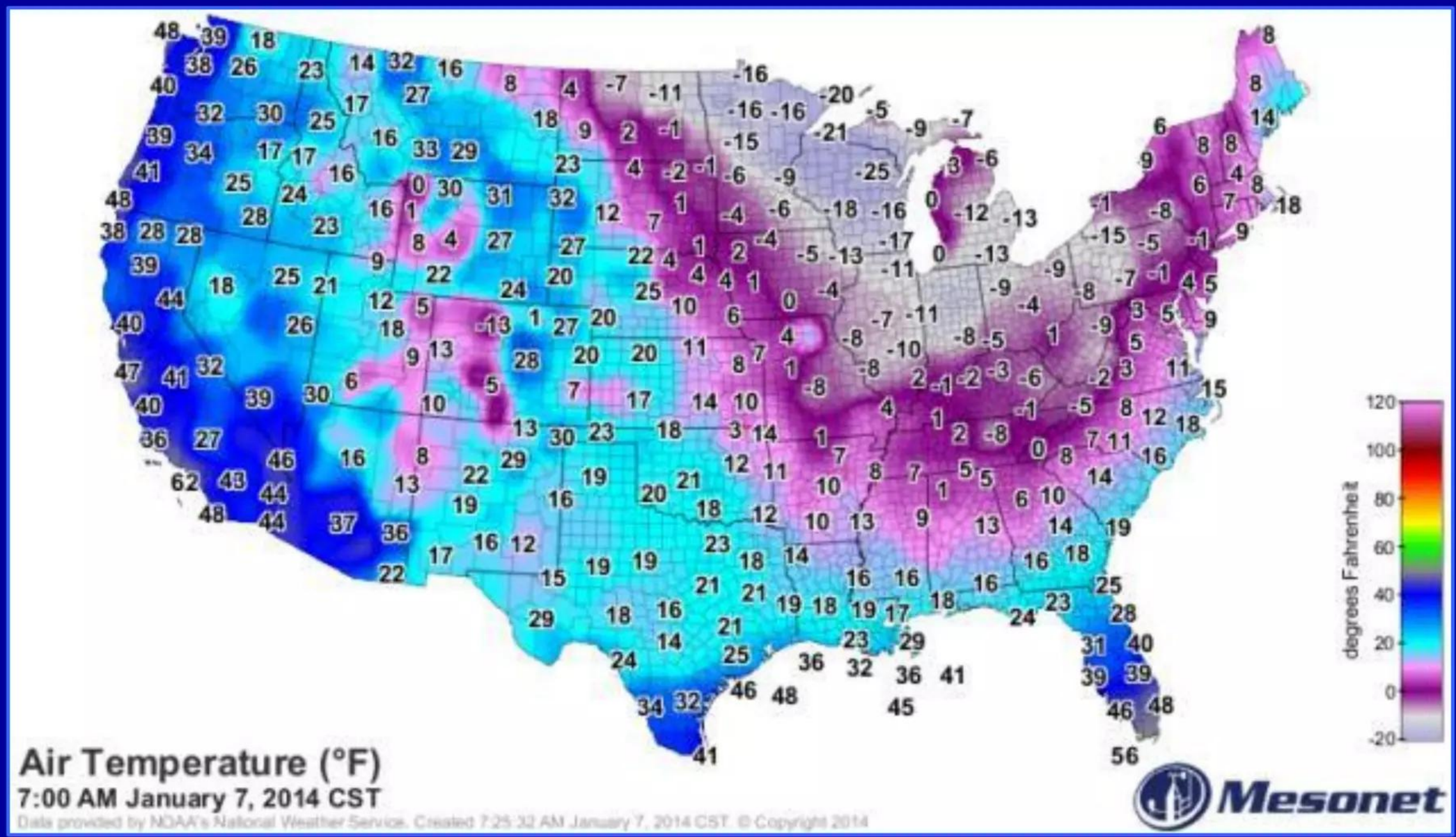
"Recent research suggests that Arctic amplification of warming could lead to increases in the probability of both cold and heat waves in the mid-latitudes"

Lattice Energy LLC, Copyright 2017 All rights reserved

Temperatures at 7:00 AM on Jan. 7, 2014 during polar vortex

Extremely cold air temperatures affected almost the entire United States

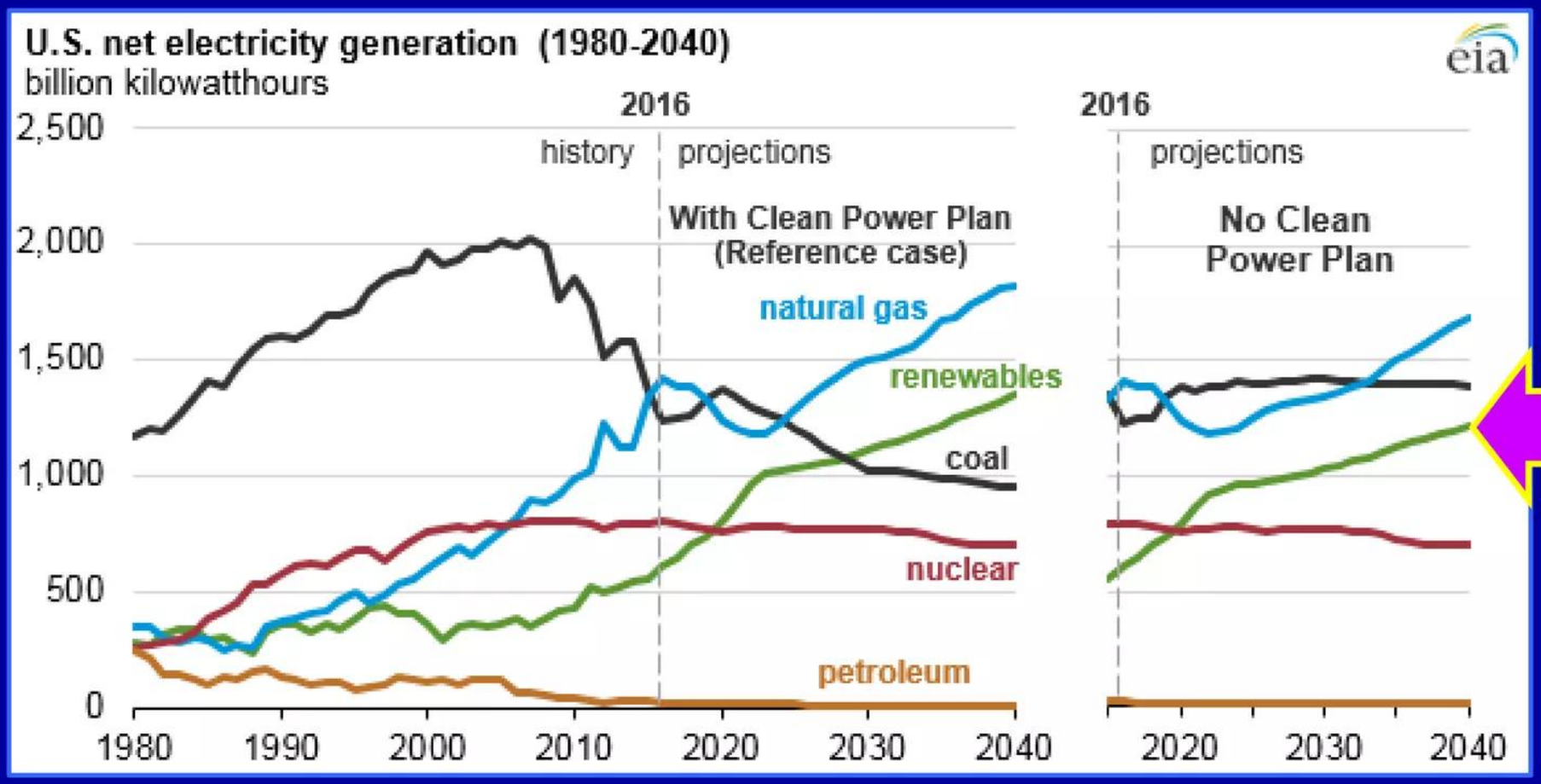
Significant probability that similar or even worse event could happen in near-term



Lattice Energy LLC, Copyright 2017 All rights reserved

Electricity generation by source: EIA projections out to 2040

Although Trump repealed Clean Power Plan renewable projection remains



EIA opinion: "Without the Clean Power Plan, there is less incentive to switch from carbon-intensive coal to less carbon-intensive natural gas or carbon-free fuels such as wind and solar. In the scenario where the Clean Power Plan is not implemented, coal again becomes the leading source of electricity generation by 2019 and retains that position through 2032, longer than in the Reference case, which includes the Clean Power Plan. Electricity generation from renewable sources remains below coal-fired electricity generation through 2040. Fewer coal plants are retired, and as a result, natural gas and renewable capacity additions are lower compared with Reference case."

Lattice Energy LLC, Copyright 2017 All rights reserved

June 2017: wind & solar produced 10% of all U.S. electricity

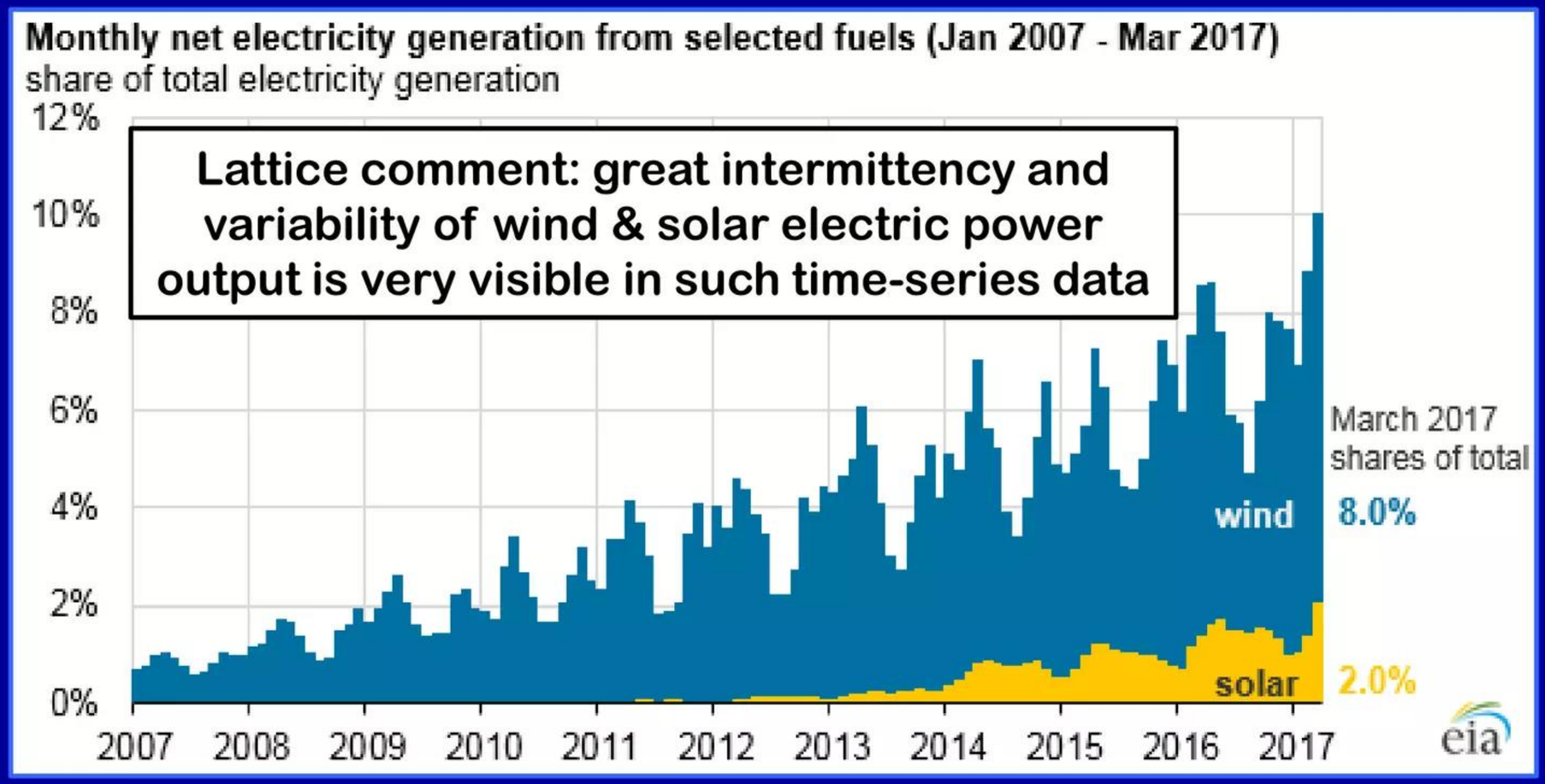
Highest-ever % of renewable electric power generation in grid's history

Grid power getting greener but also more vulnerable to extreme weather events

eia Independent Statistics & Analysis
U.S. Energy Information Administration

JUNE 14, 2017

Wind and solar in March accounted for 10% of U.S. electricity generation for first time



https://www.eia.gov/todayinenergy/detail.php?id=31632

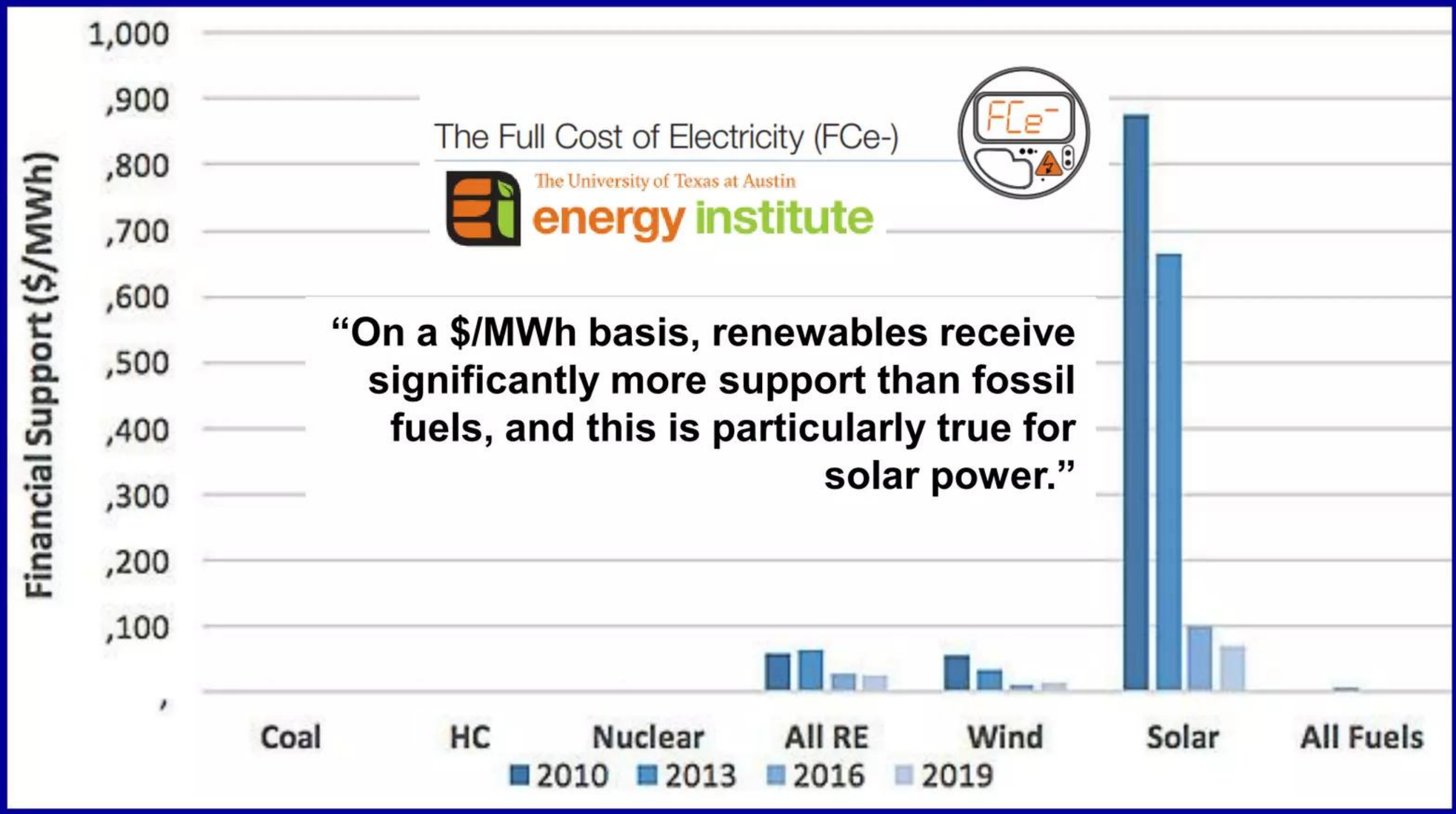
Lattice Energy LLC, Copyright 2017 All rights reserved

Obama administration 2008 - 2016 had "thumb on the scale"

Recent regulatory environment and $$$$$ subsidies favored renewables

White paper: "Federal financial support for electricity generation technologies"

UT Austin (2017) – Fig. 4 "Per-megawatt-hour subsidy by type and fuel" (US$/MWh)



https://spectrum.ieee.org/energywise/energy/policy/how-much-does-the-us-government-subsidize-electricity-generating-technologies

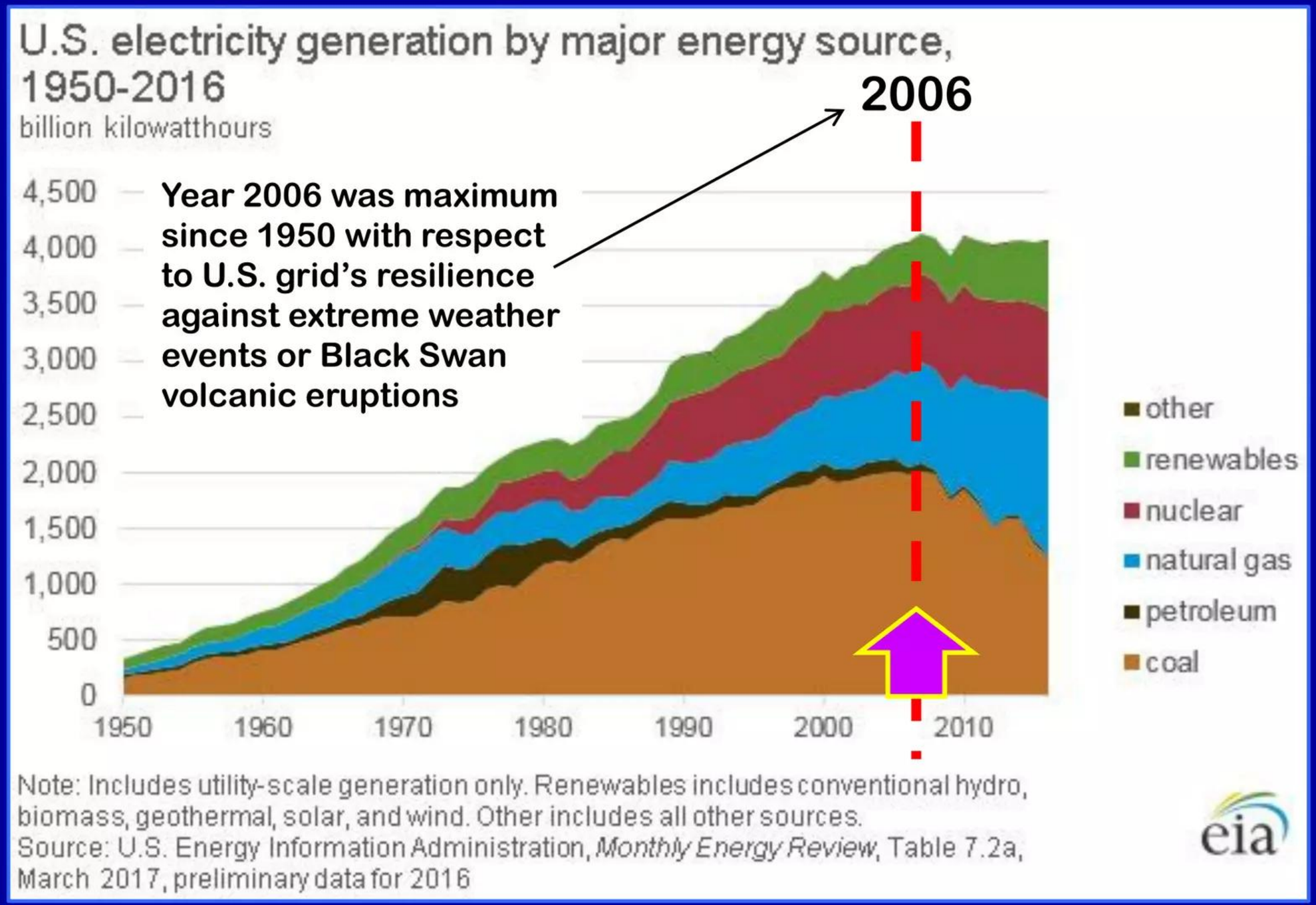
https://live-energy-institute.pantheonsite.io/sites/default/files/UTAustin_FCe_Subsidies_2017_June.pdf

Lattice Energy LLC, Copyright 2017 All rights reserved

Electricity generation by source: EIA data from 1950 - 2016

Since 2006 coal decrease offset by increases in renewables & natural gas

Coal and nuclear can store 3 - 18 months of fuel onsite; renewables & gas cannot



Lattice Energy LLC, Copyright 2017 All rights reserved

Climate change increases number of extreme weather events

Trend since 1984 is clear: reliability of U.S. electricity grids being affected

CLIMATE CENTRAL

BLACKOUT: EXTREME WEATHER, CLIMATE CHANGE AND POWER OUTAGES

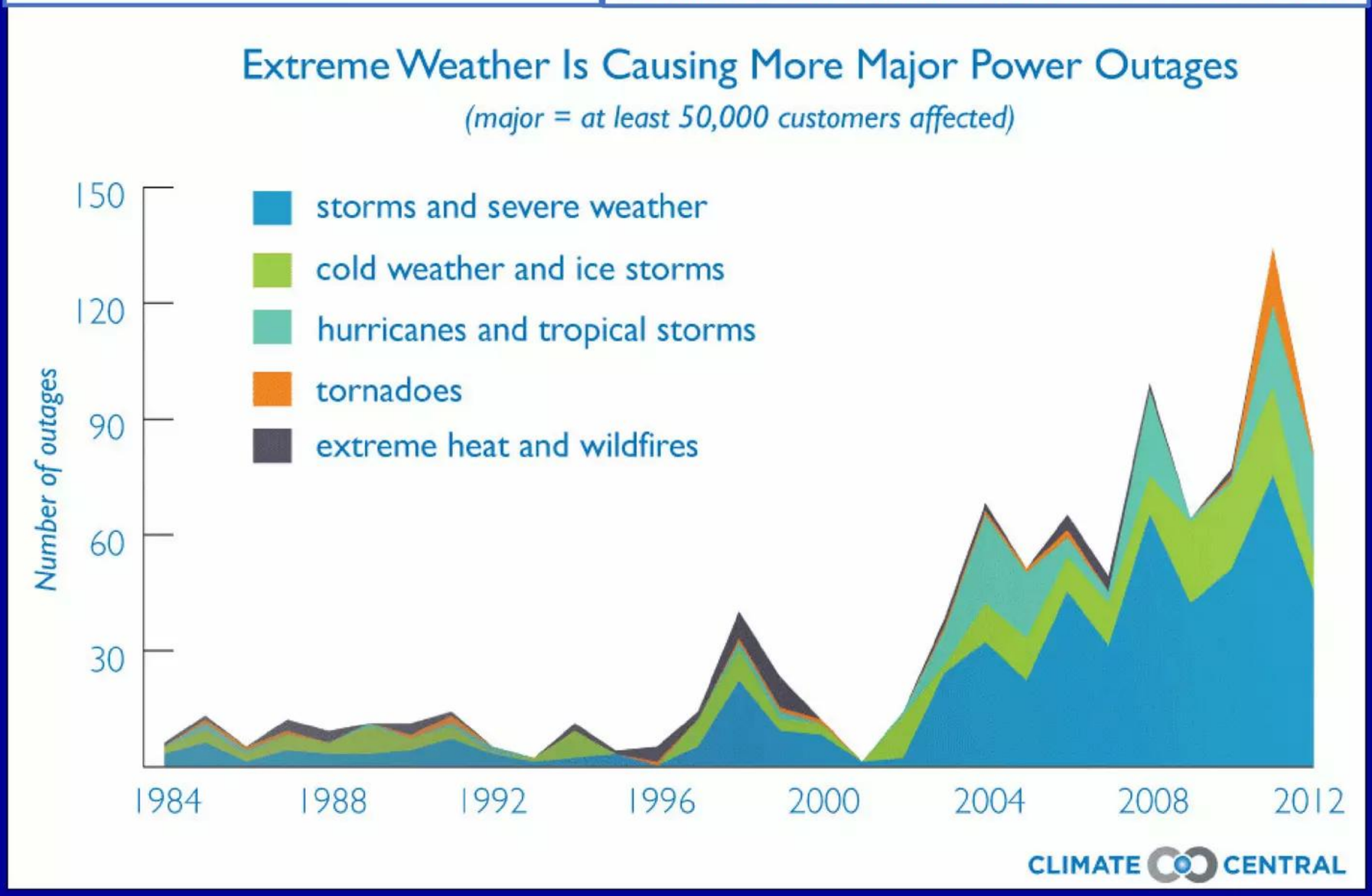


Figure in Summary on pp. 3 of report by A. Kenward and U. Raja, Climate Central (2014)

http://assets.climatecentral.org/pdfs/PowerOutages.pdf

Lattice Energy LLC, Copyright 2017 All rights reserved

Volcanic eruptions are very unpredictable Black Swan events

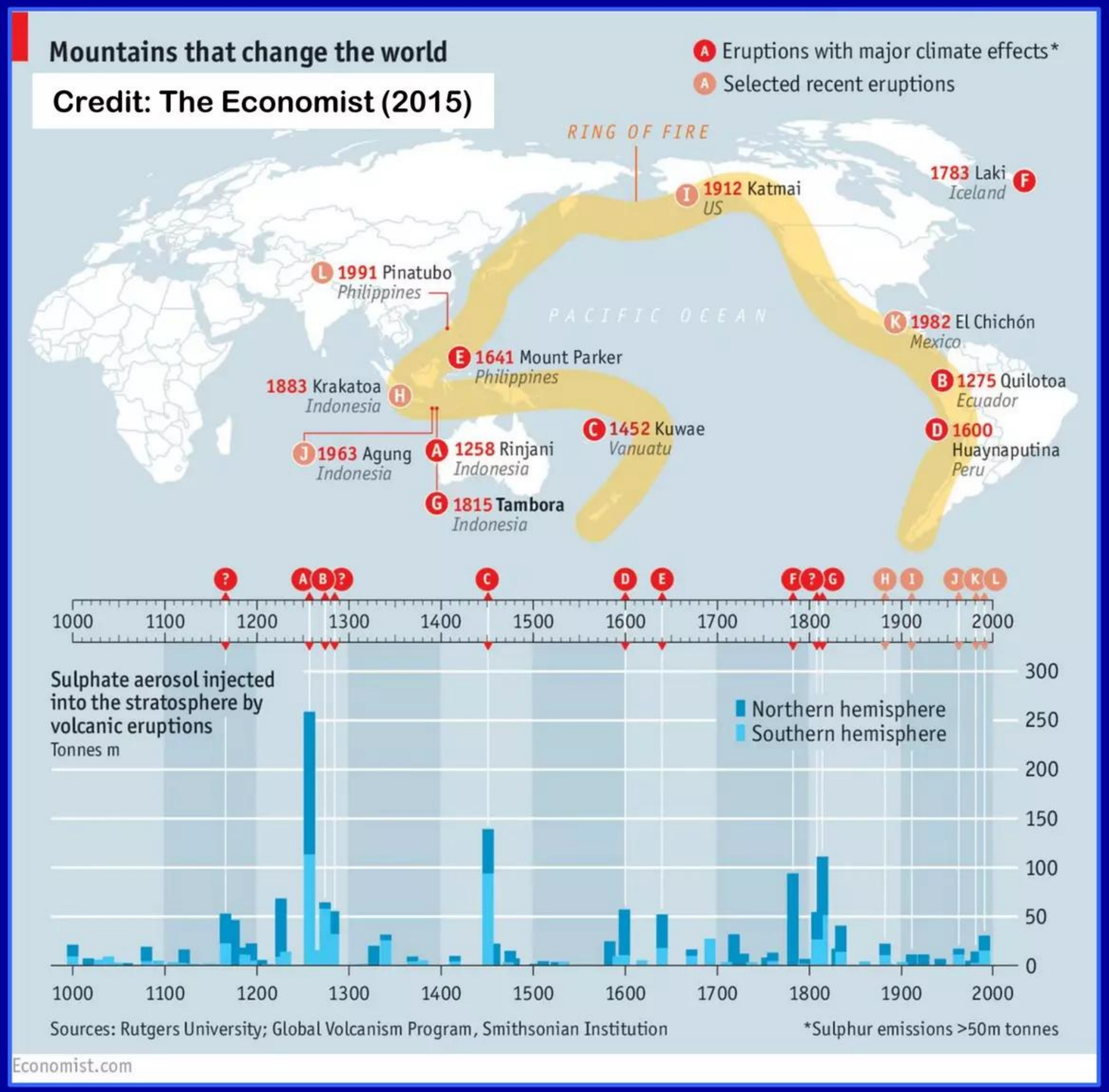
Depending on total volume and composition of gases and dust forcefully injected into Earth's atmosphere, volcanic eruptions can drastically reduce electric power output from renewable energy sources over distances up to thousands of miles and time periods ranging from days to months to years

Dust plume from eruption of Mt. St. Helens in Oregon, USA (1980)

Lattice Energy LLC, Copyright 2017 All rights reserved

Major eruptions that can affect global climate occur randomly

Dust & SO_2 will reduce sunlight & temporarily lower global temperatures



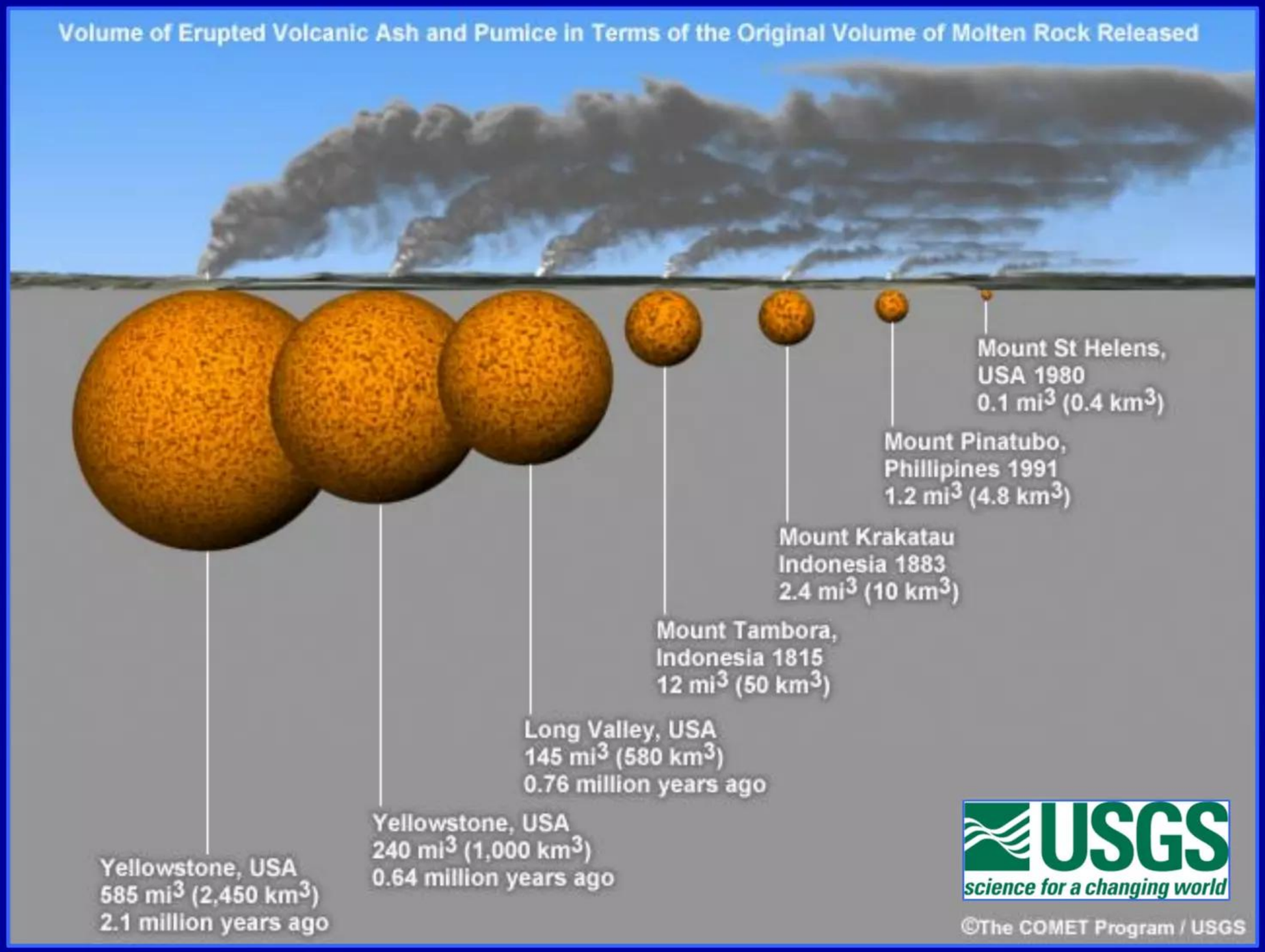
1991: Pinatubo released 17 megatons of SO_2 or sulfur dioxide into atmosphere, causing global cooling by 0.5 °C (0.9 °F) between 1991 - 1993. Dust from its ash cloud was deposited up to 1,300 miles away

Lattice Energy LLC, Copyright 2017 All rights reserved

Vastly larger volcanic eruptions have occurred in Earth's past

Mt. Pinatubo (1991) was 1,450x less dust than Long Valley, California blast

Ability of scientists to predict huge eruptions years ahead of event is nonexistent



Lattice Energy LLC, Copyright 2017 All rights reserved

Huge volcanic eruptions can drastically affect world 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."

Lattice Energy LLC, Copyright 2017 All rights reserved

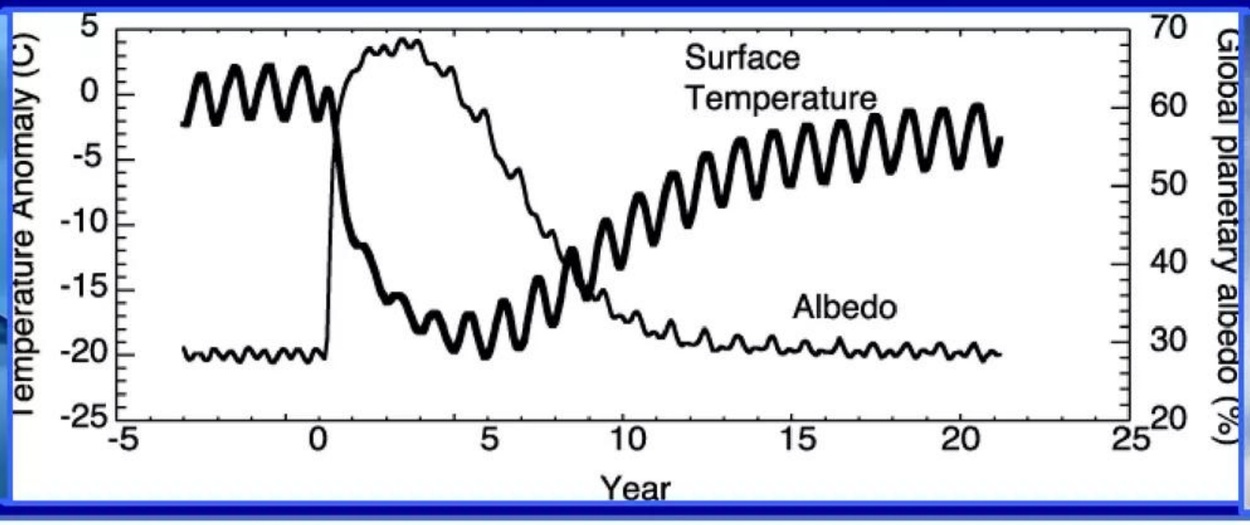
Toba eruption 74,000 yrs. ago greatly affected Earth's climate

If this happened in 2050 with 95% renewables … *adios* to electric power

"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."

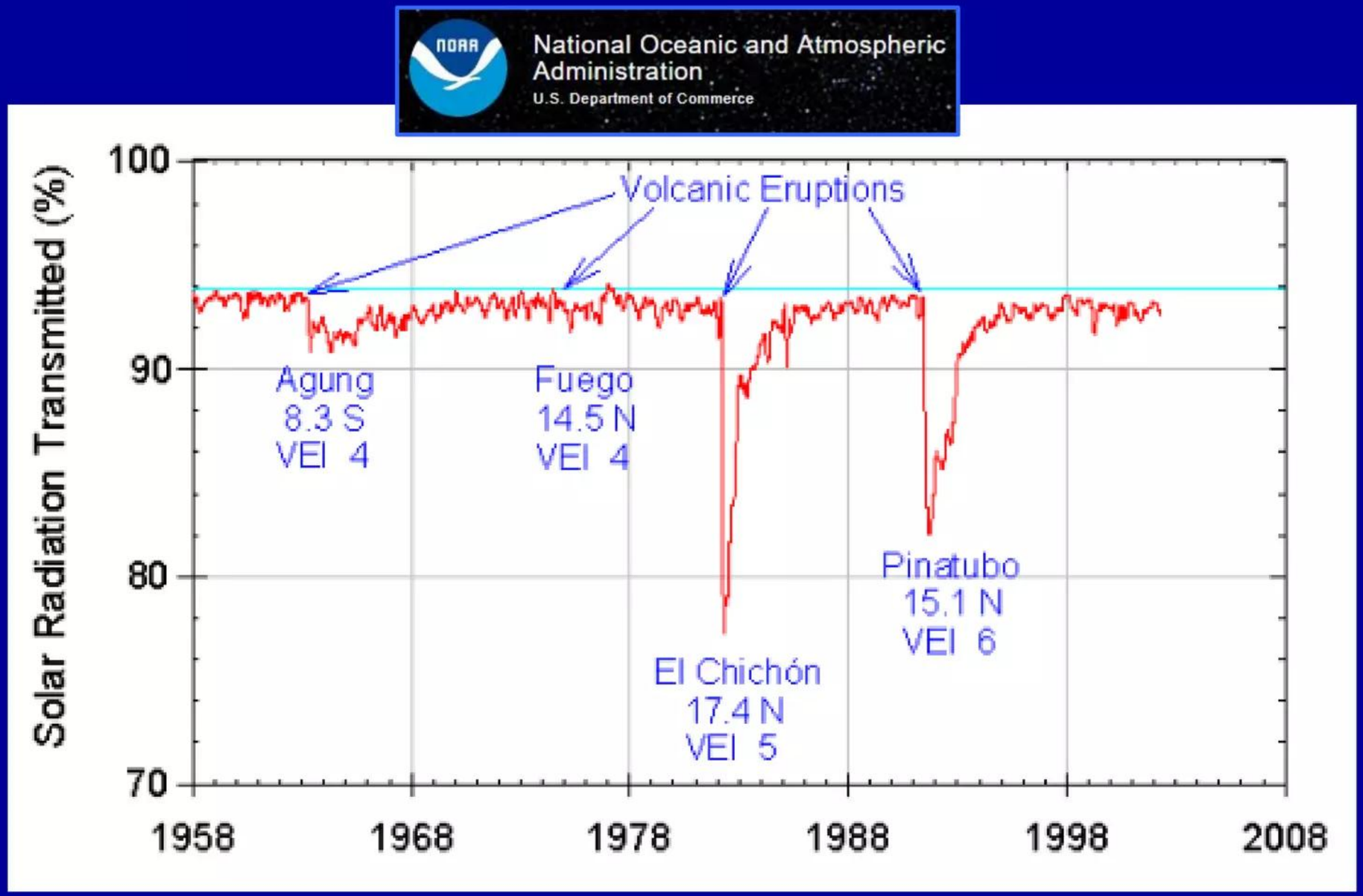
Lattice Energy LLC, Copyright 2017 All rights reserved

Large volcanic eruptions can reduce sunlight on global scale

El Chichón (1982) substantially cut world's sunlight ~16%; Pinatubo ~10%

Enormous volcanic eruptions can reduce solar power output across entire world

Atmospheric transmission at Mauna Loa Observatory in Hawaii



Lattice Energy LLC, Copyright 2017 All rights reserved

Lightning in dust plume from Eyjafjallajökull volcano (2010)

Eruption tiny vs. Mt. St. Helens but dust still disrupted European air traffic

www.stefnisson.com
© Sigurður Hrafn Stefnisson

Lattice Energy LLC, Copyright 2017 All rights reserved

Volcanic ash from eruptions cuts power output from solar PV

Fine ash causes greater reduction and is carried much further by winds

"Influence of volcanic tephra on photovoltaic (PV)-modules: an experimental study with application to the 2010 Eyjafjallajökull eruption, Iceland"

E. Zorn & T. Walter *Journal of Applied Volcanology* (2016)

https://link.springer.com/article/10.1186/s13617-015-0041-y

Abstract: "Large volcanic eruptions may lead to significant tephra dispersion, crossing borders and affecting distant and industrial societies in various ways. While the effects of volcanic ash clouds on the aviation industry have been recognized, damaging effects on the photovoltaic energy sector are poorly investigated. Here we describe the influence of volcanic tephra deposition on photovoltaic (PV) modules that we experimentally analyzed and evaluated. A systematic set of experiments was conducted under controlled conditions using an artificial light source and measuring the electrical power generated from the PV-modules with the aim to determine the dependency of the amount of tephra covering a module and its subsequent loss in power production (measured in voltage and current) as well as the influence of the tephra grain size. We find that a mass of fine tephra has a stronger influence on the PV-modules power generation than the same mass of coarser particles. An application to the fine-grained 2010 Eyjafjallajökull eruption in Iceland and the resulting ash-cloud reveals that the power produced by PV-modules in continental Europe might have been affected significantly. Deposits were thick enough to cause complete failures of PV-modules up to a distance of about 300 km downwind."

Lattice Energy LLC, Copyright 2017 All rights reserved

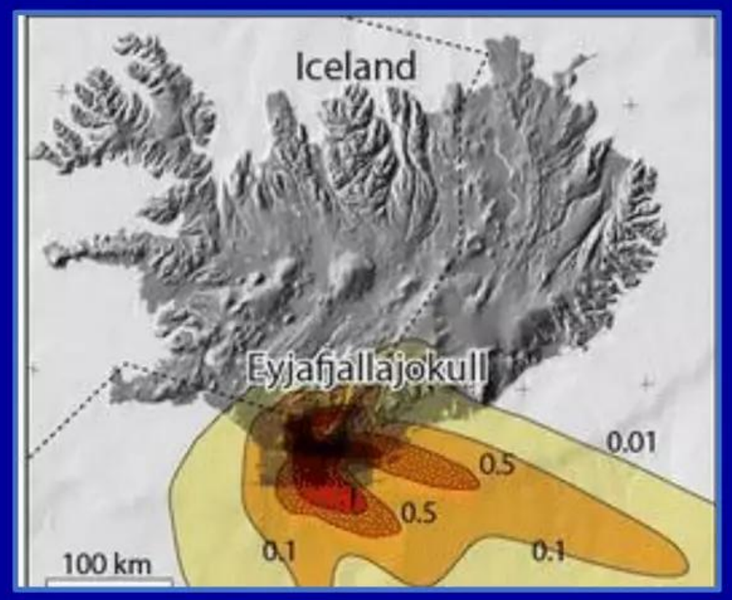
Winds carried ash from Eyjafjallajökull eruption to Europe

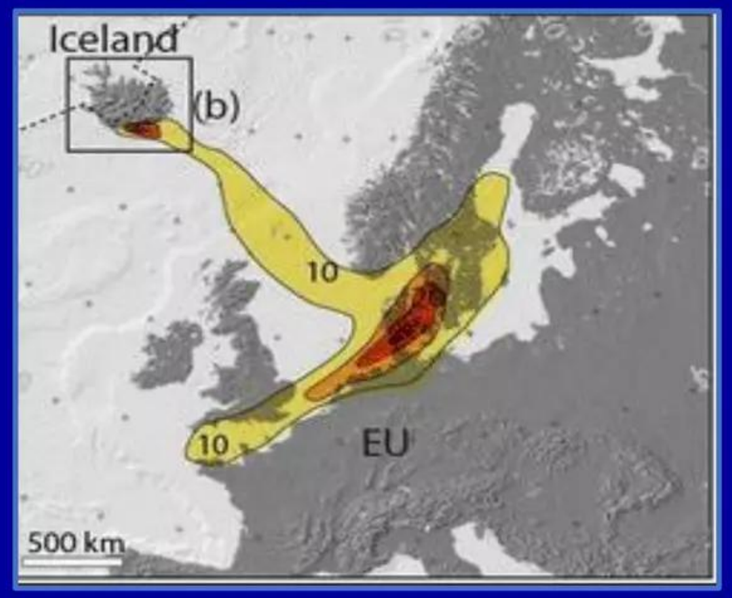
Covering solar PV panel with only 1 mm of fine ash can cause total failure

E. Zorn & T. Walter *Journal of Applied Volcanology* - continued (2016)

"From our experiments we find that a complete failure of the PV-modules would have occurred if tephra fall would have accumulated coarse ash >1.6 kg/m^2, or if fine ash would have exceeded 0.8 kg/m^2 (Fig. 5). During the 2010 eruption these values were indeed approached by a thin layer of ash only <1 mm thick, assuming a mean tephra density of 1400 kg/m^3 as determined in an independent study (Gudmundsson et al., 2012), which means ash deposition exceeding 1 mm would already cause a complete failure. A comparison to the tephra dispersion isopach maps shows that close to the volcano these values were exceeded by far. This 1 mm isopach extends as far as ~300 km downwind from the vent, therefore PV-modules located at this distance or closer would have experienced a complete failure. Even at much larger distance a significant loss in power is expected."

Fig 1. Zorn & Walter (2010)





Lattice Energy LLC, Copyright 2017 All rights reserved

Winds carried ash from Eyjafjallajökull eruption to Europe

Similar dust eruption in future could cut Europe's solar power up to 30%

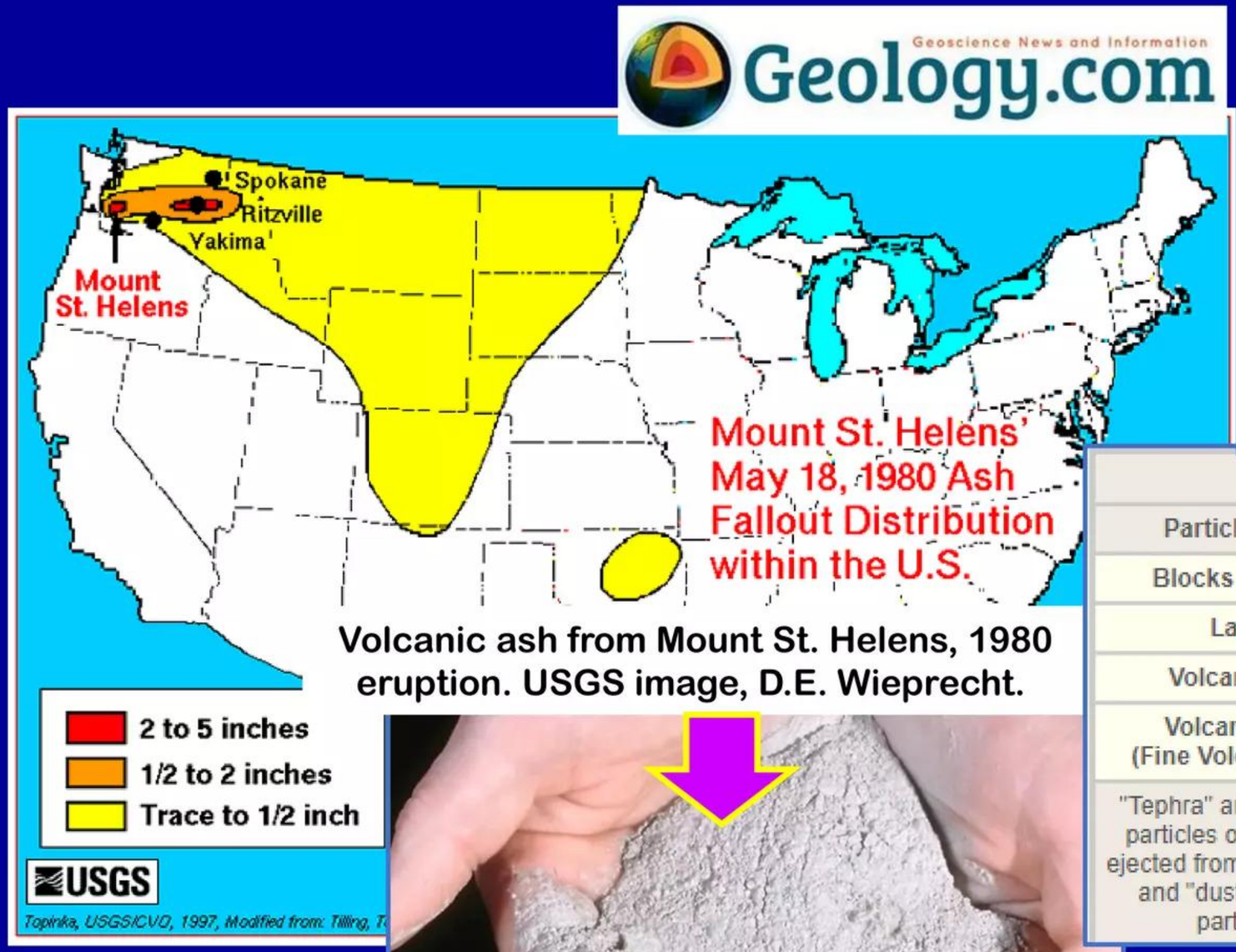
E. Zorn & T. Walter *Journal of Applied Volcanology* - continued (2016)

"We conducted experiments to explore the influence of volcanic tephra deposition on the power generation of PV-modules. Our experiments show that even minor loads of volcanic tephra deposited on a PV-module can severely decrease their performance. We showed that with an increasing tephra load, voltage decreases linearly whereas current displays an exponentially decreasing trend. We also found a strong grain size dependency, with finer particles causing a much more drastic decrease as coarser particles with the same tephra load. We applied our results to the 2010 Eyjafjallajökull eruption and found that the eruption had the capability to cause a complete failure of all PV-modules within 300 km downwind from the volcano and to reduce the electrical power generated by PV-modules in Europe by up to 30 % (although this value is likely an overestimate). The prolonged and constant generation of volcanic tephra, especially in fine grain size ranges, the suspension characteristics of the ash as well the southeastern wind conditions at the time were the main controlling factors governing the spread of the ash cloud and resulting in such widespread effects. With respect to the frequency of similar eruptions it is very likely that volcanic tephra will cause problems for electric power generated by PV-modules in the future."

Lattice Energy LLC, Copyright 2017 All rights reserved

Mt. St. Helens volcanic ash was deposited > 1,000 miles away

Solar PV power could be cut across large % of U.S. if this occurred today



Volcanic ash from Mount St. Helens, 1980 eruption. USGS image, D.E. Wieprecht.

"Volcanic ash consists of powder-size to sand-size particles of igneous rock material that have been blown into the air by an erupting volcano."

Tephra / Pyroclastic Terminology	
Particle Name	Particle Size
Blocks / Bombs	over 64 mm (2.5 inches)
Lapilli	under 64 mm (2.5 inches)
Volcanic Ash	under 2 mm (.079 inches)
Volcanic Dust (Fine Volcanic Ash)	under 0.063 mm (0.0025 inches)

"Tephra" and "pyroclastics" are general terms used in reference to particles of igneous rock material of various sizes that have been ejected from volcanoes. They are classified by size. The terms "ash" and "dust" communicate a specific size of tephra or pyroclastic particles. These are summarized in the table above.

http://geology.com/articles/volcanic-ash.shtml

Lattice Energy LLC, Copyright 2017 All rights reserved

Here Be Dragons

Prior to past several years, renewables comprised only small % of grid power generation in advanced economies. Today, it is quite different. Countries aggressively installing renewable capacity presently have no collective experience with the impact of extreme weather events or Black Swan eruptions on modern grids having a high % of renewable power. Germany's *Energiewende* is furthest along utopian pathway to 100% renewable energy --- its results to date indicate German grid is less resilient and much more fragile to effects of extreme weather events.

Lattice Energy LLC, Copyright 2017 All rights reserved

Like dire warning to TEPCO in 2006 re serious vulnerability of Fukushima reactor complex to Black Swan tsunamis …

Recent extreme weather events have issued warnings!

Excessive % of renewables in power grids reduces resilience

2014: short-lived icy cold Polar Vortex event nearly caused blackout of U.S. Northeastern grid

2015: 6-month wind 'drought' across U.S. West Coast reduced wind power output by ~ 20%

2016 - December: Germany's renewable electric power output was slashed twice during same month for 100 hrs and 50 hrs, respectively

2017 - January (Europe): one month with almost no sun or wind; on January 24, Germany narrowly avoided a national electric power blackout by dispatching last-available coal power plant

2018 - Due to climate change, significant chance for extremely cold Polar Vortex events this winter and heat extremes in summer; PV-killer Black Swan volcanic eruptions are possible anytime

Lattice Energy LLC, Copyright 2017 All rights reserved

What could happen in future if U.S. grid power suppliers and FERC regulators ignore warning signs re % of renewables?

Photo by Bob Gomel - Getty: dusk in New York City Nov. 1965: "Great Northeast blackout, which began when a power surge near Ontario set off a chain of failures across New York State and beyond, covered 80,000 square miles. 'Within four minutes the line of darkness had plunged across Massachusetts all the way to Boston,' reported *The New York Times.*" Brian Handwerk, National Geographic

Lattice Energy LLC, Copyright 2017. All rights reserved

German economist warns about excessive % of renewables

“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 Jan. 10, 2017

Lattice Energy LLC, Copyright 2017 All rights reserved

IHS issues warning about excessive % of renewable energy

"U.S. is moving toward less reliable, less resilient power generation mix"

IHS Markit IHS Markit Resilient and Efficient Electricity Generation Special Report

"Ensuring resilient and efficient electricity generation: the value of the current diverse U.S. power supply portfolio" by L. Makovich & J. Richards, Sept. 2017

"IHS Markit report: eroding cost effective diversity in U.S. power grid will result in greater price fluctuations, higher power bills and create negative impacts throughout the economy"

"Ability to reduce the magnitude and duration of disruptive events is often taken for granted and is at increasing risk of eroding. The grid-based electricity supply portfolio in the United States is becoming less cost-effective, less reliable, and less resilient owing to a lack of harmonization between federal and state energy policies and wholesale electricity market operations. Policy-driven market distortions are delaying market adjustments to achieve a reliable long-run demand and supply balance, suppressing market-clearing wholesale electricity prices and reducing market-based generator cash flows. Consequently, some power plants that are critical to maintaining reliable, resilient, and efficient electric supply are retiring before it is economic to do so; and this acceleration in the turnover of the US electric supply portfolio is moving the United States toward a less cost-effective, less reliable, and less resilient power generation mix."

Lattice Energy LLC, Copyright 2017 All rights reserved

Renewable energy less costly vs. fossil-fuel & nuclear power

Assertion now hyped in media: depends on assumptions & time-horizons

During extreme weather events uninterruptible power is most $ valuable for grid

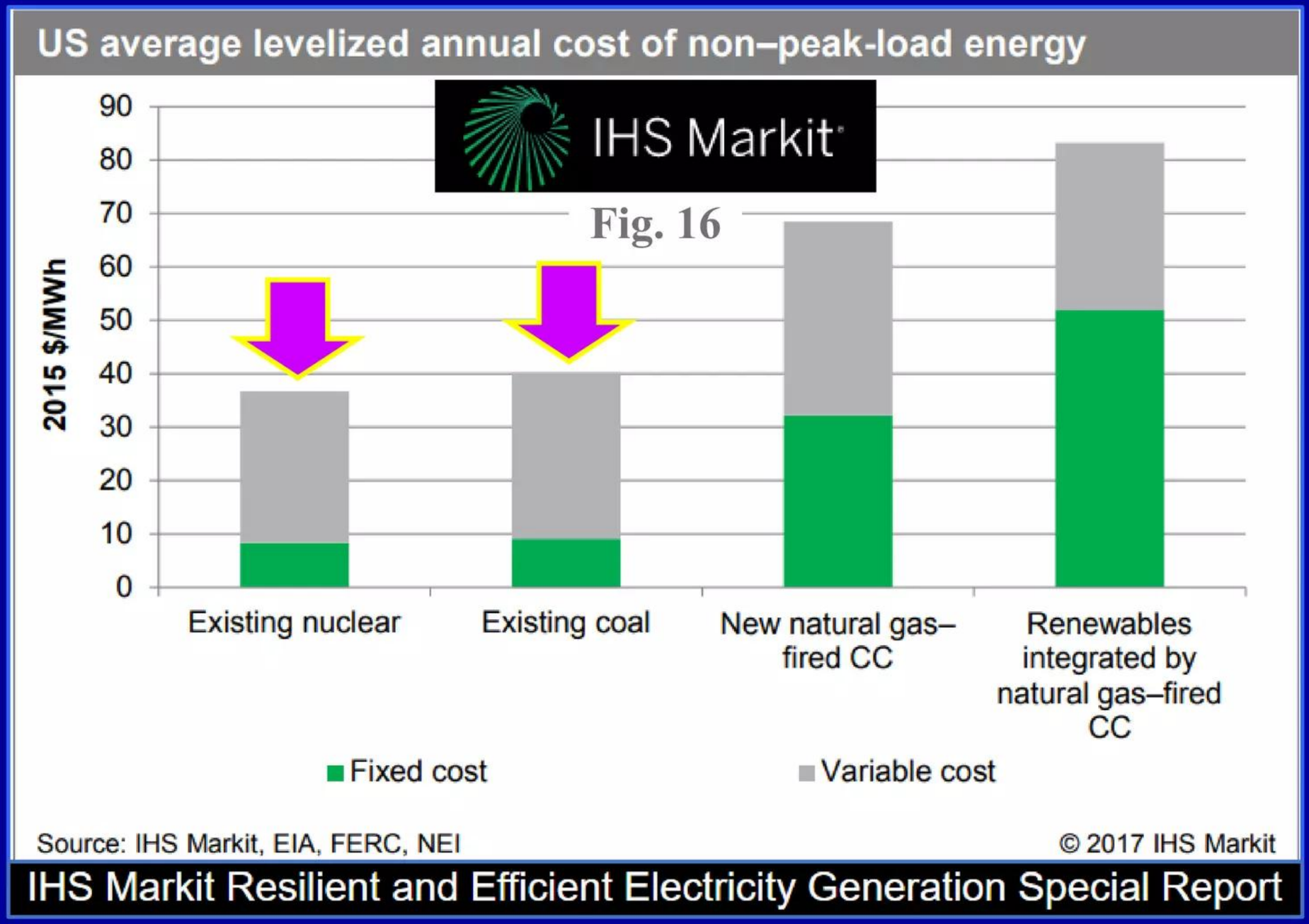
- Financial subsidies and regulatory environments have favored increase in renewable power generation capacity for a decade, so from an economics standpoint, competitive playing field has not been level for considerable time
- Under certain sets of assumptions and based on recent market data, at times it looks as though renewables are highly competitive with or even less costly than new fossil-fueled and nuclear power plants. Based on that data, overly zealous proponents of renewables argue that presently-struggling existing coal and nuclear plants should be allowed to close prematurely because they are "uneconomic" and moreover their power output can be replaced Watt-for-Watt with new solar and wind generation capacity - this logic is fatally flawed
- On next slide, IHS Markit shows how existing nuclear & coal are competitive
- During a windless, sunless, extreme Polar Vortex event, interruptible and intermittent Watts of power from renewable sources are worthless because they simply aren't being generated. Most $$$ valuable grid power sources during weather extremes are those that are effectively uninterruptible for duration of weather problems: nuclear and coal plants that have adequate onsite fuel storage to cover renewable power shortfalls during such events

Lattice Energy LLC, Copyright 2017 All rights reserved

IHS Markit argues that nuclear and coal are very competitive

Renewables integrated w. natural gas are higher $ vs. nuclear or coal

Existing nuclear & coal plants are cost-effective for grid power generation



https://www.ihs.com/Info/0917/electricity-generation-special-report.html

Lattice Energy LLC, Copyright 2017 All rights reserved

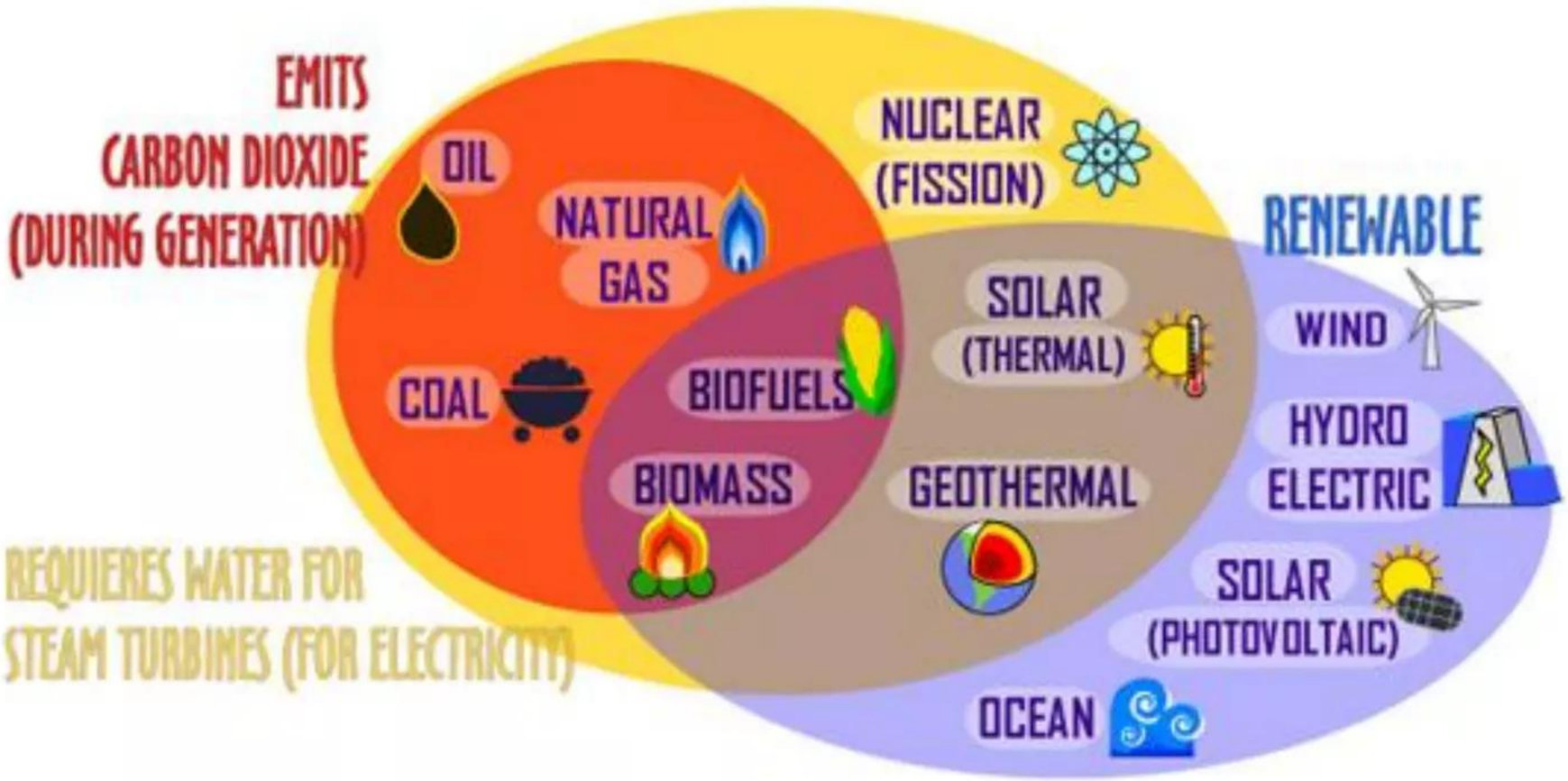
Unexampled event: high % of renewable energy in power grids

Today: only nuclear & coal able to provide resilient uninterruptible power

- High % of renewables in power grids is an "unexampled event" with no historical precedents and limited collective knowledge of such unmapped terrain. That said, one certainty is that climate change is ongoing and future extreme weather events will likely be occurring in the U.S. and elsewhere throughout the world
- One commonly overlooked key factor is that extreme weather events are not only getting more frequent, there is also a high probability that they could persist for much longer periods than recent historical weather data would indicate
- Example: worst part (lowest temperatures) of U.S. Polar Vortex event in 2014 only lasted several days. What would have happened to number of grid power outages if dangerous cold had instead persisted for an entire month or more?
- What emerges from analyzing this problematic issue is that in the future, $99^{+}\%$ uptime grids will need sufficient generation capacity from power sources having adequate onsite fuel storage so that they can provide uninterrupted power for entire duration of extreme weather or smallish Black Swan volcanic eruptions
- Today, only nuclear and coal plants are capable of delivering competitive low-cost, uninterruptible power to grids for several months nonstop. High economic and grid risk-management value of this power generation capability is not fully paid-for by 'normal' power markets when the sun is shining and winds blowing steadily; big contribution to resilience is only realized in extreme weather events

Lattice Energy LLC, Copyright 2017 All rights reserved

Recent warning signs strongly indicate that utopian goal of 100% renewable CO_2-free energy sources by 2050 *a la* Jacobson et al. (2017) is economically impractical, probably unattainable, and risky enough to be quite dangerous



Lattice believes balanced diversity of different types of grid power sources is best strategy for insuring 99^{+}% future reliability and excellent resiliency of electricity grids facing onslaughts of extreme weather events and low but non-zero probability for catastrophic Black Swan volcanic eruptions

Lattice Energy LLC, Copyright 2017 All rights reserved

Uninterruptible grid power generation will always be needed

Nuclear power is key component to insure 99+% grid availability in future

Recent gun violence in Chicago ended more lives than 60 years of nuclear power

- Today, nuclear fission plants are sole source of CO_2-free grid power capable of producing uninterruptible electricity for duration of worst-case extreme weather events or substantial portions of Black Swan volcanic eruptions. If these types of threats to future grid reliability are to be mitigated, nuclear is the only available technological option
- Unfortunately, the anti-nuclear lobby in the U.S. and elsewhere has been very effective at frightening the general public about radiation and waste dangers with fission power plants, e.g. not in my back yard
- What anti-nuclear advocates neglect to say is, except for bombing of Hiroshima and Nagasaki, nuclear technology has claimed less than 5,000 lives over past 60 years; > 5,000 people could easily perish in a scenario with 80% renewables and 4-month grid outage in mid-winter
- Comparison: gun violence in the city of Chicago, Illinois, has killed nearly 6,000 people over the past 10 years. Gun murders in Chicago are more numerous than radiation deaths from nuclear power to date

Lattice Energy LLC, Copyright 2017 All rights reserved

Natural gas and coal directly compete in power generation

Gas recently displaced large quantity of coal; this might change in future

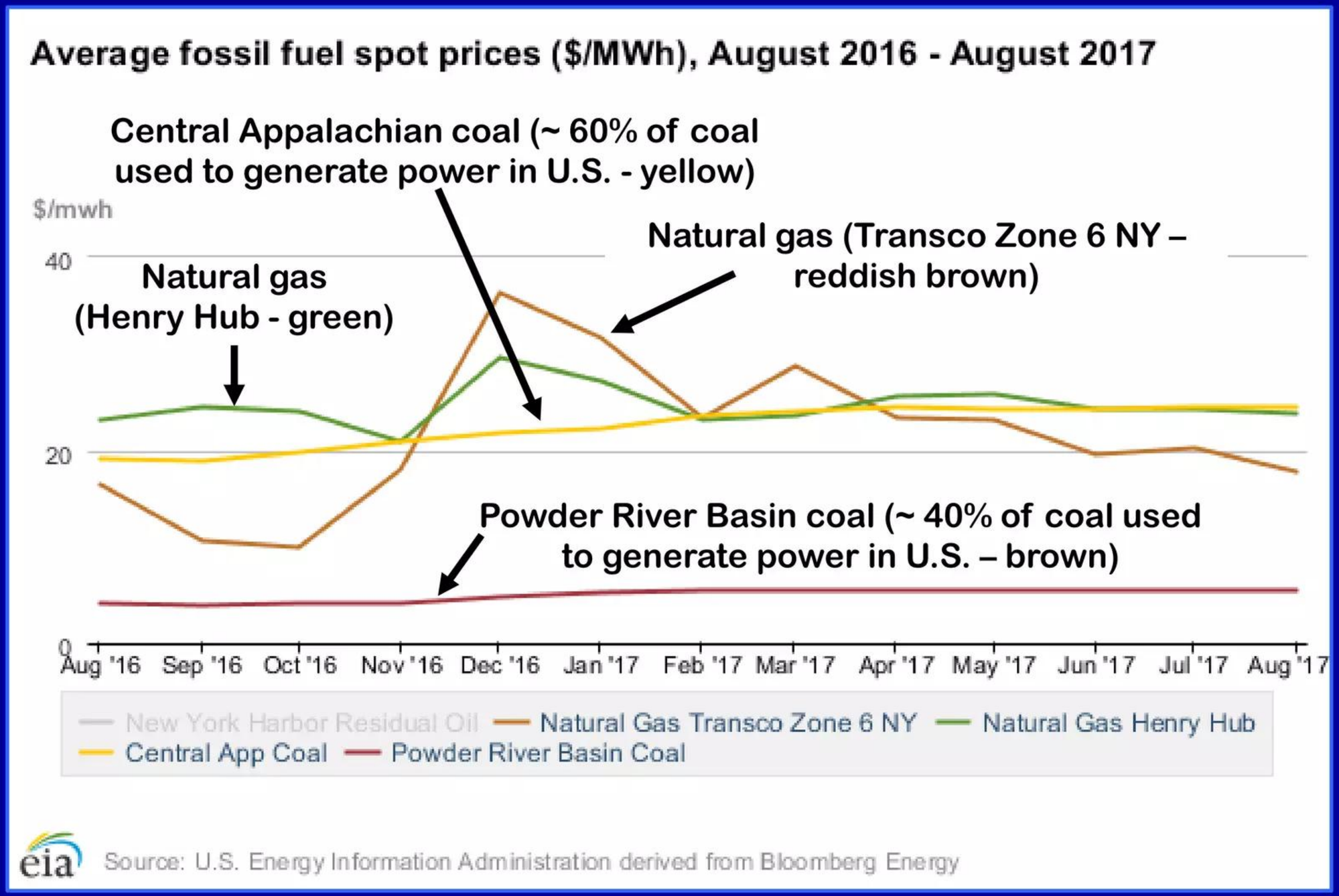
- In past 10 years, natural gas has strongly displaced coal in U.S. power generation, mainly due to depressed prices for increased supplies of natural gas resulting from fracking but also because it burns cleaner
- Natural gas pipeline operators are presently confident that current pipe capacities could handle demand increases during extreme cold snaps and grid outages should not occur along the lines of what happened in Northeastern U.S. grid during 2014 Polar Vortex event. Such extreme confidence is reminiscent of TEPCO's thinking that 13 m tsunamis were impossible and thus didn't merit any serious efforts to mitigate them
- New loading terminals now being built to enable first-time-ever large U.S. exports of liquified natural gas (LNG) to begin in 2018. There is no guarantee that extreme winter cold snap would not drastically increase U.S. natural gas prices and trigger intense competition between power plants, consumers heating homes, and exports for available supplies
- Besides fact that coal plants have 3-months of onsite fuel storage and gas plants have none, adequate coal-fired generation capacity on grids is good hedge against huge changes in supply/demand balance for gas

Lattice Energy LLC, Copyright 2017 All rights reserved

Price of natural gas vs. coal in $/MWh of generated electricity

Relative pricing below accounts for higher gas power plant efficiencies

Pricing of natural gas vs. coal could change bigly with increased LNG exports



Lattice Energy LLC, Copyright 2017 All rights reserved

Proverb: “An ounce of prevention is worth a pound of cure”

Too risky for society to put all its energy eggs into one renewable basket

Fukushima lesson: mitigate improbable extreme events if not too expensive; $200 million too costly to fix generators in 2006; ‘cure’ for 2011 costs $189 billion

- Assuming diverse, well-balanced mixture of energy sources producing electric power for grids is effective strategy for achieving 99^{+}% future grid reliability and very high resilience to extreme weather onslaughts and Black Swans, how should it be implemented? Devil is in the details
- Since high % of grid renewable energy sources is new phenomenon and unexplored territory, there aren’t preexisting road maps to guide government regulation and critical implementation by private industry
- Private companies by nature are concerned with short-term bottom line profitability and have more narrowly focused interests; by contrast, government is responsible for insuring national energy security over much longer time-frames and broader range of grid-threatening events
- Rick Perry/DOE’s controversial NOPR to FERC in September created an important opportunity for U.S. government and private industry to begin productive dialogue about how to enhance the U.S. electricity grid’s ability to maintain present reliability and adapt to climate change

Lattice Energy LLC, Copyright 2017 All rights reserved

Secretary Rick Perry/DOE's NOPR to FERC very reasonable

Lattice PowerPoint presentation covering this published Oct. 23, 2017

See presentation at URL below for details and source documents: 37 slides

https://www.slideshare.net/lewisglarsen/lattice-energy-llc-us-secretary-of-energy-rick-perrydoe-suggestions-to-ferc-re-improving-future-grid-resiliency-are-reasonable-oct-23-2017

Lattice Energy LLC

U.S. Secretary of Energy Rick Perry heavily criticized for controversial DOE letter to FERC re coal and nuclear power

Suggested coal and nuclear should be compensated somehow for special value to grid resiliency provided by uninterruptible power

Further suggested requirement for receiving such compensation would be that eligible dispatchable generation assets must be able to store enough fuel onsite to permit 90 days of uninterrupted electric power generation

Maybe DOE suggestions are reasonable when you get past energy politics?

Lewis G. Larsen
President and CEO
Lattice Energy LLC
October 23, 2017

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

Lattice Energy LLC, Copyright 2017 All rights reserved

Lattice Energy LLC, Copyright 2017 All rights reserved

Germany almost had a national blackout on January 24, 2017

Lattice PowerPoint presentation covering this published April 19, 2017

See presentation at URL below for details and source documents: 25 slides

https://www.slideshare.net/lewisglarsen/lattice-energy-llc-excessive-reliance-on-renewable-energy-sources-can-threaten-reliability-of-electricity-grids-april-19-2017

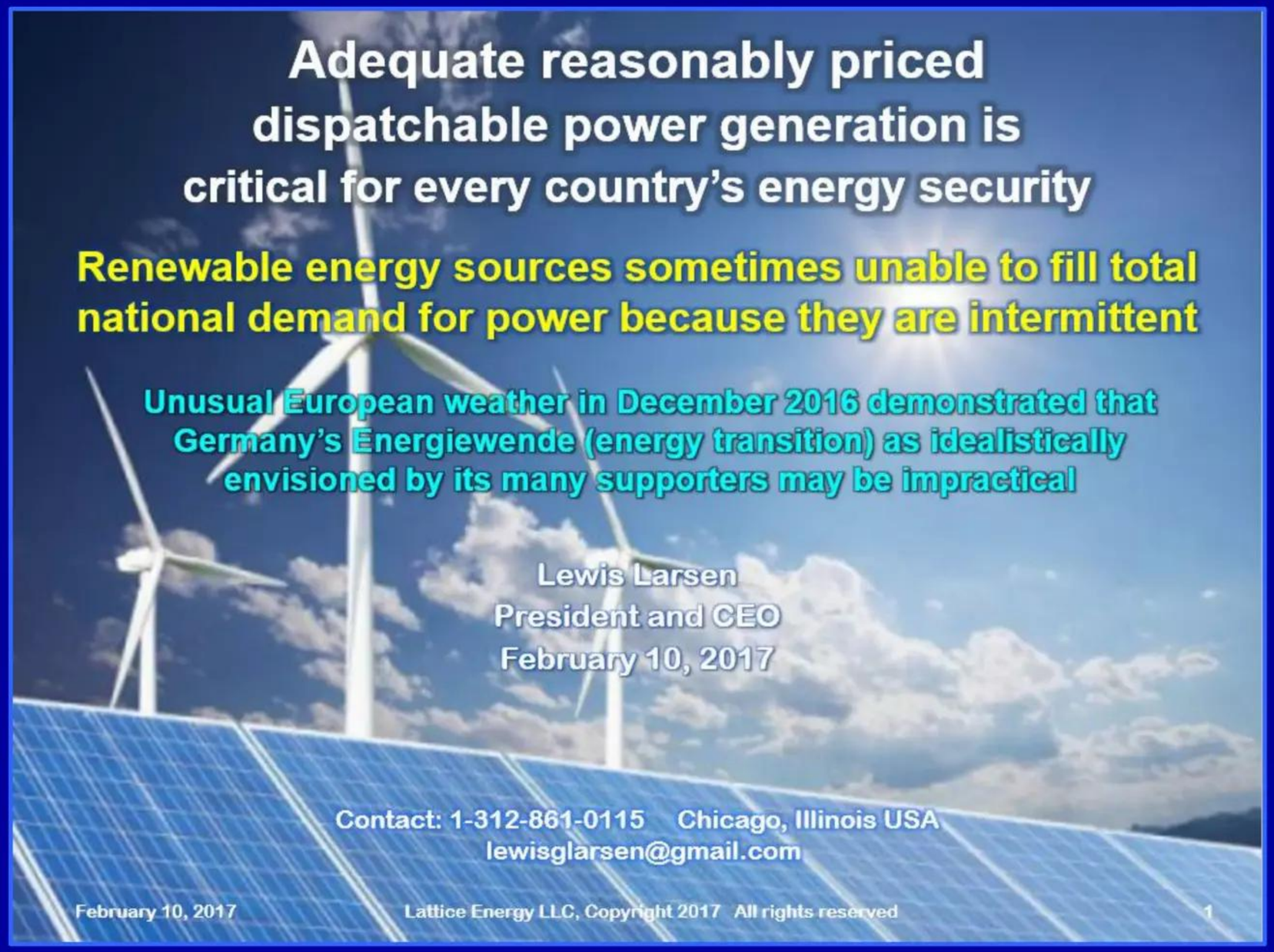
Lattice Energy LLC, Copyright 2017 All rights reserved

Dec. 2016: Germany's renewable power output slashed twice

Lattice PowerPoint presentation covering this published Feb. 10, 2017

See presentation at URL below for details and source documents: 95 slides

http://www.slideshare.net/lewisglarsen/lattice-energy-llc-adequate-reasonably-priced-dispatchable-power-generation-critical-to-national-energy-security-feb-10-2017



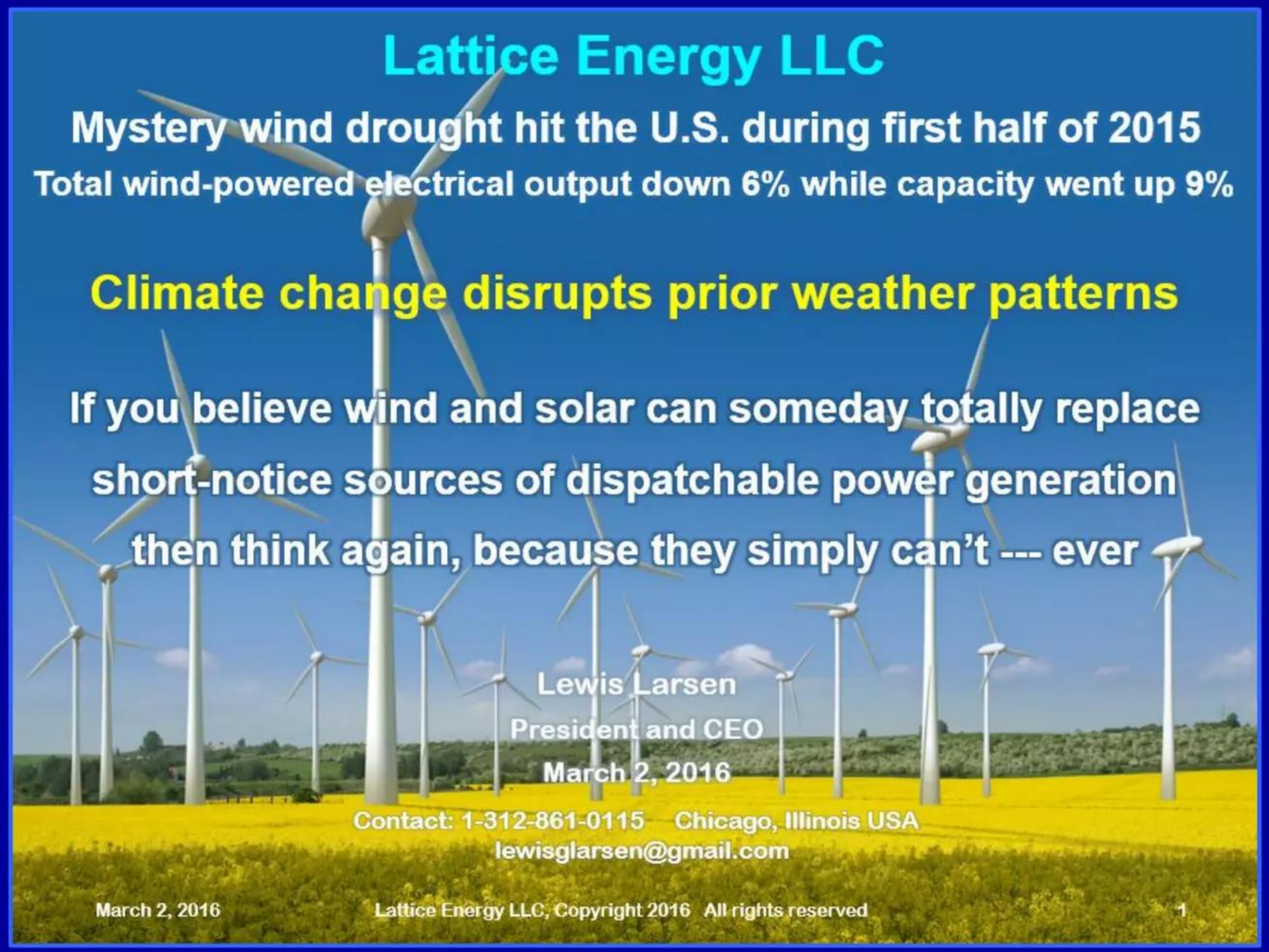
Lattice Energy LLC, Copyright 2017 All rights reserved

U.S. West Coast wind drought lasted for 6 months in 2015

Lattice PowerPoint presentation covering this published Mar. 2, 2016

See presentation at URL below for details and source documents: 66 slides

http://www.slideshare.net/lewisglarsen/lattice-energy-llc-climate-change-can-reduce-wind-and-solar-power-output-also-need-dispatchable-generation-march-2-2016



Lattice Energy LLC, Copyright 2017 All rights reserved

Lattice, Mitsubishi Heavy Industries, Toyota, and Nissan are all working on new type of nuclear power generation technology that could be much better than fission or fusion because it would be hard-radiation-free and produce negligible long-lived radioactive wastes. While still in very early stage of commercial development, ultralow energy neutron reactions (LENRs) offer great promise as a new future source of affordable CO_2-free green energy.

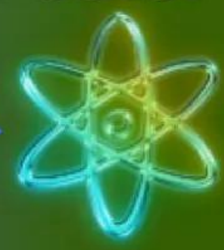
Lattice Energy LLC, Copyright 2017 All rights reserved

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)

Lattice Energy LLC, Copyright 2017 All rights reserved

Working with Lattice Energy LLC

Partnering on commercialization and consulting on certain subjects

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

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 consulting on variety of subject areas that include: Lithium-ion battery safety issues; long-term electricity grid reliability and resilience; and evaluating potential future impact of LENRs from a long-term investment risk management perspective for large CAPEX projects in the oil & gas, petrochemicals, transportation, utility, and aerospace industries

Lattice Energy LLC, Copyright 2017 All rights reserved