# NUCLEAR AND NON-NUCLEAR ENERGY TRENDS

A presentation by
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Nonproliferation Policy Education Center
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# QUESTIONS TO BE ANSWERED

I. Why bother with energy economics?

II. What are the basics of electricity production, consumption, distribution, and storage that help determine the costs of different electrical options?

III. How do nuclear and non-nuclear forms of energy perform economically at home and abroad?

# SHORT ANSWER TO QUESTION I

**A. Assessing the quality of a country's energy policies is a way to assess how sound its government is.**

**B. If an energy activity is uneconomic (e.g. reprocessing nuclear fuel), countries ought to be less insistent they have an inalienable right to pursue it. In this way, energy market signals might fortify nuclear nonproliferation (or not).**

**C. Assessing the costs of electrical power, distribution, and storage systems helps discern likely energy futures.**

# SHORT ANSWER TO QUESTION II

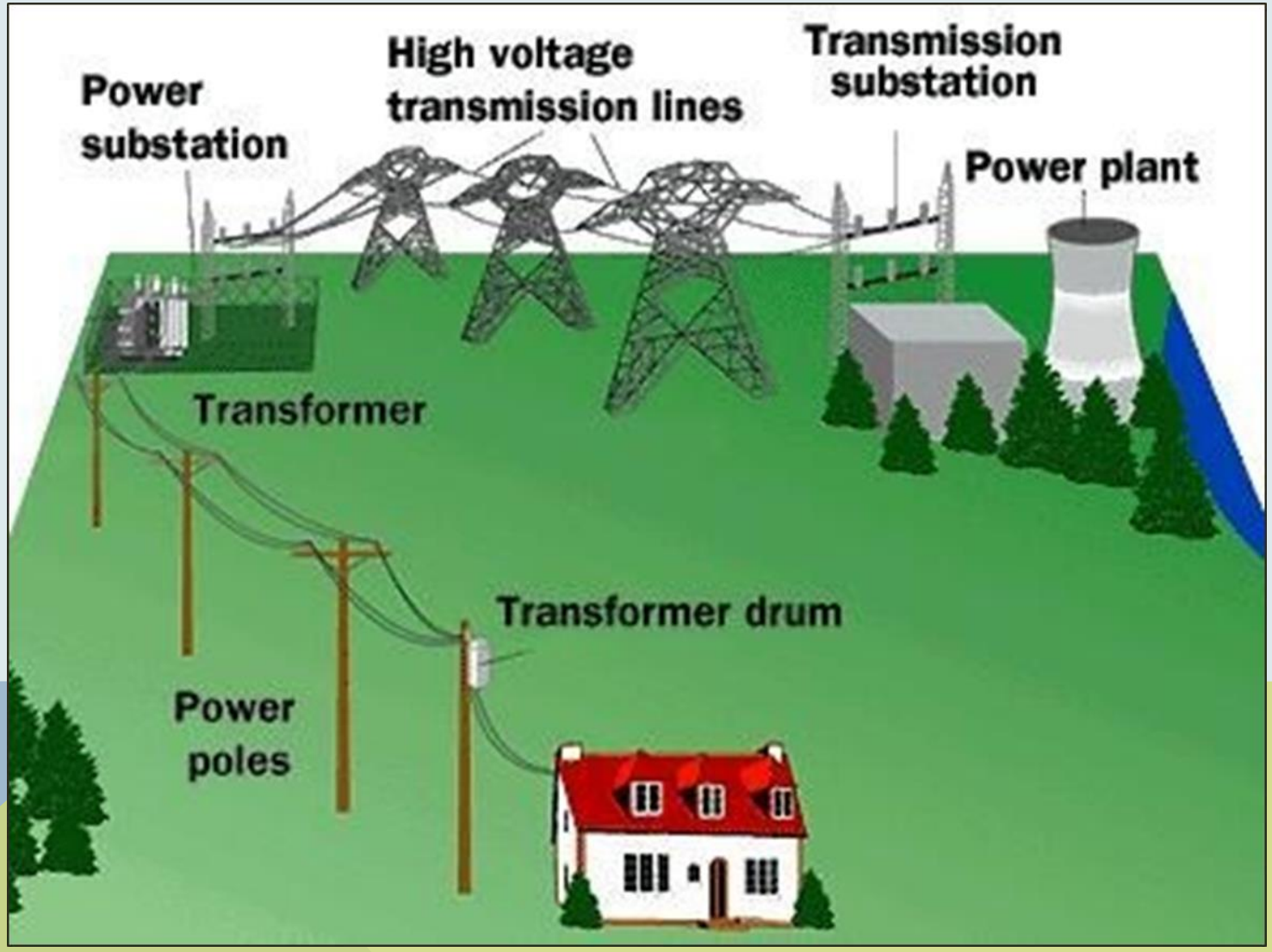
A. They’re complicated

# SHORT ANSWER TO QUESTION III

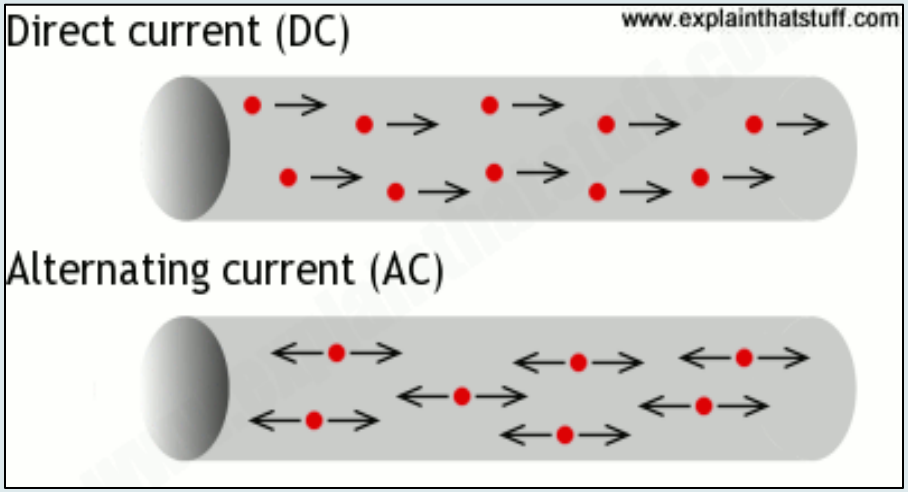
A. Natural gas is still replacing coal much more than nuclear power is.
B. Renewables likely will be competing against future investments in natural gas over the next two decades
C. Nuclear power's economic future depends on making a design breakthrough that makes it far less costly
D. Distribution and storage innovations could reduce demand for any type of large electrical generator
E. Demand to reduce greenhouse gases, even if it's taxed, is unlikely to change the above; more energy subsidies might

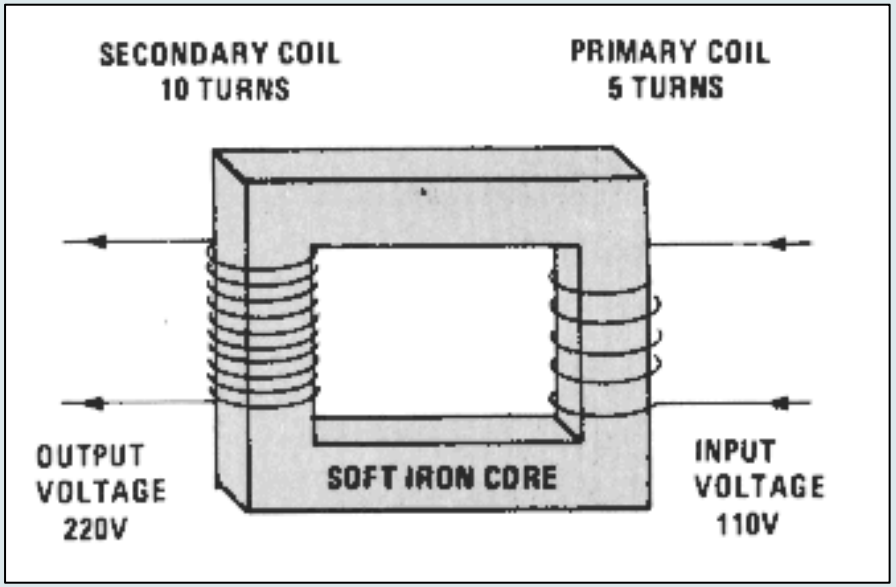
# II. ELECTRIC POWER BASICS

# BASIC ELECTRICAL GRID



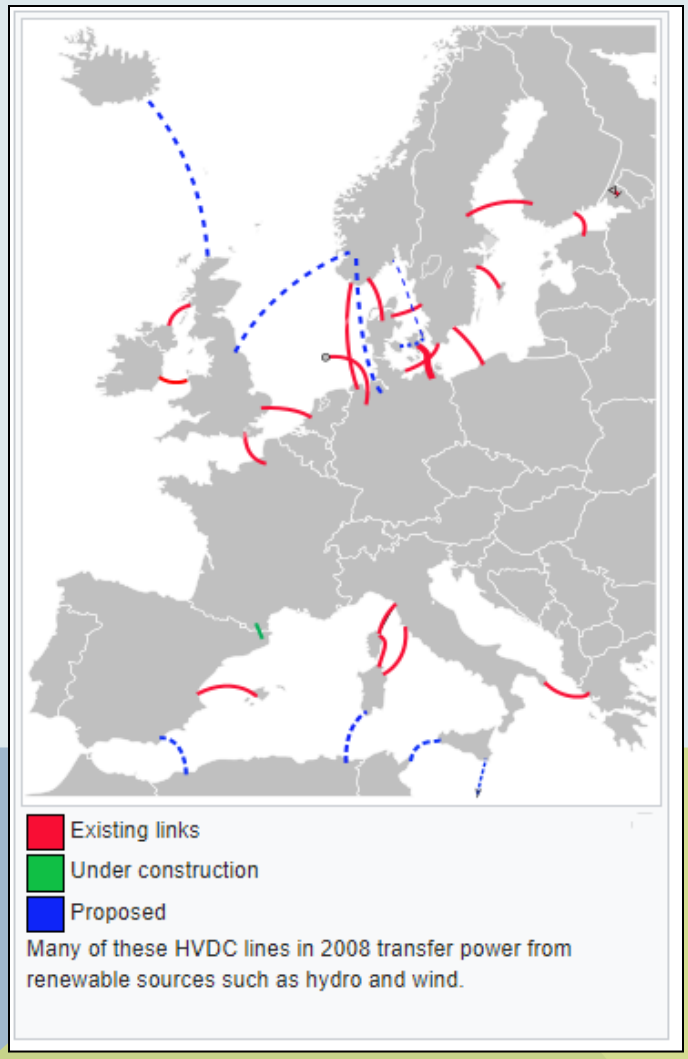
# ALTERNATING AND DIRECT CURRENT

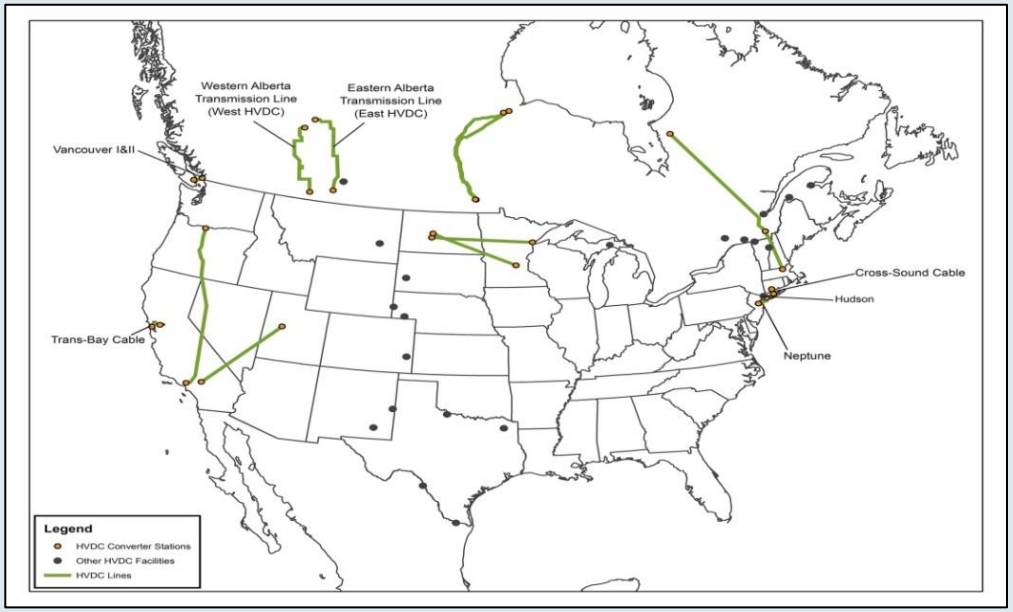


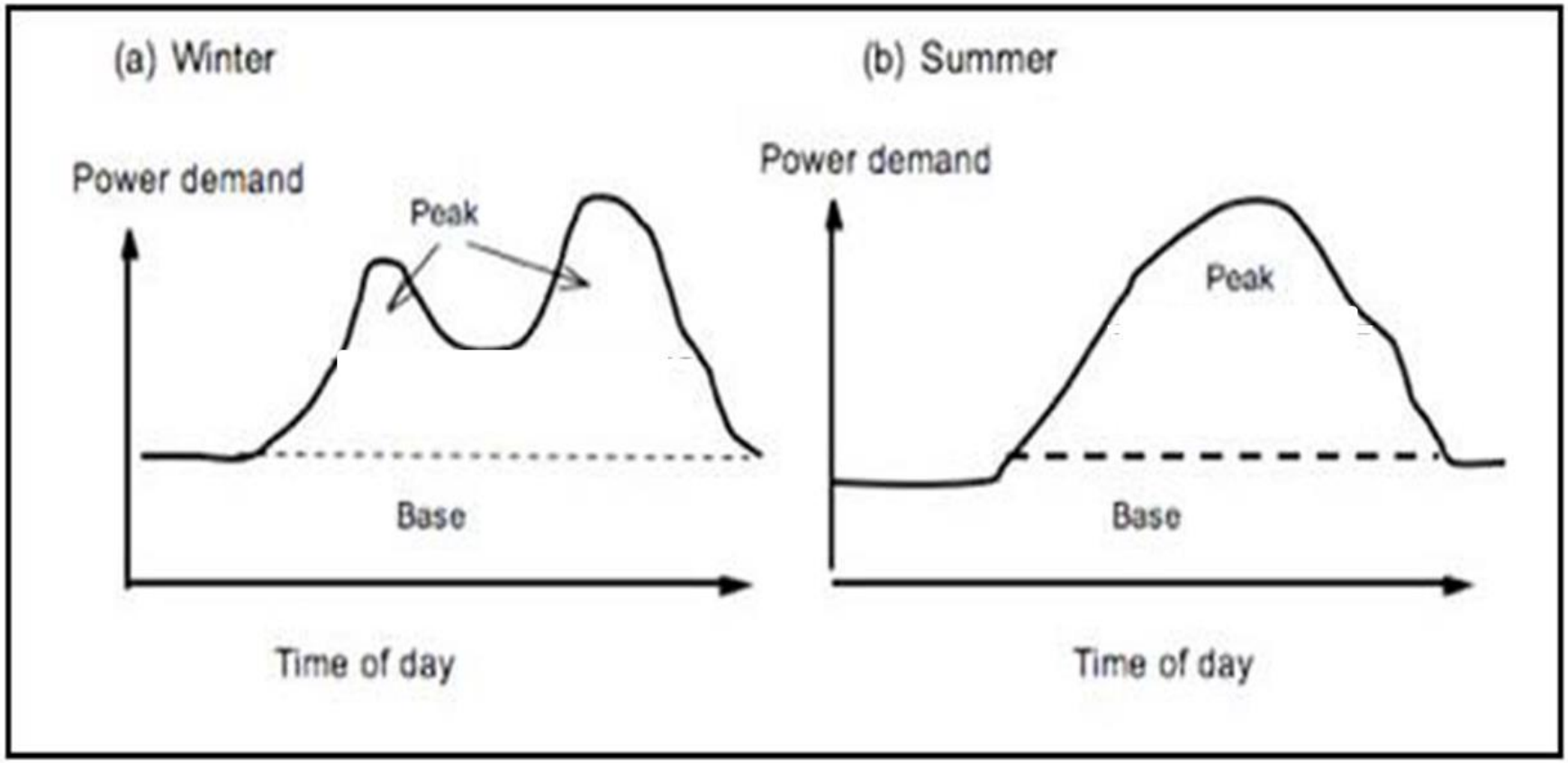

**AC Transformer basics**

# DC VOLTAGE LINES ARE BECOMING MORE POPULAR IN ADVANCED ECONOMIES



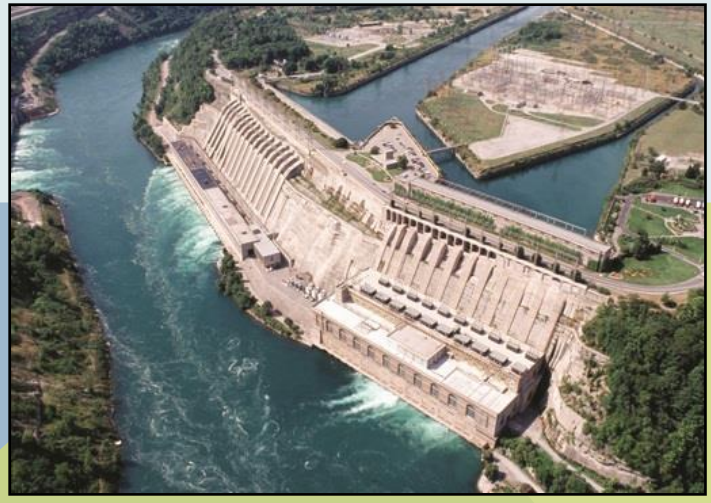
# BASE AND PEAK LOAD POWER DEMAND



# POPULAR BASE LOAD ELECTRICAL GENERATORS

COAL

NATURAL GAS



HYDRO

NUCLEAR

# POPULAR PEAK LOAD GENERATORS

*SMALL NATURAL GAS, DIESEL, PROPANE-FUELED PLANTS*

# ELECTRICAL DISTRIBUTION SYSTEMS

# N. AMERICAN TRANSMISSION SYSTEM IS MATURE, COMPLEX, AND INTERNATIONAL

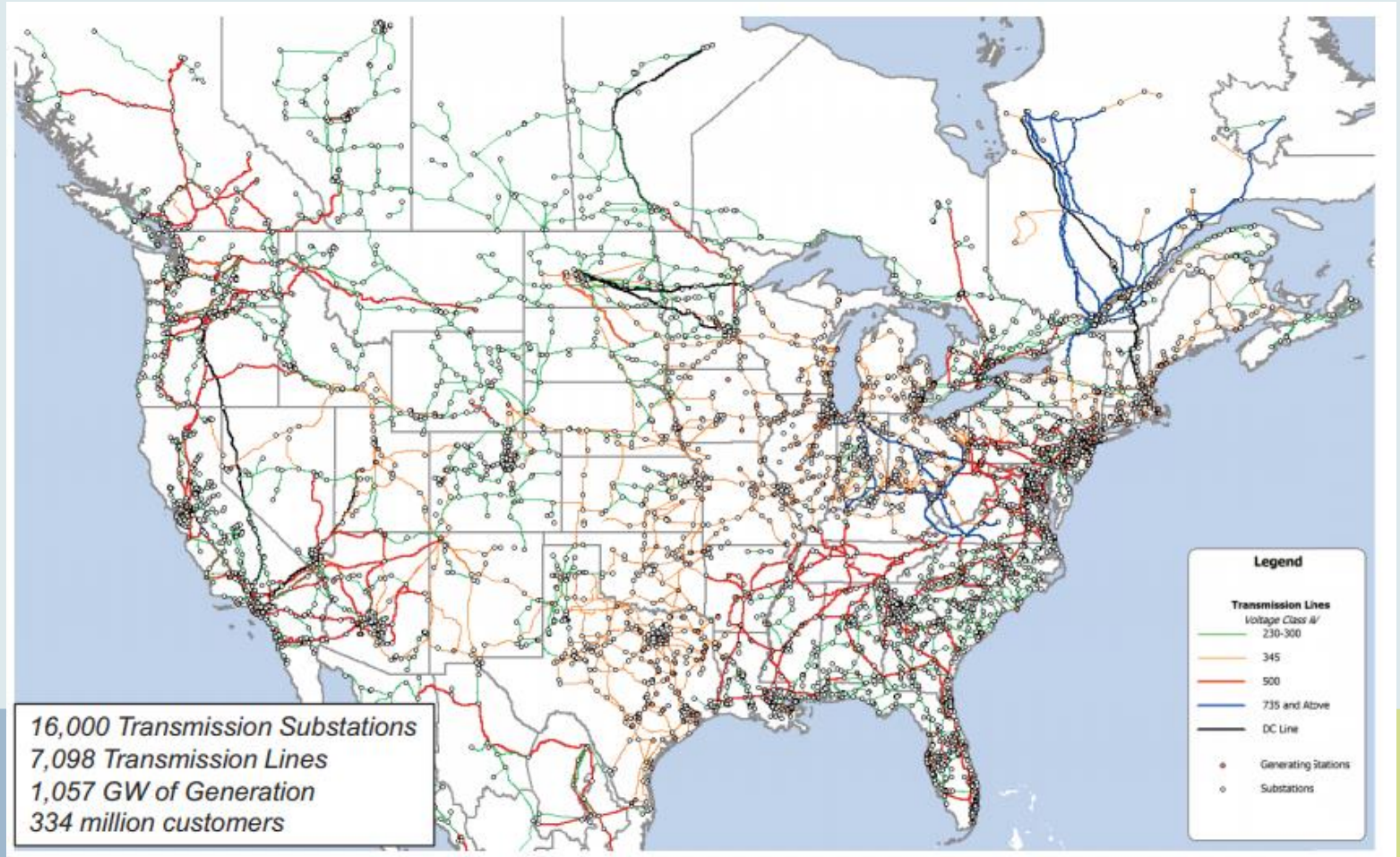
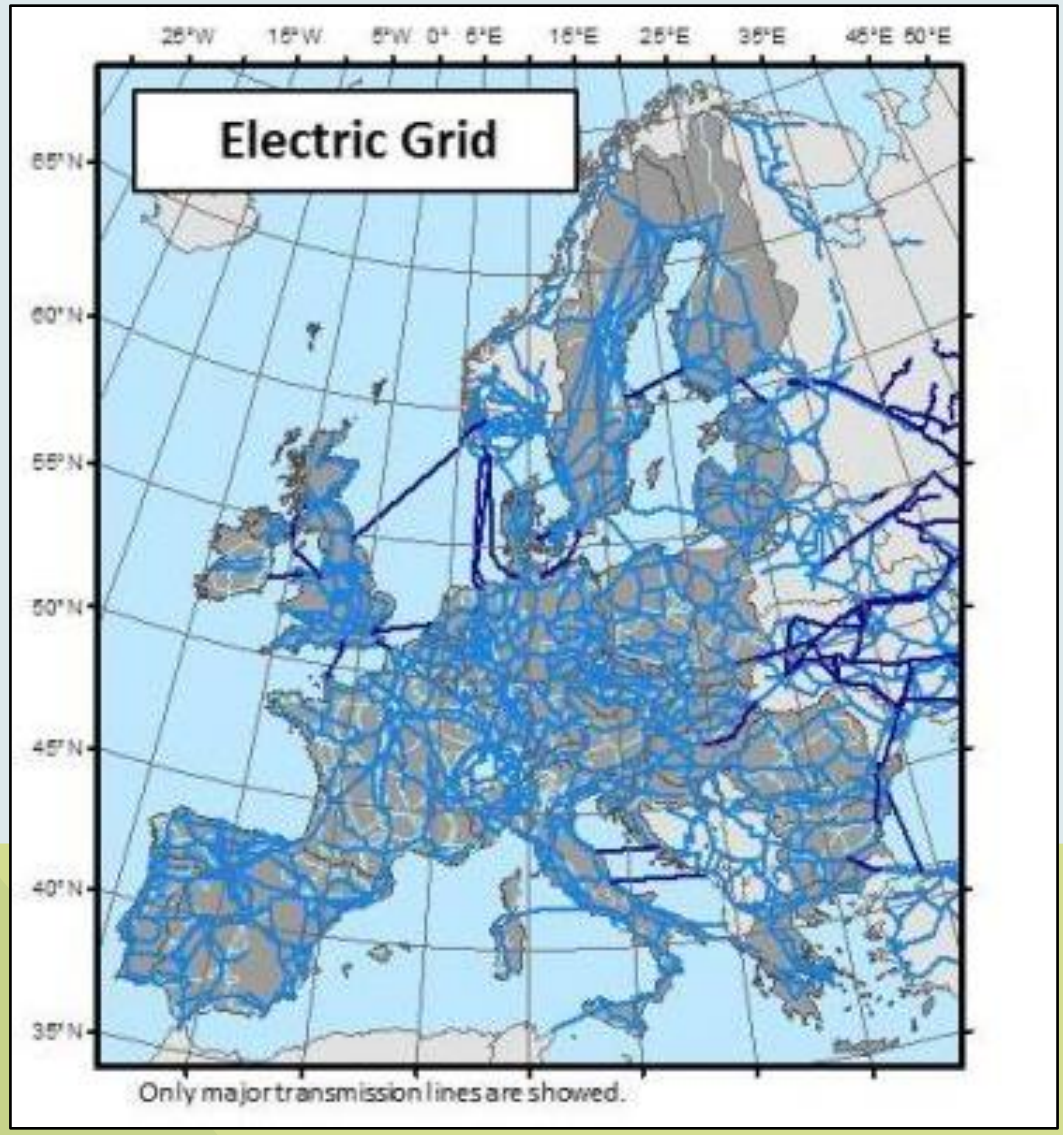



**FIGURE 2.4** The North American transmission system.
SOURCE: This information from the North American Electric Reliability Corporation's website is the property of the North American Electric Reliability Corporation and is available at http://www.nerc.com/comm/CIPC/Agendas%20Highlights%20and%20Minutes%202013/2015%20December%20Compiled%20Presentations.pdf.

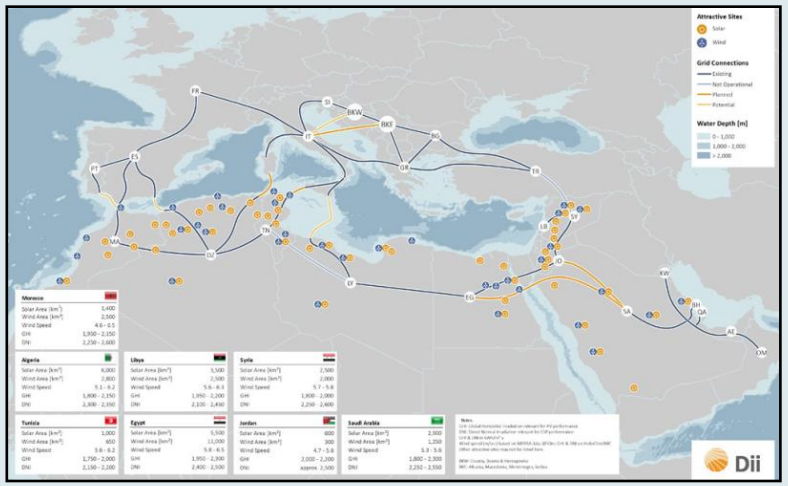
# EUROPEAN ELECTRICAL GRIDS ARE ALSO ROBUST

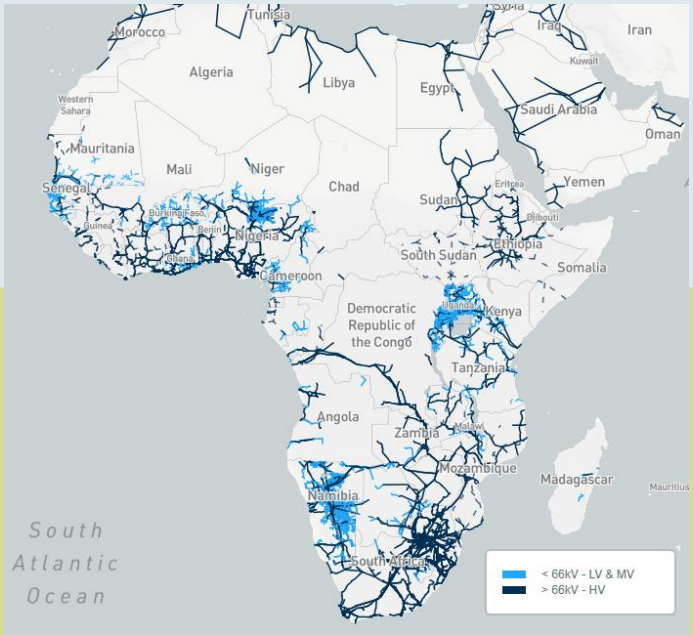



http://ses.jrc.ec.europa.eu/gas-and-power-modelling

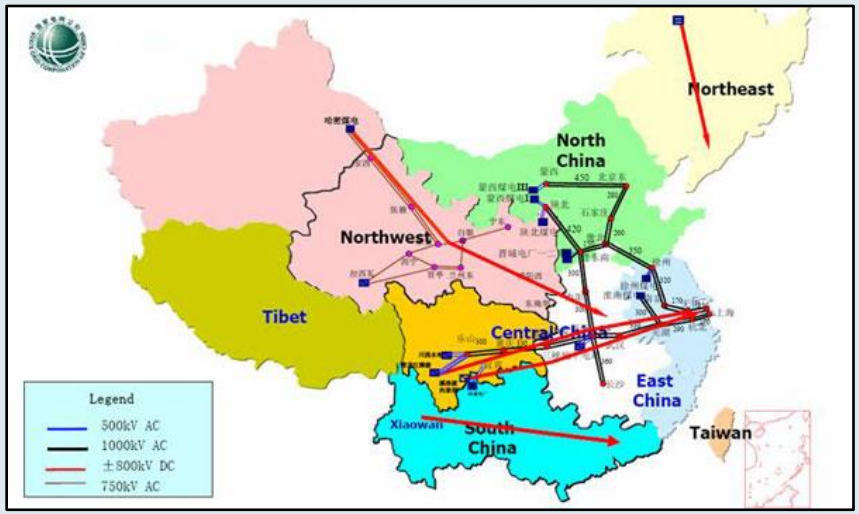
# L. AMERICA, AFRICA, MIDDLE EAST ELECTRICAL TRANSMISSION LAGS BEHIND

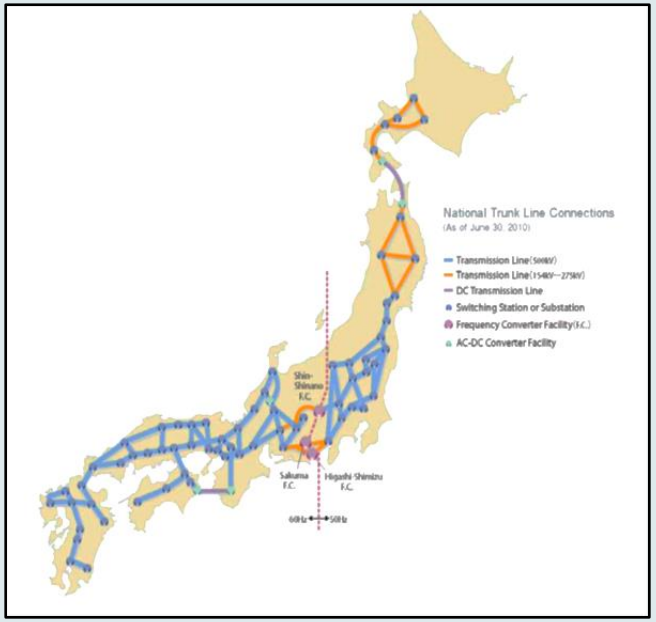
Illustration of South America's Transnational Grid Interconnections



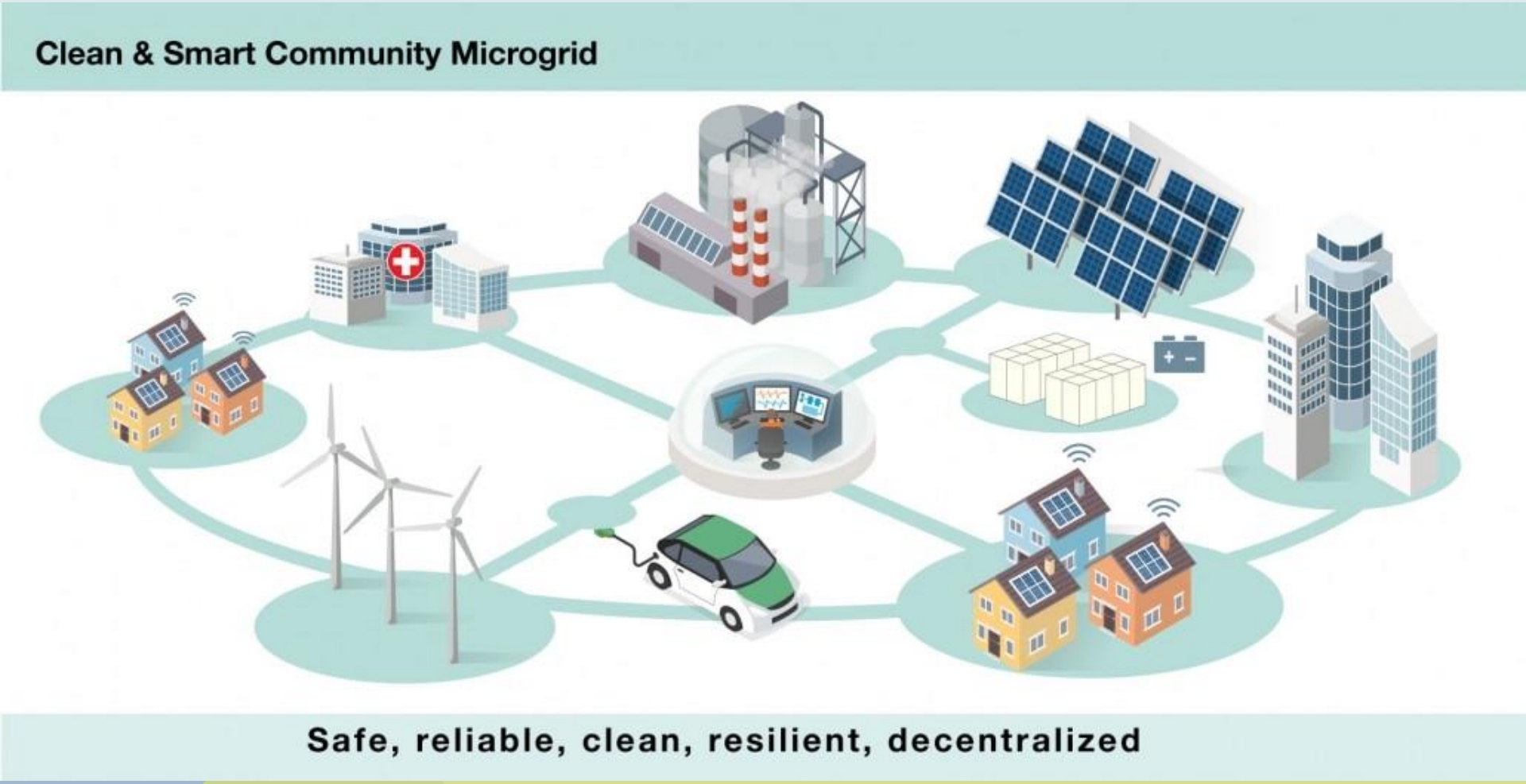



# E. ASIA'S CURRENT NATIONAL GRIDS ARE SUBOPTIMAL

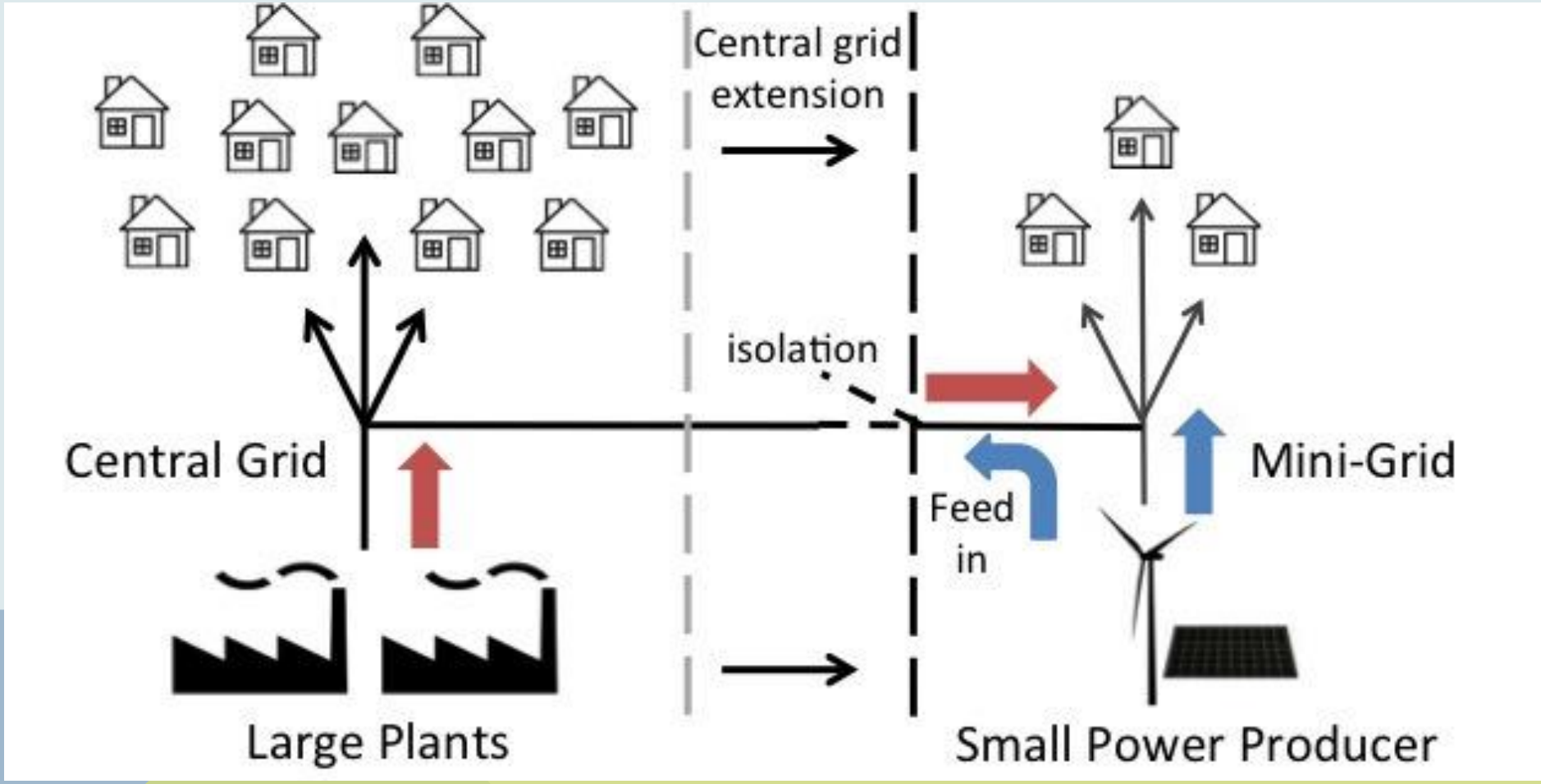



# MICROGRIDS: AN ALTERNATIVE TO CENTRALIZED GENERATION

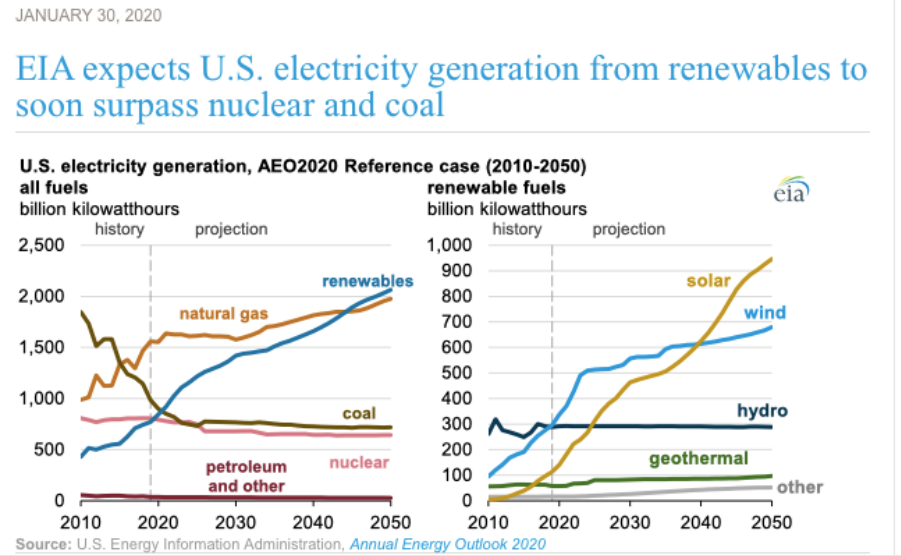


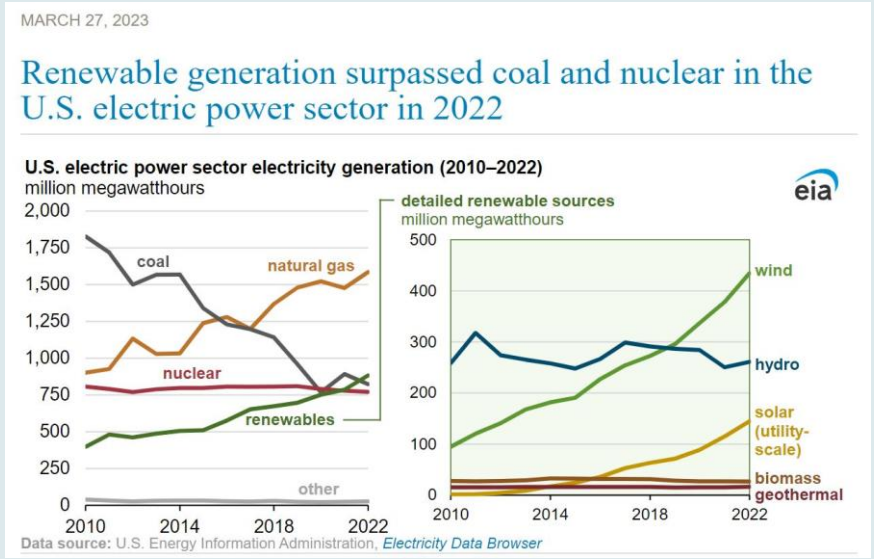
# ISLANDING ALLOWS CONNECTION TO THE GRID AND THE ABILITY TO WORK INDEPENDENTLY OF IT



# III. ECONOMICS OF NUCLEAR VS. NON-NUCLEAR POWER: NATURAL GAS SUBSTITUTION FOR COAL AND NUCLEAR

# US NATURAL GAS: FIRING MORE ELECTRICAL GENERATION

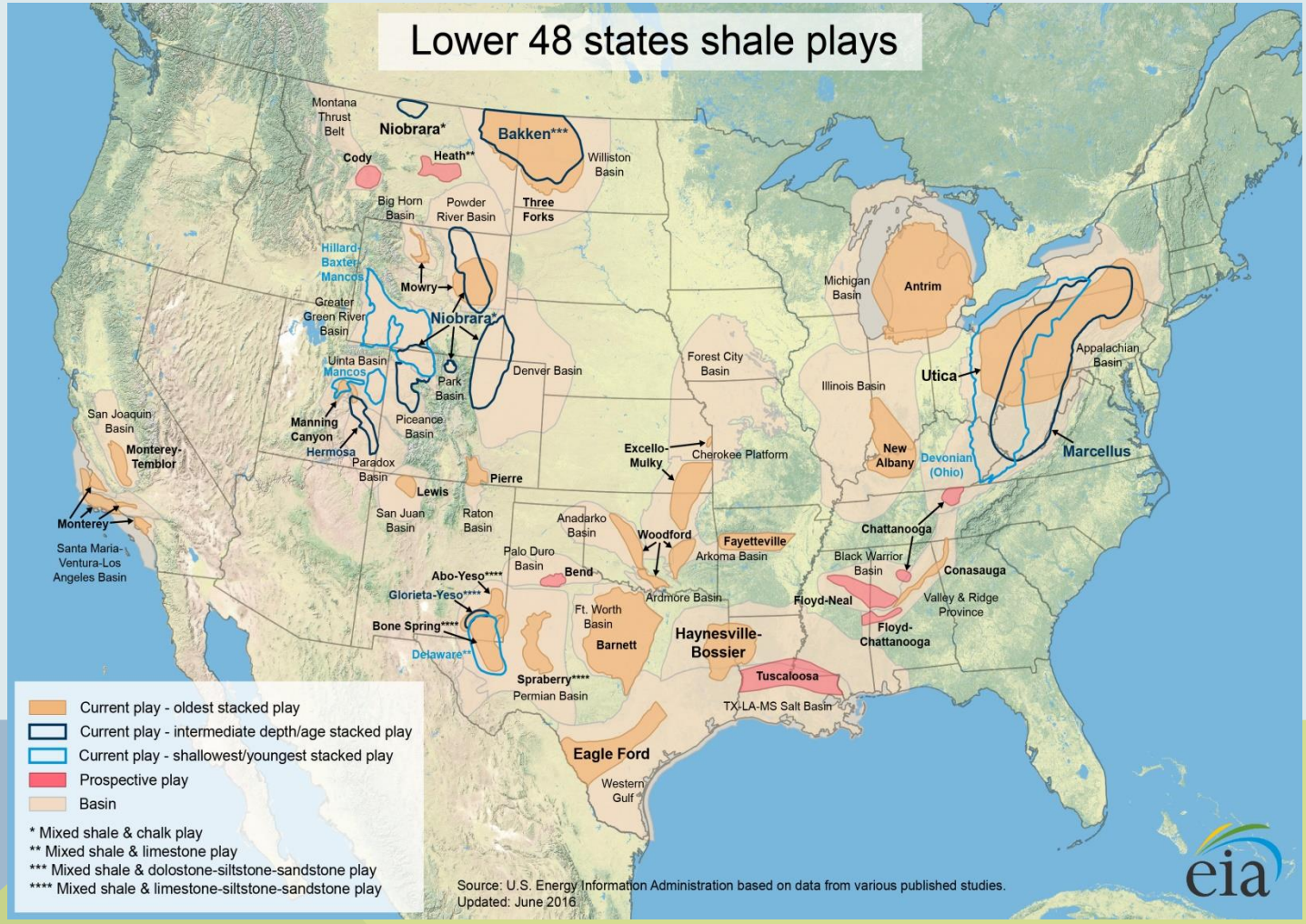



https://www.eia.gov/todayinenergy/detail.php?id=42655

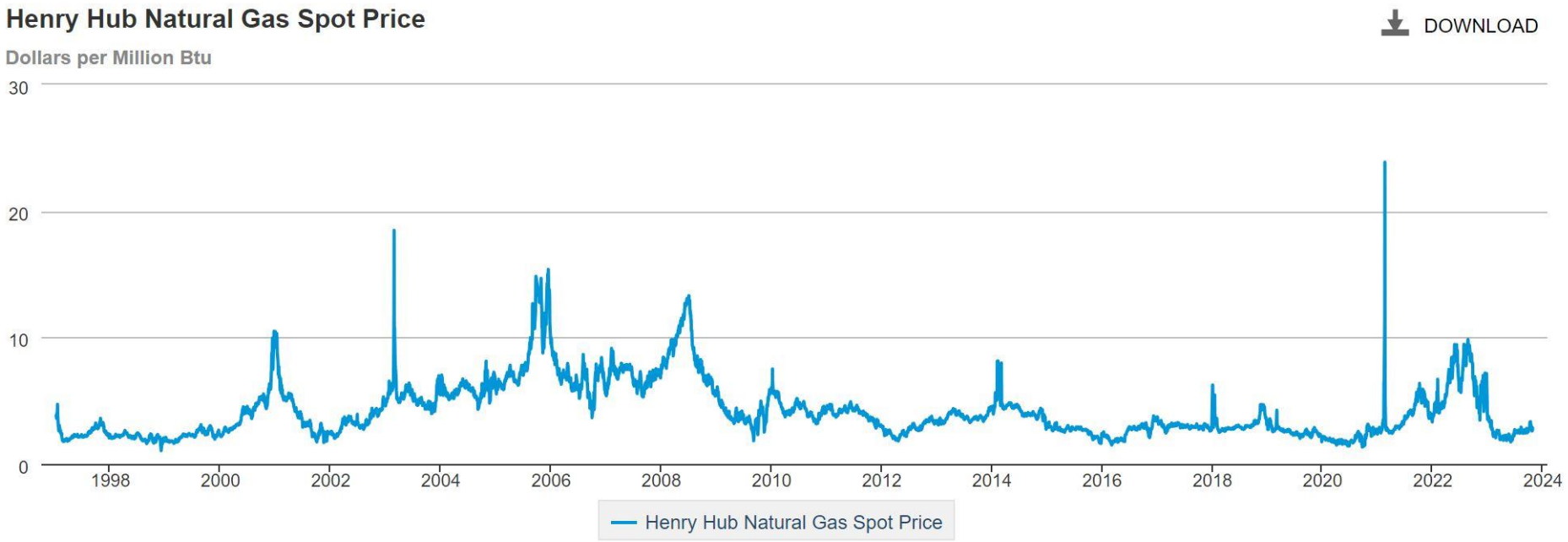
https://www.eia.gov/todayinenergy/detail.php?id=55960#:~:text=We%20forecast%20that%20the%20solar,year%20to%2017%25%20in%202023.

# US NATURAL GAS RESOURCES, 2016




https://www.eia.gov/maps/maps.htm

# HENRY HUB NATURAL GAS SPOT PRICE




**October 24, 2023 $2.85 per Million Btu**

https://www.eia.gov/dnav/ng/hist/rngwhhdd.htm

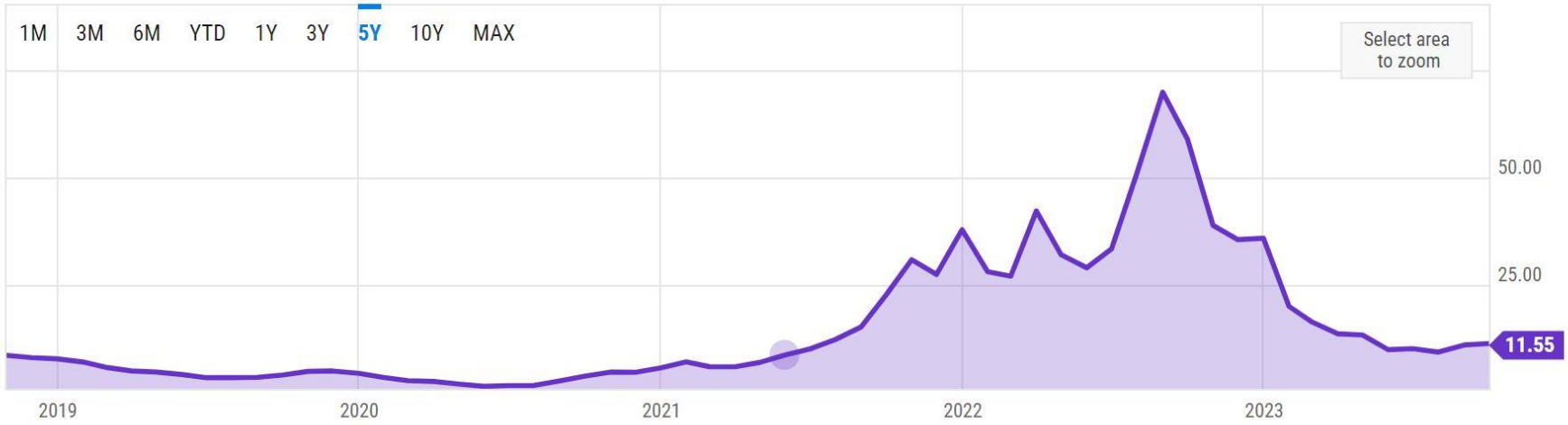
# SPOT PRICE OF EUROPEAN NATURAL GAS

**European Union Natural Gas Import Price (I:EUNGIP)**

11.55 USD/MMBtu for Sep 2023

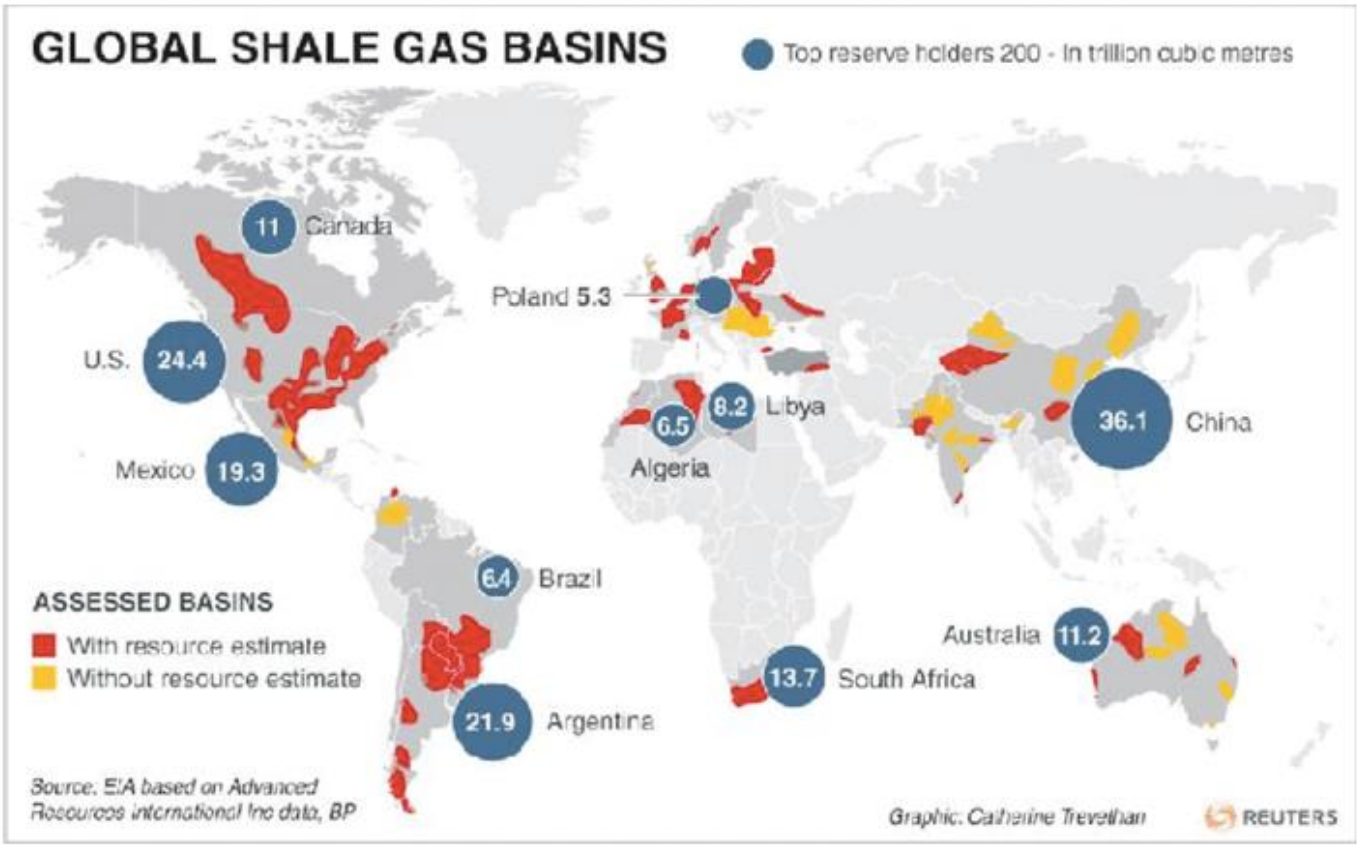
Overview | Interactive Chart

Level Chart — VIEW FULL CHART




https://ycharts.com/indicators/europe_natural_gas_price

# GLOBAL SHALE GAS BASINS, TOP RESERVE HOLDERS

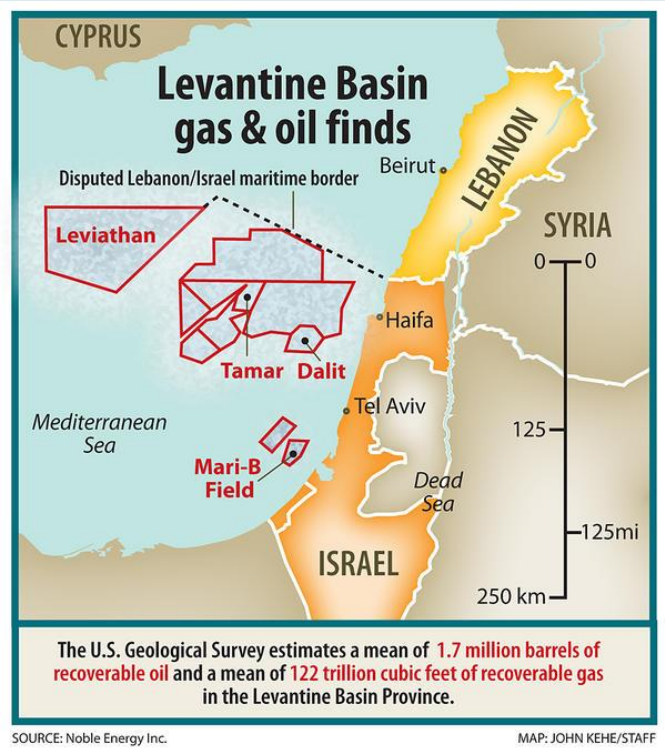


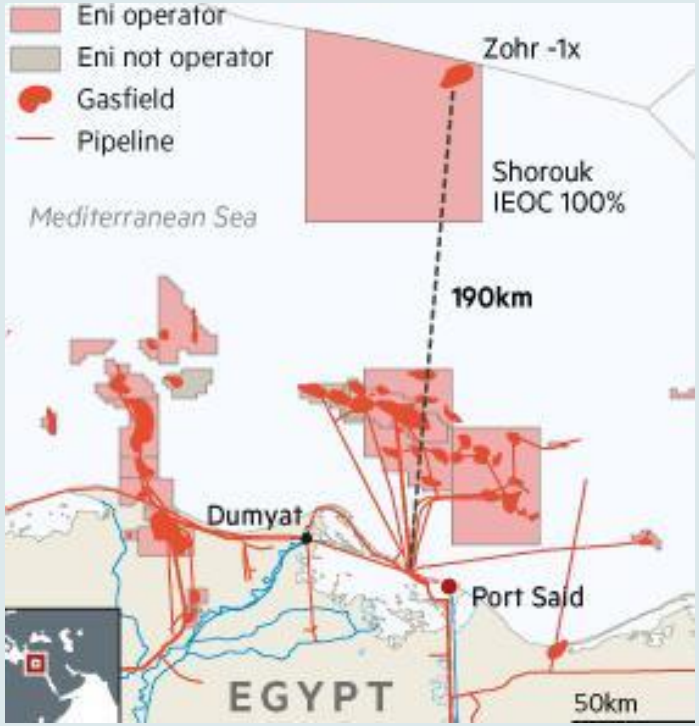

Global Shale Gas Basins: Source EIA, Reuters (Refs. 14 & 19), Advanced Resources Inc.

February 2018

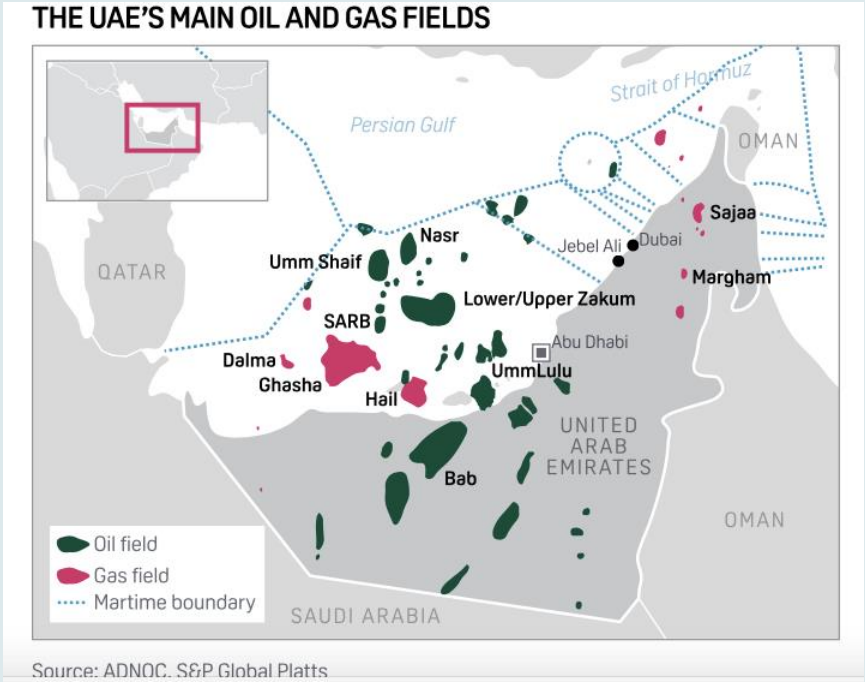
https://www.researchgate.net/figure/Global-Shale-Gas-Basins-Source-EIA-Reuters-Refs-14-19-Advanced-Resources-Inc_fig1_323691748

# LEVANTINE AND ZOHR: MASSIVE NATGAS DISCOVERIES



# RECENT UAE GULF AND TURKISH BLACK SEA GAS DISCOVERIES



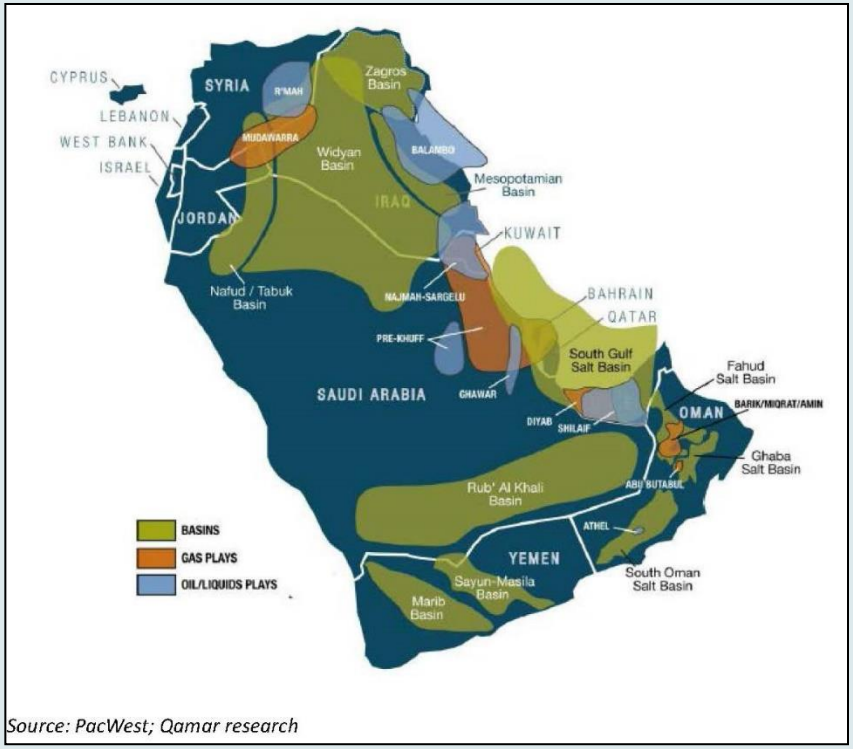


The biggest gas find in 15 years, UAE now self sufficient

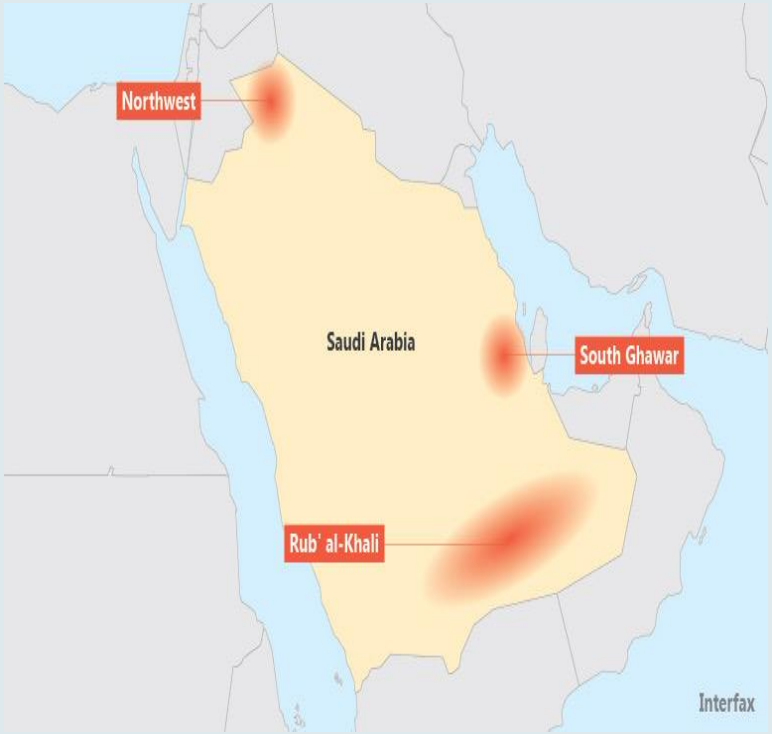
https://www.spglobal.com/platts/es/market-insights/latest-news/natural-gas/020320-adnoc-to-develop-huge-onshore-gas-find-near-dubai

https://www.google.com/imgres?imgurl=https://steelguru.com/uploads/news/turkey-black-sea-natural-gas-discovery_5704.jpg&imgrefurl=https://steelguru.com/gas-oil/turkey-announces-black-sea-natural-gas-discovery/562466&tbnid=aP0BTkaLcb9fhM&vet=1&docid=fY4K_2qraRB1yM&w=1668&h=1000&hl=en&source=sh/x/im

# SAUDI ARABIA NEW GAS OPTIONS



*Source: PacWest; Qamar research*



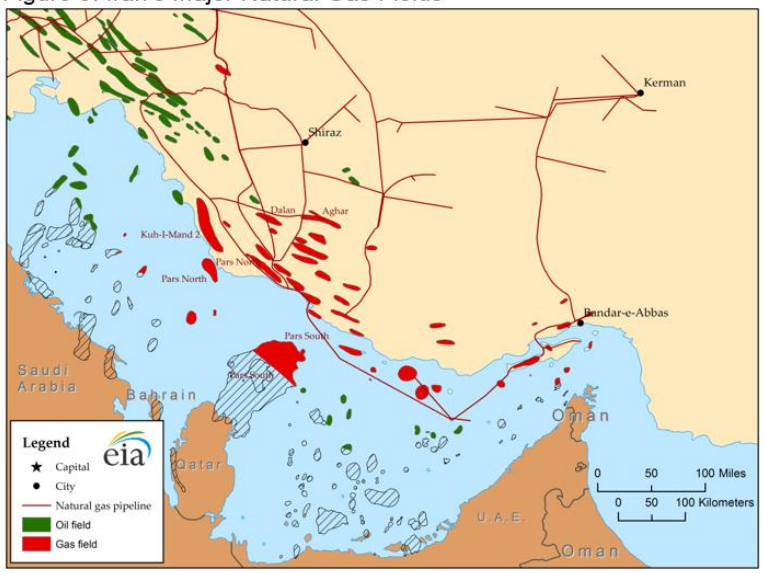

https://www.eia.gov/beta/international/analysis_includes/countries_long/Iran/pdf/iran_bkgd.pdf

2 reactors at $12-24 b versus $334 billion for shale gas development by 2025

https://interfaxenergy.com/article/22179/saudi-aramco-presses-on-with-shale-gas

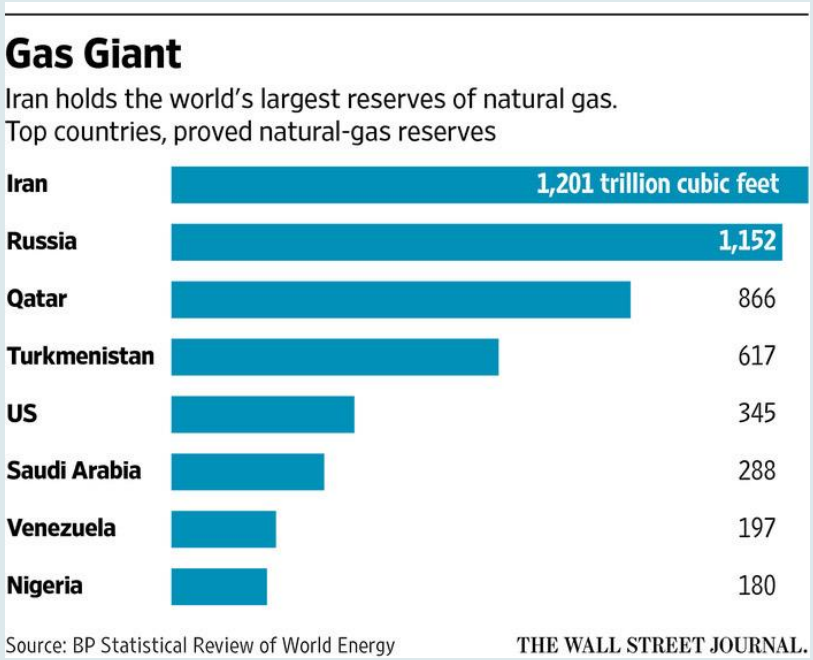
# IRANIAN GAS

Figure 3. Iran's Major Natural Gas Fields



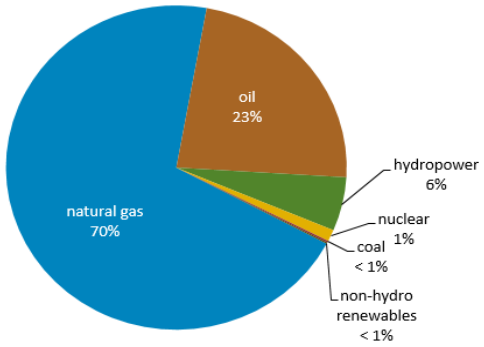

Source: U.S. Energy Information Administration, IHS Markit Midstream Database (via IHSM EDIN).

https://www.eia.gov/beta/international/analysis_includes/countries_long/Iran/pdf/iran_bkgd.pdf



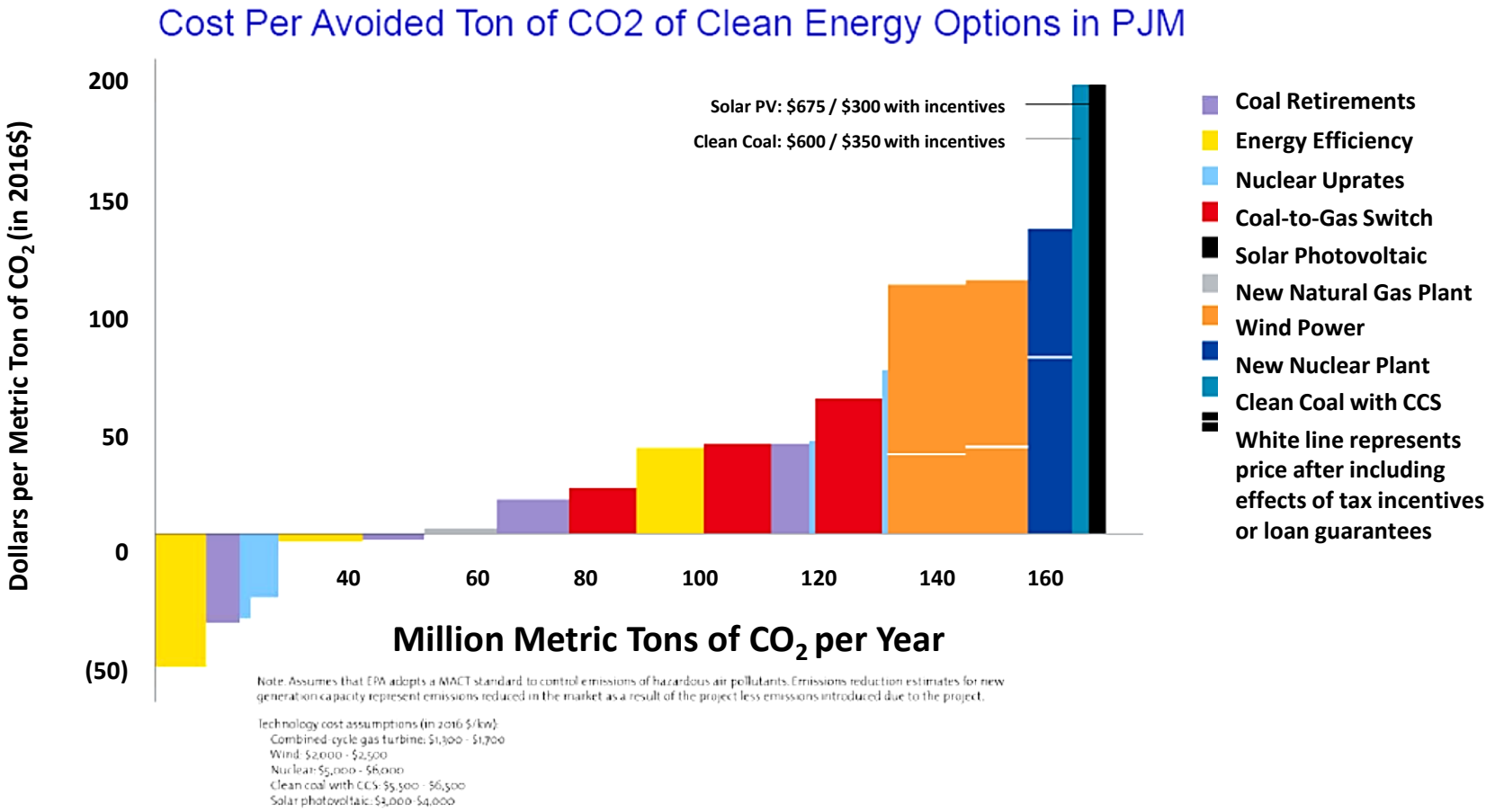

https://www.wsj.com/articles/iran-seeks-rapid-reboot-for-natural-gas-exports-1453821547

Figure 9. Iran's electricity generation capacity by fuel, 2016



# ECONOMICS OF NUCLEAR VS. NON-NUCLEAR POWER

# ABATING CARBON SHOULD START WITH THE CHEAPEST, QUICKEST METHODS 1ST




*Source: Exelon*

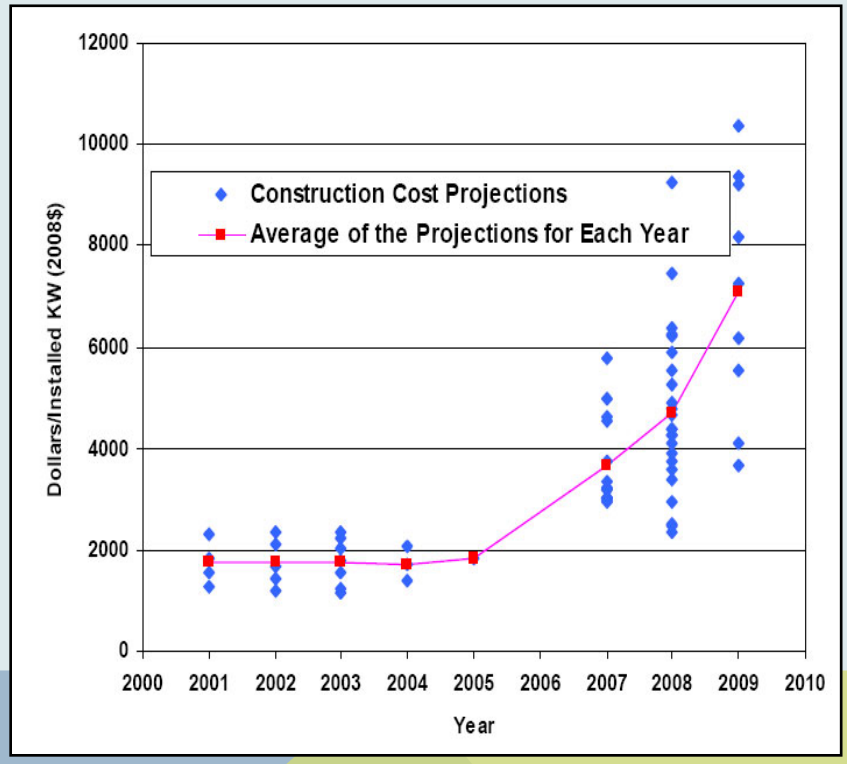
# BREAK EVEN #s FOR BUILDING NEW NUCLEAR MAKES GOVERNMENT SUBSIDIES ESSENTIAL

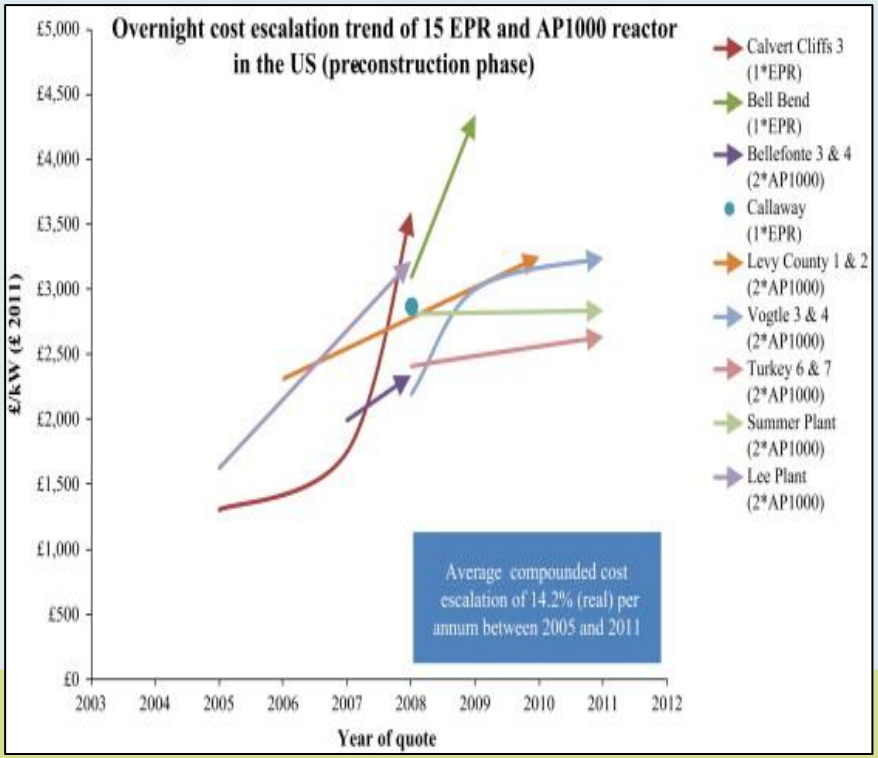
To build a reactor in 2011 cost $9.8 billion. In 2023 dollars, that reactor would cost $17.5 billion to build – 78% more. This increases the natural gas break even price to $19.58 per MBTU and the CO2 tax number to $44.50 per ton.

| **Spot natural gas prices:** | **CO2 Gas Number:** |
|---|---|
| US: $2.85 MBTU | No national market |
| EU: $11.55 MBTU | $130 per ton |
| East Asia: $13.35 MBTU | No market |

**Bottom Line:** Nuclear construction today only makes sense where government weighs in heavily – Europe and China.

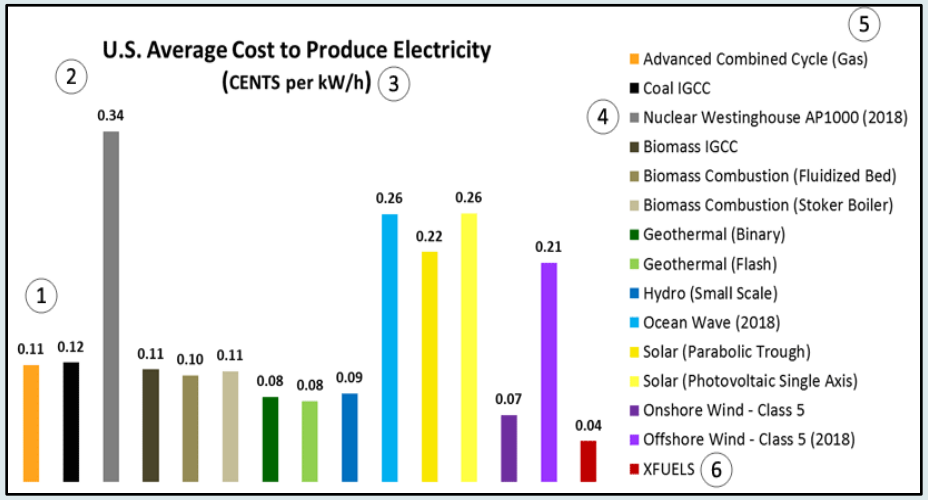
# SO FAR, OVERNIGHT REACTOR COSTS HAVE ONLY CLIMBED

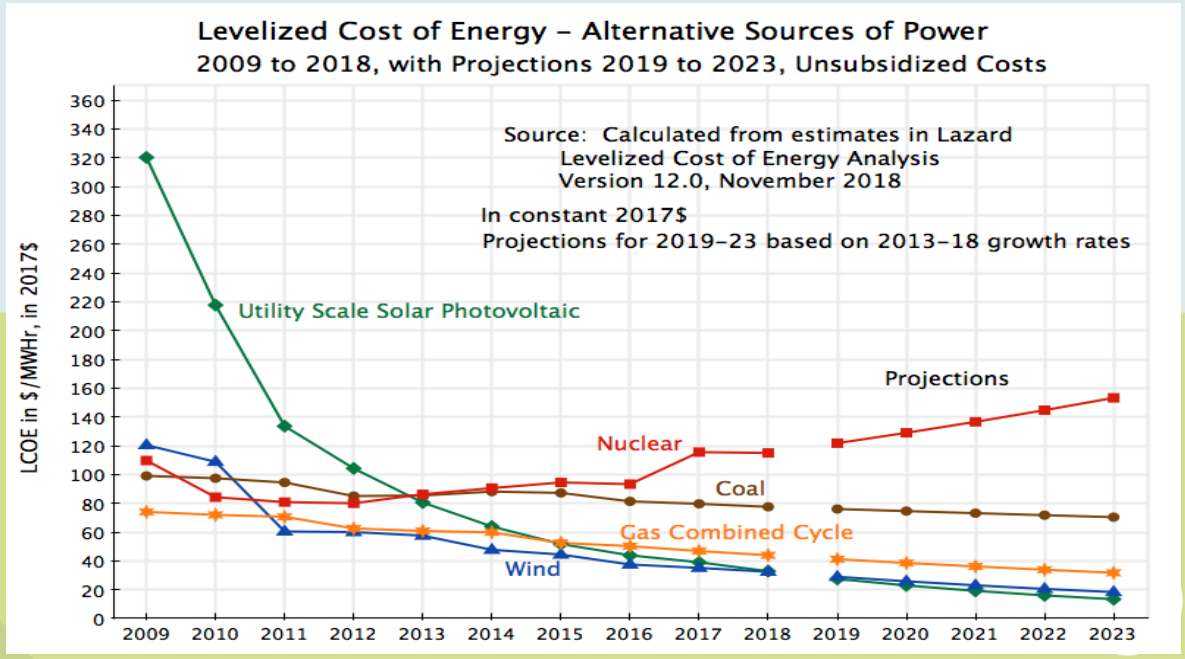


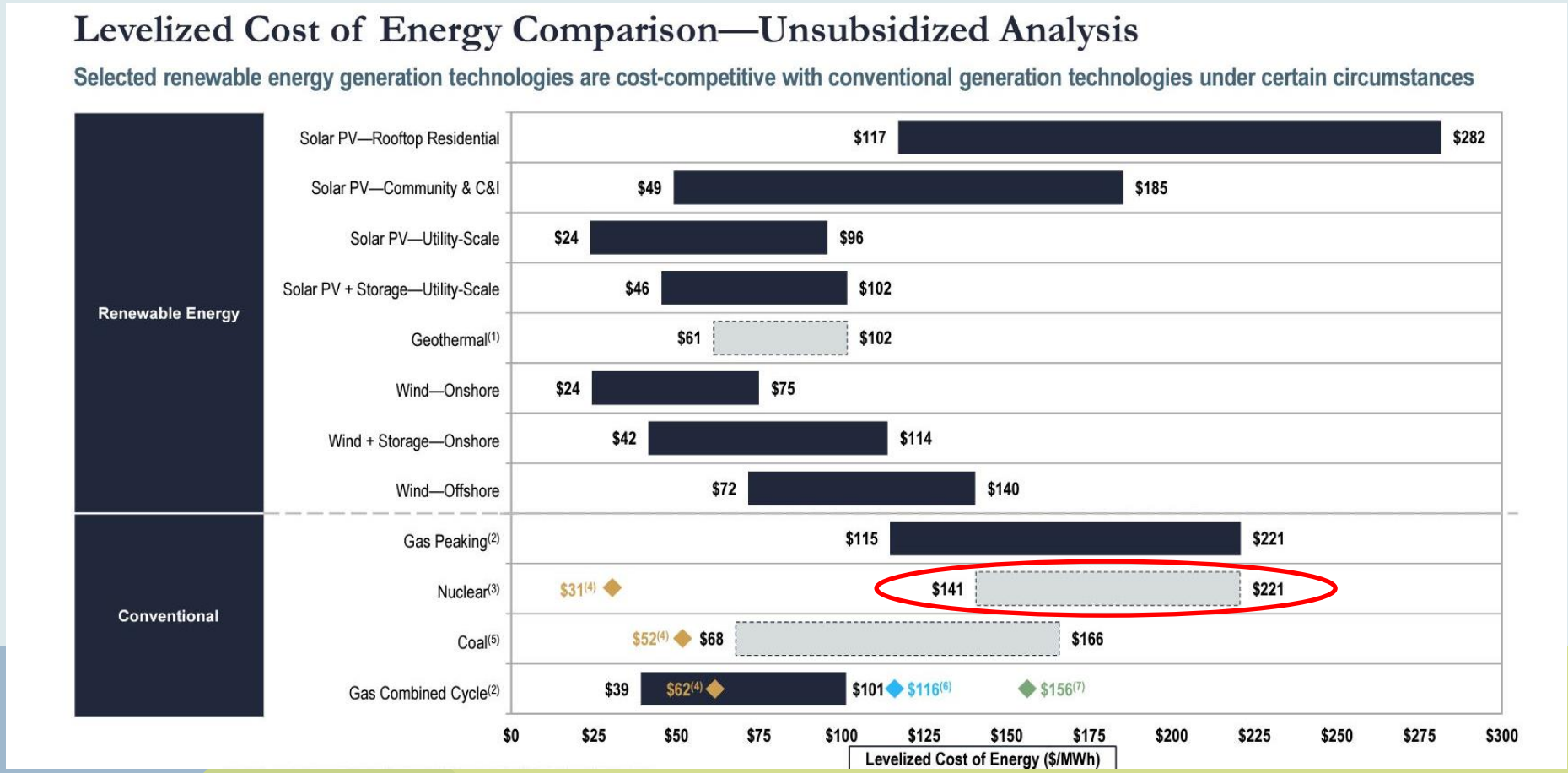

- Overnight cost in 2017 £6,666 per kilowatt Vogtle 3 and 4 ($10,000)

# LEVELIZED COSTS ARE RISING AS WELL

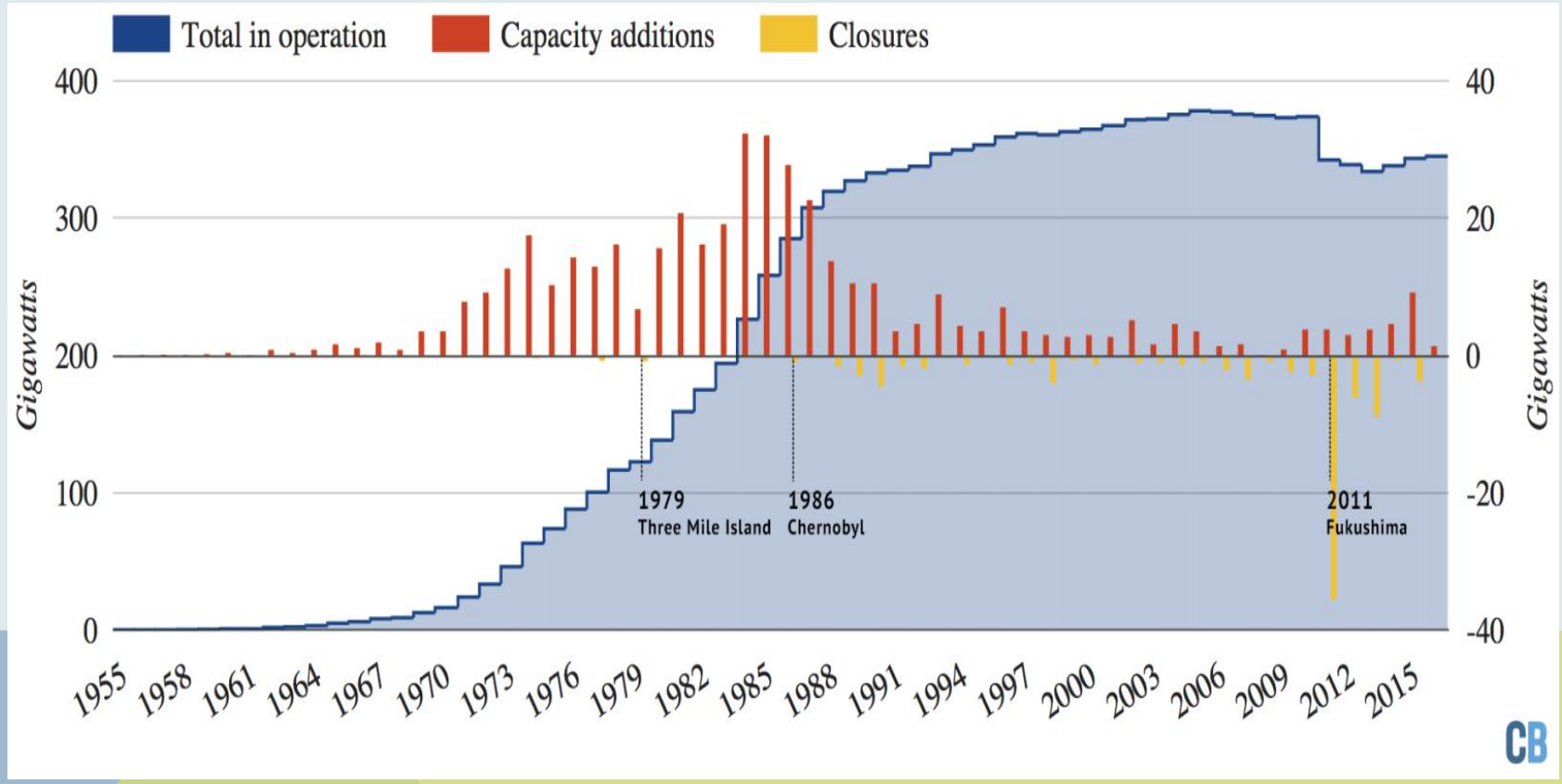


# TODAY, LARGE REACTOR BUILDS CAN'T COMPETE ECONOMICALLY WITH NONNUCLEAR ALTERNATIVES - 2023



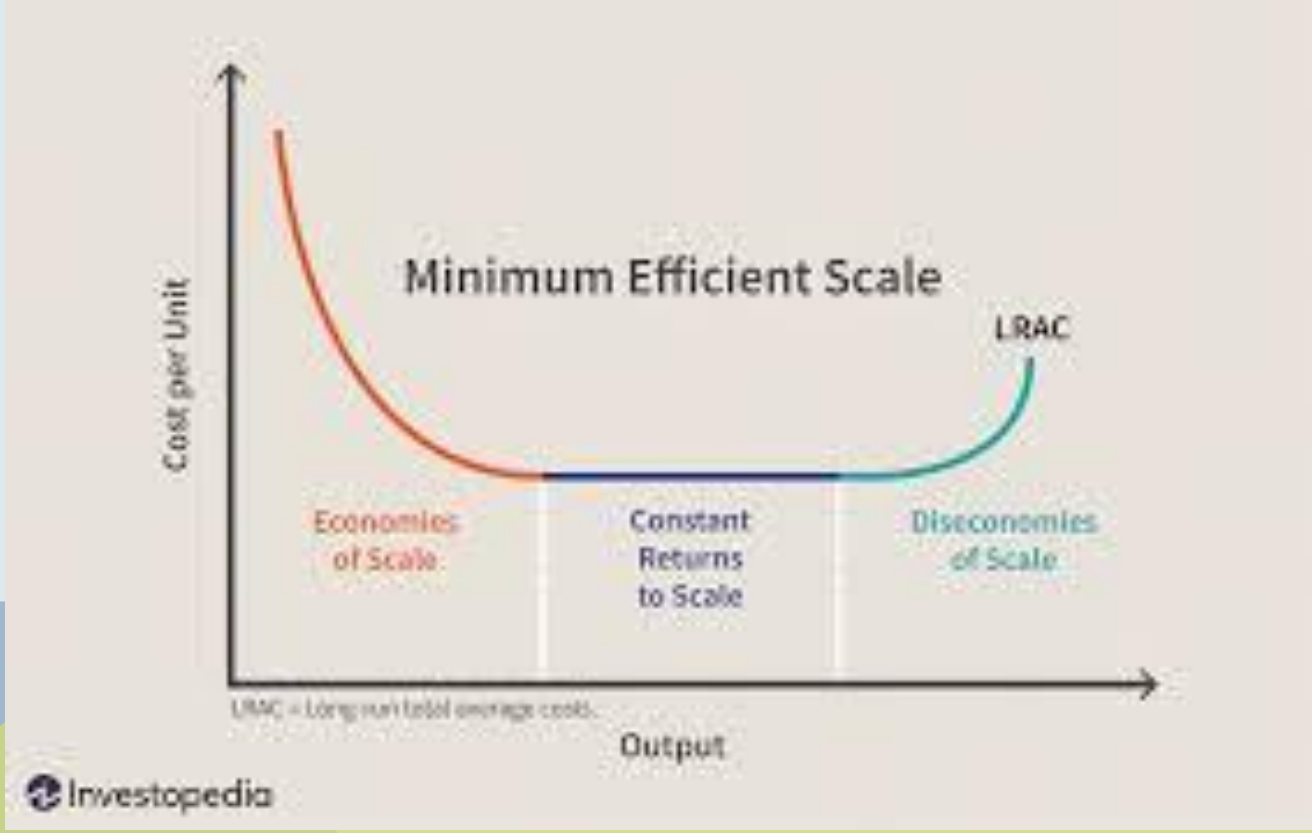
# THIS HAS DISCOURAGED NEW LARGE REACTOR BUILDS



# THE ECONOMIC CASE FOR SMALL REACTORS, ADVANCED AND MODULAR

- Cost less (individually projected to cost $1 - $3 billion, not $14 billion)
- Should fit more readily on the grid and can be sited nearer customers to afford district or commercial heating
- Many may not need to be refueled frequently
- Don’t emit carbon

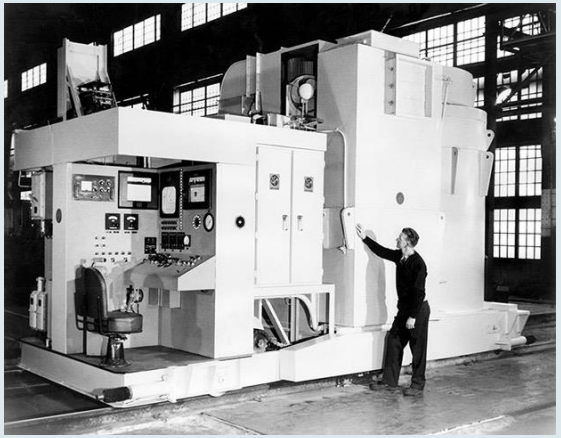
# WITH BIGGER REACTORS, CAPITAL COSTS OF PRODUCING ELECTRICITY SHOULD DECLINE. WITH SMALL REACTORS, ELECTRICITY PRICES DECLINE IF REACTORS ARE CHEAP



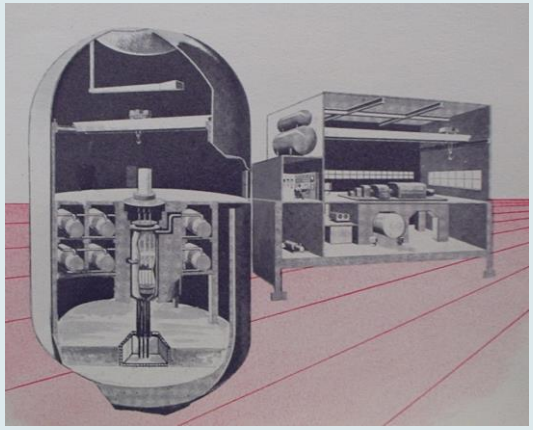
# THE ECONOMIC CASE AGAINST SMALL AND ADVANCED MODULAR REACTORS

- Small reactors may have difficulty achieving scale of economies (promoters presume mass production will overcome high capital cost/installed KW). History suggests otherwise.
- Most proposed small reactors rely on new fuels that require significant government development and support
- Most “advanced” small reactors toy with historically costly fast reactor technologies—use plutonium or HEU or at least 20%
- There are cheaper, quicker ways to reduce greenhouse gases
- Some of the proposed designs are not so small

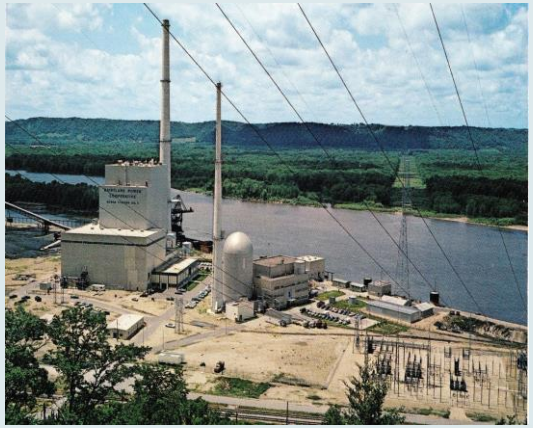
# UNKIND HISTORY: EARLIER SMALL REACTORS WERE TOO SMALL AND UNRELIABLE TO COMPETE



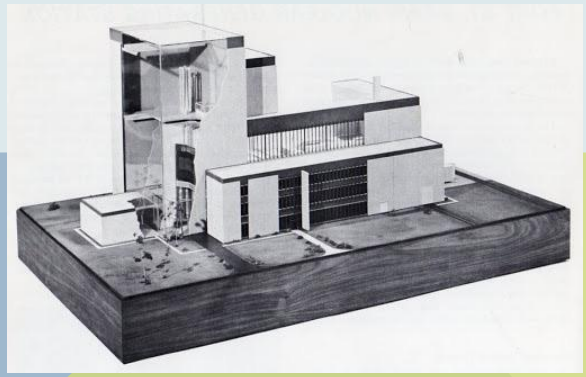
Fermi 1, 69 MWe



Elk River, 22 MWe



LaCrosse, 50 MWe



Fort St. Vrain, 185 MWe

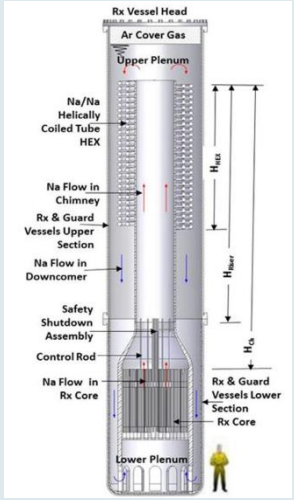
Piqua, Ohio, 12 MWe

Punta Higuera, Puerto Rico, 17 MWe

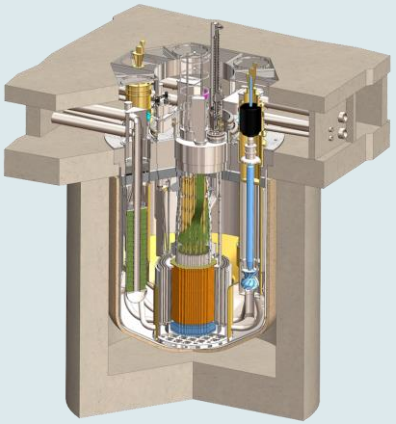
# MORE UNKIND HISTORY: GEN III REACTORS ALSO WERE MODULAR

**Two ACP100 modular reactors have been given construction go ahead** Brian Wang | November 17, 2011 (projected to come online 2013 but didn't)

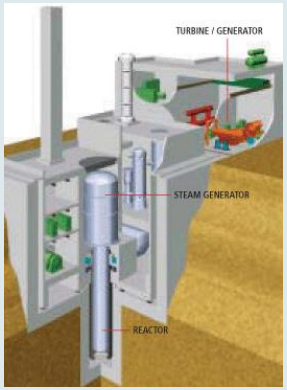
# DOE NOW WANTS SMALL REACTORS TO BE "ADVANCED"-- FAST



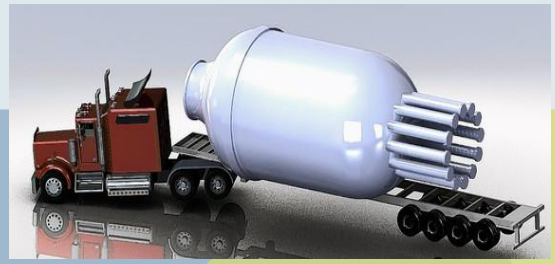

SLIMM



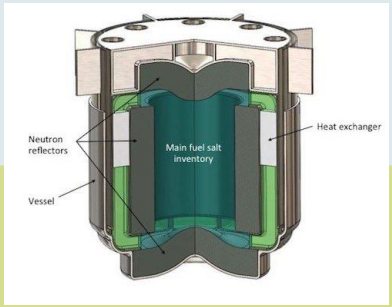
Traveling Wave Reactor



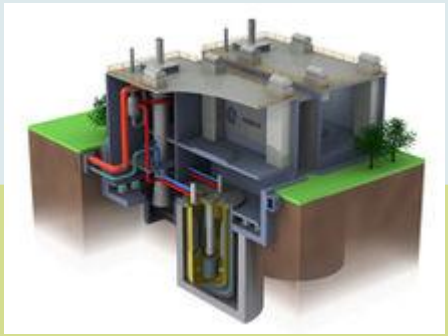

Toshiba 4s Reactor



Energy Multiplier Module

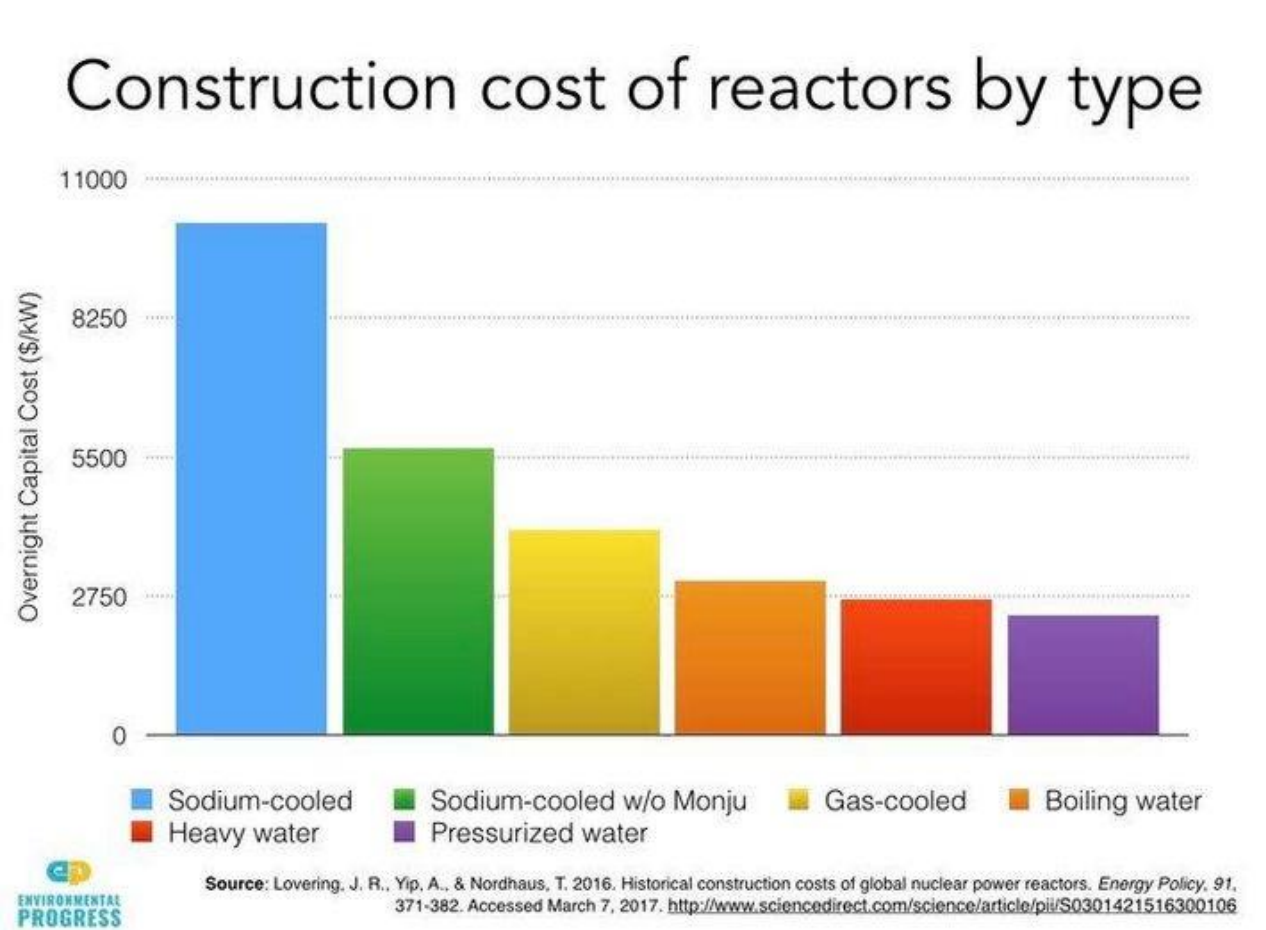



Molten Chloride Fast Reactor

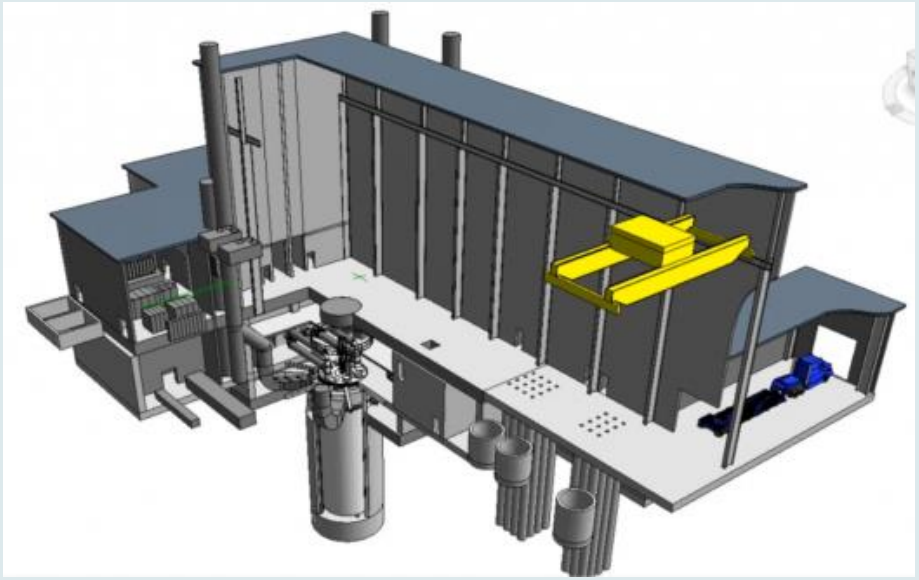


PRISM reactor

# YET, HISTORICALLY FAST REACTORS HAVE PROVED THE MOST COSTLY TO BUILD



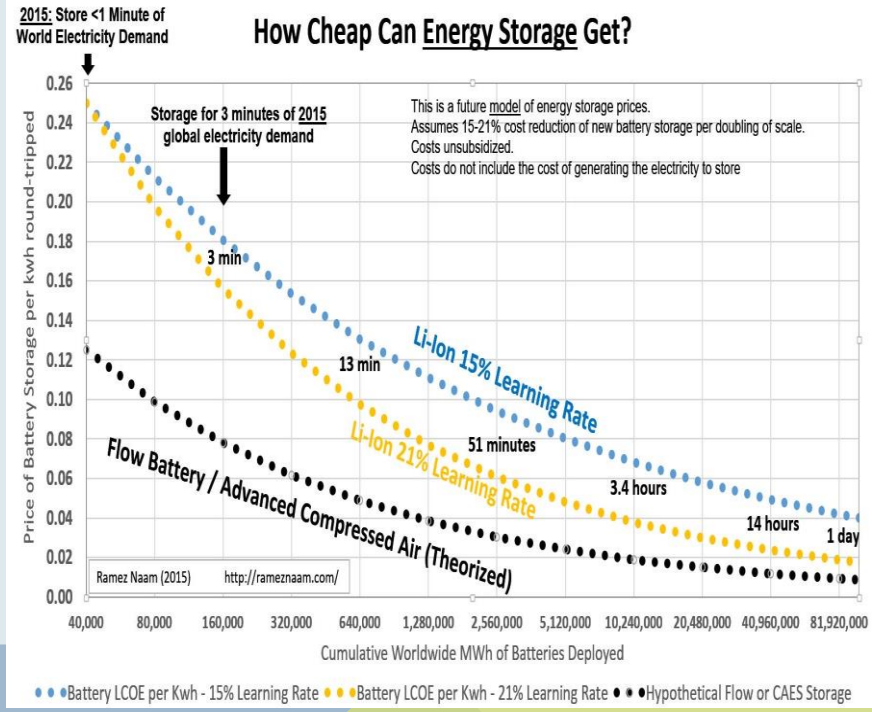
# TO HELP OUT, DOE PLANS TO SPEND BILLIONS ON ADVANCED NUCLEAR FUELS IN SUPPORT OF SMRS

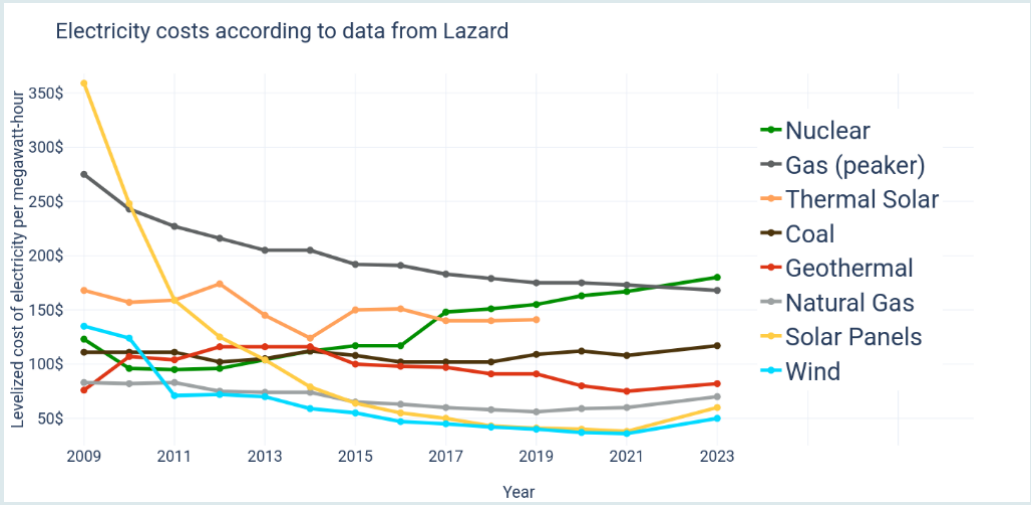


Versatile Test Reactor, $3-6 B

American Centrifuge Plant, Pinkerton, OH or DOE alternative, $10 B?

# NONNUCLEAR ECONOMIC COMPETITION IS PROJECTED TO GET STIFFER

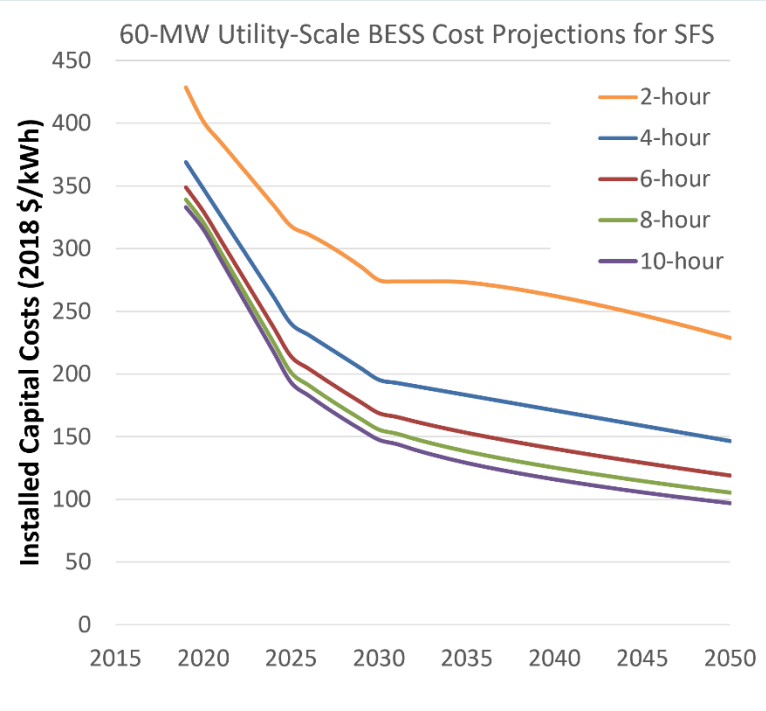


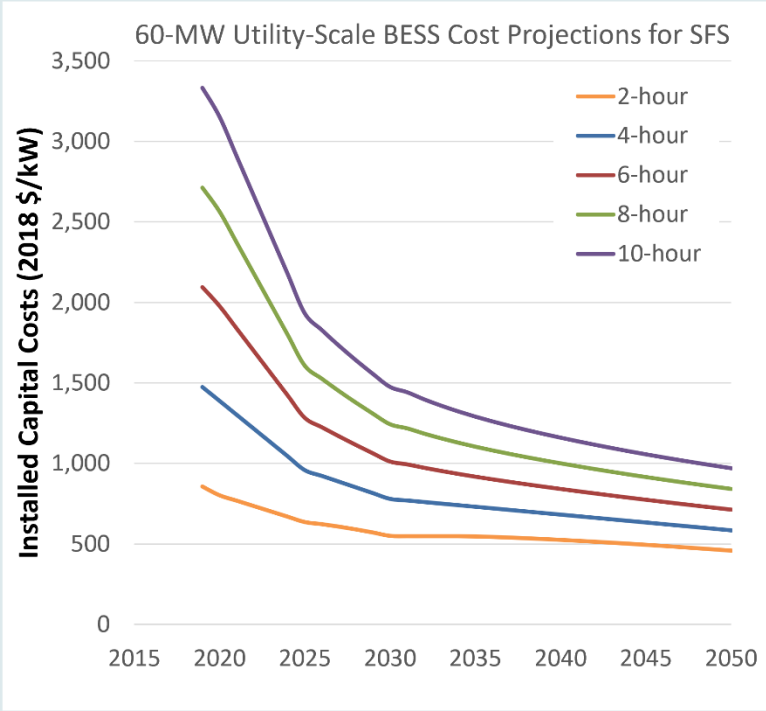




https://en.wikipedia.org/wiki/Levelized_cost_of_electricity

2021 there were 56 gigawatt hours of grid battery storage deployed worldwide https://about.bnef.com/blog/global-energy-storage-market-to-grow-15-fold-by-2030/

# GRID BATTERY STORAGE IS COMING DOWN AS WELL

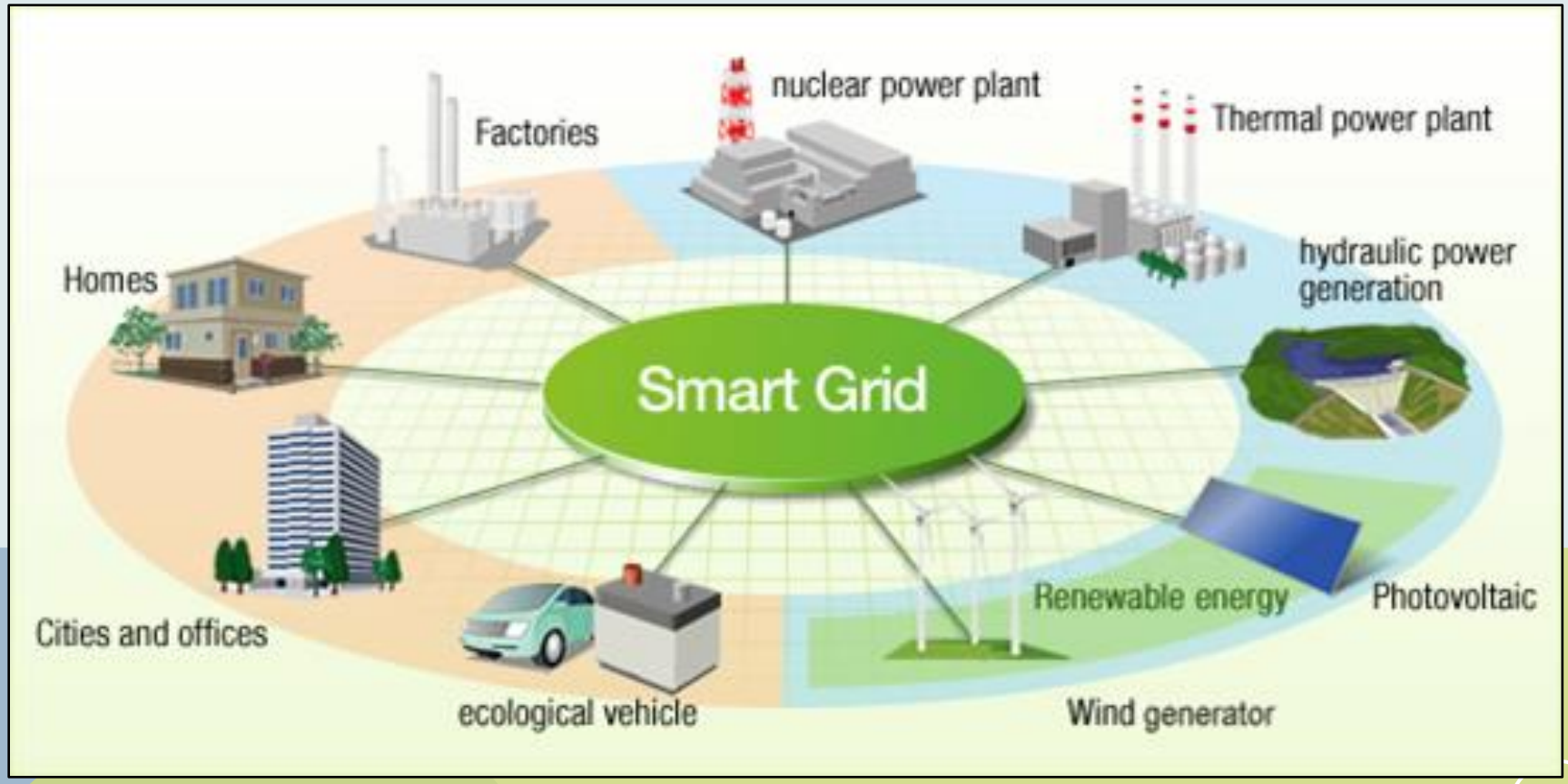



https://atb.nrel.gov/electricity/2022/utility-scale_battery_storage

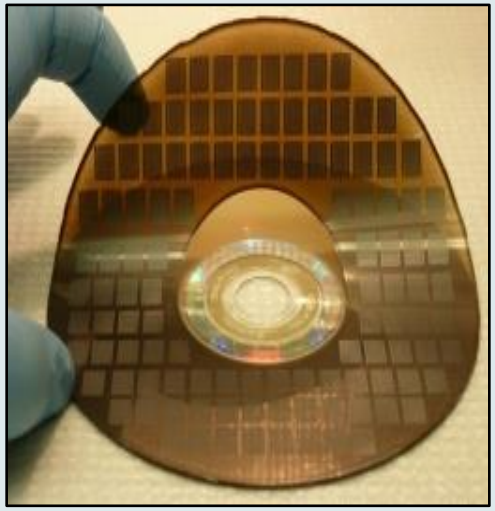
# NEW ENERGY TECHNOLOGY DEVELOPMENTS REINFORCE MOVE AWAY FROM NUCLEAR AND COAL

# SMART GRIDS BALANCE A WIDE # OF ELECTRICAL SOURCES & REDUCE BASE LOAD REQUIREMENTS



# TECHNOLOGIES FOR SMART GRIDS

*Super Capacitors, Switches, Batteries, Direct Current Systems*



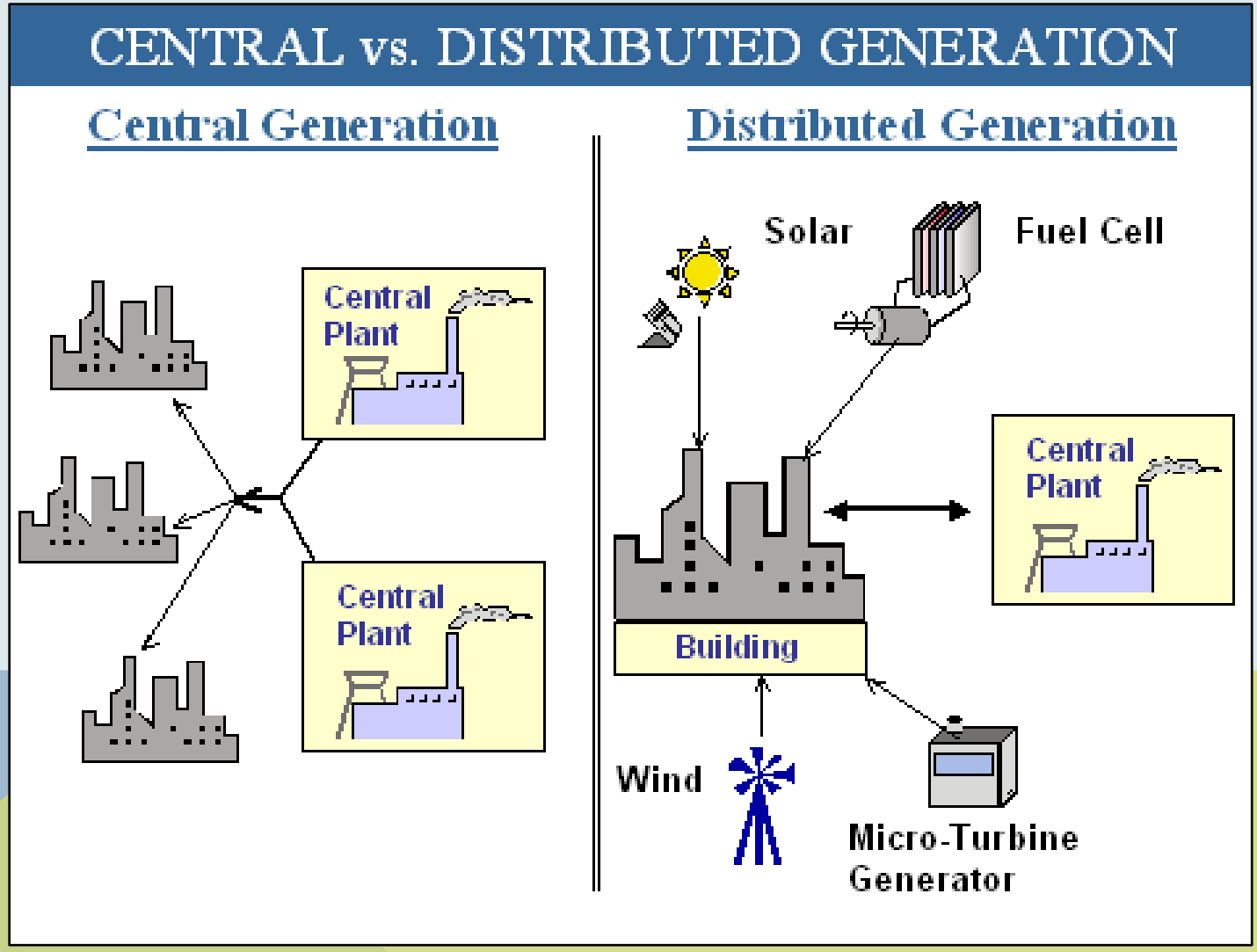
**MICRO SUPERCAPACITOR**

**WIND FARM BATTERY BANK**


**SMART MONITOR**

**High Voltage Direct Current Grid**

# TECHNOLOGIES FOR SMART GRIDS ALSO CAN BE USED IN DISTRIBUTED SYSTEMS

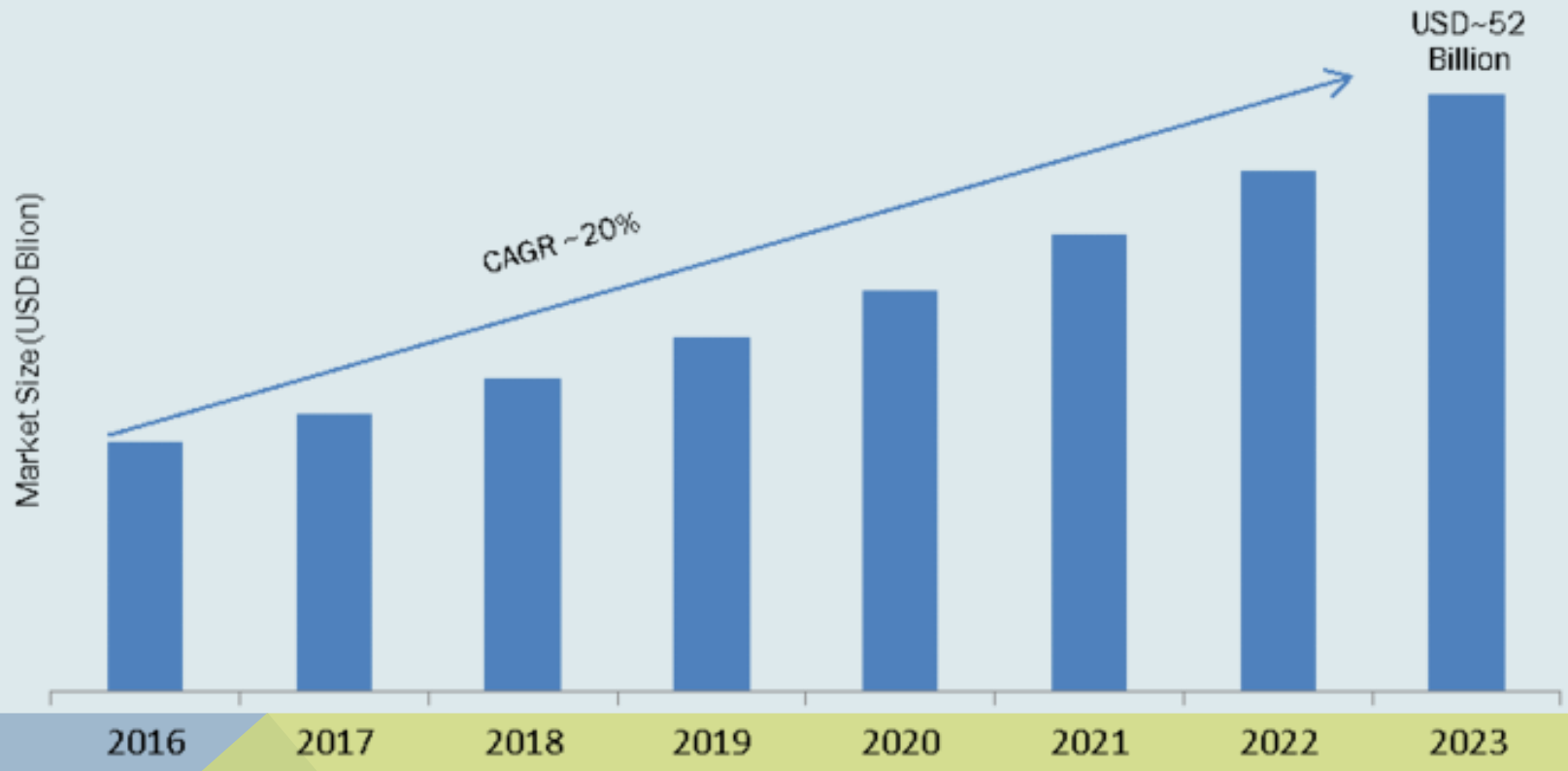


# DISTRIBUTED ELECTRICAL SYSTEMS WOULD MAKE THE GRID A BACKUP SYSTEM

| Conventional Model | | Bloom Model |
|---|---|---|
|  | Primary |  |
| Grid | | Bloom Energy Server (non-interruptible power supply) |
| + | | + |
|   | Backup |  |
| Backup Generator Batteries | | Grid |
| Sunk Capital in equipment<br>Also use of backup power supply is limited even if blackout lasts long | | Realize a Stable Power Supply<br>Grid and gas pipe are independent |

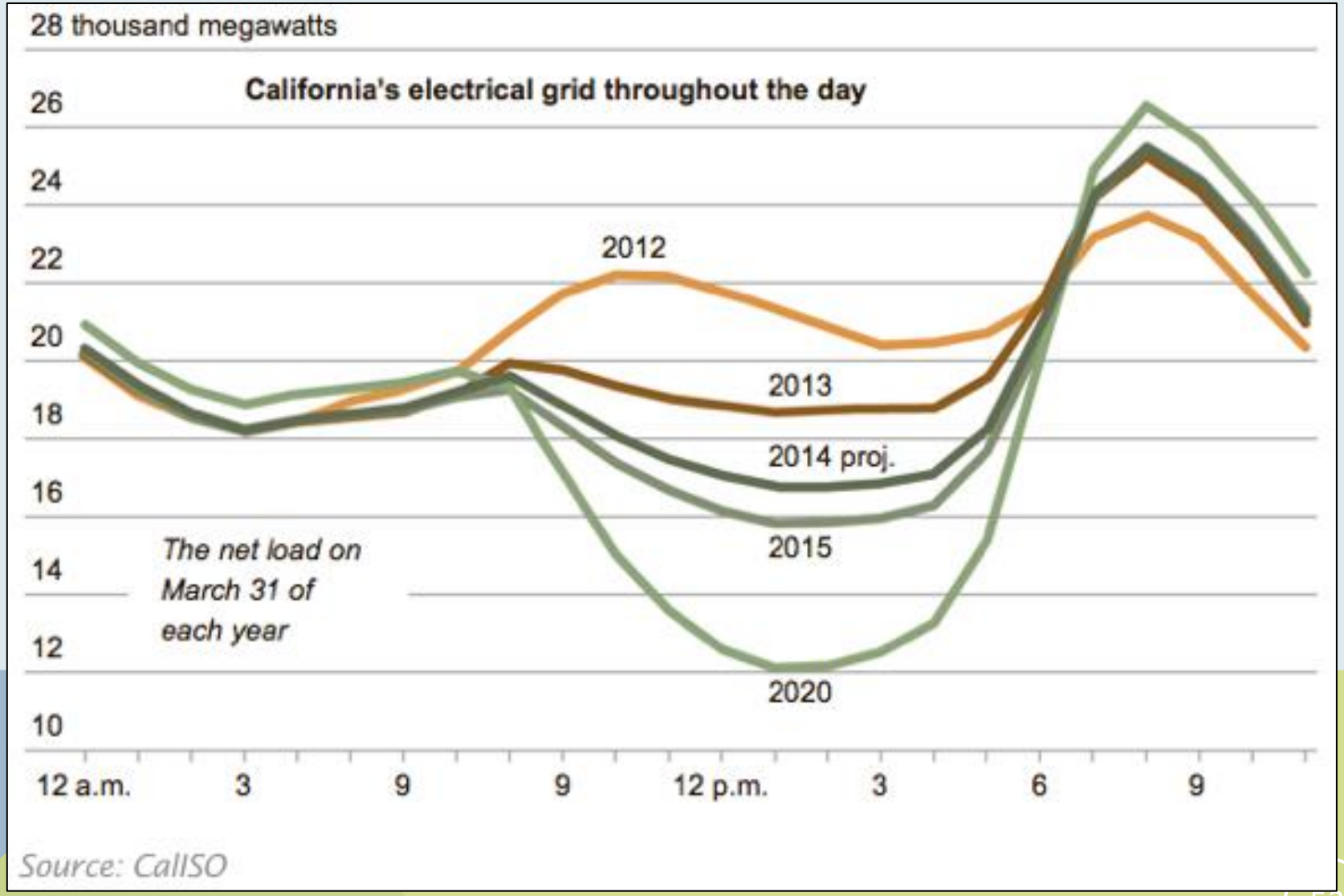
35

# SMART GRIDS: GROWING MARKETS




https://www.marketresearchfuture.com/reports/smart-grid-market-1110

# THE GRID MANAGEMENT CHALLENGE
# RENEWABLES PRESENT



# LITHIUM-ION GIGA-BATTERY FACTORIES

planned Brandenburg

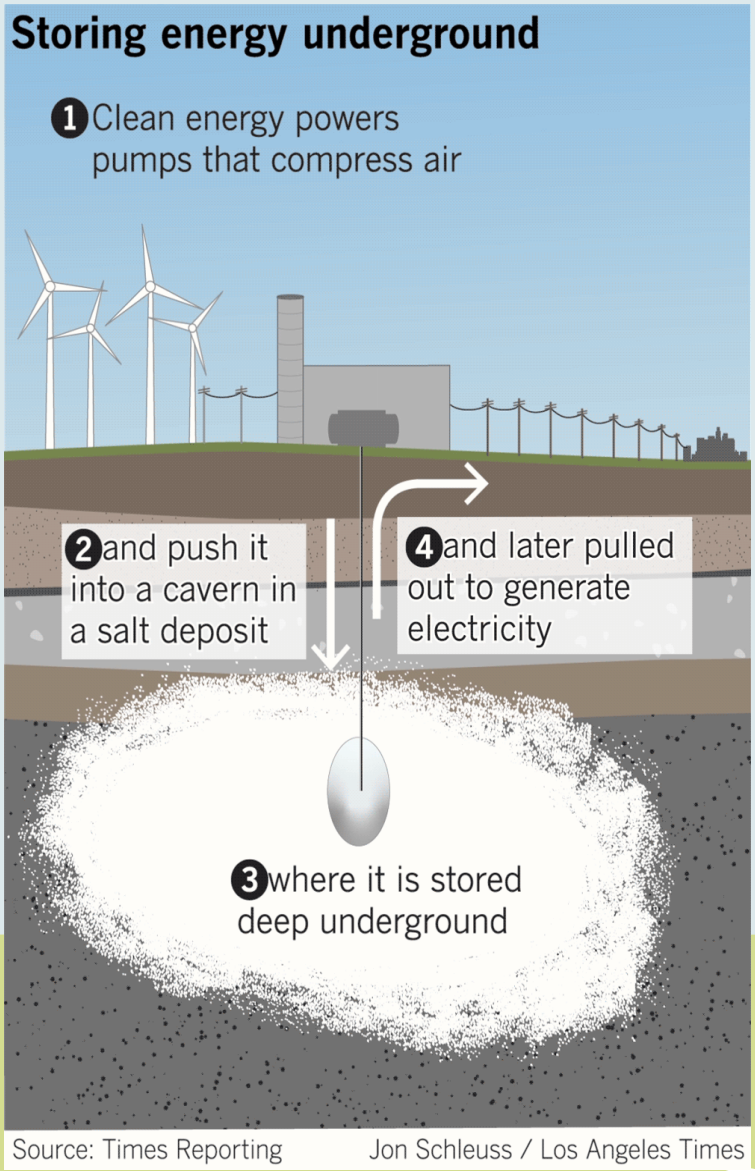

Netherlands

Nevada


https://merics.org/en/analysis/chinas-battery-industry-powering-global-competition

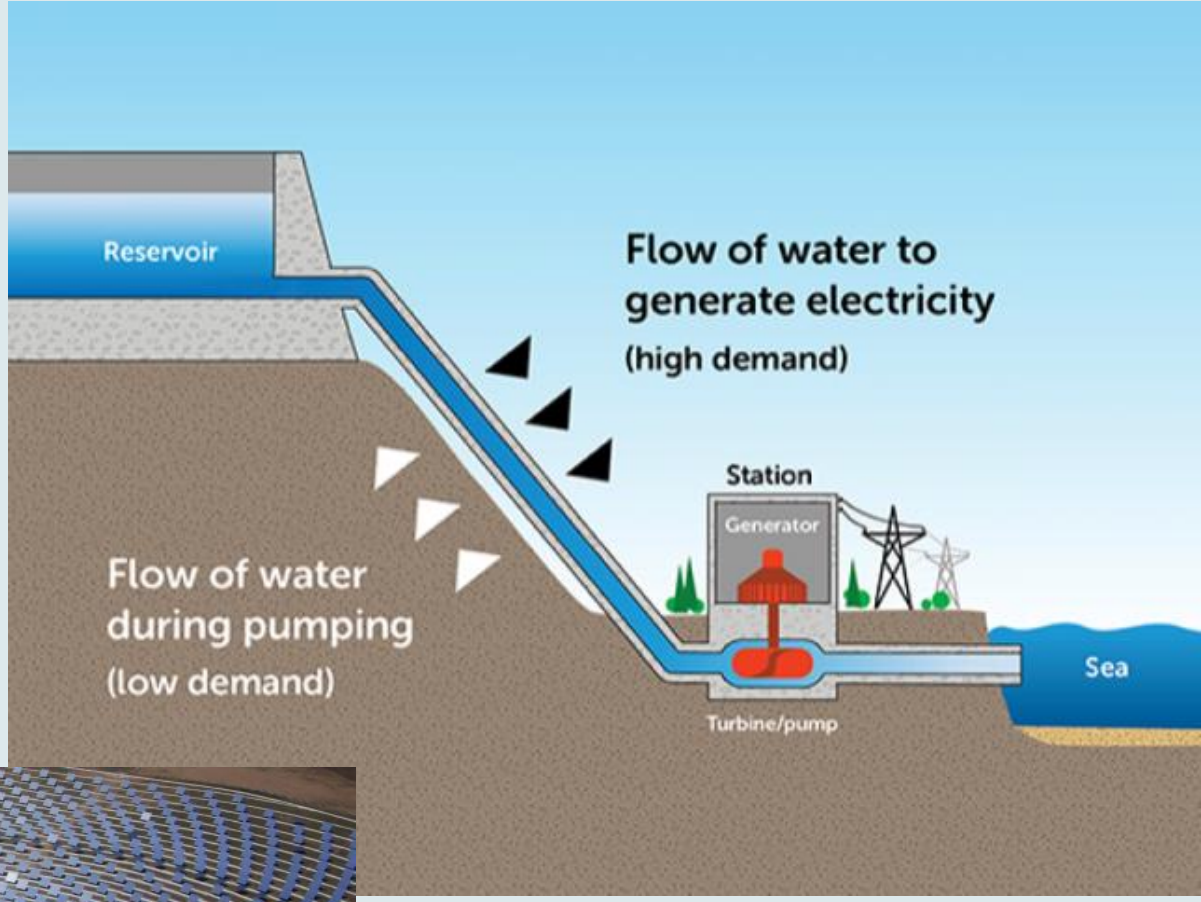
# OTHER KINDS OF BATTERIES

**Flow battery, California, 2 megawatt 8 megawatt hours**




**Utah plans 1 gigawatt**

# MORE BATTERIES




**Pumped storage**

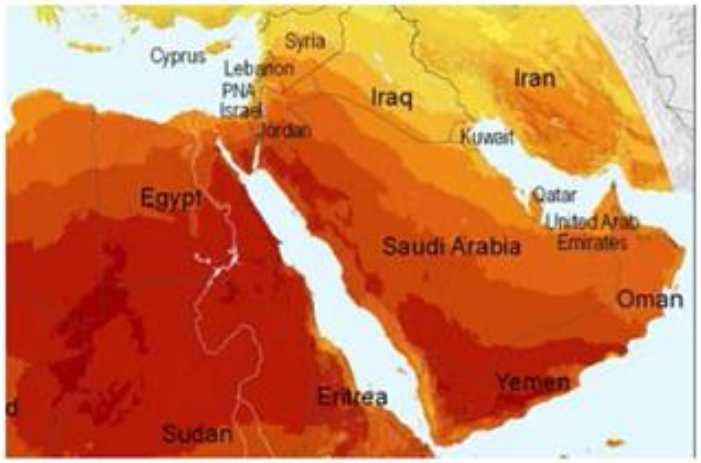
**Concentrated solar plant, Spain**

# BATTERY STORAGE IS INCREASING NATURAL GAS'S COMPETITIVE EDGE

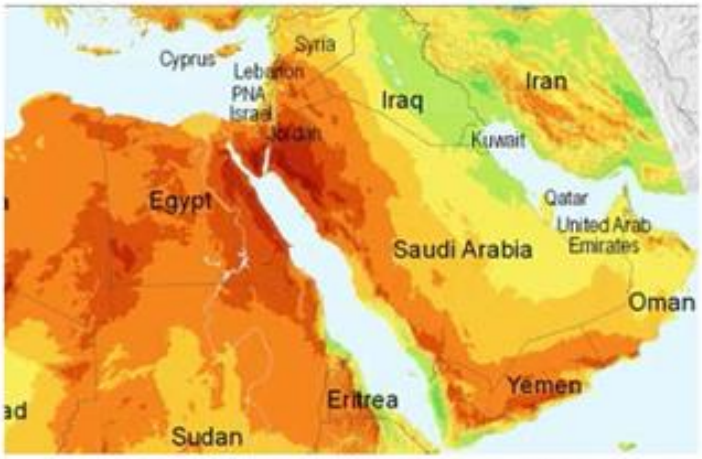

**2. Center Peaker facility's** battery dispatches power immediately upon receiving the CAISO dispatch signal and continues to provide power while the gas turbine/generator starts up

# RENEWABLES ARE BECOMING MORE ATTRACTIVE IN THE MIDDLE EAST

# THE MIDDLE EAST IS RICH IN RENEWABLE ENERGY POTENTIAL

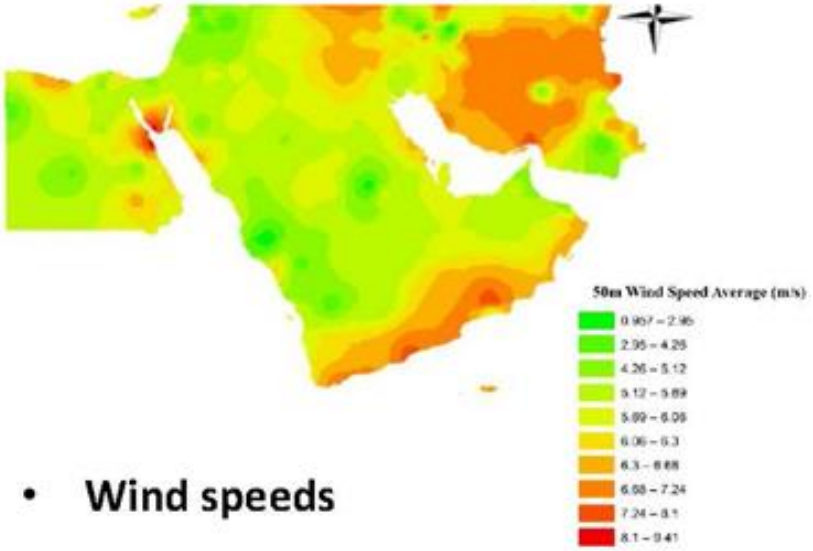



- Total solar radiation (PV)




- Direct solar radiation (CSP)

- GCC focuses on Solar PV because it is cheaper
- Advantage of CSP is its thermal storage
- Possibility of PV power with storage




- Wind speeds

# CONCENTRATED SOLAR POWER COSTS:
# NOW WELL BELOW NUCLEAR

## Falling Prices for CSP Plants with Molten Salt

The prices for electricity from concentrated solar power (CSP) plants with molten salt energy storage have dropped by more than half since SolarReserve started developing its Crescent Dunes plant in 2009. Some recent bids to build new plants show the price trajectory.

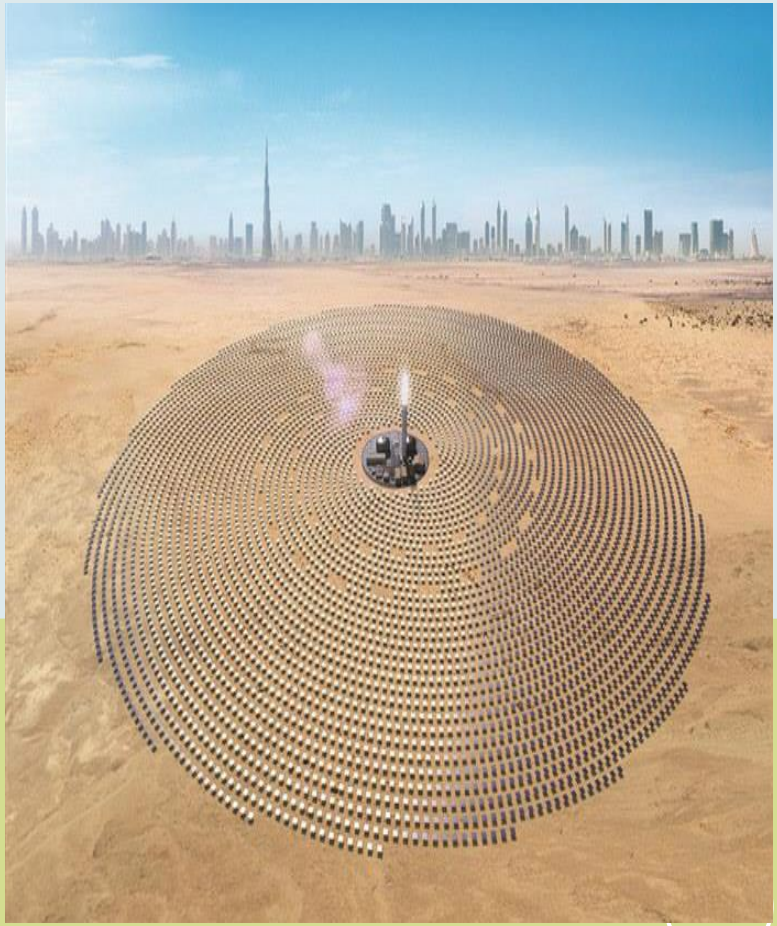
**CSP MOLTEN SALT TOWER PROJECTS**

| PROJECT/LOCATION | DEVELOPER(S) | CAPACITY/ STATUS | POWER PRICE | DATE PRICED |
|---|---|---|---|---|
| **Crescent Dunes** *Tonopah, Nevada* | SolarReserve | 110 MW *(operating)* | **13.5¢/ kWh** | 2009 |
| **Noor III** *Ouarzazate, Morocco* | ACWA Power, Sener | 150 MW *(under construction)* | **15¢/ kWh** | 2014 |
| **Redstone** *Postmasburg, South Africa* | SolarReserve, ACWA Power | 100 MW *(preferred bidder)* | **12.4¢/ kWh** | 2015 |
| **MBR Solar Park Phase 4** *Dubai, UAE* | ACWA Power, Shanghai Electric | 100 MW* *(construction to begin 2018)* | **7.3¢/ kWh** | 2017 |
| **Aurora** *Port Augusta, South Australia* | SolarReserve | 150 MW *(construction to begin 2018)* | **6¢/ kWh** | 2017 |
| **Copiapo** *Copiapo, Chile* | SolarReserve | 260 MW *(pending bid)* | **<5¢/ kWh** | 2017 |

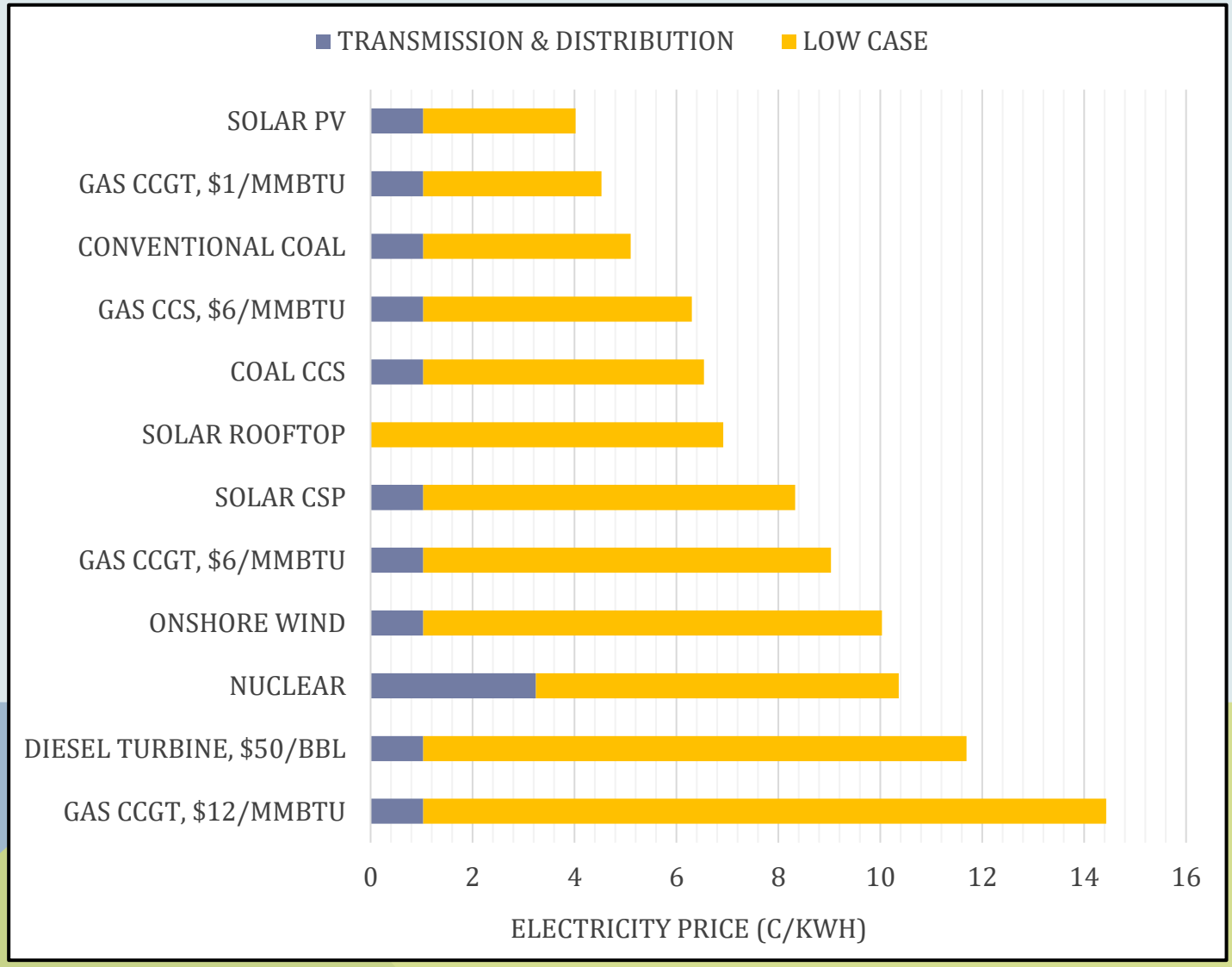
*Power price is based on the power purchase agreement (PPA) signed by the developer for power from the project; it may not reflect other sources of project income such as the sale of environmental credits or excess power.*
**PPA for this project covers a mix of trough and CSP tower facilities.*

SOURCES: SolarReserve; National Renewable Energy Laboratory

PAUL HORN / InsideClimate News



# SAUDI ARABIA'S BEST BET IS NOT NUCLEAR



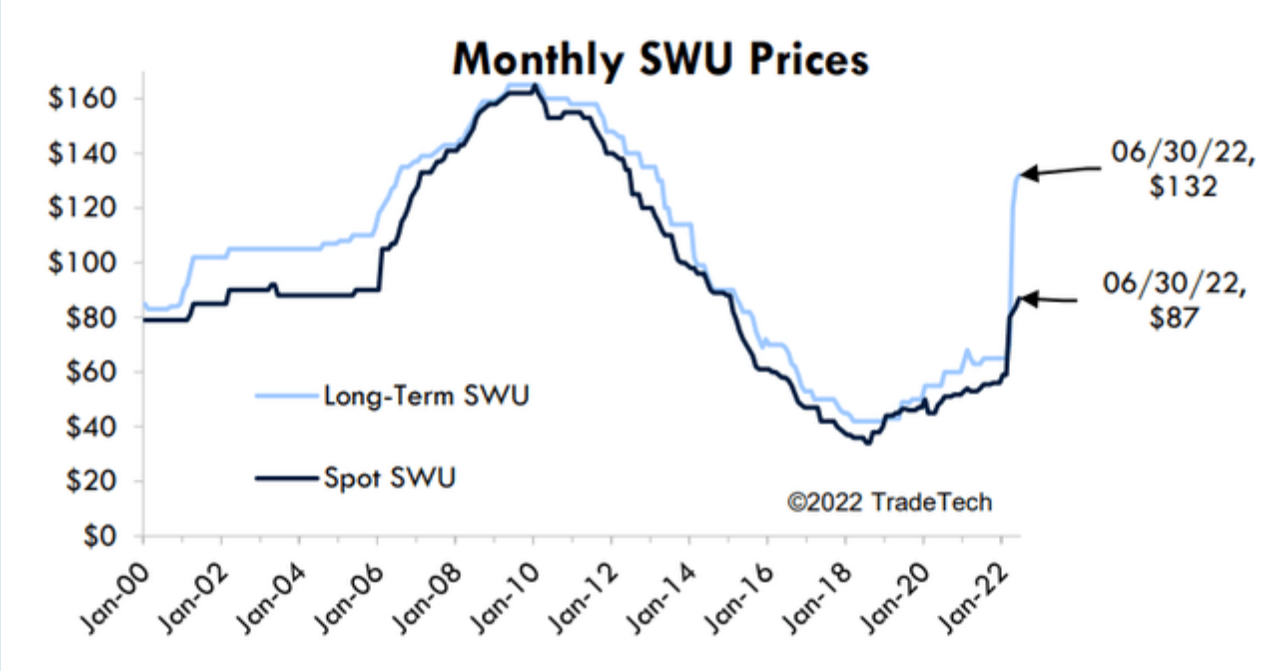

*Source: Qamar research*

# URANIUM: PLENTIFUL AND CHEAP ~$53.20/POUND, 11/2023


https://world-nuclear.org/information-library/nuclear-fuel-cycle/uranium-resources/uranium-markets.aspx

https://ycharts.com/indicators/uranium_spot_price#:~:text=Uranium%20Spot%20Price%20is%20at,9.16%25%20from%20one%20year%20ago.

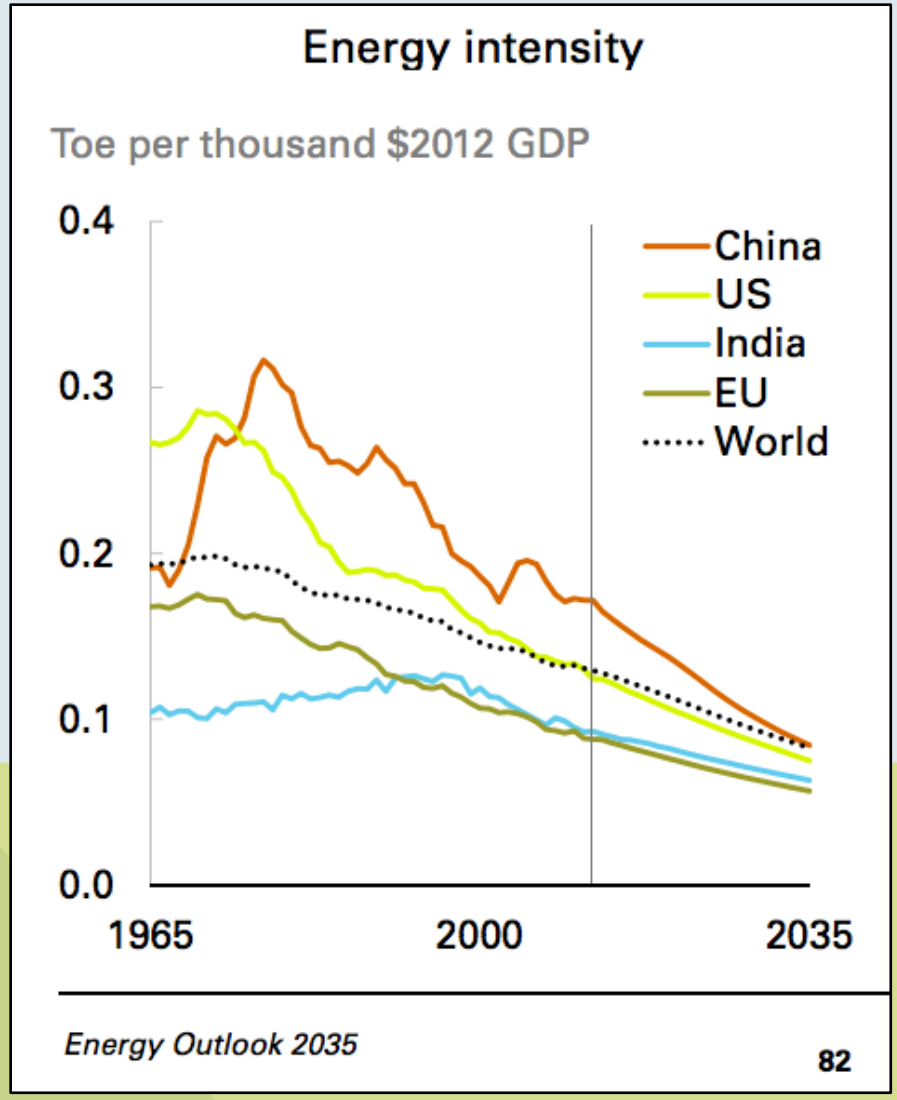
# ENRICHMENT SERVICES: CLIMBING ON SPECULATION ($130/SWU 4/23)



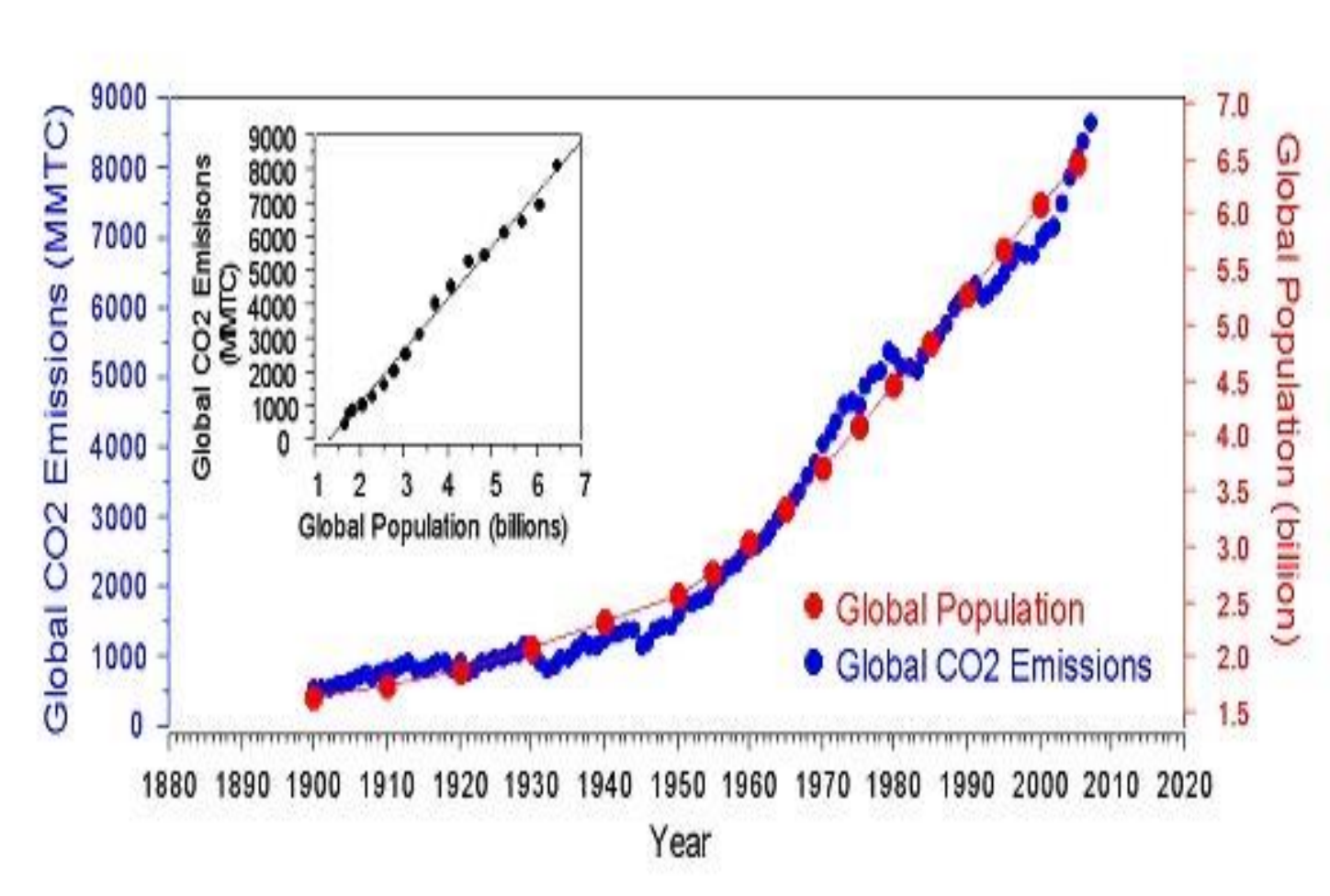

https://seekingalpha.com/article/4556160-centrus-energy-reiterating-bullish-thesis

# FUTURE NON-ECONOMIC VARIABLES OF INTEREST

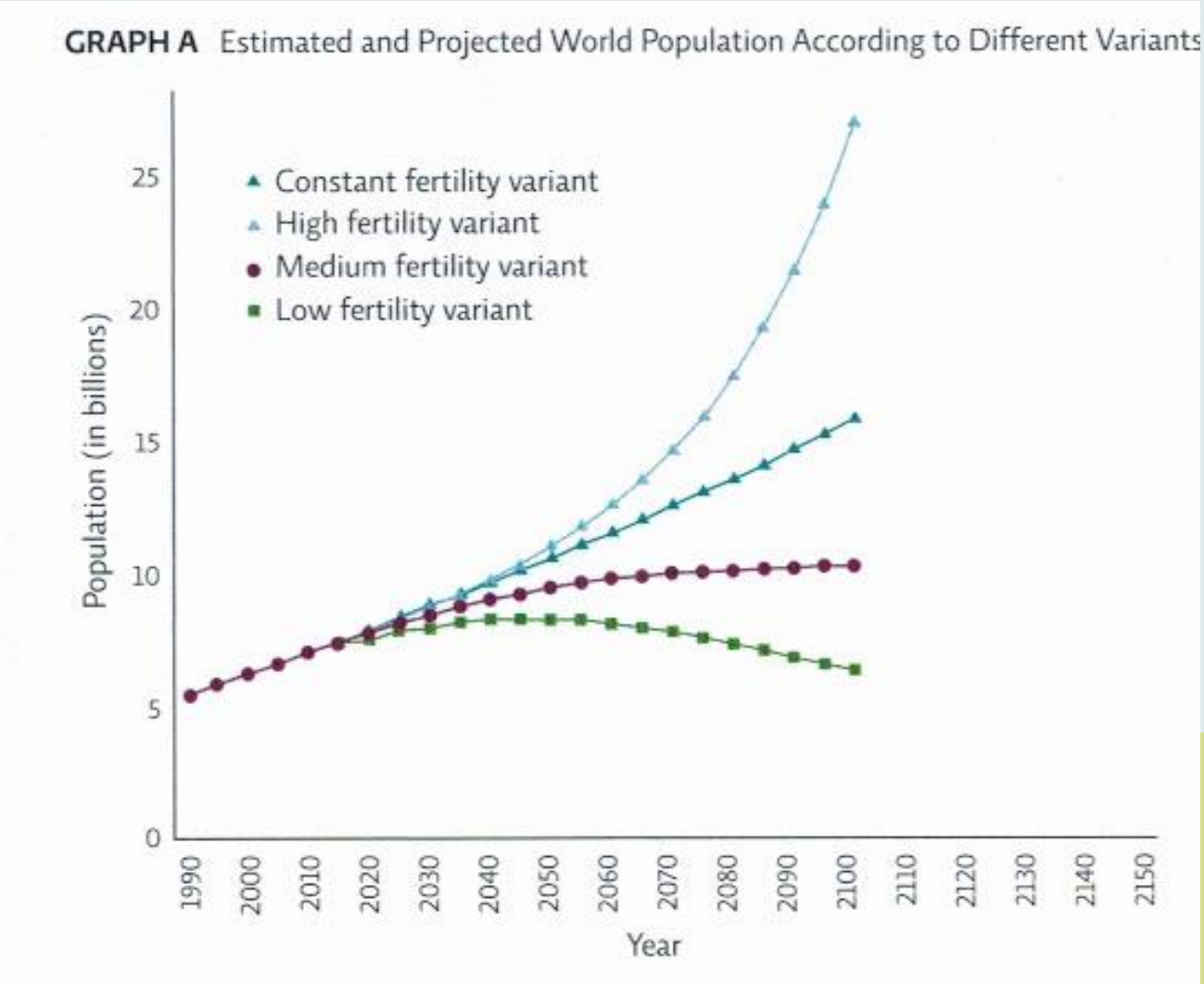
# ENERGY INTENSITY OF GDP IS DECLINING



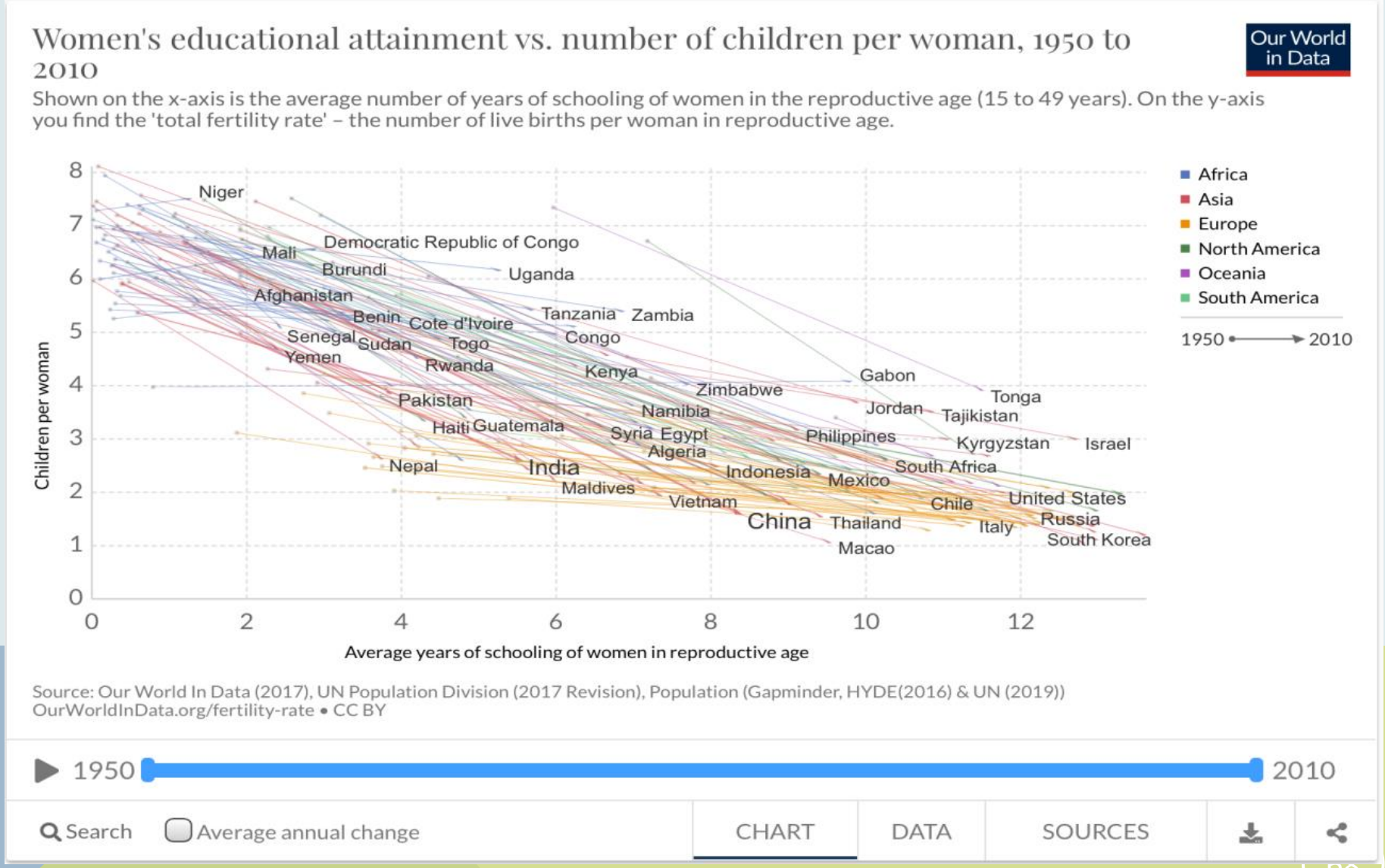
# CURRENT GLOBAL WARMING MODELS ASSUME MEDIAN POPULATION GROWTH



# IT'S UNCLEAR IF POPULATION WILL DECLINE OR RISE AFTER 2040

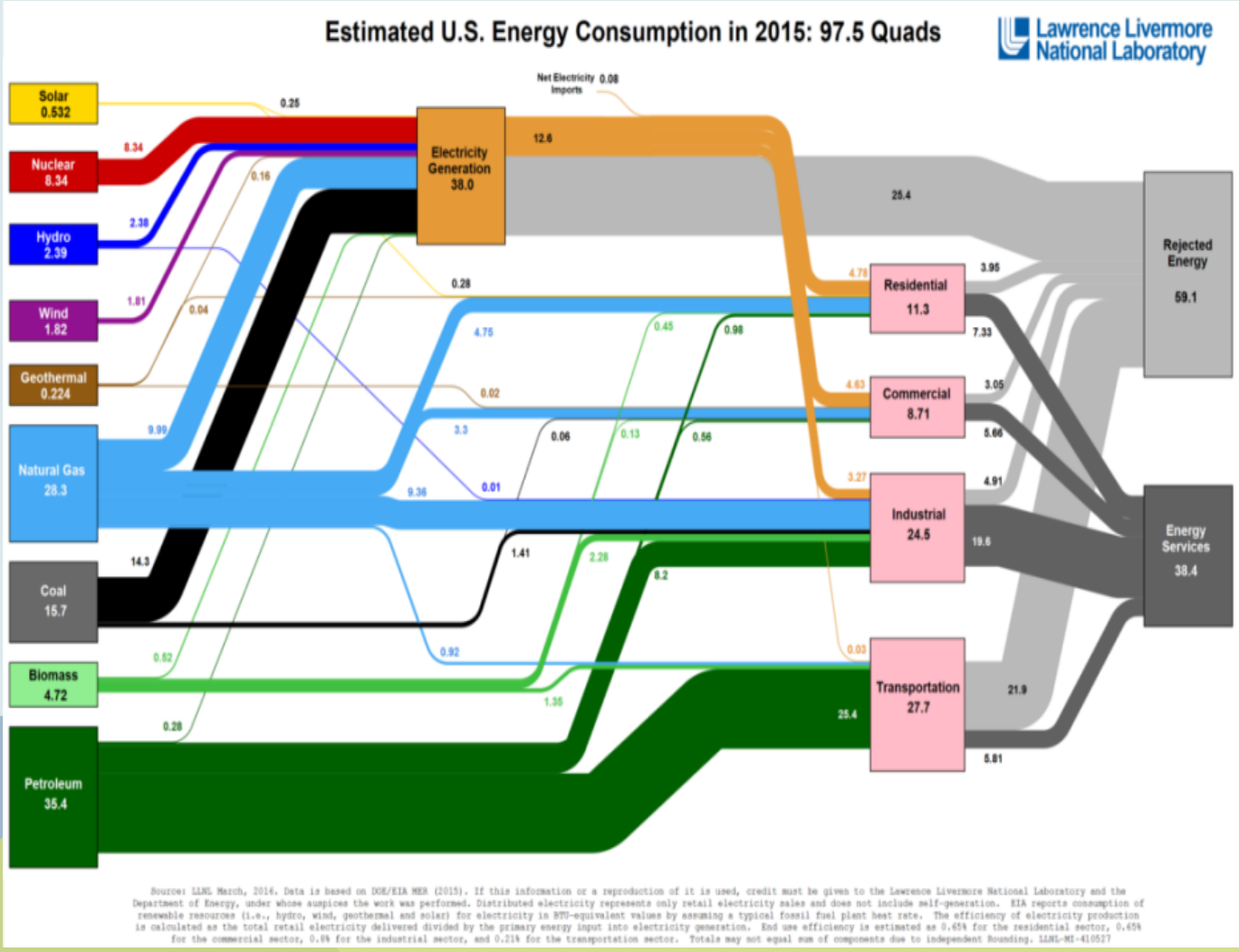


# FERTILITY HAS DECLINED WITH EDUCATION

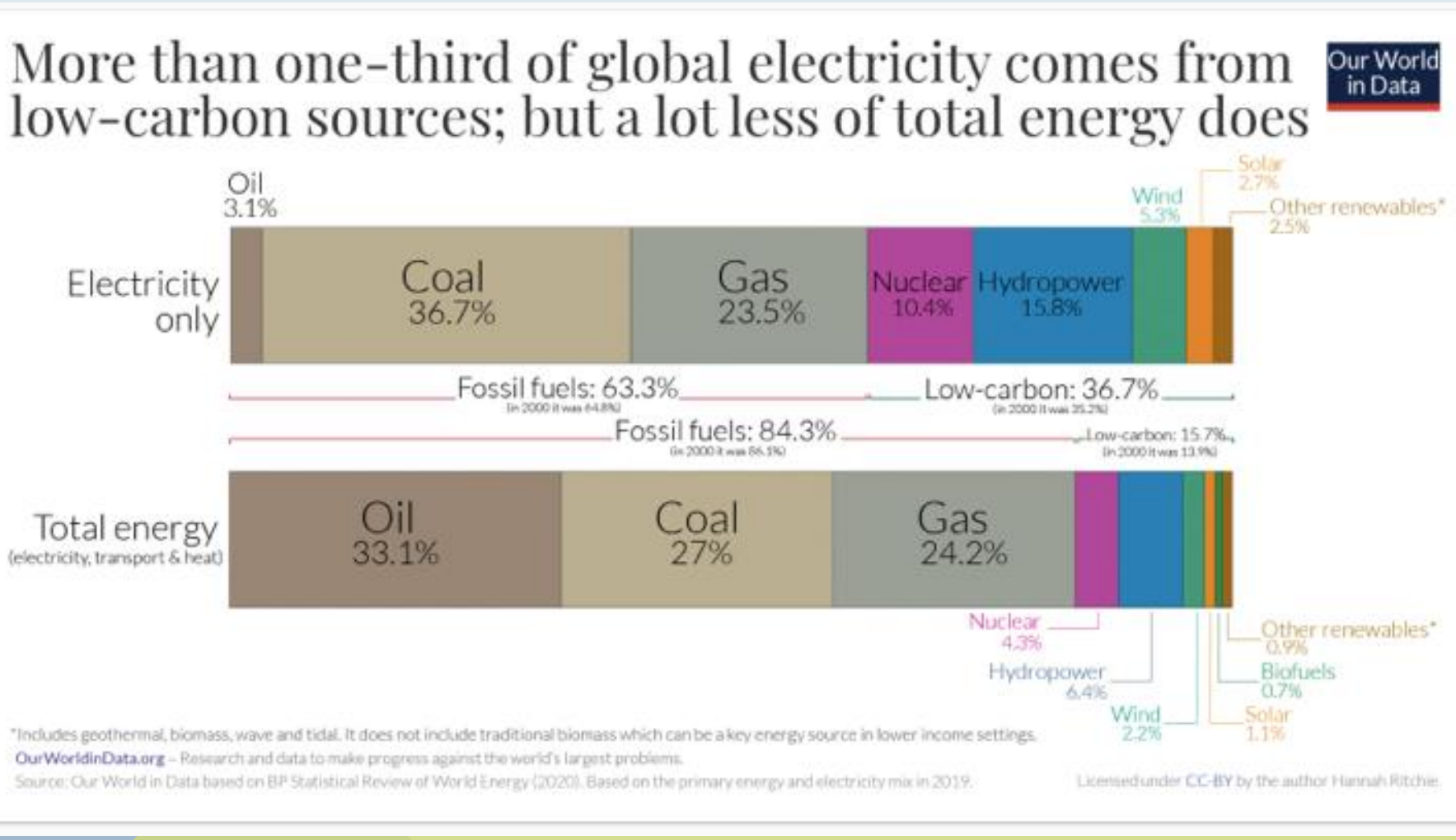



https://ourworldindata.org/grapher/womens-educational-attainment-vs-fertility

# WE STILL WASTE MORE THAN HALF THE ENERGY WE PRODUCE



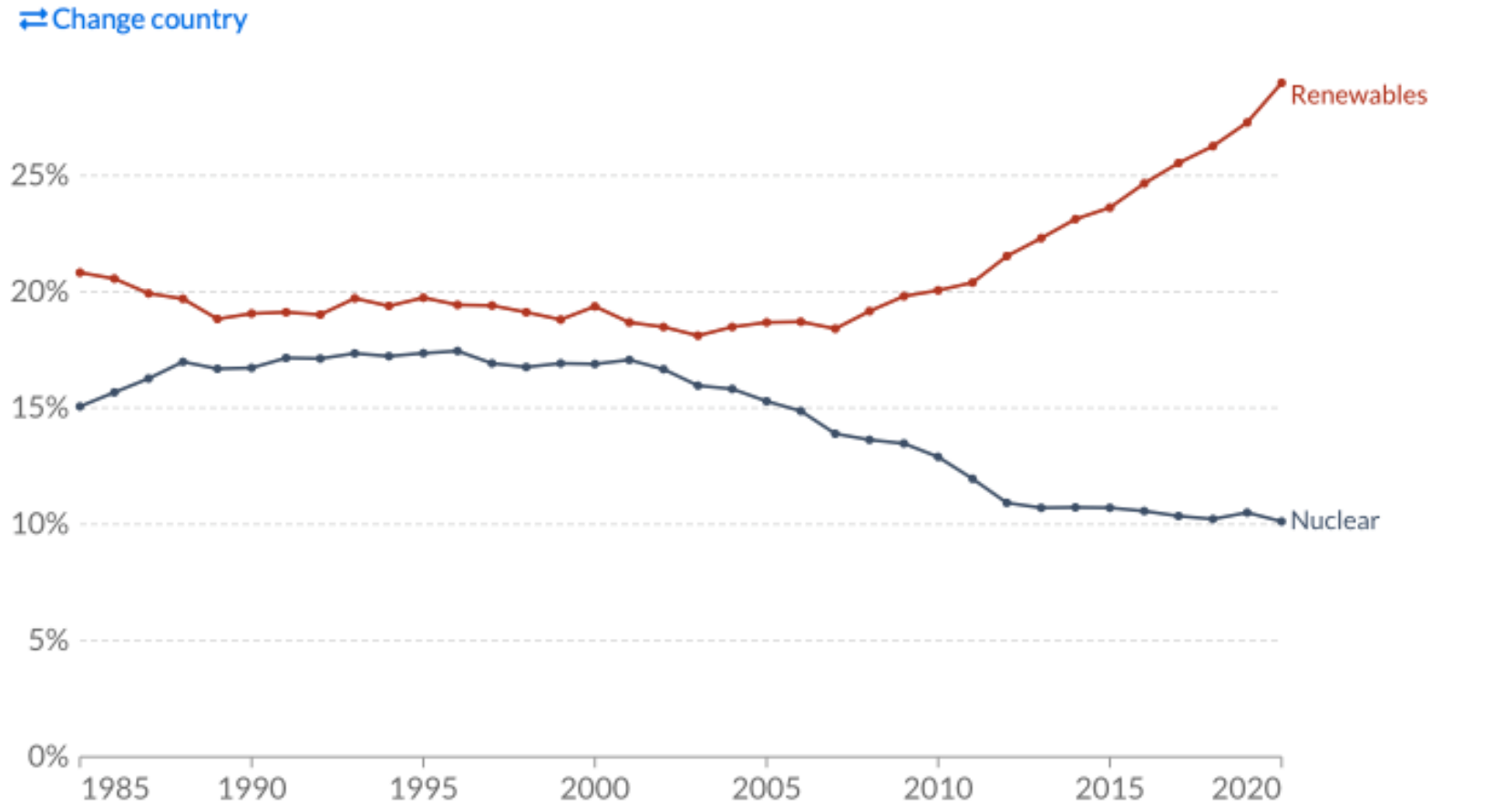
# ADDITIONAL SLIDES


More than one-third of global electricity comes from low-carbon sources; but a lot less of total energy does
Our World in Data
Electricity only
Oil 3.1%
Coal 36.7%
Gas 23.5%
Nuclear 10.4%
Hydropower 15.8%
Wind 5.3%
Solar 2.7%
Other renewables* 2.5%
Fossil fuels: 63.3%
(in 2000 it was 64.8%)
Low-carbon: 36.7%
(in 2000 it was 35.2%)
Fossil fuels: 84.3%
(in 2000 it was 86.1%)
Low-carbon: 15.7%
(in 2000 it was 13.9%)
Total energy
(electricity, transport & heat)
Oil 33.1%
Coal 27%
Gas 24.2%
Nuclear 4.3%
Hydropower 6.4%
Wind 2.2%
Solar 1.1%
Biofuels 0.7%
Other renewables* 0.9%
*Includes geothermal, biomass, wave and tidal. It does not include traditional biomass which can be a key energy source in lower income settings.
OurWorldinData.org – Research and data to make progress against the world's largest problems.
Source: Our World in Data based on BP Statistical Review of World Energy (2020). Based on the primary energy and electricity mix in 2019.
Licensed under CC-BY by the author Hannah Ritchie

# The share of nuclear and renewables in total electricity production, World

Our World in Data

'Renewables' includes hydropower, biomass, wind, solar, geothermal and marine production; it does not include nuclear or traditional biomass.




Source: BP Statistical Review of World Energy & Ember

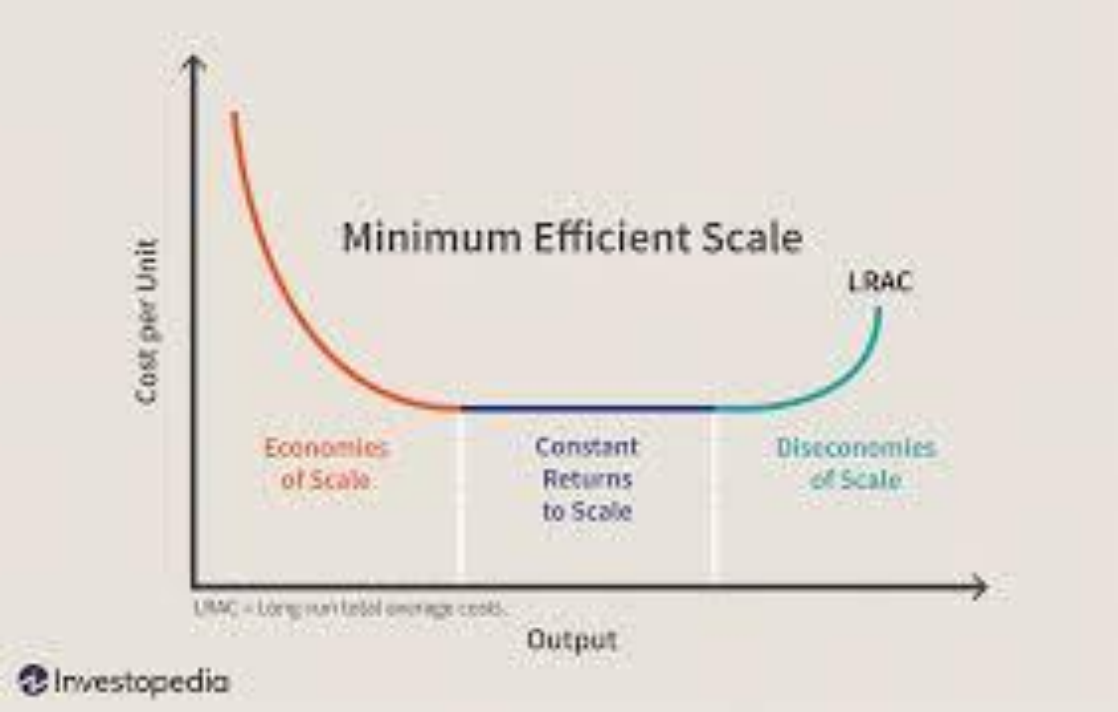
CC BY

1985 2020

CHART TABLE SOURCES DOWNLOAD

# THEORETICALLY, AS REACTORS GET BIGGER, THE CAPITAL COSTS OF PRODUCING ELECTRICITY SHOULD DECLINE

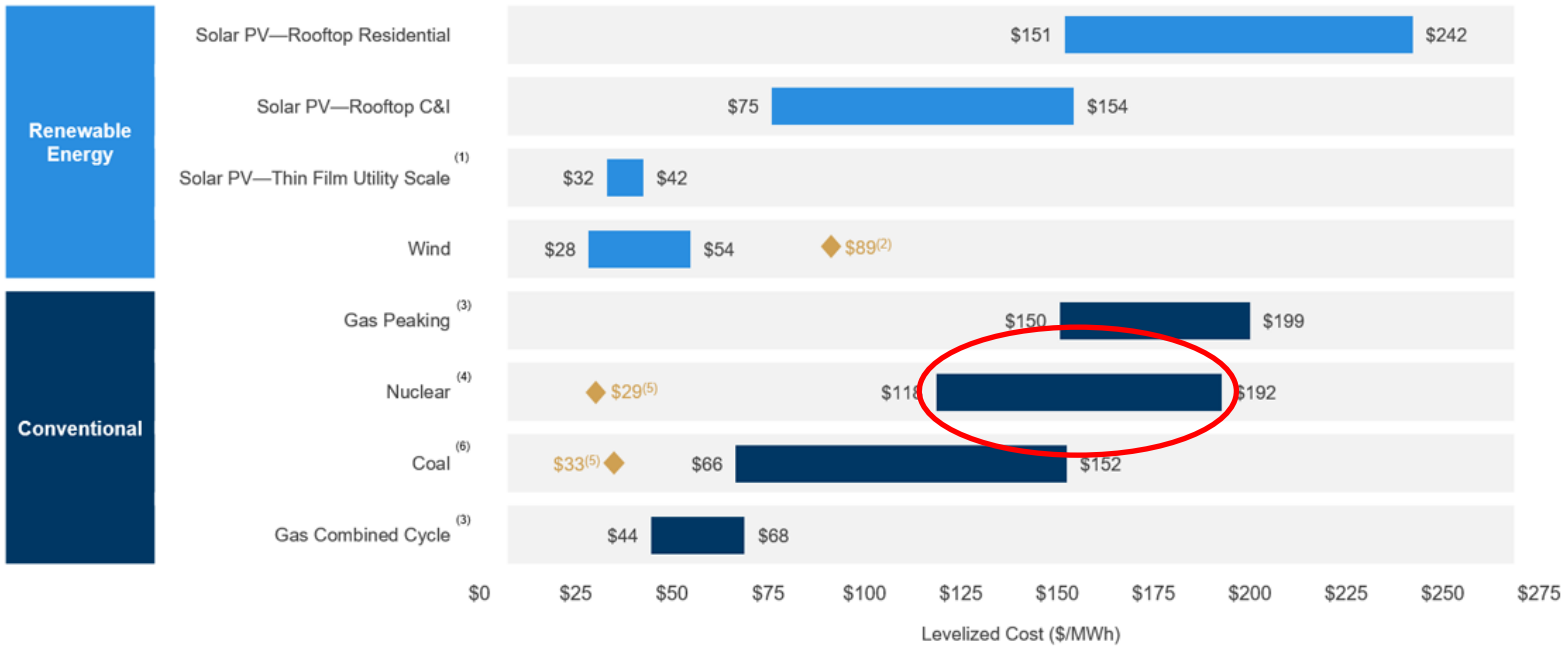
**The larger the reactor, the more electricity it produces. Making them bigger was supposed to reduce the cost of an installed kilowatt hour**



# Today, Large Reactor Builds Can't Compete Economically with Nonnuclear Alternatives

**Levelized Cost of Energy Comparison—Unsubsidized Analysis**

**Selected renewable energy generation technologies are cost-competitive with conventional generation technologies under certain circumstances**




*Source:* *Lazard estimates.*

Note: Here and throughout this presentation, unless otherwise indicated, the analysis assumes 60% debt at 8% interest rate and 40% equity at 12% cost. Please see page titled "Levelized Cost of Energy Comparison—Sensitivity to Cost of Capital" for cost of capital sensitivities. These results are not intended to represent any particular geography. Please see page titled "Solar PV versus Gas Peaking and Wind versus CCGT—Global Markets" for regional sensitives to selected technologies.

(1) Unless otherwise indicated herein, the low end represents a single-axis tracking system and the high end represents a fixed-tilt system.

(2) Represents the estimated implied midpoint of the LCOE of offshore wind, assuming a capital cost range of approximately $2.33 – $3.53 per watt.

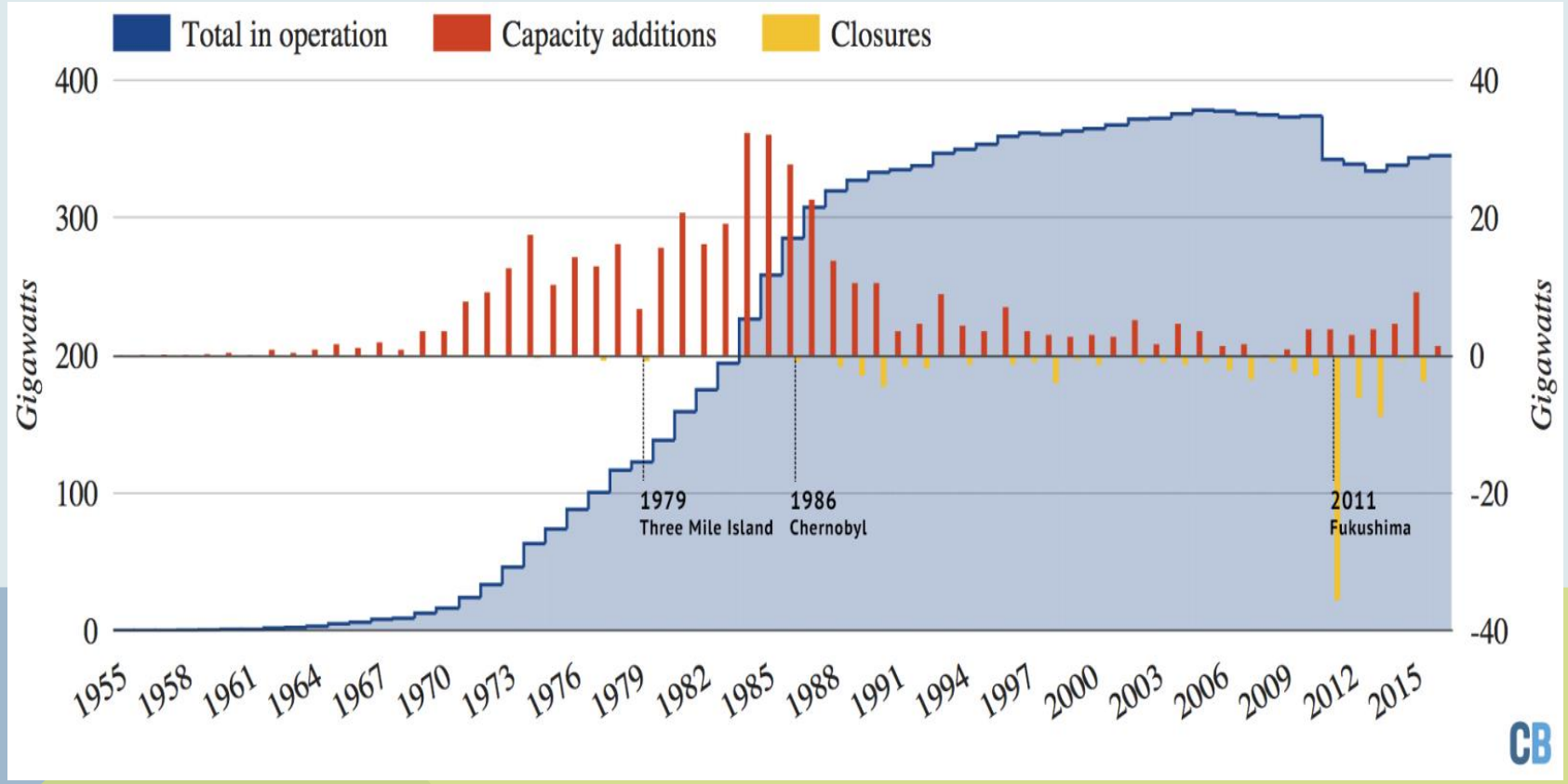
(3) The fuel cost assumption for Lazard's global, unsubsidized analysis for gas-fired generation resources is $3.45/MMBTU.

(4) Unless otherwise indicated, the analysis herein does not reflect decommissioning costs, ongoing maintenance-related capital expenditures or the potential economic impacts of federal loan guarantees or other subsidies.

(5) Represents the midpoint of the marginal cost of operating coal and nuclear facilities, inclusive of decommissioning costs for nuclear facilities. Analysis assumes that the salvage value for a decommissioned coal plant is equivalent to its decommissioning and site restoration costs. Inputs are derived from a benchmark of operating coal and nuclear assets across the U.S. Capacity factors, fuel and variable and fixed operating expenses are based on upper and lower quartile estimates derived from Lazard's research. Please see page titled "Levelized Cost of Energy Comparison—Renewable Energy versus Marginal Cost of Selected Existing Conventional Generation" for additional details.

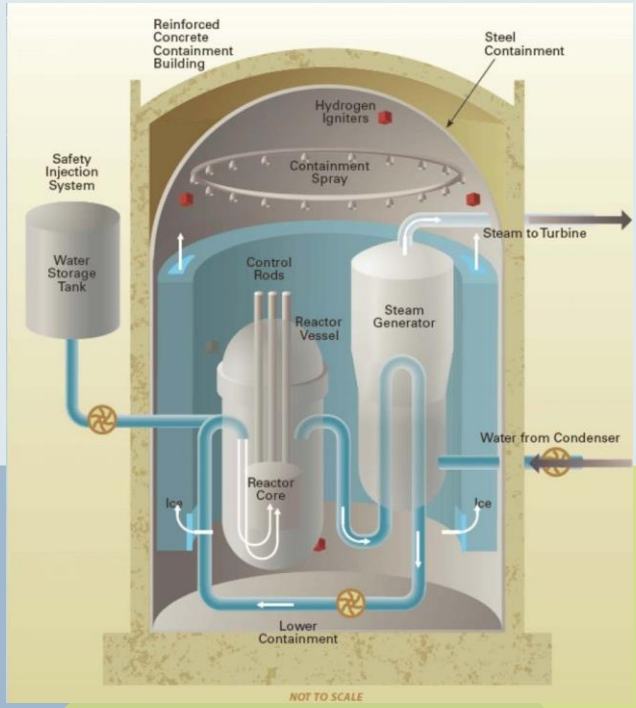
(6) High end incorporates 90% carbon capture and compression. Does not include cost of transportation and storage.

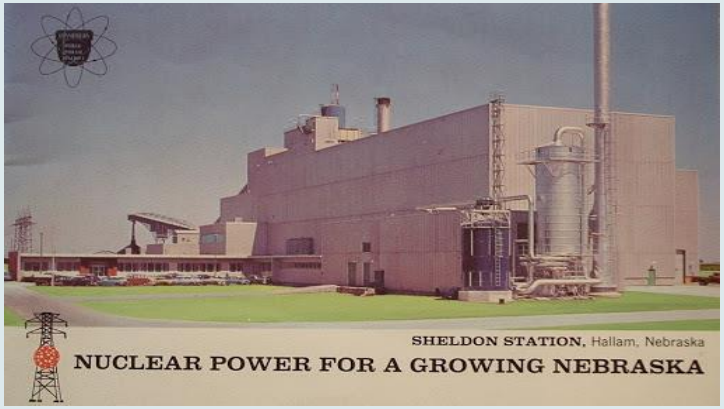
# THIS HAS DISCOURAGED NEW REACTOR BUILDS



# AS REACTORS GREW LARGER, ECONOMICS RECOMMENDED THAT CONTAINMENT REQUIREMENTS BE LOOSENED

FUEL FAILURES AND CORE MELTDOWNS WERE PRESUMED UNLIKELY

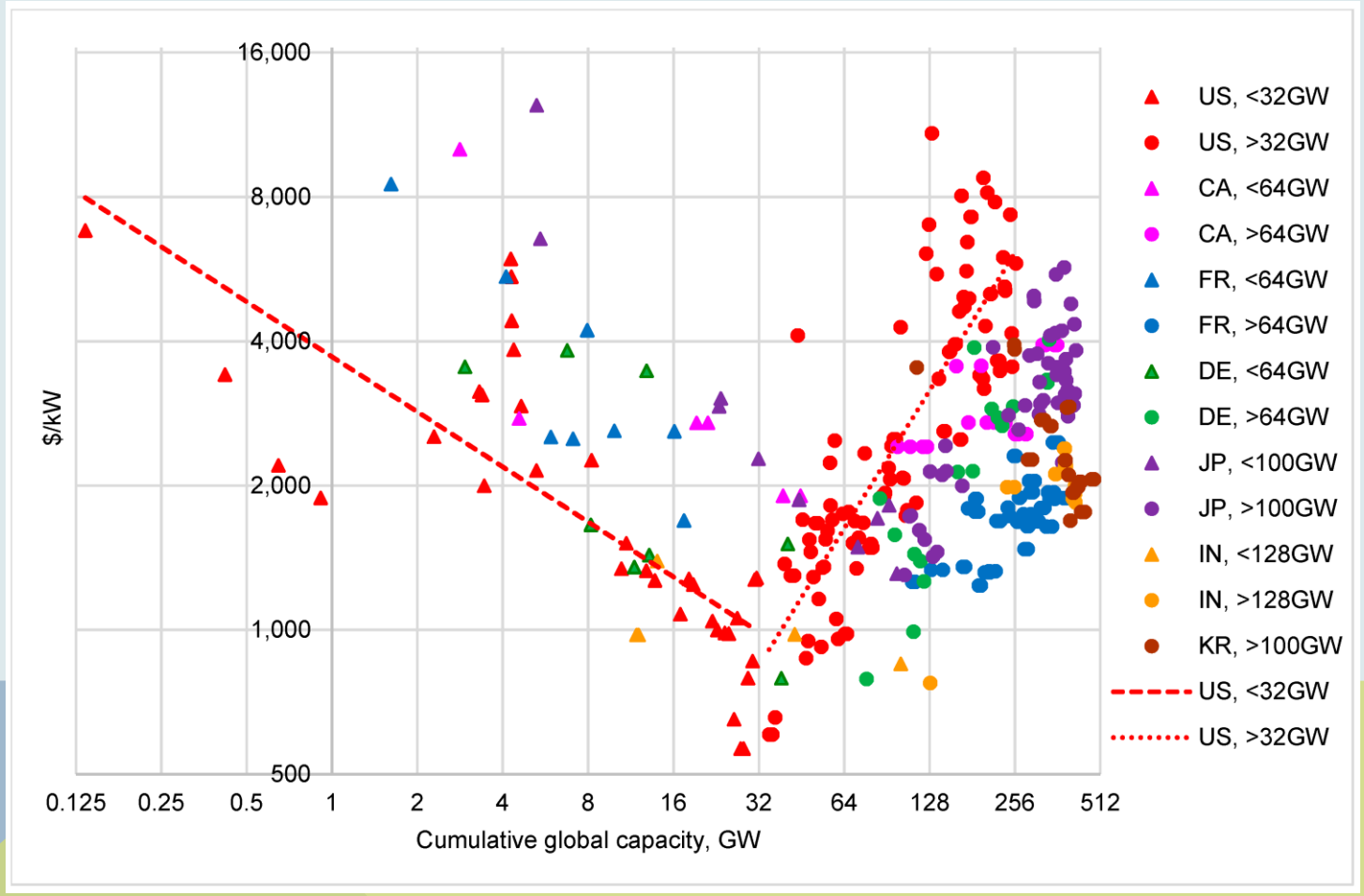


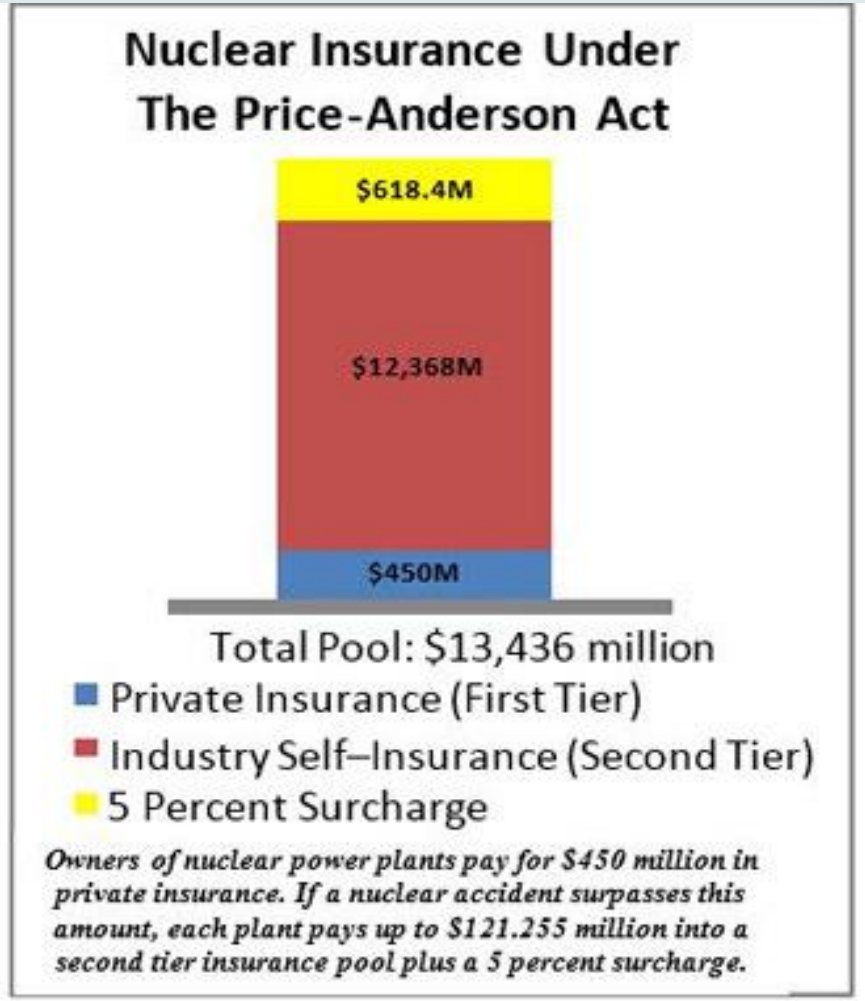

Hallam Nuclear Power Plant, 240 MWe, 1962

Three Mile Island, 2x 812 MWe

# AND EVEN WITH MORE LAX CONTAINMENT REQUIREMENTS, REACTOR COMPLEXITY, CONSTRUCTION COSTS STILL GREW



# INCREASED COSTS HAVE HARDLY ENCOURAGED NUCLEAR INDUSTRY TO COVER FULL LIABILITIES, WHICH, IN TURN, DISCOURAGES INDUSTRY FROM MAKING SAFETY INVESTMENTS



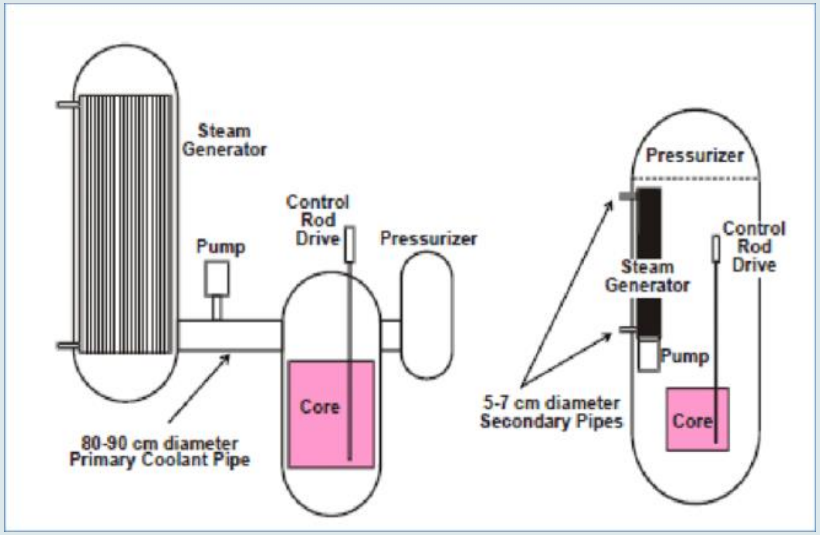

**Fukushima**: $200 b to >$700 b.

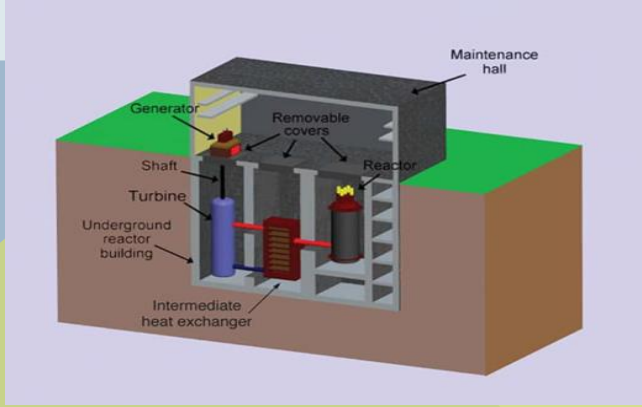
**Chernobyl**: >$200 b

**Three Mile Island** ~$1.78 b

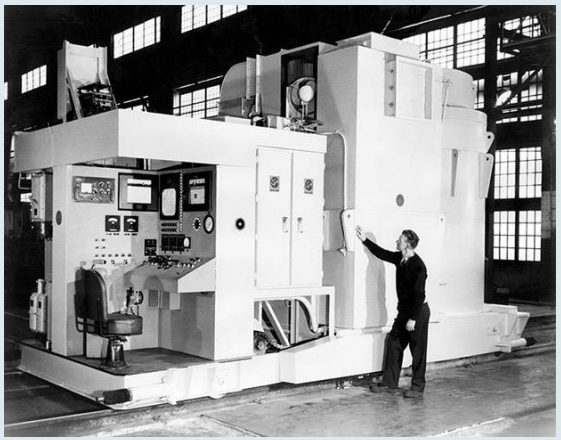
# THE SAFETY CASE FOR SMALL REACTORS, ADVANCED AND MODULAR

- Small reactors produce less radiation and waste per reactor
- Some designs can be passively cooled (without pumps), "self-regulating"
- Can incorporate most nuclear components within a single pressurized vessel
- Can be built underground

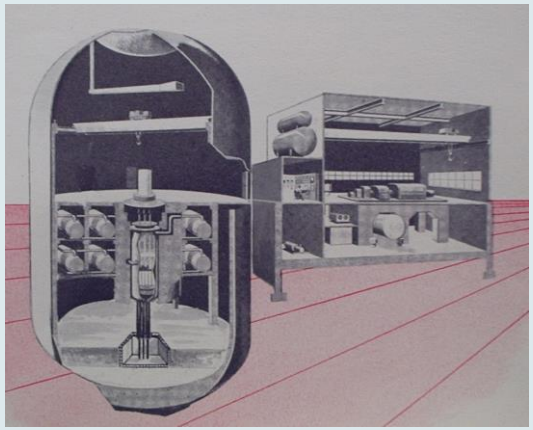


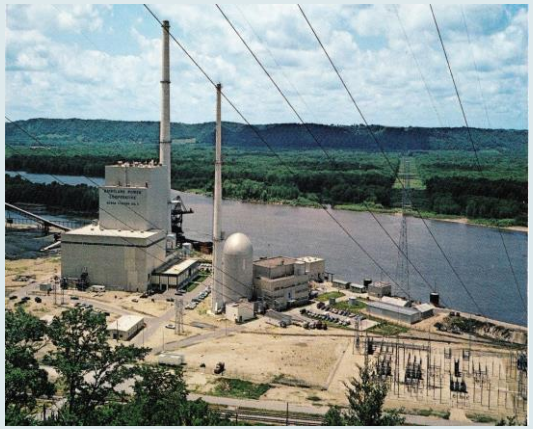
# UNKIND HISTORY: PREVIOUS SMALL REACTORS PROVED TOO SMALL TO COMPETE ECONOMICALLY



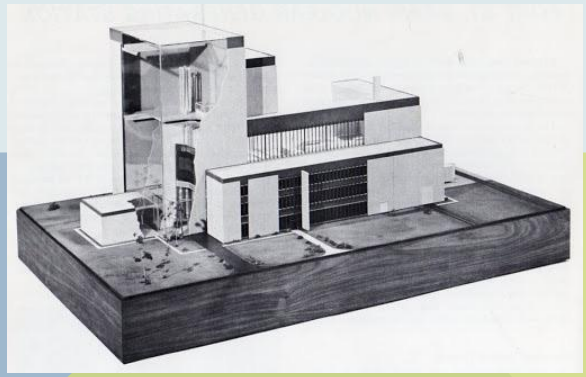
Fermi 1, 69 MWe



Elk River, 22 MWe



LaCrosse, 50 MWe

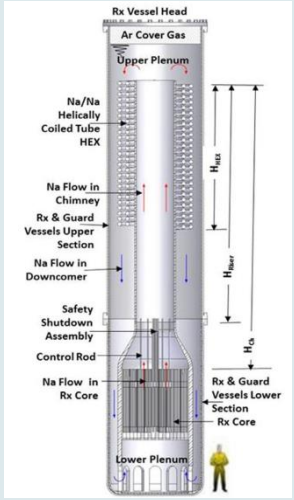


Fort St. Vrain, 185 MWe

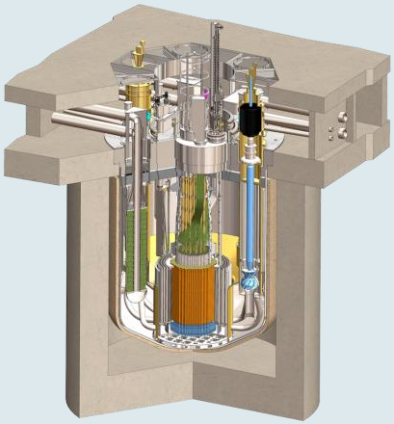
Piqua, Ohio, 12 MWe

Punta Higuera, Puerto Rico, 17 MWe

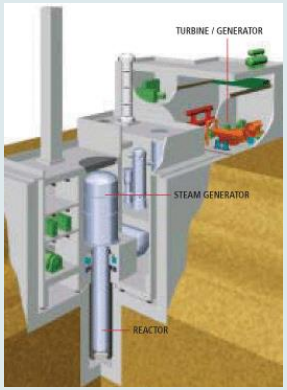
# DOE Now Wants Small Reactors to Go Fast



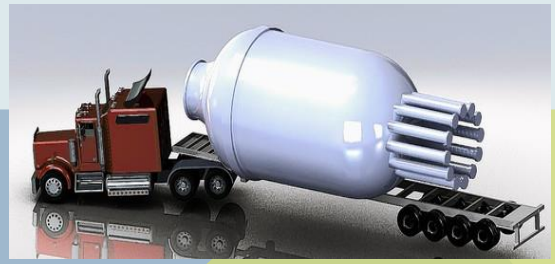

SLIMM



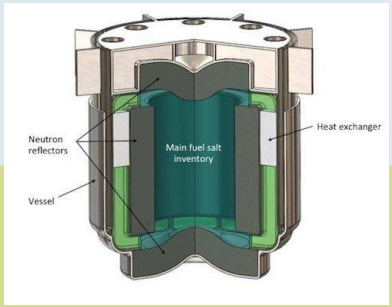
Traveling Wave Reactor



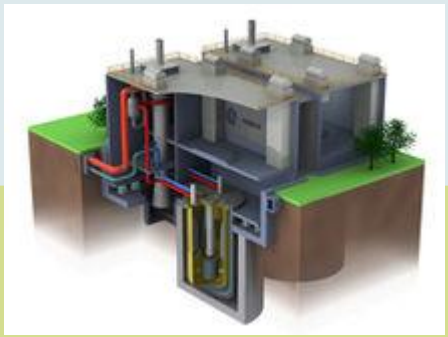

Toshiba 4s Reactor



Energy Multiplier Module

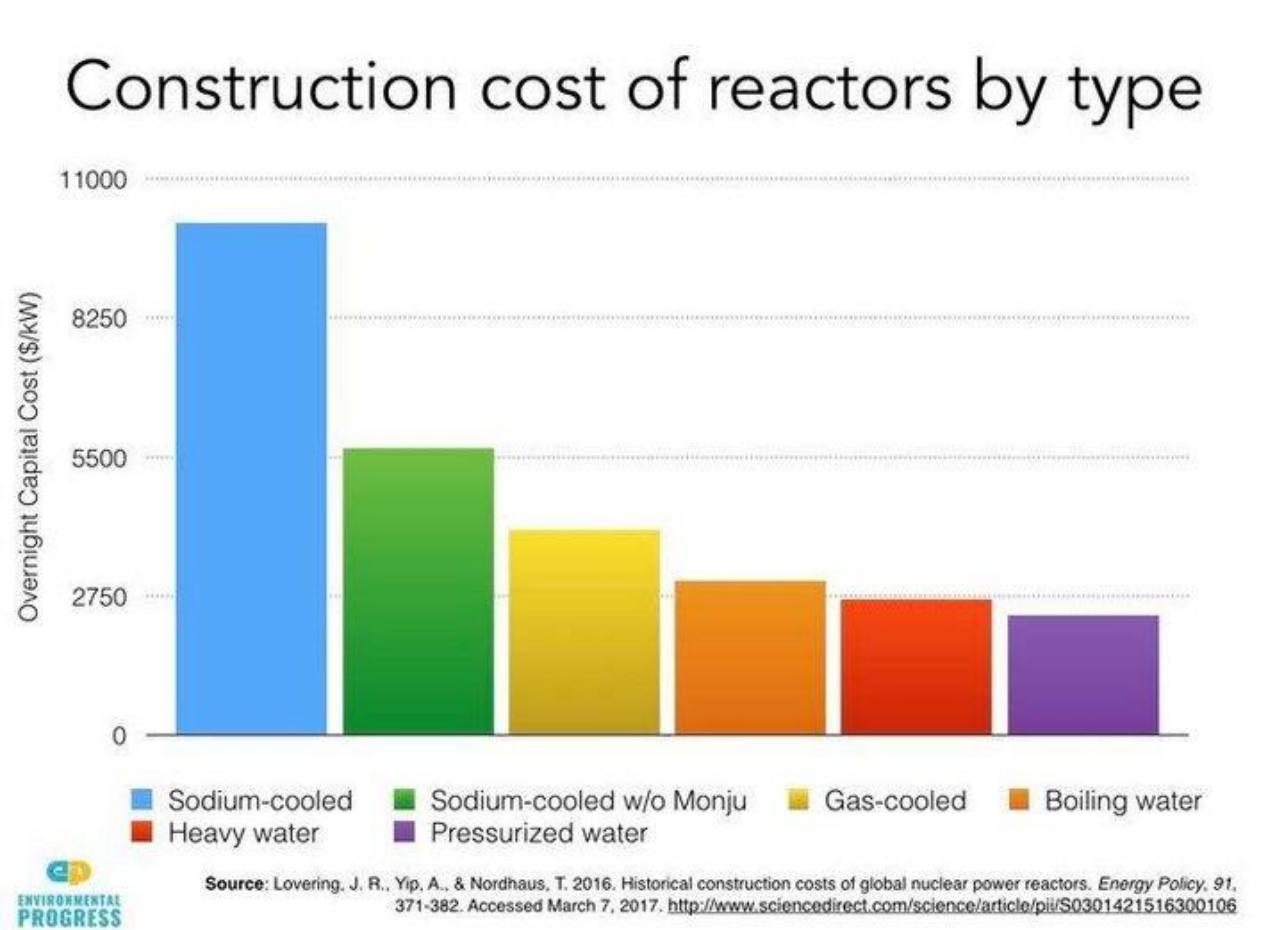



Molten Chloride Fast Reactor

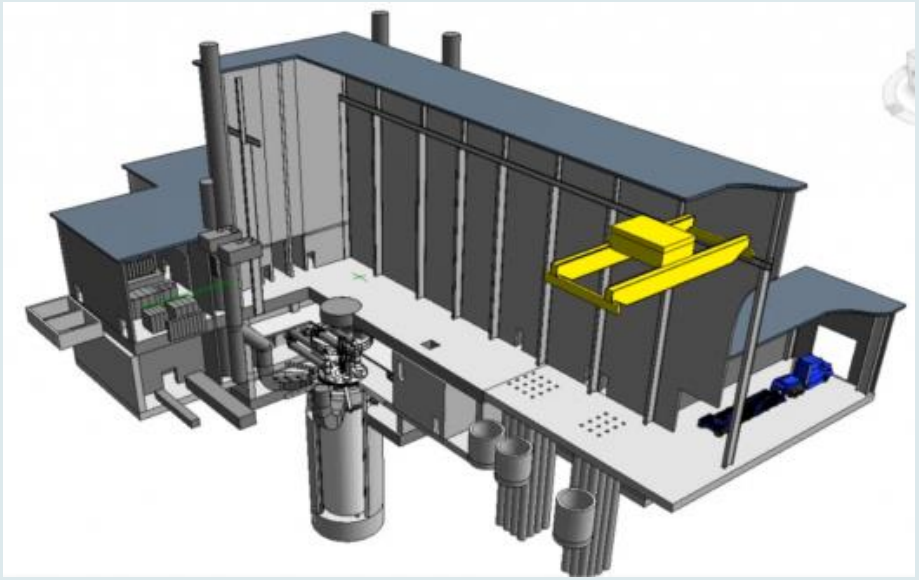


PRISM reactor

# YET, HISTORICALLY FAST REACTORS HAVE PROVED THE MOST COSTLY TO BUILD



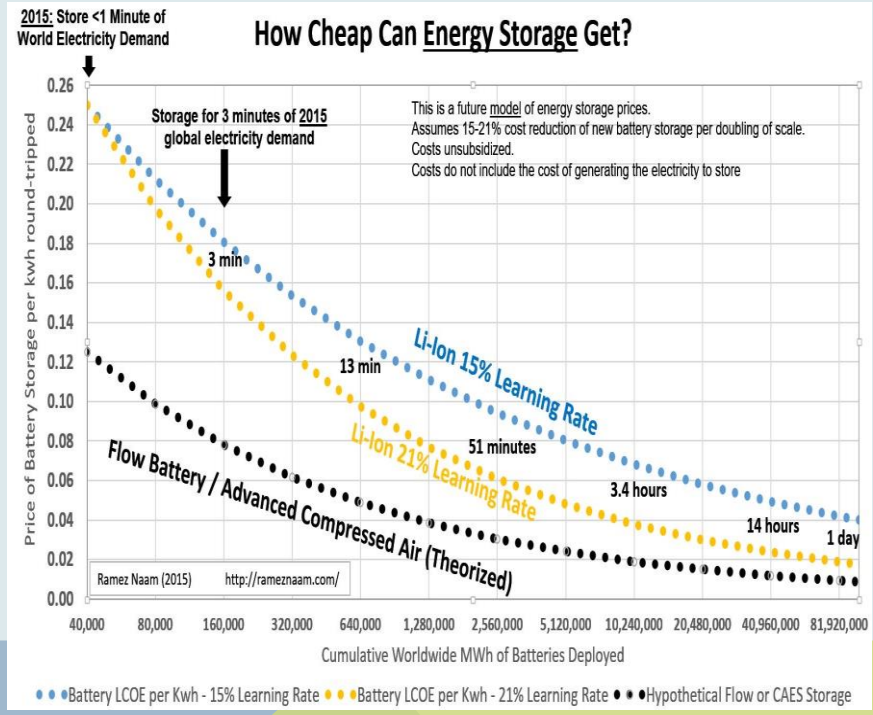
# TO HELP OUT, DOE PLANS TO SPEND BILLIONS ON ADVANCED NUCLEAR FUELS IN SUPPORT OF SMRS

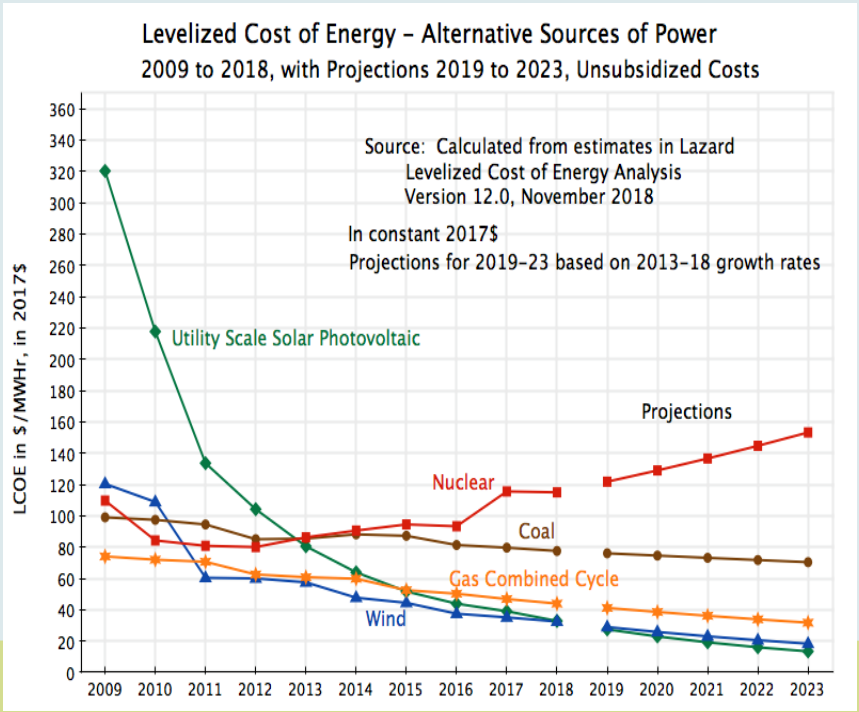


Versatile Test Reactor, $3-6 B

American Centrifuge Plant, Pinkerton, OH or DOE alternative, $10 B?

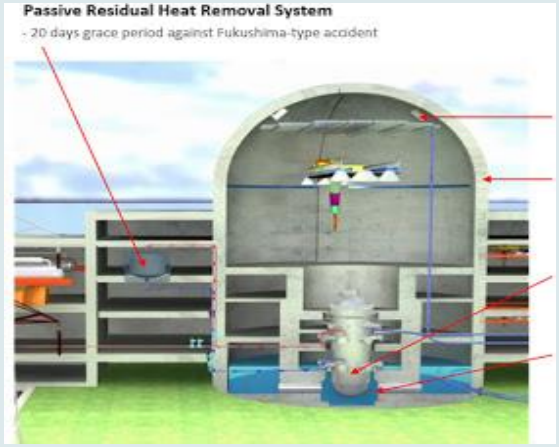
# THE ECONOMIC COMPETITION IS PROJECTED TO GET STIFFER



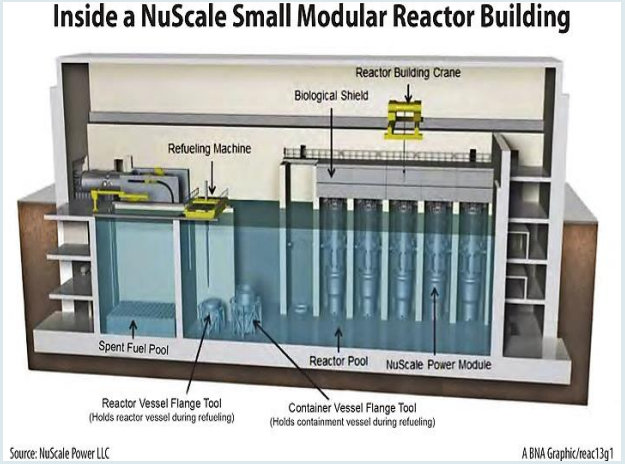




2018 there were 12 gigawatt hours of grid battery storage deployed worldwide

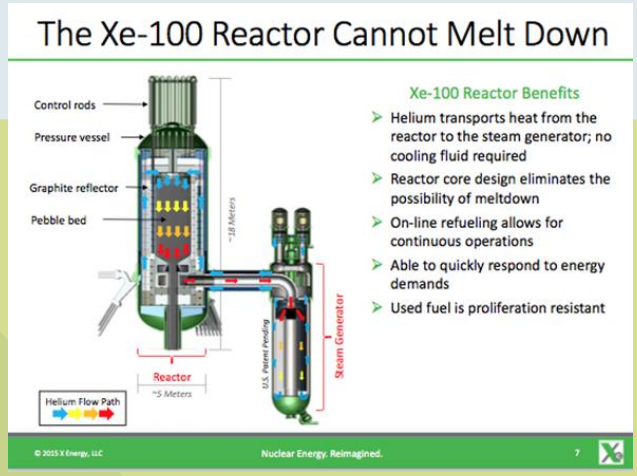
# INDUSTRY COUNTING ON EXPORTING SMALL REACTORS TO THE MIDDLE EAST




SMART Reactor, Saudi Arabia




NuScale Reactor, Jordan

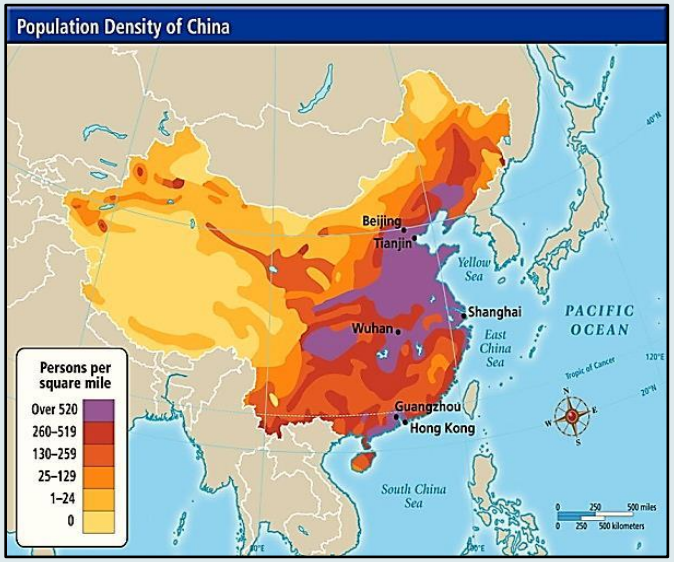



Jordan

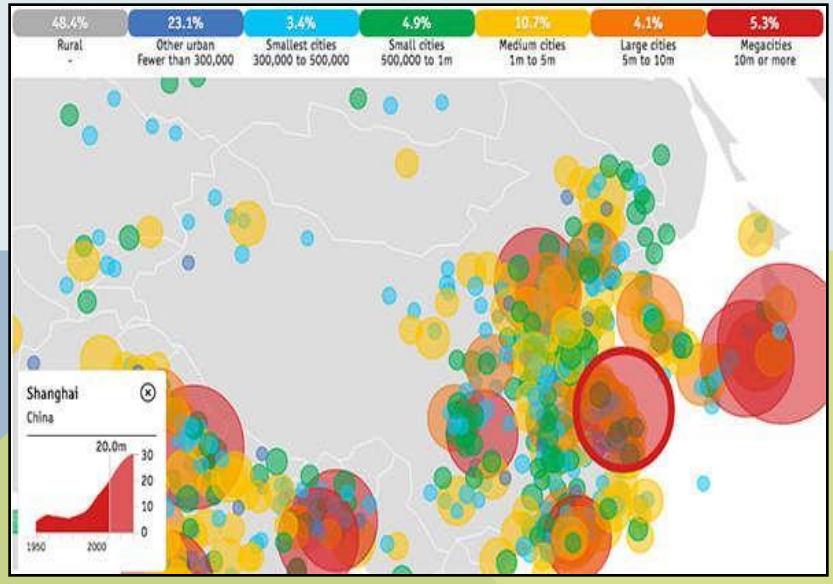
# WHAT NUCLEAR ACTIVITIES MAKE MONEY

- **Existing Uranium enrichment**
- **Nuclear fuel fabrication ~ $23 billion**
- **Production of industrial, agricultural, and medical isotopes ~ $30 billion**

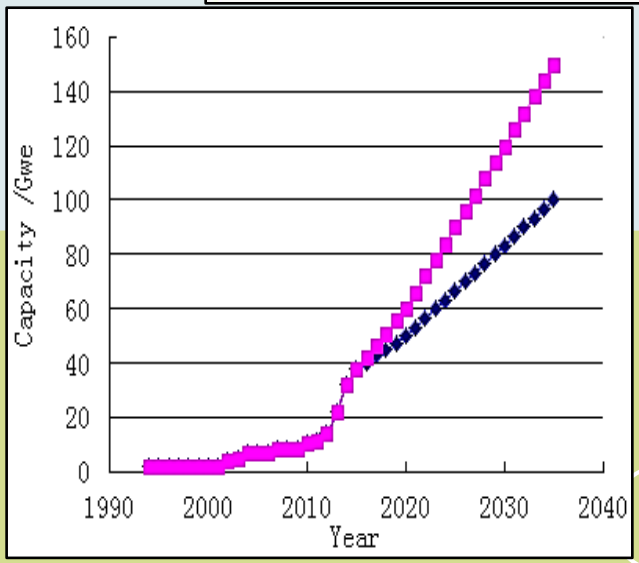
# SAFETY IS A MUCH BIGGER ISSUE






Global City Populations




Low & High Nuclear Growth Scenarios

# SOUND NUCLEAR SAFETY METHODOLOGY: WHAT'S CURRENTLY LACKING INTERNATIONALLY

**NRC argues**

**Risk = Probability x Consequence**

**(focuses on prompt deaths, exposure calculations, assumes evacuation success, manipulates calculations for "reactor years" between accidents).**

**Concludes probability is too low to question safety**

**Nuclear industry refuses to assume any risk whatsoever for off-site damage in the case of nuclear accidents**

# UNCERTAIN ENERGY FUTURES: LAST HALF OF THE 19TH CENTURY

- **Lighting:** Whale oil, gas, candle, electricity
- **Heating:** Oil, coal, gas, wood, electricity
- **Locomotion:** Steam, electricity, gasoline, diesel
- **Electricity:** AC, DC

# UNCERTAIN ENERGY FUTURES: 1950

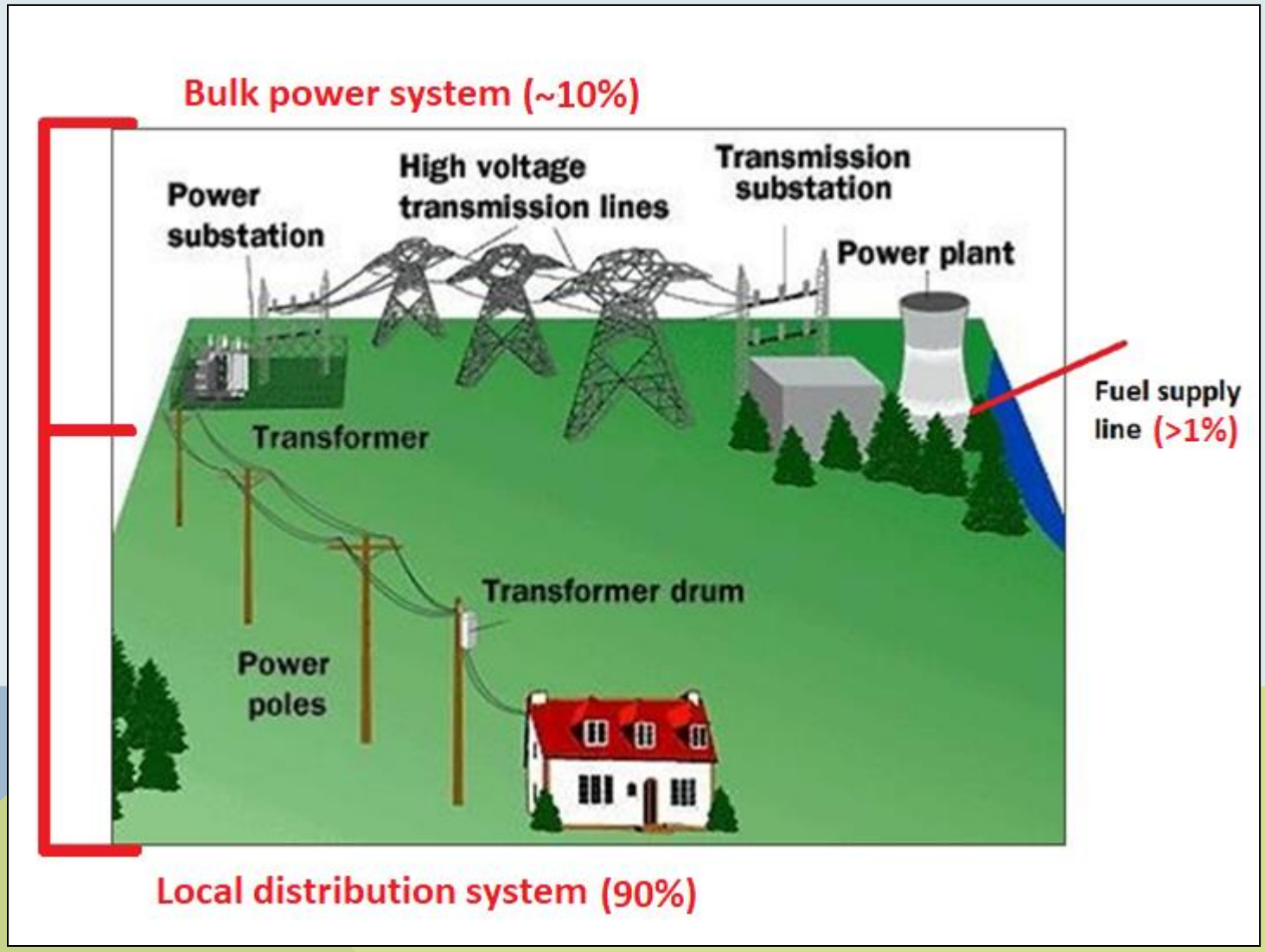
- **Lighting:** Electricity (centrally generated, grid distributed)
- **Heating:** Gas, electric, fuel oil
- **Locomotion:** Gasoline, diesel
- **Electricity:** AC, Coal, oil fueled, hydro

# UNCERTAIN ENERGY FUTURES: NEXT HALF CENTURY

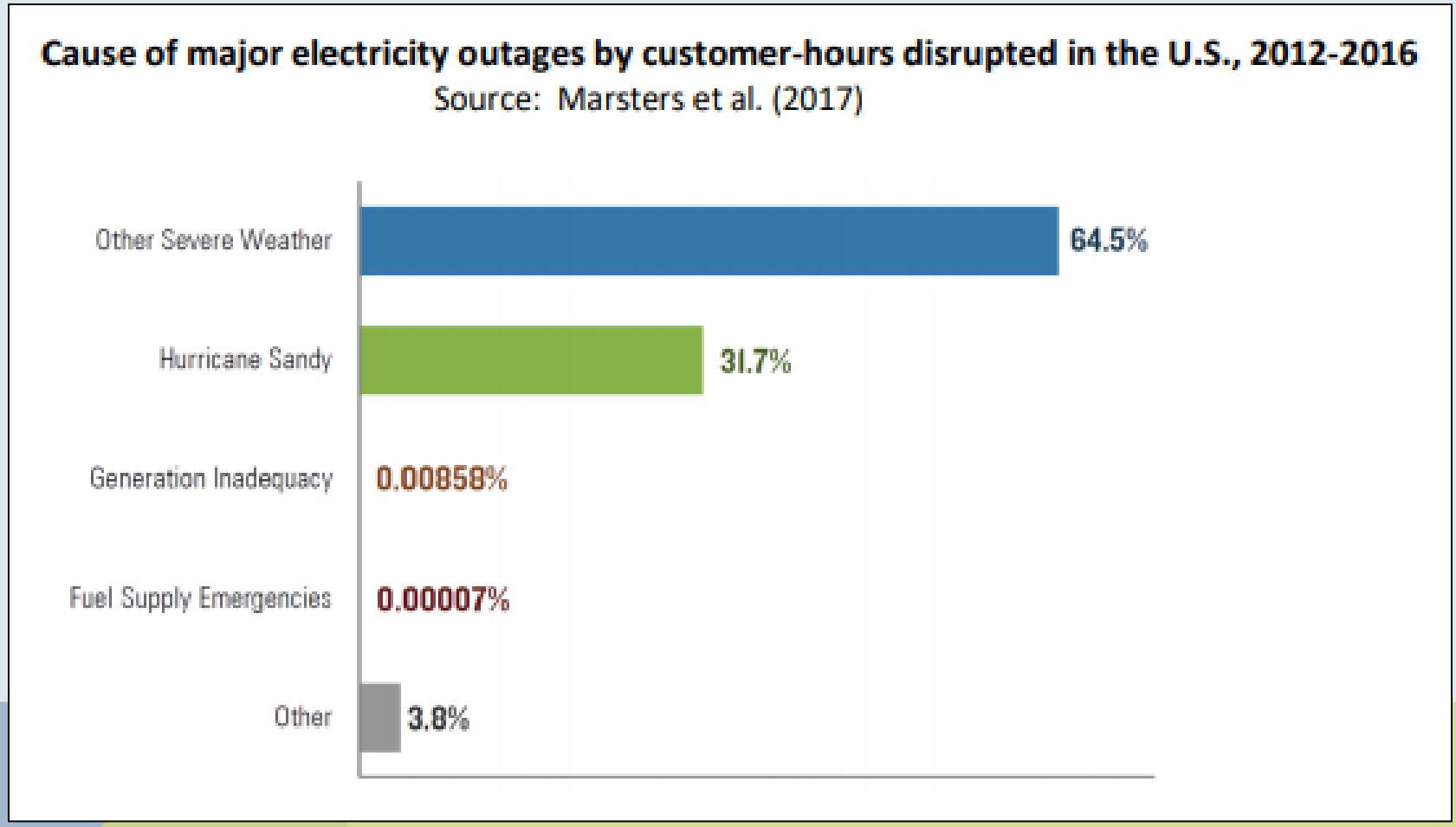
- **Lighting:** Incandescent, fluorescent, LED
- **Heating:** Electricity, gas, biomass, solar, geothermal
- **Locomotion:** Electric vehicles, gasoline, fuel cell, diesel
- **Electricity:** AC, DC, distributed, central, flow batteries, fuel cells, smart switching, photovoltaics, small reactors

# ELECTRICAL GRID RESILIENCE BASICS

# DISTRIBUTION OF ENERGY INTERRUPTIONS



# US ENERGY INTERRUPTIONS: 2012-2016



# CAUSES OF ENERGY INTERRUPTIONS

Trees/Weather


Vegetation

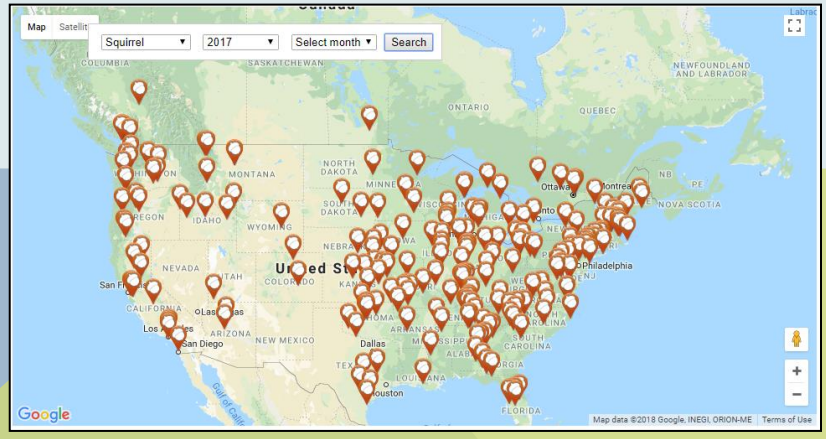
Ice Storms

Equipment Failure

# SQUIRRELS, OTHER ANIMALS ARE ALSO A PROBLEM

| Agent | Success |
|---|---|
| Squirrel | 1182 |
| Bird | 620 |
| Snake | 113 |
| Raccoon | 106 |
| Rat | 51 |
| Cat | 26 |
| Marten | 25 |
| Jellyfish | 13 |
| Monkey | 12 |
| Human | 3* |

**Power outages caused by animals since 1987**




**Confirmed power outages caused by Squirrels in 2017**

Source: https://cybersquirrel1.com/

# WHAT CAN BE DONE TO REDUCE OUTAGES?

Go off-grid

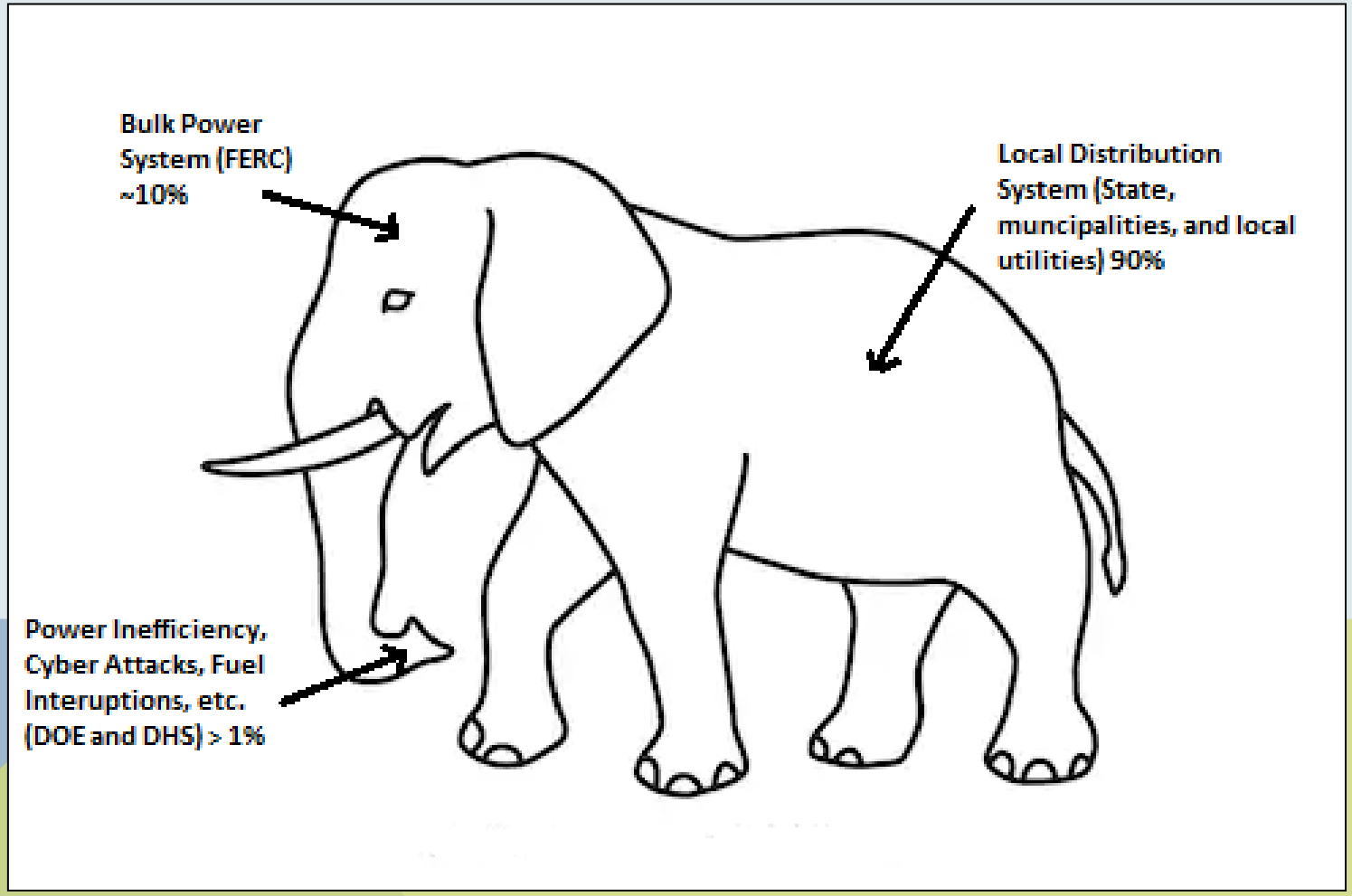
Upgrade local electrical repair teams

Clear trees and vegetation

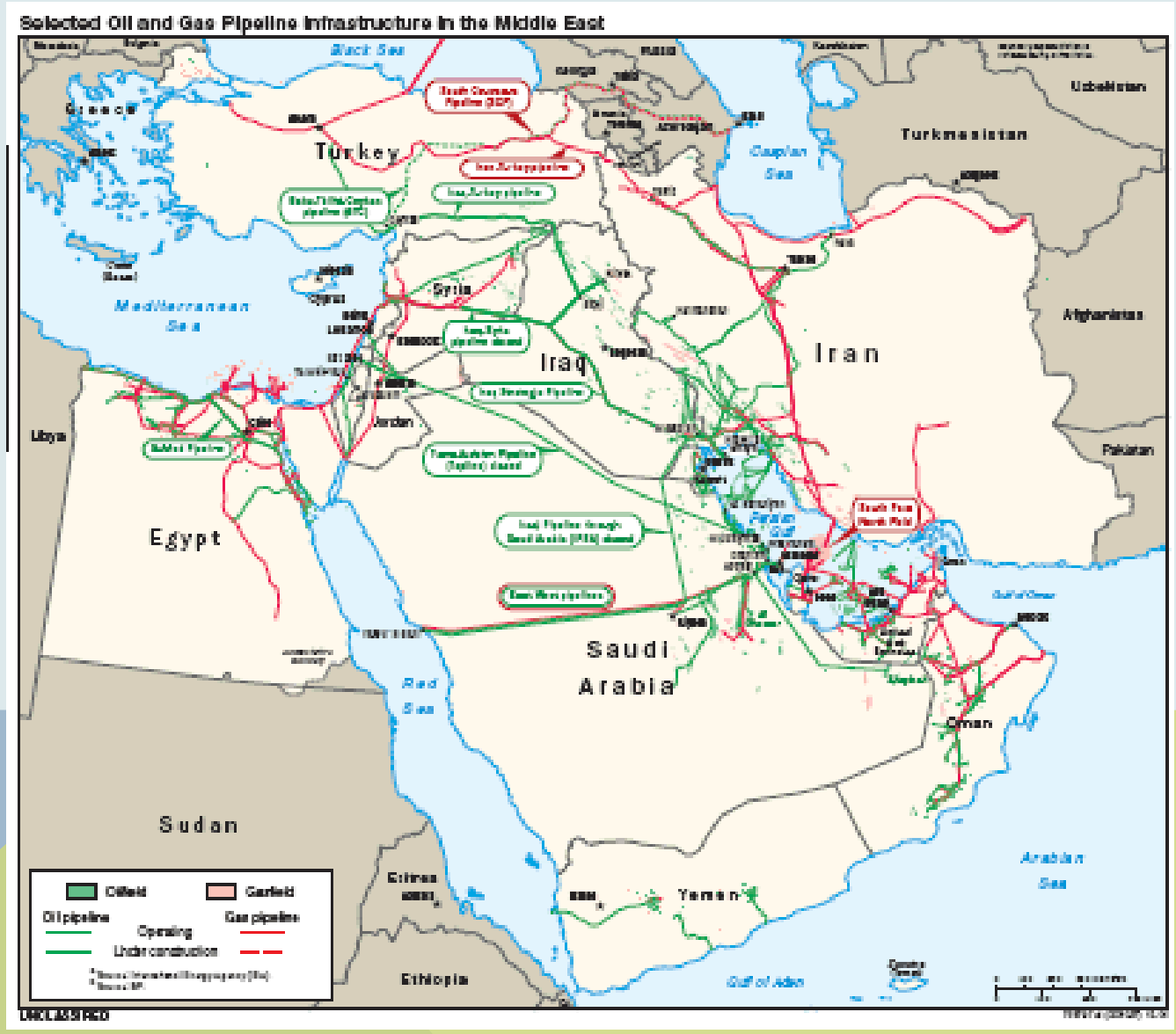
**FIGURE 6.3** Three ABB single-phase 345 kV compact replacement transformers being moved from St. Louis, Missouri, to a substation in Houston, Texas, under a Department of Homeland Security demonstration project.
SOURCE: DHS (2012).

Create a transformer reserve for quick replacement

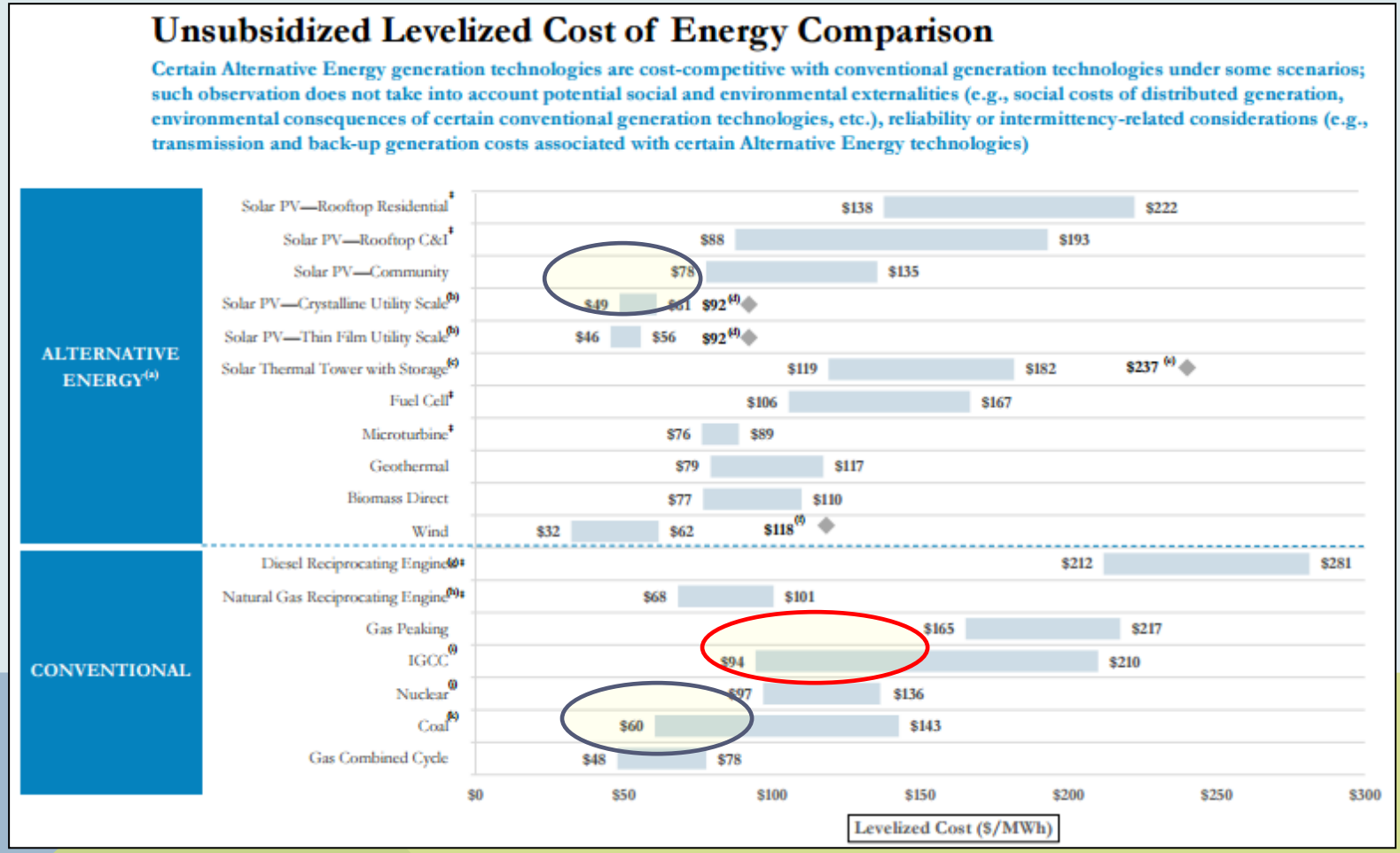
# WHAT INTERRUPTIONS GOVERNMENT OFFICIALS FOCUS ON IS A FUNCTION OF THEIR AUTHORITY



# GAS DISTRIBUTION IS GROWING BUT STILL DISCONNECTED



# LEVELIZED ENERGY COST COMPARISONS AFTER FUKUSHIMA

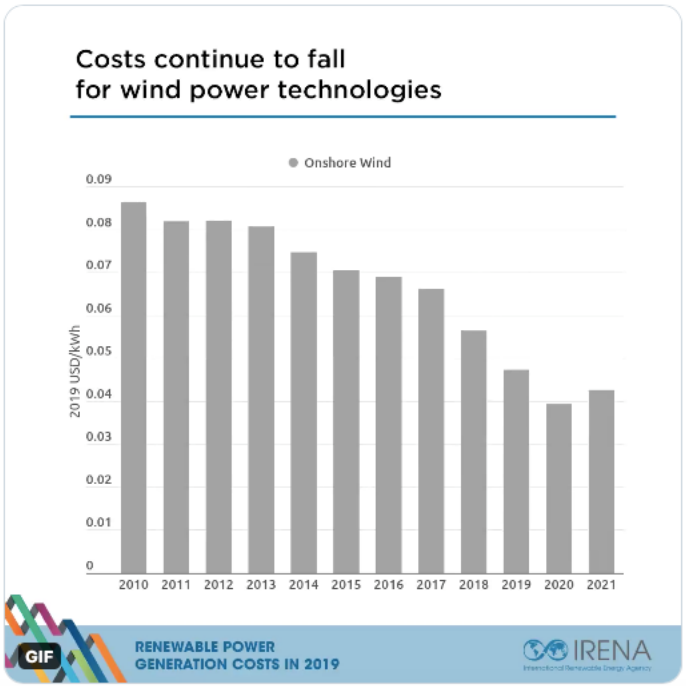



Source: Lazard “Levelized Cost of Energy Analysis - Version 10.0”

**IRENA** @IRENA · 9h

Latest @IRENA #Renewables Costs report shows onshore & offshore #wind both fell about 9% year-on-year, reaching USD 0.053/kWh & USD 0.115/kWh, respectively, for newly commissioned projects.

See why #renewableenergy is a cost-competitive investment 👉 bit.ly/2MpKAna

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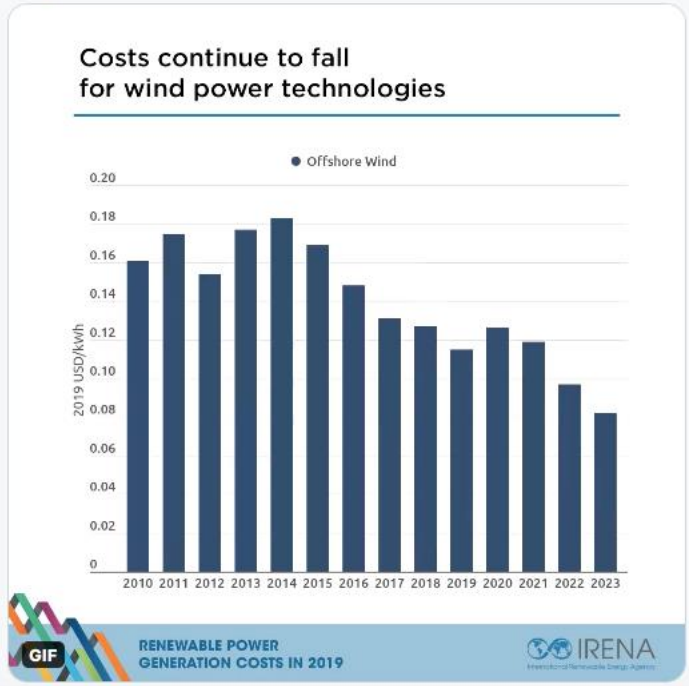
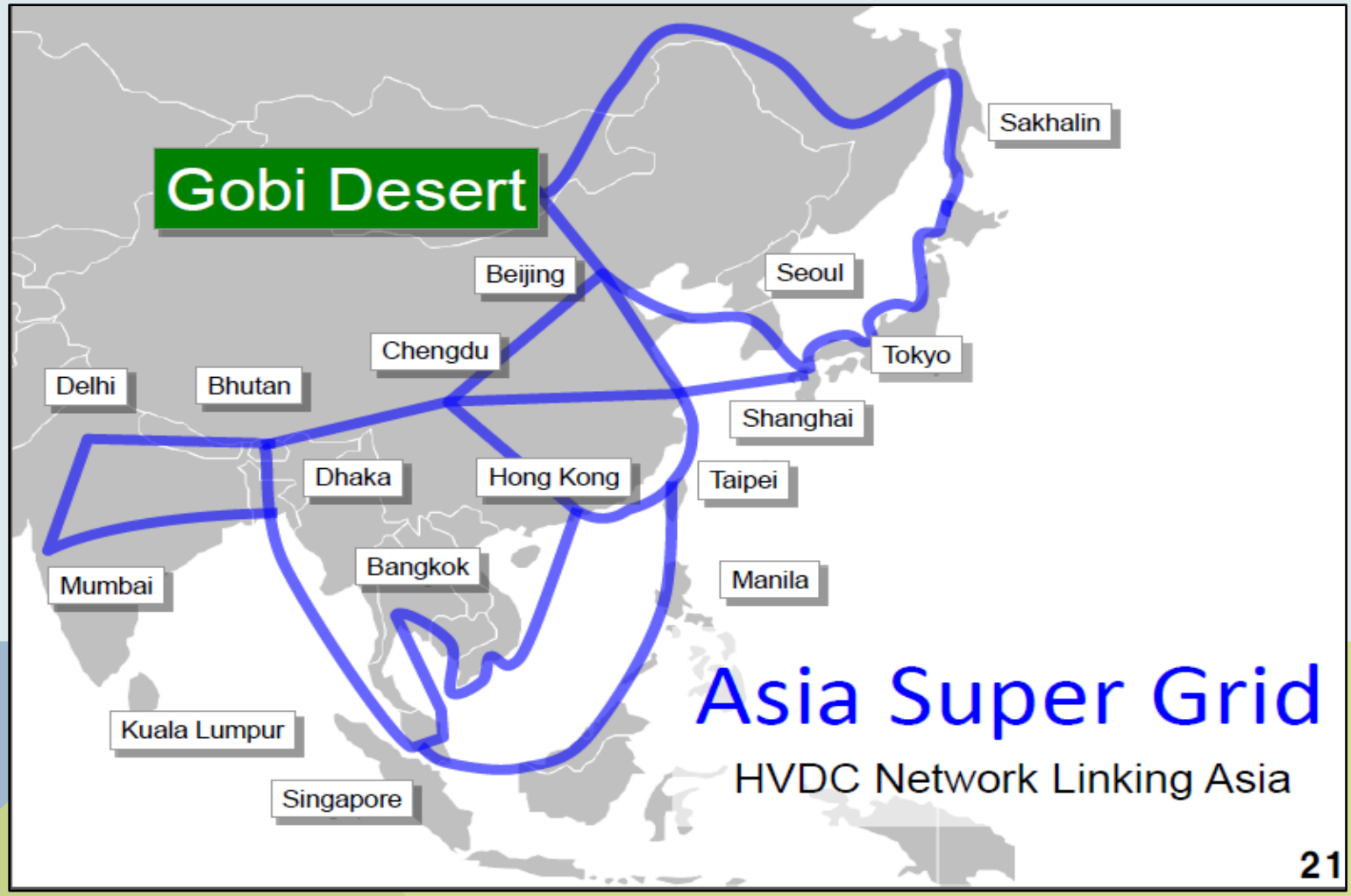
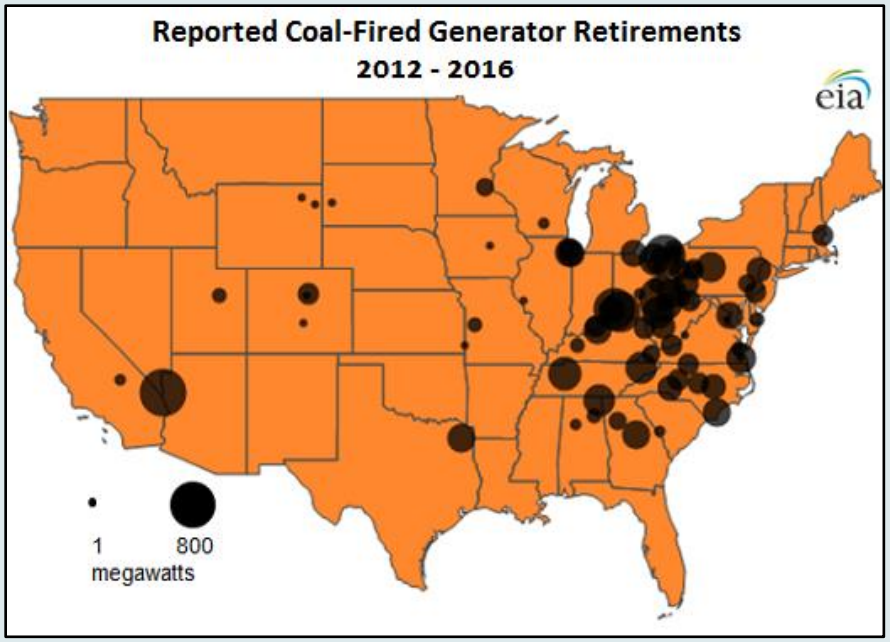
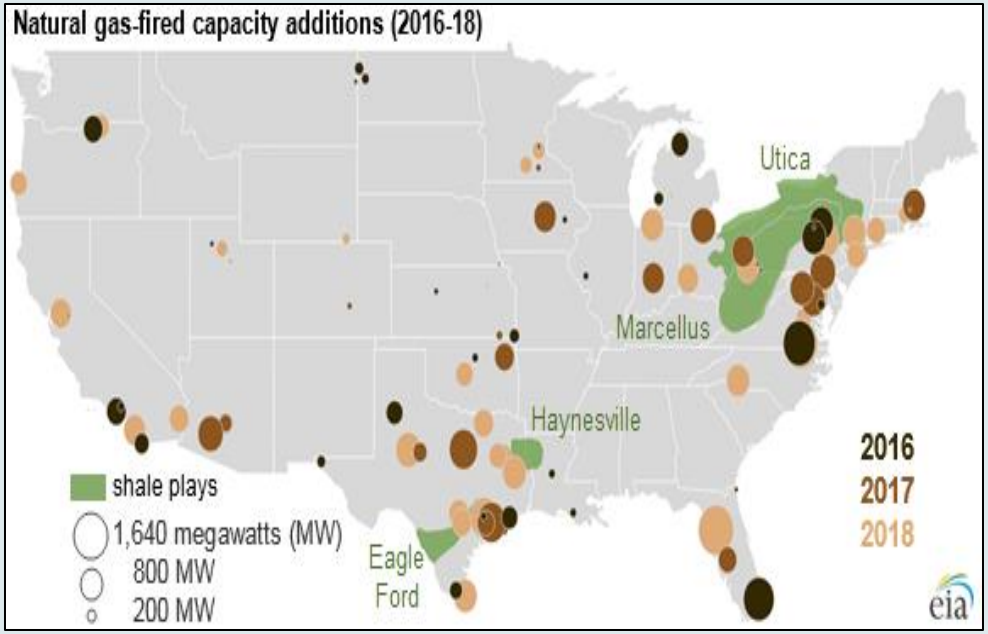


# AN ALTERNATIVE: AN ELECTRIC CONNECTED ASIA



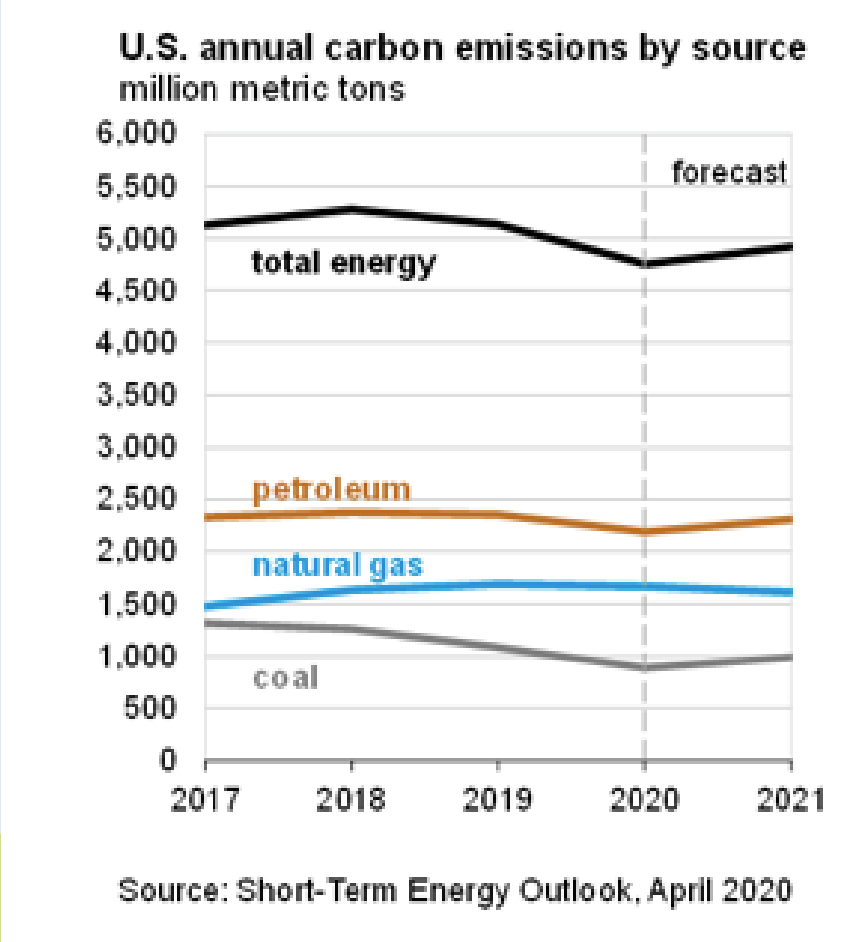
# US CARBON ABATEMENT: COAL RETIREMENTS AND GAS SUBSTITUTES




https://www.eia.gov/todayinenergy/detail.php?id=7290 and
https://www.eia.gov/todayinenergy/images/2016.05.19/main.png

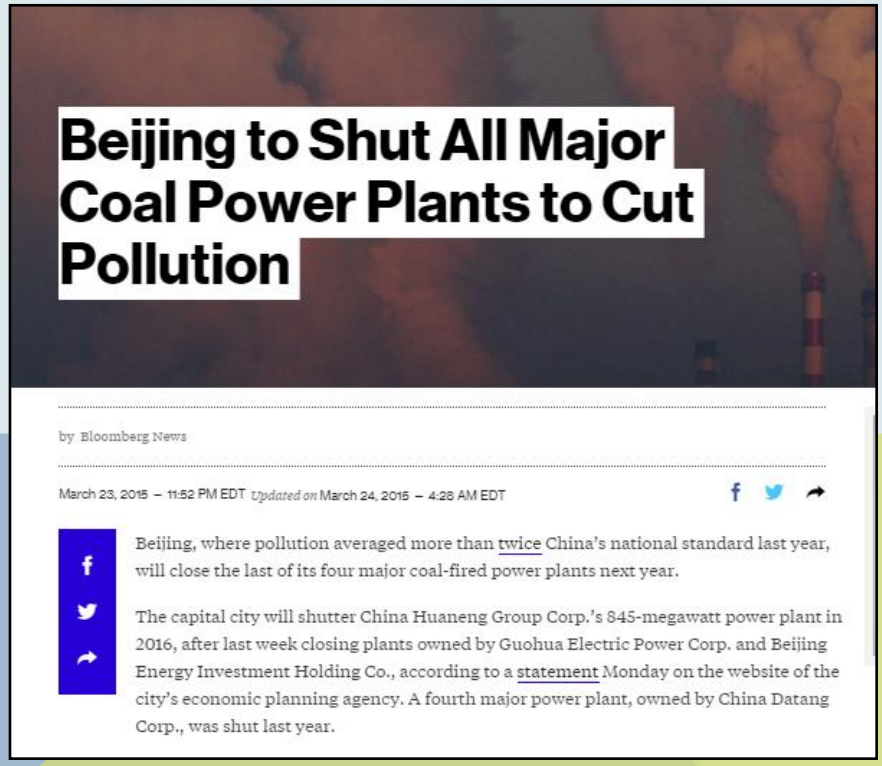
# US CARBON EMISSIONS FLAT TO DECLINING




https://www.mprnews.org/amp/story/2020/04/08/us-greenhouse-gas-emissions-may-fall-75percent-in-2020

**“Beijing to shut all major coal power plants to cut pollution”**–Bloomberg News, March 23, 2015

**China aims to shut 8.7 GW of coal power by year-end – regulator** – Reuters, September 29, 2019 (1,000 GWe of coal power still operating today)



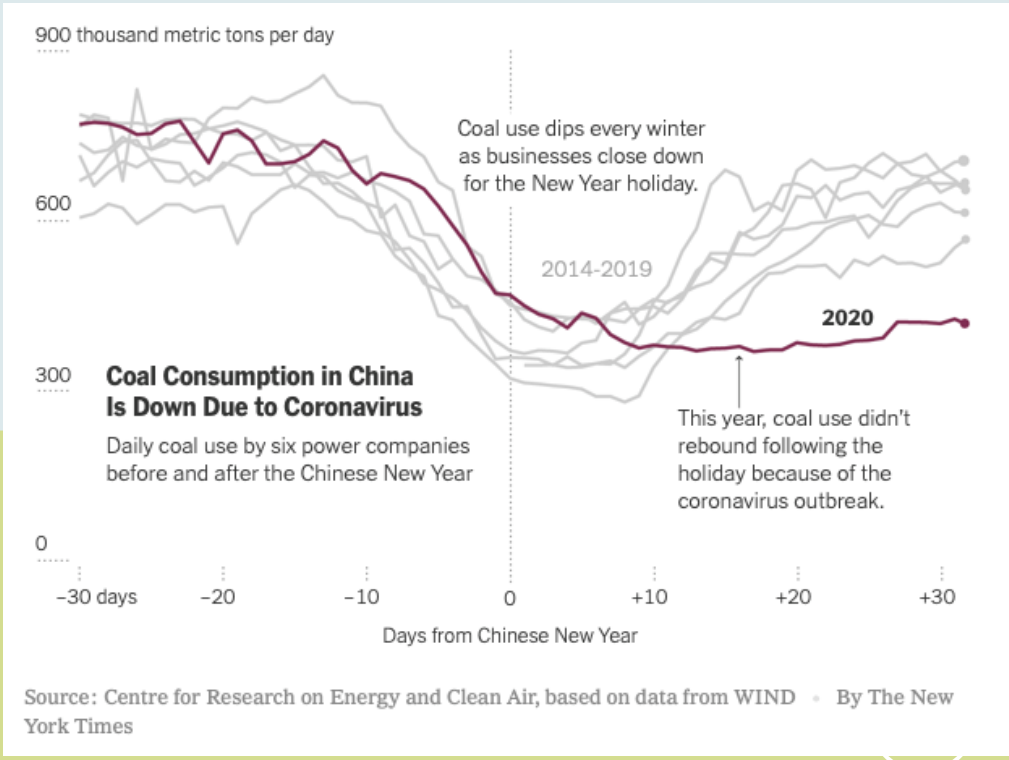
**Beijing to Shut All Major Coal Power Plants to Cut Pollution**

by Bloomberg News

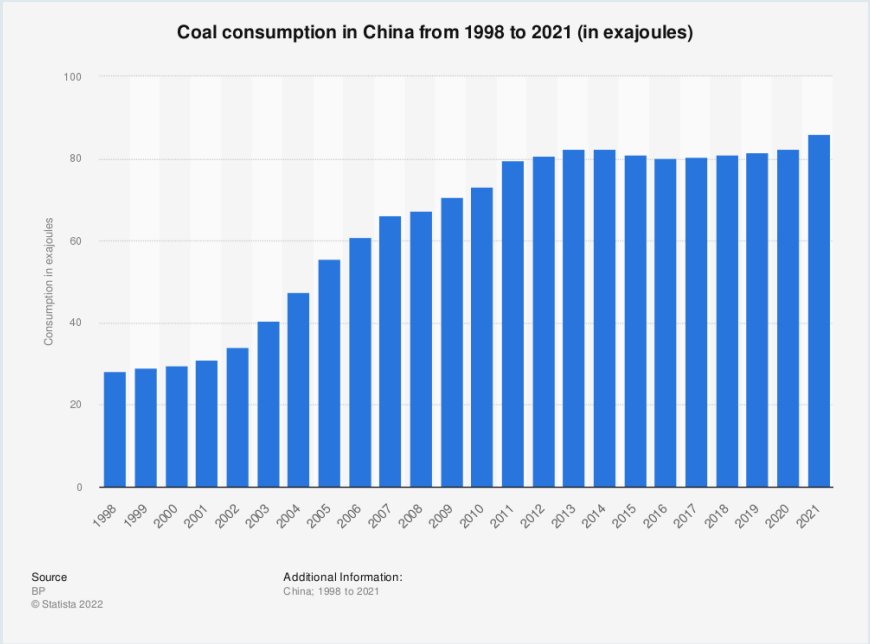
March 23, 2015 – 11:52 PM EDT *Updated on* March 24, 2015 – 4:28 AM EDT

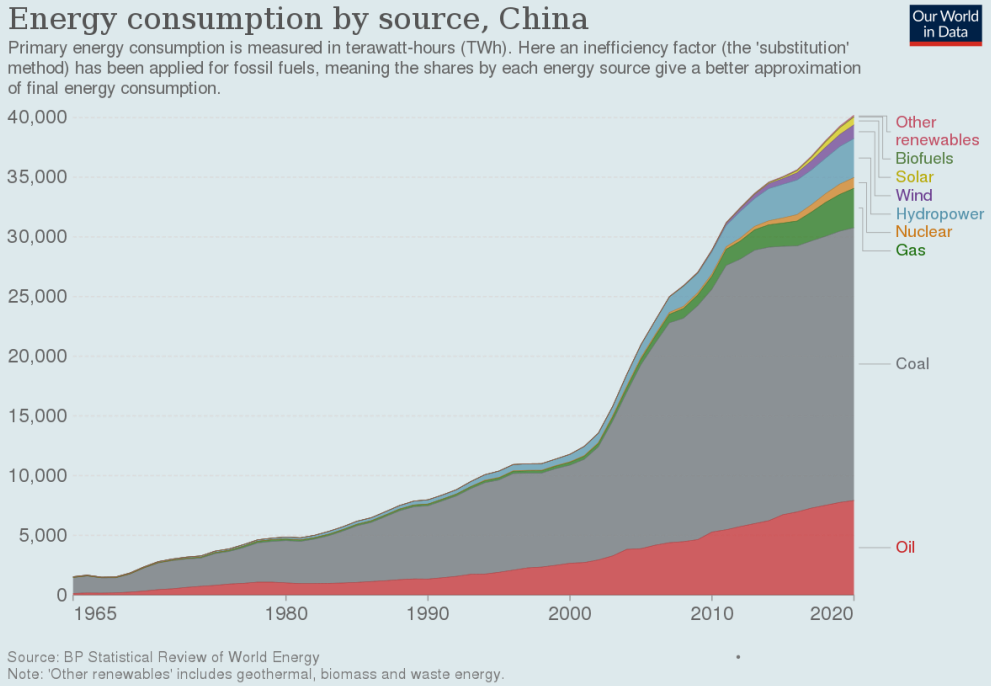
Beijing, where pollution averaged more than twice China's national standard last year, will close the last of its four major coal-fired power plants next year.

The capital city will shutter China Huaneng Group Corp.'s 845-megawatt power plant in 2016, after last week closing plants owned by Guohua Electric Power Corp. and Beijing Energy Investment Holding Co., according to a statement Monday on the website of the city's economic planning agency. A fourth major power plant, owned by China Datang Corp., was shut last year.



# AFTER COVID, BEIJING IS BURNING LOTS OF COAL

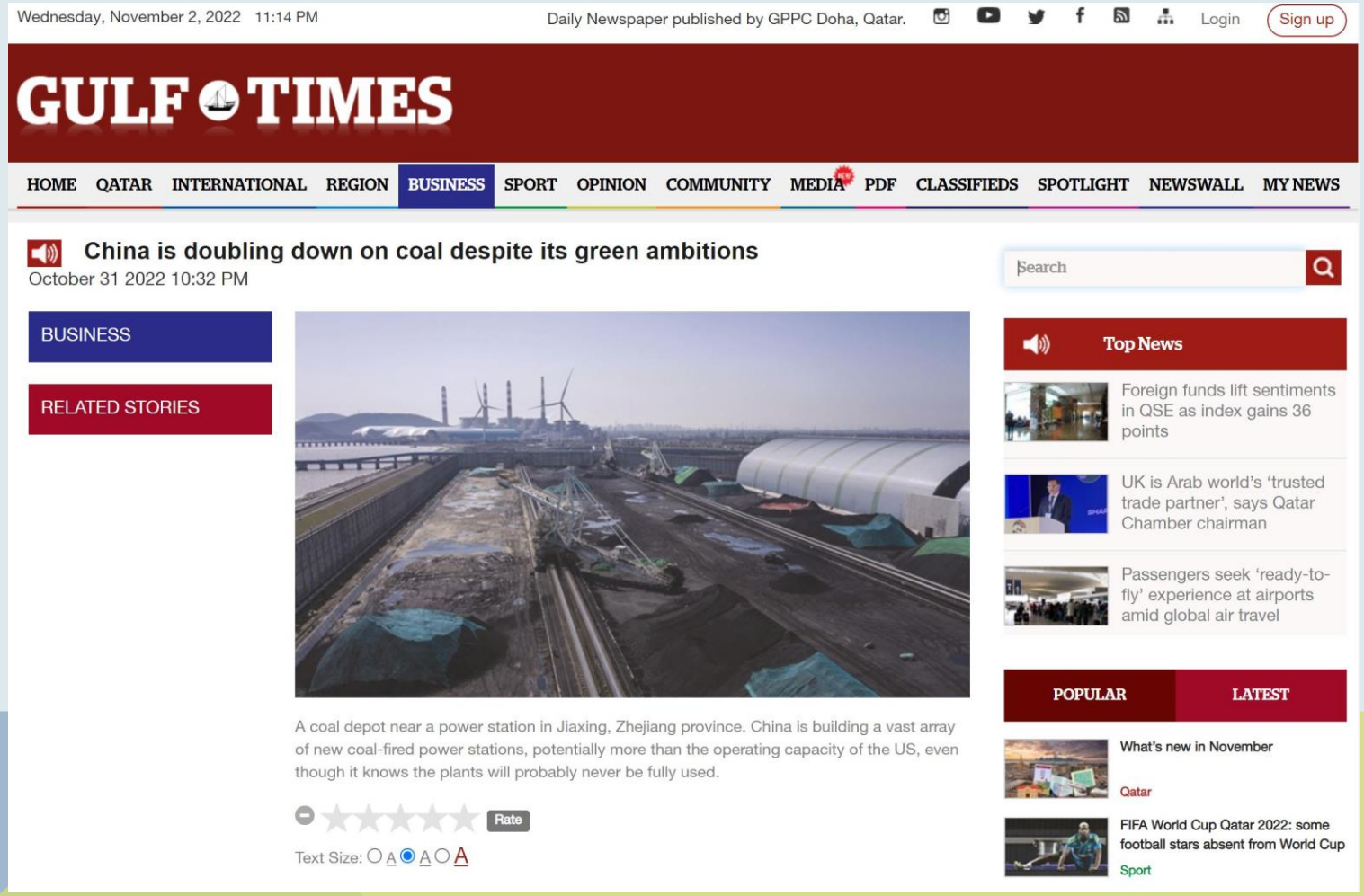


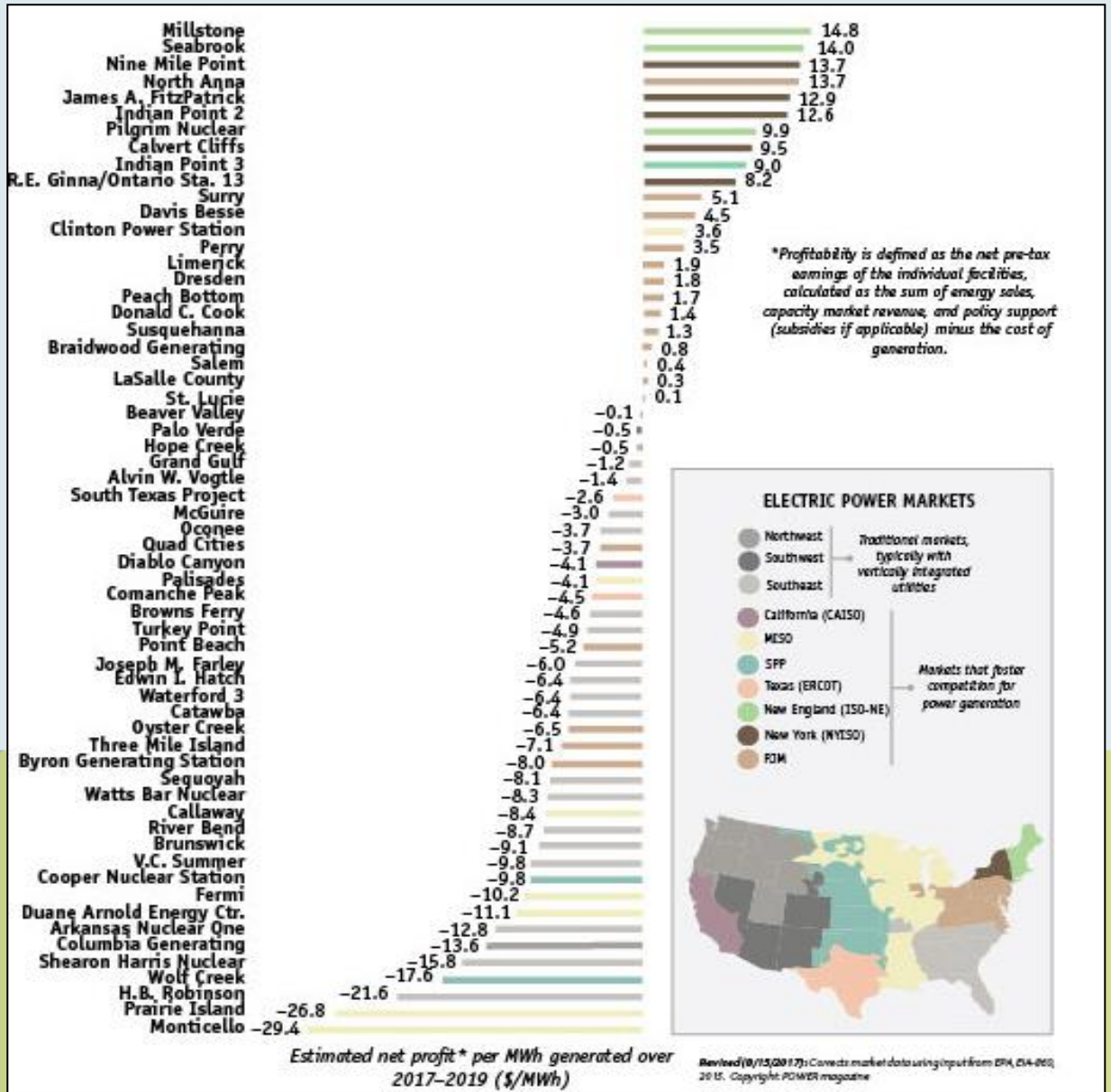

https://www.statista.com/statistics/265491/chinese-coal-consumption-in-oil-equivalent/

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

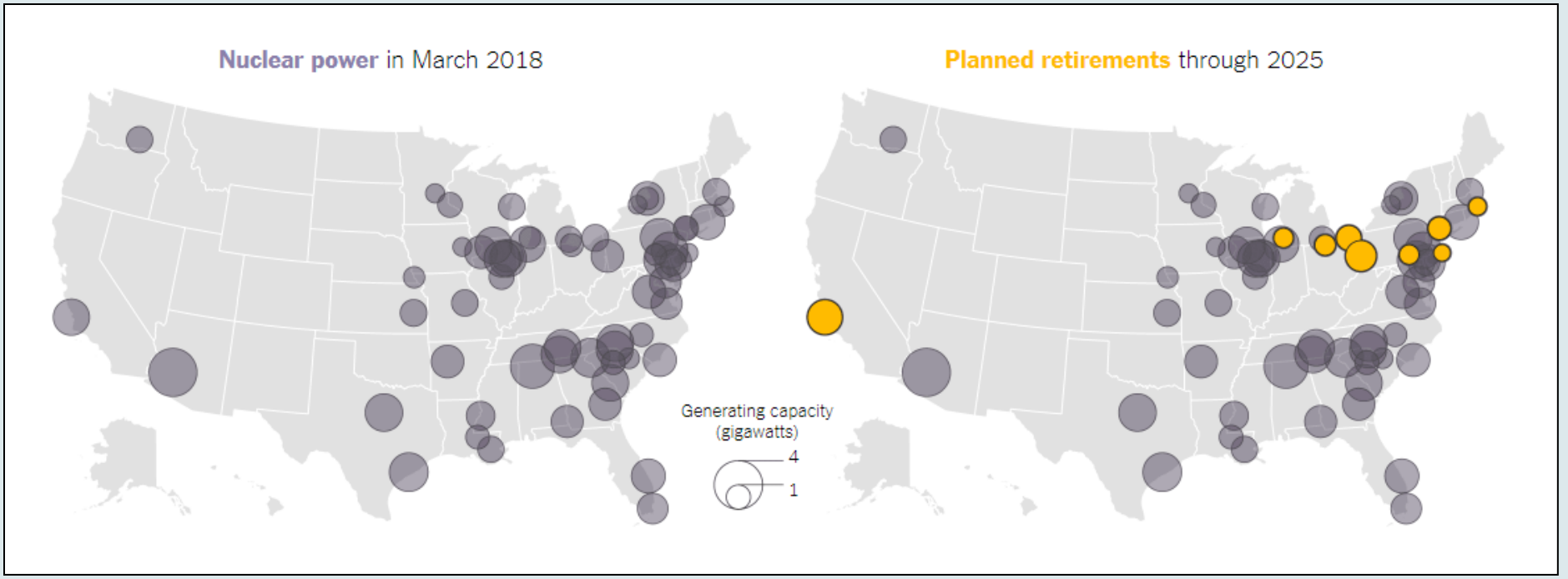
# CHINA PROJECTED TO BUILD 270 GW OF NEW COAL – BURNING GENERATORS BY 2025



# PROFITABILITY OUTLOOK FOR ALL US NUCLEAR PLANTS, 2017-2019

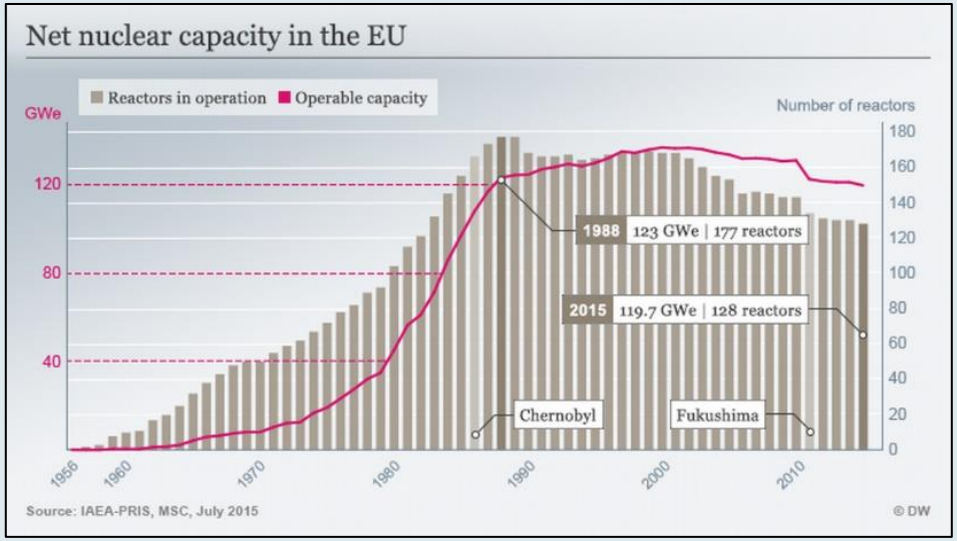


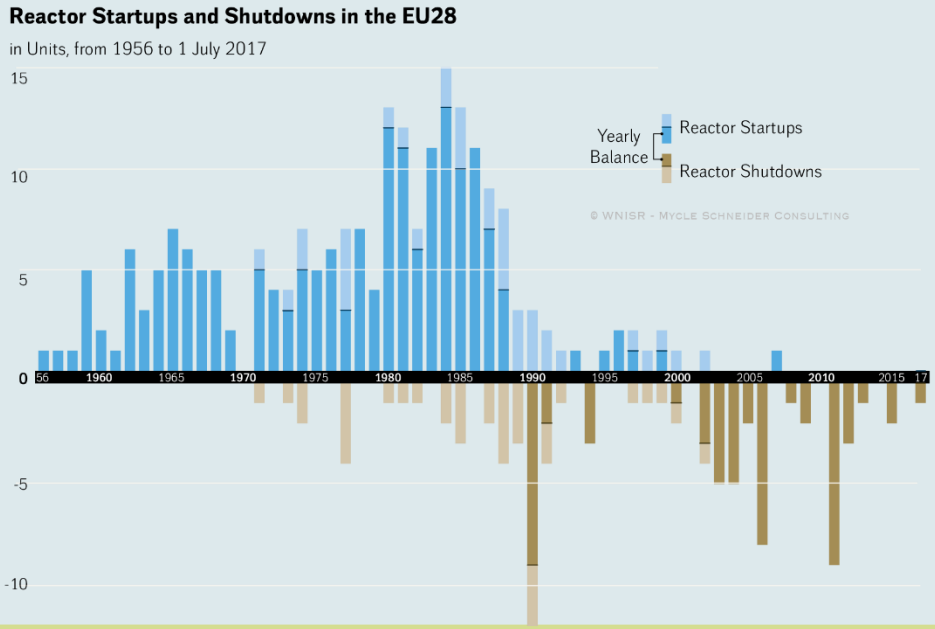
# US LARGE REACTOR GROWTH LIKELY TO BE NEGATIVE

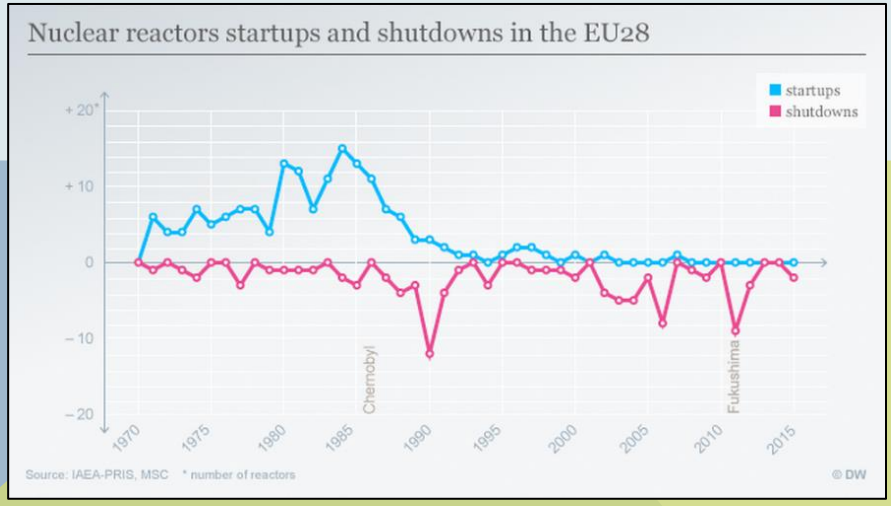



https://www.nytimes.com/interactive/2018/06/13/climate/coal-nuclear-bailout.html

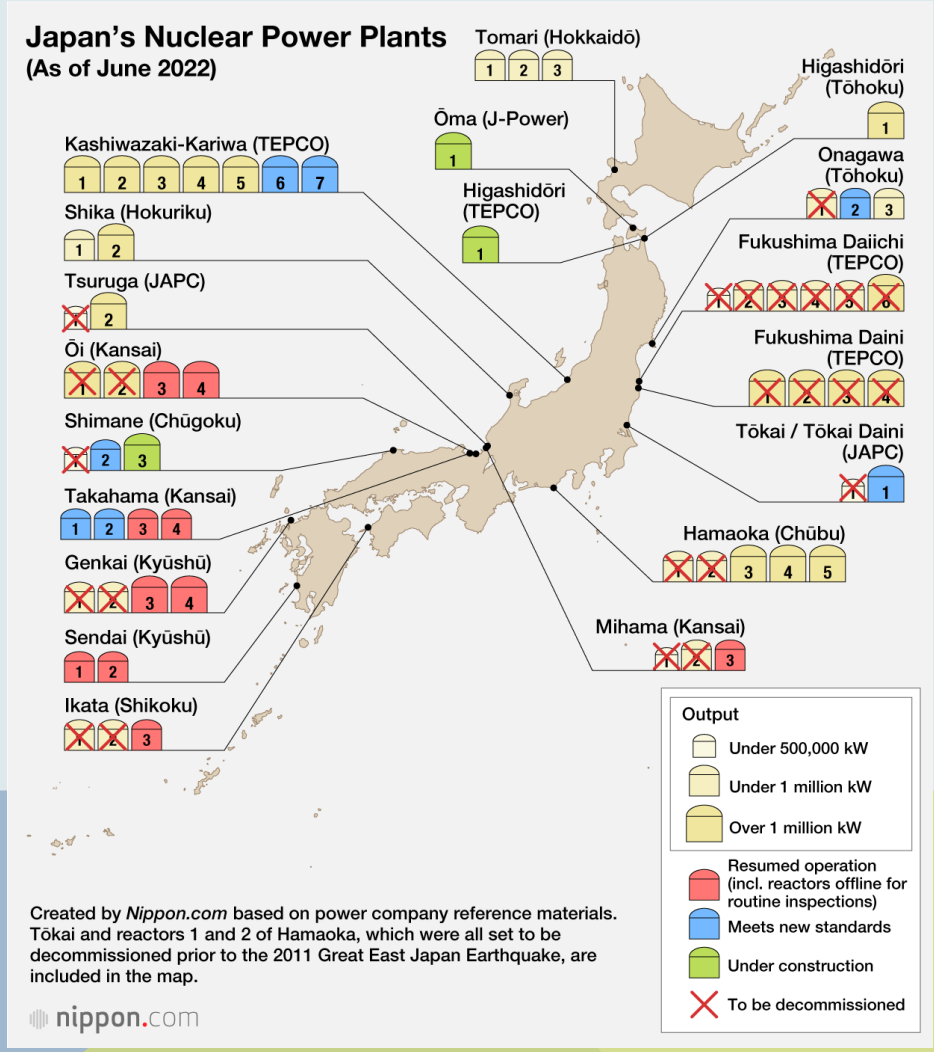
# NUCLEAR RETIREMENTS UNTIL RECENTLY, WERE CLEARLY OUTSTRIPPING CONSTRUCTION IN EUROPE



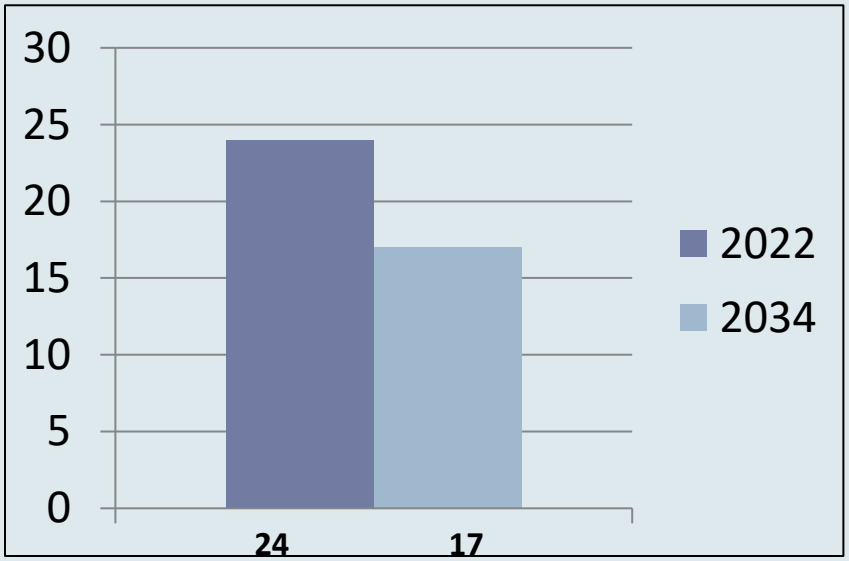



# THIS WAS ALSO HAPPENING IN JAPAN AND SOUTH KOREA




Japan ~ 20% by 2030



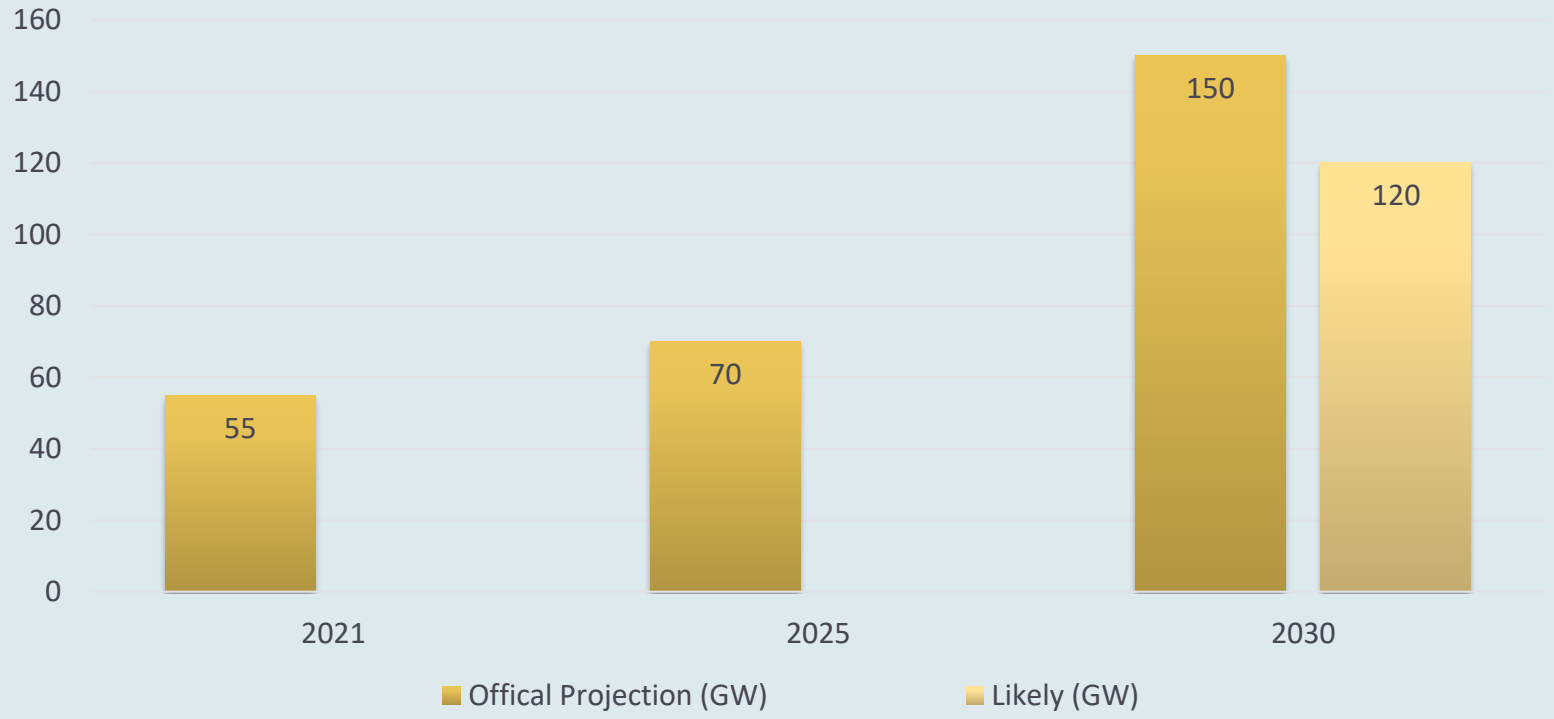

**Number of Nuclear Reactors in South Korea, Current and Projected**

https://en.yna.co.kr/view/AEN20220310003900320#:~:text=South%20Korea%20now%20has%20a,total%20power%20generation%20by%202030

In 2021, ROK nuclear = 27.4%

New plan for 2030 ~ 30%

# NUCLEAR GROWTH IN CHINA, SLOWING DOWN




https://asia.nikkei.com/Business/Energy/China-greenlights-6-new-nuclear-reactors-in-shift-away-from-coal

# ALLAM CYCLE GENERATOR: ECONOMIC, ZERO EMISSIONS AT 4-5 CENTS/KWH?