# SEEING THE LIGHT

The Case for NUCLEAR POWER in the 21st Century - by Scott Montgomery and Thomas Graham Jr, 2017.

Reviewed by Richard Steeves at PLATO meetings, Oct 22 & 24, 2018

# SCOTT MONTGOMERY

- A geoscientist – (M.S. in petroleum science) and a petroleum consultant for 23 years.
- A professor – at the University of Washington (Seattle) who has lectured widely in north America and Europe.
- An author - published 12 books and many articles, essays and papers in the sciences and humanities.
- His 2010 book, *The Powers That Be*, is widely used as a text in energy courses.
- His 2015 book with Daniel Chirot, *The Shape of the New*, was selected by the NYT as among the 100 best books of the year.

# AMBASSADOR (RETIRED) THOMAS GRAHAM JR.


- Executive Chairman of Lightbridge Corporation (developing nuclear fuels).
- Teaches extensively at Stanford University and Oregon State University.
- Since 2009 he worked on the International Advisory Board for the United Arab Emirates' peaceful nuclear power program.
- A leading authority on international arms control and nonproliferation.

# ESSENCE OF THE BOOK

- Nuclear power is not an option for the future, but an absolute necessity.
- Global threats of climate change and lethal air pollution make it clear that **nuclear and renewable energy must work together** as key non-carbon sources of energy.
- Fortunately, a new era of growth in nuclear power is underway in developing nations, **though not yet in the West**.
- This is the first book to clarify these realities and to portray their implications for the coming decades. Revealed are how, why and where the new era is happening, what new technologies are involved, and what this means for preventing the proliferation of weapons.

# SORRY, FIRST A LITTLE BIT OF HISTORY

- 1.7 billion years ago, in the Oklo area in SE Gabon, the world's first nuclear reactor operated cheaply and safely for ~150,000 years, without equipment breakdown.
- A natural accumulation of U-235 occurred in porous sands with water, which acted as a moderator and coolant. When fission established a chain reaction, the water heated up until it boiled away and the reaction stopped. When enough water re-accumulated in the sandstone, fission recommenced and so on, until the amount of U-235 decreased until a chain reaction was no longer possible.


# 20TH CENTURY: USA CHOSE WATER

- Fast forward 2 billion years and planet Earth now has 449 artificial reactors, most still using water as moderator and coolant, a LWR technology still dominant for the last 60 years. (Relax: abbreviations are defined in the next slide.)

- WHY? … Because USA (under the banner of military secrecy) refused to share technical info with its own allies. So … Britain, Canada, Norway, Netherlands and Russia all went their separate ways.

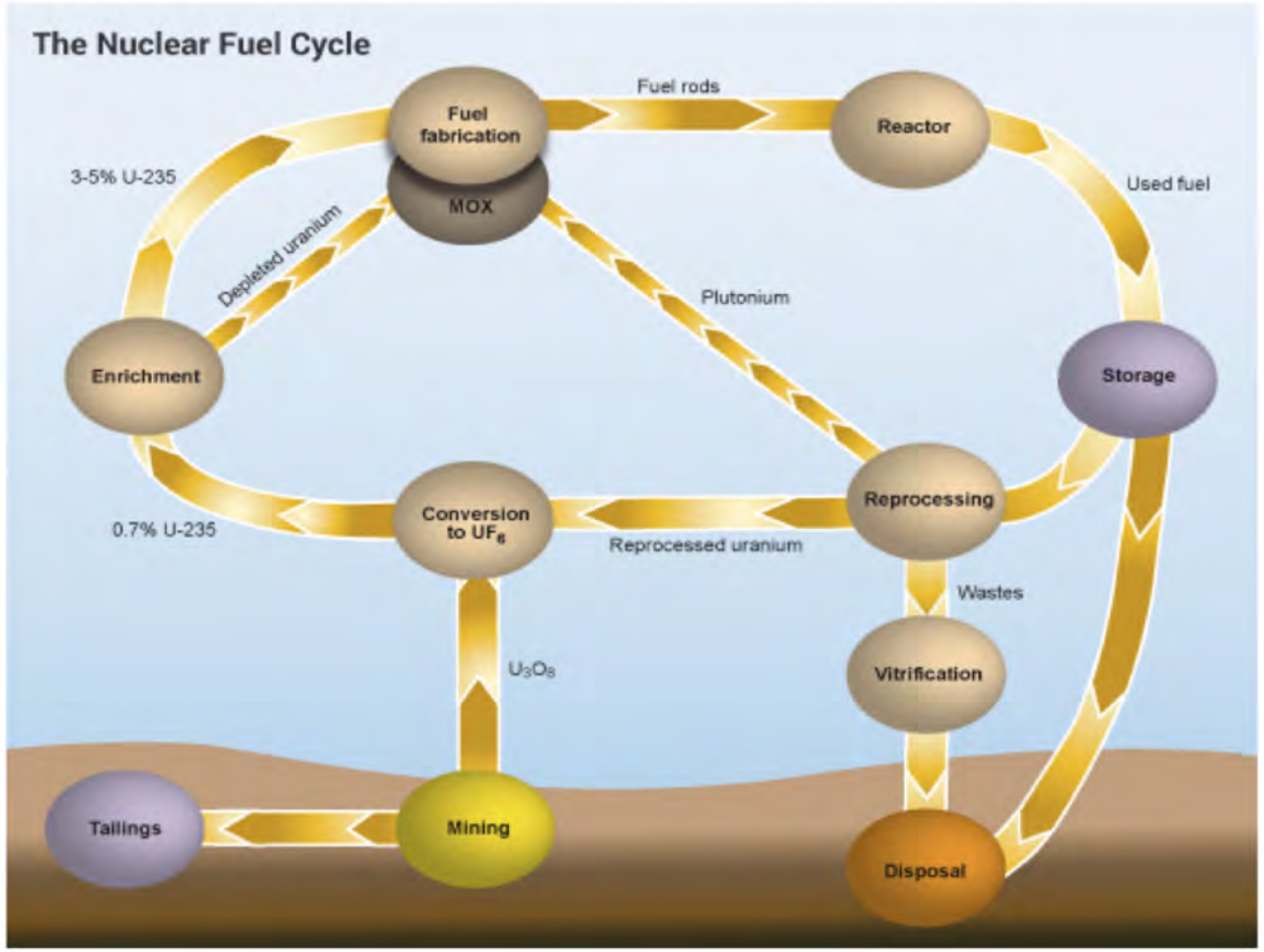
- The first civilian nuclear station went "critical" at Shippingport, PA on Dec 2, 1957, (15 year post-Fermi) with an ex-Naval (HEU) reactor, overseen by Hyman Rickover. He was a strong advocate of LWRs for land-based civilian power as well. But by 1982 Rickover said he would sink his nuclear navy if he could, revealing his latent fears as an engineer who did not fully comprehend nuclear physics.

# TIME OUT FOR ABBREVIATIONS

- LWR – Light water reactor (as compared with heavy water [CANDU] reactors).
- BWR – Boiling water reactor (boiling water directly drives a steam turbine).
- PWR – Pressurized water reactor (the water doesn't boil under pressure).
- EBR – Experimental breeder reactor (in Idaho) makes excess plutonium.
- LSR – Liquid sodium reactor (is an advanced, fast-neutron reactor).
- IFR – Integral fast reactor (is very efficient; EBR-II was a working prototype).
- MSR – Molten salt reactor (uses liquid fuel mixed with coolant at normal pressure)
- HEU – highly enriched uranium.
- LCOE – Levelized cost of electricity (takes into account cost of materials).
- Closed Fuel Cycle – uranium fuel can be "reprocessed"…see next slide.

# CLOSING THE FUEL CYCLE

## Reprocessing Would Sure Help!



# USA MISSED THREE BIG CHANCES

- **EBR-II, a sodium-cooled fast breeder reactor** (ID, 1964-94) was shut by Clinton/Gore. It had a "closed" fuel cycle; it burned original fuel, reprocessed the spent fuel, and then burned the result. It also validated a pool-type design and had passive safety.

- **Molten Salt Reactor Experiment (MSRE)** operated at Oak Ridge TN (1966-69). Developed by Alvin Weinberg, its fuel (U or Th) was dissolved in the coolant, and reprocessing occurred chemically during reactor operation. Weinberg liked that it couldn't melt or explode, its high efficiency, and it could be refueled while running.

- **Cancellations & Premature Closures**: Of the 253 nuclear power reactors originally ordered in USA from 1953 to 2008, 120 were cancelled and 28 were prematurely shut down. Jane Fonda probably meant well, but had those reactors been operated as planned, we would not be in the pickle that we find ourselves today.

# HALF OF THEM ARE LISTED HERE

## Cancelled nuclear reactors [edit]

| Name[n 1] | Unit | Type | Status | Location | State | Net capacity in MW | Gross capacity in MW | Contract year | Construction start | Project close |
|---|---|---|---|---|---|---|---|---|---|---|
| Allens Creek | 1 | BWR | Cancelled Plan | Wallis | Texas | 1,160 | 1,207 | 1973 | - | 1982-09-01 |
| Allens Creek | 2 | BWR | Cancelled Plan | Wallis | Texas | 1,160 | 1,207 | 1973 | - | 1976-09-01 |
| Alabama Power Co | 1 | BWR | Cancelled Plan | Selma | Alabama | | | - | - | - |
| Alabama Power Co | 2 | BWR | Cancelled Plan | Selma | Alabama | | | - | - | - |
| Atlantic (offshore) | 1 | PWR | Cancelled Plan | Atlantic City | New Jersey | 1,150 | 1,211 | 1972 | - | 1978-12-01 |
| Atlantic (offshore) | 2 | PWR | Cancelled Plan | Atlantic City | New Jersey | 1,150 | 1,211 | 1972 | - | 1978-12-01 |
| Atlantic (offshore) | 3 | PWR | Cancelled Plan | Atlantic City | New Jersey | 1,150 | 1,211 | 1973 | - | 1978-12-01 |
| Atlantic (offshore) | 4 | PWR | Cancelled Plan | Atlantic City | New Jersey | 1,150 | 1,211 | 1973 | - | 1978-12-01 |
| Bailly (converted to coal) | 1 | BWR | Cancelled Construction | Westchester | Indiana | 660 | 686 | 1967 | 1974-01-01 | 1981-08-01 |
| Barton | 1 | BWR | Cancelled Plan | Clanton | Alabama | 1,209 | 1,254 | 1972 | - | 1977-11-01 |
| Barton | 2 | BWR | Cancelled Plan | Clanton | Alabama | 1,209 | 1,254 | 1972 | - | 1977-11-01 |
| Barton | 3 | BWR | Cancelled Plan | Clanton | Alabama | 1,209 | 1,254 | 1974 | - | 1975-11-01 |
| Barton | 4 | BWR | Cancelled Plan | Clanton | Alabama | 1,209 | 1,254 | 1974 | - | 1975-11-01 |
| Bell Bend | 1 | PWR | Cancelled Plan | Salem | Pennsylvania | 1,600 | 1,720 | - | - | - |
| Bell Station | 1 | | Cancelled Plan | Lansing | New York | 838 | | 1967 | - | 1972 |
| Bellefonte | 1 | PWR | Suspended Construction | Scottsboro | Alabama | 1,235 | 1,263 | 1970 | 1974-09-01 | 1988-01-01 |
| Bellefonte | 2 | PWR | Suspended Construction | Scottsboro | Alabama | 1,235 | 1,263 | 1970 | 1974-09-01 | 1988-01-01 |
| Bellefonte | 4 | PWR | Cancelled Plan | Scottsboro | Alabama | 1117 | | - | - | - |
| Black Fox | 1 | BWR | Cancelled Construction | Inola | Oklahoma | 1,150 | 1,226 | 1973 | 1978-07-01 | 1982-02-01 |
| Black Fox | 2 | BWR | Cancelled Construction | Inola | Oklahoma | 1,150 | 1,226 | 1973 | 1978-07-01 | 1982-02-01 |
| Blue Hills (formerly Sunken Log) | 1 | PWR | Cancelled Plan | Jasper | Texas | 930 | 957 | 1973 | - | 1978-08-01 |
| Blue Hills (formerly Sunken Log) | 2 | PWR | Cancelled Plan | Jasper | Texas | 930 | 957 | 1974 | - | 1978-08-01 |
| Bodega Bay | 1 | BWR | Cancelled Construction | Bodega Head | California | 313 | 589 | - | 1958 | 1964 |
| Callaway | 2 | PWR | Cancelled Construction | Callaway | Missouri | 1,120 | 1,176 | 1973 | 1975-10-01 | 1981-10-01 |
| Callaway | 2 | PWR | Cancelled Plan | Callaway | Missouri | 1,600 | | 2008 | - | - |
| Calvert Cliffs | 3 | PWR | Cancelled Plan | Calvert County | Maryland | 1,600 | 1,720 | - | - | 2015-06-08 |
| Carroll County | 1 | PWR | Cancelled Plan | Savanna | Illinois | 1,120 | 1,150 | 1978 | - | 1988-12-01 |
| Carroll County | 2 | PWR | Cancelled Plan | Savanna | Illinois | 1,120 | 1,150 | 1978 | - | 1988-12-01 |
| Central Iowa | 1 | BWR | Cancelled Plan | | Iowa | 1,100 | 1,160 | - | - | 1975-09-01 |
| Cherokee | 1 | PWR | Cancelled Construction | Gaffney | South Carolina | 1,280 | 1,343 | 1973 | 1976-06-01 | 1983-04-01 |
| Cherokee | 2 | PWR | Cancelled Construction | Gaffney | South Carolina | 1,280 | 1,343 | 1973 | 1976-06-01 | 1982-11-01 |
| Cherokee | 3 | PWR | Cancelled Construction | Gaffney | South Carolina | 1,280 | 1,343 | 1973 | 1976-06-01 | 1982-11-01 |
| Clinch River | 1 | FBR | Cancelled Plan | Oak Ridge | Tennessee | 350 | 380 | 1973 | - | 1983-11-01 |
| Clinton | 2 | BWR | Cancelled Construction | Clinton | Illinois | 933 | 985 | 1973 | 1975-10-01 | 1983-10-01 |
| Columbia (WNP-1/WPPSS-1) | 1 | PWR | Cancelled Construction | Richland | Washington | 1,259 | 1,339 | 1972 | 1975-08-01 | 1983-01-01 |
| Columbia (WNP-4/WPPSS-4) | 4 | PWR | Cancelled Construction | Richland | Washington | 1,250 | 1,340 | 1974 | 1975-08-01 | 1982-01-01 |
| Comanche Peak | 3 | PWR | Suspended Plan | Somervell County | Texas | 1,700 | | - | - | 2013-11-07 |
| Comanche Peak | 4 | PWR | Suspended Plan | Somervell County | Texas | 1,700 | | - | - | 2013-11-07 |
| Crystal River | 4 | PWR | Cancelled Plan | Crystal River | Florida | 897 | 940 | 1971 | - | 1972-07-01 |
| Davis Besse | 2 | PWR | Cancelled Plan | Oak Harbor | Ohio | 910 | 960 | 1973 | - | 1980-01-01 |
| Davis Besse | 3 | PWR | Cancelled Plan | Oak Harbor | Ohio | 910 | 960 | 1973 | - | 1980-01-01 |
| Douglas Point (US) | 1 | BWR | Cancelled Plan | Douglas Point | Maryland | 1,178 | 1,206 | 1972 | - | 1980-05-01 |
| Douglas Point (US) | 2 | BWR | Cancelled Plan | Douglas Point | Maryland | 1,178 | 1,206 | 1972 | - | 1978-01-01 |
| Erie | 1 | PWR | Cancelled Plan | Berlin Heights | Ohio | 1,260 | 1,300 | 1976 | - | 1980-01-01 |
| Erie | 2 | PWR | Cancelled Plan | Berlin Heights | Ohio | 1,260 | 1,300 | 1976 | - | 1980-01-01 |
| Floating | 1 | PWR | Cancelled Plan | Jacksonville | Florida | 1,150 | 1,211 | - | - | 1979-01-01 |
| Floating | 2 | PWR | Cancelled Plan | Jacksonville | Florida | 1,150 | 1,211 | - | - | 1979-01-01 |
| Forked River | 1 | PWR | Cancelled Construction | Forked River | New Jersey | 1,070 | 1,123 | 1969 | 1973-08-01 | 1980-11-01 |
| Fort Calhoun | 2 | PWR | Cancelled Plan | Fort Calhoun | Nebraska | 1,136 | 1,182 | 1972 | - | 1977-02-01 |
| Fulton | 1 | HTGR | Cancelled Plan | Lancaster | Pennsylvania | 1,160 | 1,200 | 1971 | - | 1976-03-01 |
| Fulton | 2 | HTGR | Cancelled Plan | Lancaster | Pennsylvania | 1,160 | 1,200 | 1971 | - | 1976-03-01 |
| Galena | 1 | SFR | Proposal Cancelled | Galena | Alaska | 10 | | 2008 | - | - |
| Grand Gulf | 2 | BWR | Cancelled Construction | Port Gibson | Mississippi | 1,250 | 1,302 | 1972 | 1974-05-01 | 1990-12-01 |
| Grand Gulf | 3 | BWR | Cancelled Plan | Port Gibson | Mississippi | 1,520 | 1,600 | 1973 | - | 2015-02-09 |
| Greene County | 1 | PWR | Cancelled Plan | Clementon | New Jersey | 1,191 | 1,277 | 1974 | - | 1979-04-01 |
| Greenwood | 2 | PWR | Cancelled Plan | Port Huron | Michigan | 1,208 | 1,268 | 1972 | - | 1980-03-01 |
| Greenwood | 3 | PWR | Cancelled Plan | Port Huron | Michigan | 1,208 | 1,268 | 1972 | - | 1980-03-01 |
| Hartsville | A1 | BWR | Cancelled Construction | Hartsville | Tennessee | 1,233 | 1,269 | 1972 | 1976-04-01 | 1984-08-01 |
| Hartsville | A2 | BWR | Cancelled Construction | Hartsville | Tennessee | 1,233 | 1,269 | 1972 | 1976-04-01 | 1984-08-01 |
| Levy County | 1 | PWR | Cancelled Plan | Levy County | Florida | 1,117 | | 2008 | - | 2013-08-01 |
| Levy County | 2 | PWR | Cancelled Plan | Levy County | Florida | 1,117 | | 2008 | - | 2013-08-01 |
| Malibu | 1 | PWR | Cancelled Plan | Corral Canyon | California | 462 | | 1963 | - | 1972 |
| Marble Hill | 1 | PWR | Cancelled Construction | Paynesville | Indiana | 1,030 | 1,090 | 1973 | 1977-07-01 | 1984-01-01 |
| Marble Hill | 2 | PWR | Cancelled Construction | Paynesville | Indiana | 1,130 | 1,190 | 1973 | 1977-07-01 | 1984-01-01 |
| Mayport | 1 | | | Mayport | Florida | | | 1969 | - | - |
| Mayport | 2 | | | Mayport | Florida | | | 1969 | - | - |
| Midland | 1 | PWR | Cancelled Construction | Midland | Michigan | 491 | 526 | 1968 | 1973-03-01 | 1986-07-01 |
| Midland | 2 | PWR | Cancelled Construction | Midland | Michigan | 816 | 855 | 1968 | 1973-03-01 | 1986-07-01 |
| Montague | 1 | BWR | Cancelled Plan | Montague | Massachusetts | 1,150 | 1,298 | 1974 | - | 1980-12-01 |
| Montague | 2 | BWR | Cancelled Plan | Montague | Massachusetts | 1,150 | 1,298 | 1974 | - | 1980-12-01 |
| New Bold Island | 1 | BWR | Cancelled Plan | Bordentown | New Jersey | | | - | - | - |
| New Bold Island | 2 | BWR | Cancelled Plan | Bordentown | New Jersey | | | - | - | - |
| New England (NEP) | 1 | PWR | Cancelled Plan | Charlestown | Rhode Island | 1,150 | 1,194 | 1974 | - | 1980-01-01 |
| New England (NEP) | 2 | PWR | Cancelled Plan | Charlestown | Rhode Island | 1,150 | 1,194 | 1974 | - | 1980-01-01 |
| New Haven | 1 | PWR | Cancelled Plan | New Haven | New Jersey | 1,250 | 1,300 | 1977 | - | 1980-01-01 |
| New Haven | 2 | PWR | Cancelled Plan | New Haven | New Jersey | 1,250 | 1,300 | 1977 | - | 1980-01-01 |
| Nine Mile Point | 3 | PWR | Cancelled Plan | Scriba | New York | 1,600 | | 2008 | - | 2013-11-25 |
| North Anna | 3 | PWR | Cancelled Construction | Mineral | Virginia | 907 | 950 | 1971 | 1971-06-01 | 1982-11-01 |
| North Anna | 4 | PWR | Cancelled Construction | Mineral | Virginia | 907 | 950 | 1971 | 1971-12-01 | 1980-11-01 |
| North Coast (formerly Aguirre/Isolte) | 1 | PWR | Cancelled Plan | Arecibo | Puerto Rico | 583 | 614 | 1970 | - | 1978-12-01 |

# WHY NUCLEAR POWER, AND WHY NOW?

- **This time the future will be different**: 2/3 of humanity now live in nuclear-powered countries; 449 reactors could rise to 600 by 2035, 1,000 by 2050, in spite of poor press in USA and Western Europe. The global significance of Fukushima was overstated.
- **A New Era Underway**: In 2015, 70 new reactors are under construction; 165 planned. Some European nations (Swed/Belg/Swit) rejected nuclear closures after rethinking.
- **Air Pollution: World's Deadliest Killer:** In China at least ¼ million people die annually. This has been documented by the WHO for decades, mostly from Hrt. Dis./strokes. Globally air pollution kills more people than malaria, dengue, TB & AIDS combined.
- **The Climate Factor**: Imagine our atmosphere as a 1990 km sphere over a 1700 km square of the world's cities, and then imagine factory, car & truck emissions: get it?
- **The Nuclear Alternative**: 560 coal plants (90% in Asia) are under construction; if any are cancelled, we will need a nuclear alternative. (1 nuclear plant =~4 coal plants.)
- **A First Conclusion**: The world cannot afford pessimistic thinking about nuclear power while carbon pollution kills more each year than died at Hiroshima + Nagasaki.

# RENEWABLE ENERGY: CURRENT STATUS

- Like nuclear power, Renewables had their time of troubles…especially after 1980, when Reagan snuffed them out in favor of market forces and small government.

- Now they are enjoying a popularity that is out of step with reality. They are plagued by high cost, low efficiency, large footprint, low predictability, short life span, and intermittency. The need for energy storage has not been met, nor are there signs that it will happen soon.

- The authors do not consider hydro energy in the "renewables" category, based upon future projections of their reduction through climate change.
- By 2040 wind/solar are expected to max out at 15-20% of world power generation. (See page 252.)

# NUCLEAR POWER TODAY: AN OVERVIEW

- Over 20 years (1965-86) # of civilian reactors rose from a handful to 424.
- Over the next 20 years (post-Chernobyl) many orders cancelled: -> 435 by 2010.
- U.S. carbon emissions have risen dramatically since 1986, while research slipped.
- Globally, 602 more reactors are planned or under construction, 80% in non-OECD countries, including Turkey, UAE, Ghana, S. Africa, Cuba, Chile, Vietnam.
- At present, nuclear accounts for 22% of power in Europe, 18% in N. America.
- The first problem lies in **conceiving renewable and nuclear energy as antagonists.**
- It's fashionable to promote "100% renewables", but the implied or explicit rejection of nuclear power is unrealistic, and counter-productive.

# THE SECOND PROBLEM IS: **FEAR**

# ORIGINS OF NUCLEAR ANXIETY

- **History**: Spencer Weart's *The Rise of Nuclear Fear* (2012) on popular culture.
- **Perception & proportion**: Common fear of radiation far exceeds actual risks.
- **Pandoras' touch**: *Biological Effects of Atomic Radiation* (BEAR-1) & H Muller.
- **Bodega Bay**: (Hitchcock's *The Birds*) huge protest in 1958 over PG&E plans.
- **Lessons from the Clamshell Alliance & Amory Lovins**: a "soft energy path".
- **Anti-nuclearism in Europe**: affected by 2 world wars + the cold war vs USSR.
- **1980 – 2000**: Rising fear of nuclear terrorism; post-Chernobyl fear-mongering.
- **Is Nuclear Anxiety Global**? Yes, but climate change alters the balance of fear. Approval ratings vary from 20% (Greece) to 70% (China); internet exaggerations.
- **Conclusions**: Fear is the enemy of Fact. Without facts, the public is left with distrust and suspicion. The media has done more to frighten people than to inform them about what the risks and problems actually are. Fear of radiation is an institution of belief that has a central role in the history of nuclear power.

# WHY ***NOT*** NUCLEAR?

- **Risky**: 2 major accidents (1 with fatalities) does NOT qualify a technology of nuclear power's scale to be classed as being "accident-prone" or "risky".
- **Chernobyl contaminated huge area**: True, but 10 yr. later 85% residents can return.
- **Waste disposal is unsolvable**: 60 yr of global nuclear waste = 1 coal plant's waste/yr.
- **Aging nuclear plants are a threat**: Mean global age = 29 yrs; inspections going to 80.
- **U mining has a high environmental cost**: Mining for civilian use is now privatized/safe.
- **Nuclear plants use/contaminate lots of water**: BWR=> N-16; PWR => tritium; both safe.
- **Big Issue => COST**: LCOE (2015) nuclear = 95 $/MWh, < solar; >wind/hydro (EIA).
- **Nuclear reactors/weapons are too closely linked**: While both involve fission, many countries build reactors without developing weapons.
- **Conclusion: Beyond MYTH**: People have learned to fear nuclear power far more than they have learned to understand it. Those who understand it, do not fear it.

# OUR BIG ACCIDENTS: WHAT HAVE WE LEARNED?

- 1. Large-scale accidents are far less dangerous than believed or expected.
- 2. Primary enemy of public safety is panic and terror over fear of radiation.
- 3. Major type of cancer after radiation exposure is thyroid, which is very treatable.
- 4. Chernobyl was a unique situation; it will likely remain the worst such event in history.
- 5. Officials suppressed information and lied to the public, creating anger & distrust.
- 6. Regular review of nuclear plant facilities must occur, and upgrades inspected.
- 7. Core meltdowns do not lead to a "China Syndrome".
- 8. Inspections should be performed by an independent organization of paid experts.
- 9. Such an organization could provide information to educators and the media.
- 10. Far more fear and worry have been inspired by the 2 accidents than thousands of nuclear weapons that remain deployed today. Nuclear power must be understood.

# HOW DANGEROUS….REALLY?

- Our current system for estimating the biological risks of radiation remains overly "indebted" to the fearful view of Hermann Muller.
- There are concentration thresholds for neurotoxins, poisons, bacteria and viruses, but only radiation is treated as if a single photon were harmful.
- The 60,000 residents of Ramsar, Iran, live exposed to radiation levels 5X the limit for radiation workers, yet they enjoy the same life expectancy and have half as many genetic abnormalities as residents in other parts of Iran with lower levels of back-ground radiation. Limits defined by LNT theory are not relevant to chronic exposure.
- Professionals agree that the fear industry around radiation is
- much more perilous to public health than radiation itself.
- At some point society must come to its senses about radiation.

# HERMANN MULLER & THE LNT HYPOTHESIS

- In the 1920's Muller discovered that X-rays could induce mutations in fruit flies.
- During his 1946 Nobel acceptance speech, he claimed that 99% of mutations were harmful, and that there was no X-ray dose threshold for these bad effects.
- He had little trouble extending his conclusions from insects to humans, and he had a powerful influence as fallout continued from nuclear weapons-testing.
- He later contributed to part of a highly influential National Academy report (1956). Called the Biological Effects of Atomic Radiation (BEAR) report, it established the *Linear, No-Threshold* (LNT) model, which remains today the core for estimating risk.
- New data (from irradiated mice) refute the LNT model, which should be challenged. **Problem:** The LNT tends to exaggerate risk levels, and leads to unnecessary costs.
- A competing hypothesis, called ***hormesis***, claims that low radiation doses stimulate DNA repair and immune system responses to benefit our health. Accepted in France, Japan, China and Korea, it is, of course, rejected in USA, most of Europe and the U.N.

# ELECTRICITY….OVER THE NEXT 30 YEARS

- A billion humans have no electricity; for 2 billion more it is only intermittent.
- Future demands for energy will come mostly from developing nations.
- As the world continues to urbanize, and as we appreciate the need to reduce our carbon emissions, we'll have to change our current energy policies away from consuming mostly carbon-emitting fuels for making electricity.
- To accomplish this, realism is a required starting point. In developing nations, the goal has been to increase electricity at the lowest cost and without carbon fees, especially in countries with large coal reserves (China, India, Indonesia, Russia).

# The Global Race for Advanced Nuclear


**Reactor Design Types**

- Molten Salt Reactor
- Fluoride Salt-cooled High Temperature Reactor
- Liquid Metal-cooled Fast Reactor
- High Temperature Gas Reactor
- Pebble Bed Reactor
- Nuclear Battery Reactor
- Small Modular Reactor
- Fusion Reactor
- Super-Critical $CO_2$ Reactor
- Super-Critical Water-Cooled Reactor

third way
fresh thinking

# FIGURE CAPTIONS

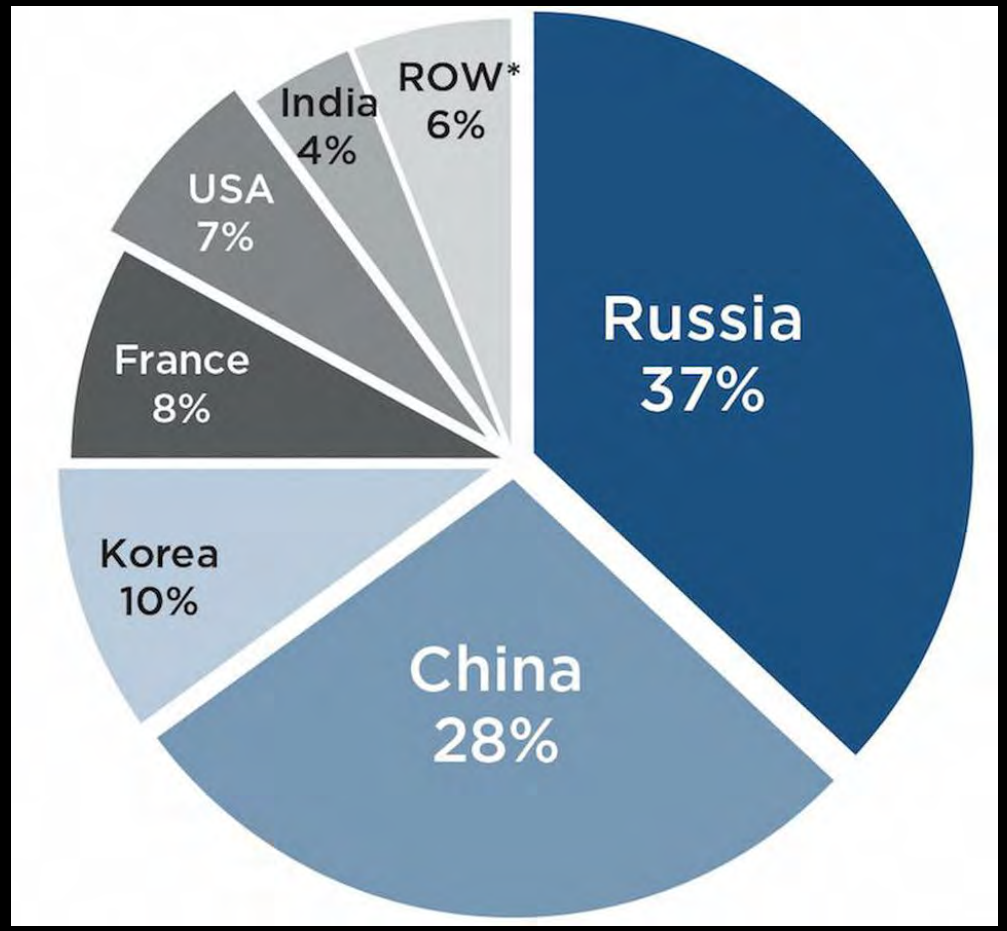
- *The advanced nuclear landscape includes over a hundred advanced nuclear reactor projects under development in more than 20 countries, including small modular, molten salt, pebble bed and others.*

- Even more surprising, there are 81 advanced nuclear reactor projects in 20 other countries. USA leads in the number of technologies being developed, and our designs are better, so why do we seem to be behind in the race to capture the nuclear market?

- Sixty years ago, the United States began the civilian nuclear power industry. Exporting nuclear technologies and reactors gave the U.S. significant economic and national security leverage. It enabled us to establish the fundamental nuclear safety standards that have made nuclear the safest of all energy sources.

# COUNTRIES PLANNING ADVANCED REACTORS

- *<u>Reactors Planned/ Under Construction by Home Country Vendor, by 10/2015.</u>*
- *ROW = Rest of World. These totals include reactor deals that are being negotiated as well as domestic projects.*
- American products used to dominate this sector, but Russia, Korea, and China have passed us. The U.S. could easily compete for these billion-dollar contracts using advanced reactors.
- *Russia's Rosatom has a B–O–O approach.*



# URBANIZATION INCREASES NUCLEAR NEED

- Power reactors under construction: UAE, Belarus.
- Contracts signed, legal and regulatory infrastructure well-developed or developing: Turkey, Bangladesh, Lithuania, Vietnam (but deferred).
- Committed plans, legal and regulatory infrastructure developing: Jordan, Poland, Egypt.
- Well-developed plans but commitment pending: Thailand, Indonesia, Kazakhstan, Saudi Arabia, Chile; or commitment stalled: Italy.
- Developing plans: Israel, Nigeria, Kenya, Laos, Malaysia, Morocco, Algeria.
- Discussion as policy option: Namibia, Mongolia, Philippines, Singapore, Albania, Serbia, Croatia, Estonia & Latvia, Libya, Azerbaijan, Sri Lanka, Tunisia, Syria, Qatar, Sudan, Cuba, Venezuela, Bolivia, Paraguay, Peru, Uzbekistan.
- Officially not a policy option at present: Australia, New Zealand, Portugal, Norway, Ireland, Kuwait, Myanmar, Cambodia, Tanzania, Zambia.

# ENERGY SECURITY: WHY SO IMPORTANT ?

- Energy must be sufficient, reliable, affordable and non-damaging, to avoid climate harm.
- Interdependence on other regions improves stability and resilience among grids (Europe).
- Nuclear plants are the workhorses of any system, adding baseload  security.
- Uranium supply comes from Australia, USA and Canada, even from seawater, so it could be considered at least “sustainable”.

# UNITED ARAB EMIRATES

- Founded in 1971; includes 7 states (emirates), including Dubai & Abu Dhabi.
- In 2007 experts saw the need to triple e-production by 2020; not with wind/solar.
- Didn't want to use its principal export (oil); needed e- for desalination plants.
- Began with 4 large reactors (1.4 GW), all the same design, all on time & budget.
- Located in Barakah, the first APR-1400 Korean reactor started up this year.
- Since the Gulf sea temp is 35°C (8° > in Korea), bigger heat exchangers are used.
- The U.S. Congress agreed to this plan, called the "gold standard", after the UAE resolved to forego domestic enrichment and reprocessing.

# LAUNCHING A NEW NUCLEAR STATE

# Desalination in the UAE

## NUCLEAR NEWCOMER – UNITED ARAB EMIRATES

GEN IV International Forum™

- Drastically increasing energy demand
  - Especially for water desalination
- Currently entirely dependent on natural gas and oil for domestic energy supply
  - Strong desire to reduce dependence while meeting growing energy needs
- Public opinion changing in favor of increased nuclear
  - 66% in favor in 2011
  - 82% in favor in 2012
- Four reactors currently under construction at the Barakah plant site
  - First unit expected to come on-line in 2017

Barakah plant under construction (Source: UAE Interact)

# TURKEY: LIMITED OPTIONS

- With 80 million people and rapidly urbanizing, Turkey needs $e^-$ urgently.
- A growing dependence on methane is unpopular, for obvious reasons.
- Nuclear, long delayed, is planned with 2 of 3 sites on the Black Sea.
- The Mediterranean site (Akkuyu), by Rosatom, will have 4.8 GW by 2025.
- The Black Sea units, being built by Mitsubishi/Areva and China, are similar.
- Four reactors are planned at each site, all are earthquake-resistant/Gen III+.
- Turkey wants to set a precedent for other nations with large power needs in concentrated areas.

# GHANA: 1 OF 48 SUB-SAHARAN NATIONS

- African Progress Panel: "No region has made a smaller contribution to C.C., yet Africa will pay the highest price for [our] failure to avert catastrophe. Energy deficits there reinforce inequities linked to health, gender and the rural-urban divide."
- 850 million people in the 48 sub-Saharan nations have only 90 GW to use, the same amount used by 27 million people in PA and IL, USA. Half of it comes from South Africa, the only country so far with nuclear power.
- Ghana is planning for its first nuclear reactor, a Westinghouse AP 600 in 2020.
- Ghana plans to integrate nuclear with hydro, solar/wind and methane.

# TRENDS IN GLOBAL ENERGY

- Despite hopes and dreams that a "green energy revolution" will take over the world in a few decades, no serious analysis today shows this to be happening.
- Wind/solar have grown this century to 7% of global power by 2017, but future growth to even 15 or 20% by 2040 will be difficult, concentrated in wealthy nations such as China and Persian Gulf states.
- Renewable energy is not the lone answer to climate change. Encouraged by progress made so far, many are asking more of these technologies than they can deliver.
- The healthiest way to look at renewables today is as an essential part of humanity's non-carbon energy shift. This places them together with nuclear power, hydro and geothermal power; all 3 of these can deliver baseload electricity.
- Proposals for using only renewables lead to impossible ideas of dealing with climate change, air pollution, energy poverty, urbanization and security, all at once. One such "roadmap" is a fantasy, no more helpful than revealing how much actually needs ro be done to decarbonize our energy systems.

# PAGE 259: - IN CONCLUSION

- The strong return to renewables and away from nuclear power (in a handful of European nations & USA) will not become a global model, least of all for the anticipated new demands from developing countries.

- The real problem to settle now is the current tendency to conceive of renewable and nuclear energies as antagonists.

- Efforts to find compatibility between renewables and nuclear will accomplish much more to lower global carbon emissions than participating in a showdown between the two non-carbon sources with the greatest capability to reduce emissions.

# NUCLEAR POWER IN RUSSIA (2018)


- Russia is moving steadily forward with plans for an expanded role of nuclear energy, including development of new reactor technology.
- It is committed to closing the fuel cycle, and sees fast reactors as a key to this.
- Exports of nuclear goods and services are a major policy and economic objective. Over 20 nuclear power reactors are confirmed or planned for export construction. Foreign orders totaled $133 billion at the end of 2016. BOO = Build/Operate/Own
- Russia is a world leader in fast neutron reactor technology.

# RUSSIAN NUCLEAR ICE-BREAKERS

- A **nuclear-powered icebreaker** is purpose-built for use in waters covered with ice. The only country constructing them is Russia. They have been constructed primarily to aid shipping along the Northern Sea Route in the frozen Arctic waterways north of Siberia. Nuclear-powered icebreakers are much more powerful than their diesel-powered ice-breakers, which have heavy fuel demands and range limitations.
- In winter, the ice along the Northern Sea Route varies from 3.9 to 6.5 feet. The ice in central parts of the Arctic averages 8.2 ft thick. Nuclear-powered icebreakers can force through this ice at speeds up to 10 knots. I
- In August 2012 Russia's state-owned nuclear corporation, Rosatom, signed a contract to begin construction on what will be the world's largest nuclear icebreaker, a "universal" vessel that could navigate both shallower rivers and the freezing depths of the Arctic.

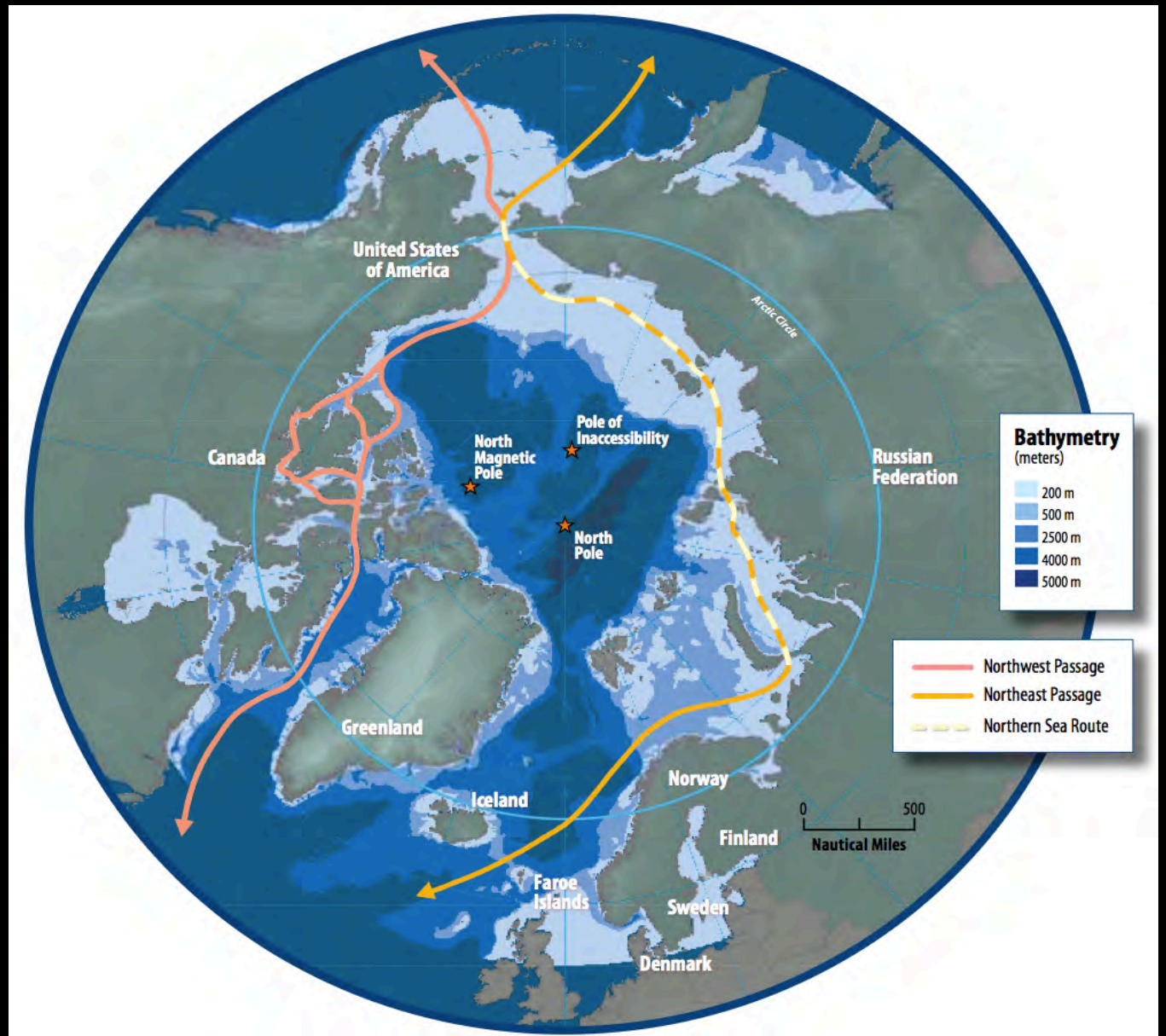
# RUSSIAN ICE-BREAKER: *YAMAL*

# RUSSIAN NUCLEAR VESSELS

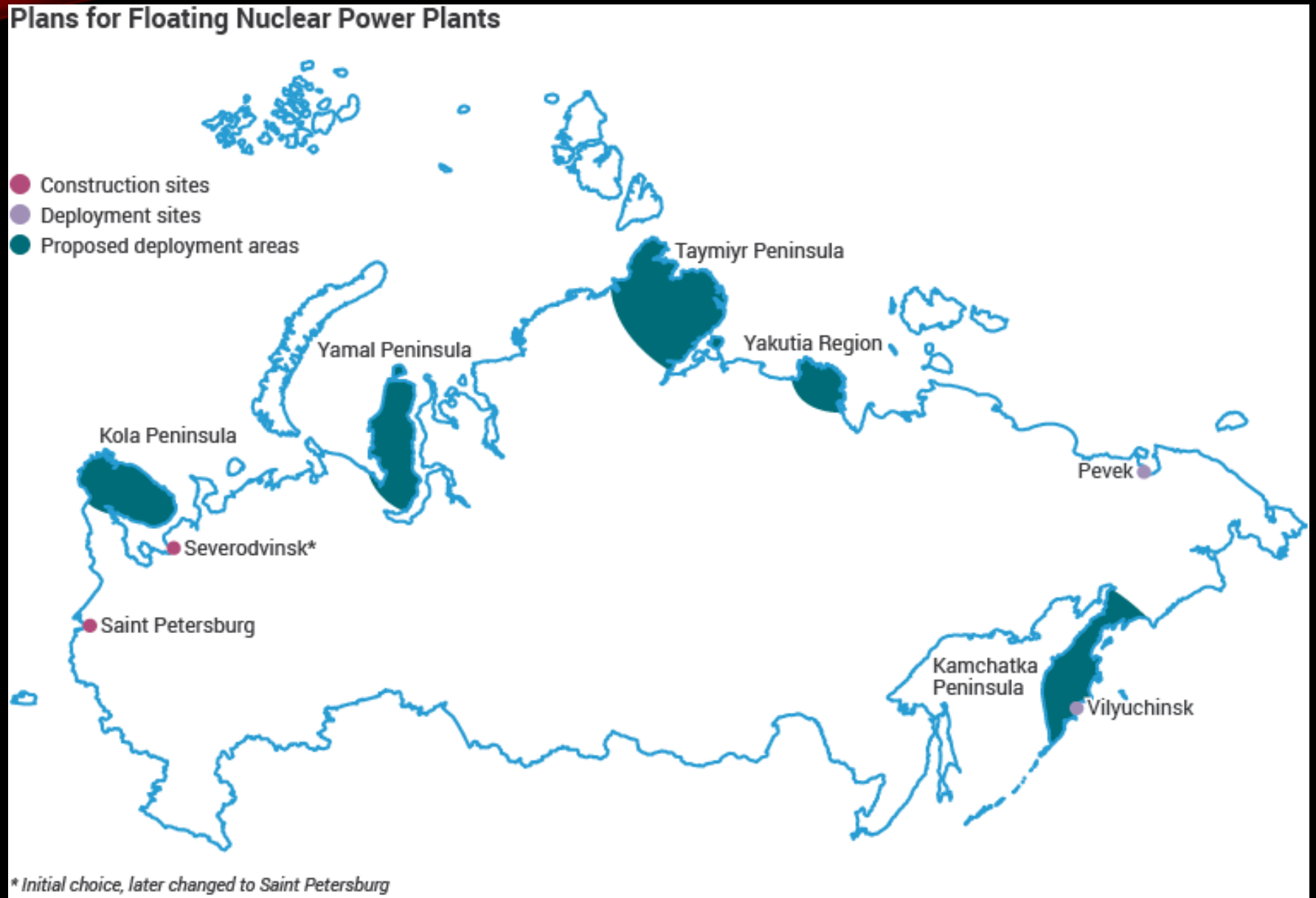
## Vessels [ edit ]

| Ship Name | In Service | Project Number | Type | Class | Comments |
|---|---|---|---|---|---|
| *Lenin* | 1959 | 92M | Icebreaker | — | Decommissioned 1989. Museum ship. |
| *Arktika* | 1975 | 1052-1 | Icebreaker | *Arktika* | Not operational. |
| *Sibir* | 1977 | 1052-2 | Icebreaker | *Arktika* | Defueled and not operational since 1993. |
| *Rossiya* | 1985 | 10521-1 | Icebreaker | *Arktika* | Not operational since 2013. |
| *Sevmorput* | 1988 | 10081 | Container ship | — | Has ice-breaking bow |
| *Taymyr* | 1989 | 10580-1 | River icebreaker | *Taymyr* | |
| *Sovetskiy Soyuz* | 1990 | 10521-2 | Icebreaker | *Arktika* | |
| *Vaygach* | 1990 | 10580-2 | River icebreaker | *Taymyr* | |
| *Yamal* | 1993 | 10521-3 | Icebreaker | *Arktika* | |
| *50 Let Pobedy* | 2007 | 10521 | Icebreaker | *Arktika* | Built as *Ural*, completed in 2007. |

# NORTHWEST & NORTHEAST PASSAGES



# RUSSIAN FLOATING NUCLEAR REACTORS



# FLOATING REACTORS IN RUSSIA/CHINA

# CHINA: COAL VS. NUCLEAR POWER

| YEAR | COAL | NUCLEAR |
|---|---|---|
| 1985 | 0.7 b. tons/yr. | |
| 1995 | 1.5 b. tons/yr. | 1 reactor in 1991 |
| 2013 | 3.2 b. tons/yr. | 6 reactors by 2013 |
| 2017 | 3.9 b. tons/yr. | 36 reactors (4%)<br>21 more under constr. |

# CHINA'S 4 GEN IV REACTORS

| LOCATION | TYPE | OUTPUT (MW) | DATE TESTED |
|---|---|---|---|
| Beijing | Pool-type, Sodium-cooled | 20 | 2010 |
| Shandong | Pebble-bed | 105 X 2 | 2018 |
| Jiangxi | Pebble-bed | 600 | 2019 |
| Small, floating | Molten salt, small, modular | 60 - 140 | 2020 - 30 |

# CHINA: ADVANCED NUCLEAR POWER

- China routinely includes nuclear power in the same “clean energy” category as WWS.
- That a country soon to become a global leader in nuclear power views carbon-free energy this way is significant.

# NUCLEAR **NON**PROLIFERATION

- The 45-year-old Cold War  between East and West ameliorated in 1988, when Reagan and Gorbachev took a stroll together in Red Square.
- What have we learned in 30 years since then? Or in the 70 years of living with nuclear energy and its wartime product, nuclear weapons?
- 1. Massive nuclear weapon confrontation between USA and USSR was avoided, but our relations with Russia have turned hostile again, and over 1,000 nuclear weapons remain in each country, so threats linger.
- 2. Peaceful use of nuclear power has a more stable outlook, although the "gold standard" (to avoid reprocessing, as agreed to by the UAE) was not accepted by Jordan or Vietnam.
- 3. May the world community cooperate sufficiently to use it as a principal response to climate change! The authors endorse Gwyneth Cravens' title of her famous book: ***Power to Save the World***.

# CONCLUSION: NUCLEAR POWER IS ESSENTIAL

- Nuclear power continues to be the largest form of non-carbon energy globally.
- It is also the most concentrated, most reliable, lowest environmental impact among all baseload sources, with the lowest # of accidents, injuries, fatalities.
- Therefore, the idea of letting this ESSENTIAL power source die off, a reactor at a time, represents a pathway to carbon and climate failure.
- But we must recognize that nuclear power has two major limiting factors: expensive to build and finance, and public fear with related myths.
- Meanwhile, China, Russia, India and S. Korea focus on closed fuel cycles while the West dithers.
- Placing coal and nuclear in the same category of risk, OR saying that nuclear is the lesser of 2 evils, reveals self-deception in the extreme. Nature cannot wait.
- Let us hope that Asia will carry the ball, and that the West will soon wake up.

# GLOBAL UPDATE FROM THE WNA

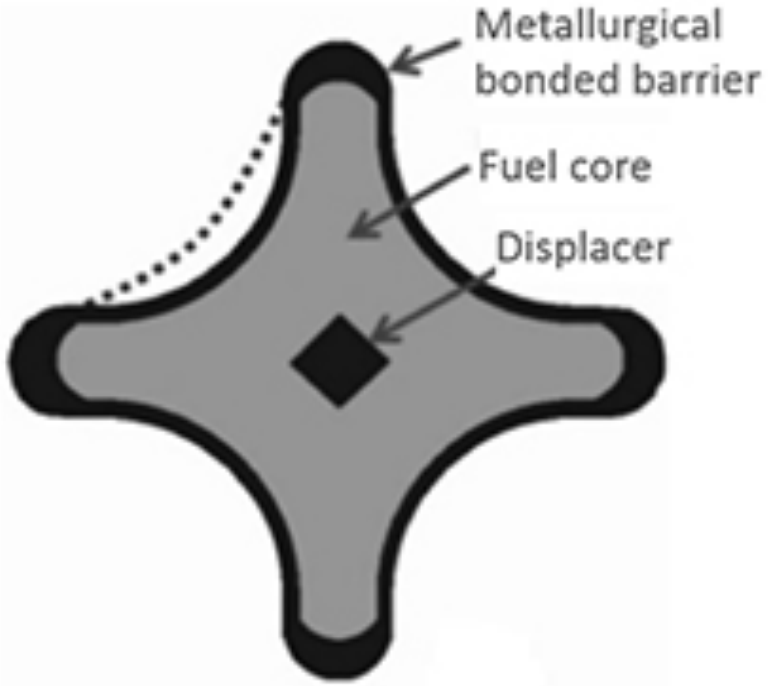
- The world's nuclear reactors performed excellently in 2017. Global nuclear electricity output was 2506 TWh, an increase of 29 TWh compared to 2016. This marked the fifth successive year that nuclear output has increased.

- At the end of 2017 the global nuclear capacity of the 448 operable reactors stood at 392 GWe, up 2 GWe from the end of 2016 .

- There were 59 reactors under construction at the end of 2017. The median average construction time for the four reactors grid connected last year was 58 months. In 2015 and 2016 there were 10 more grid connections, with more new ones in 2018 than in the whole of 2017.

- The capacity factor for the global fleet stood at 81%, maintaining the high availability of ~ 80% since 2000, and up from the 60% average capacity factor at the start of the 1980s.

# BETTER FUEL FROM LIGHTBRIDGE

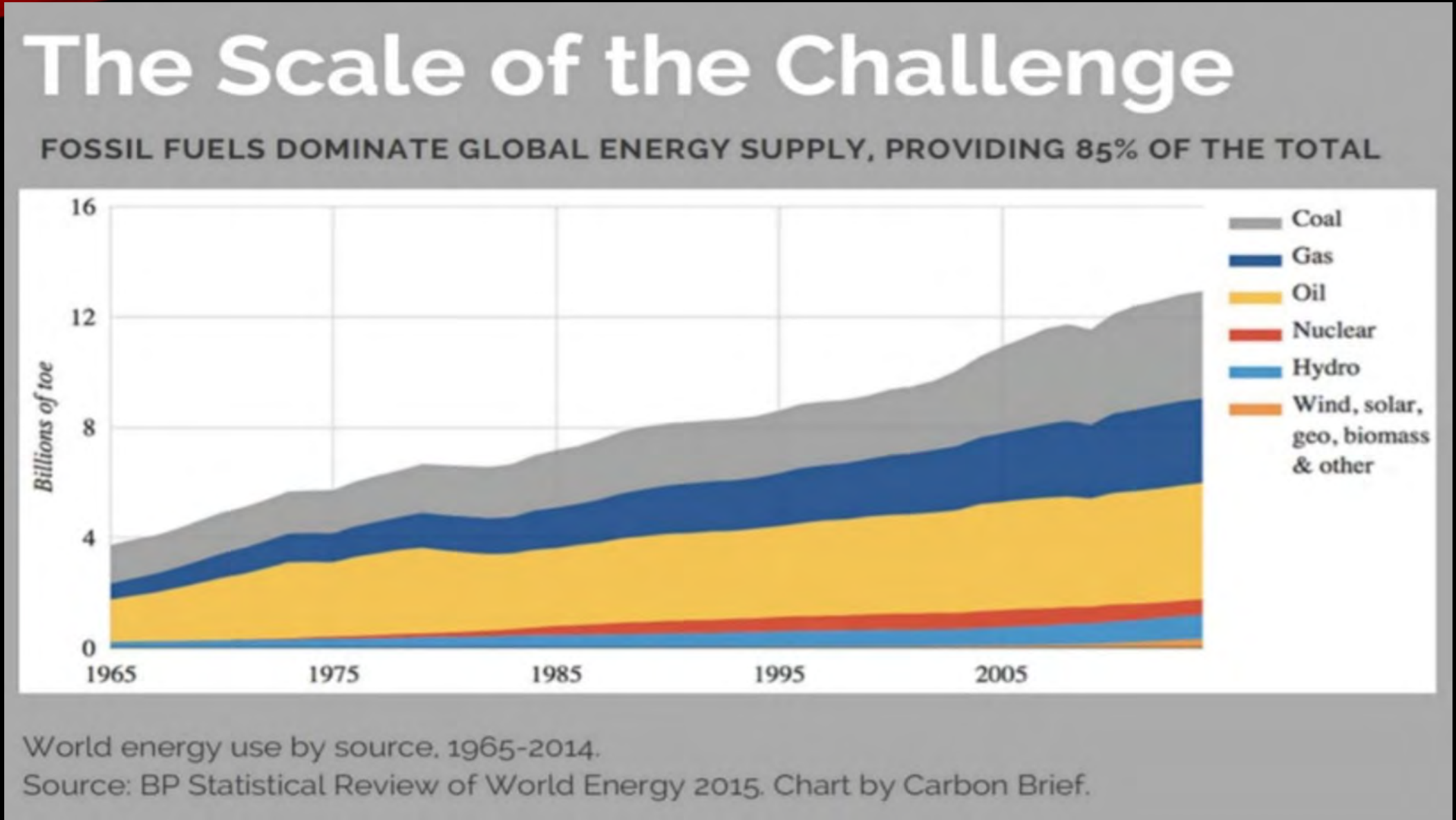



Lightbridge's four-lobe metallic fuel rod cross-section

Lightbridge's all-metal fuel rods used in thermal-hydraulic and vibration testing.

Lightbridge's 5x5-pin full commercial length all-metal fuel assembly mockup used in thermal-hydraulic testing.

# HOW TO LEAVE THE FOSSILS UNDERGROUND?



# A DATA CENTER FOR THE FUTURE?