
¹ While it is generally not disputed that wars are fought primarily over resources, the following two sources provide useful background material:

Klare, Michael T et al. "*The public health implications of resource wars.*" American journal of public health vol. 101,9 (2011): 1615-9. doi:10.2105/AJPH.2011.300267

United States Armed Forces Joint Forces Command – "*The Joint Operating Environment 2008 - Challenges and Implications for the Future Joint Force.*"

https://www.jcs.mil/Portals/36/Documents/Doctrine/concepts/joe_2008.pdf

² The United States annually consumes 4 trillion kilowatt-hours of electricity each year. A 300% increase of this figure is 12 trillion kWh. Energy Information Agency. "Electricity Explained."

<https://www.eia.gov/energyexplained/electricity/use-of-electricity.php>

³ As of 2022, the average price of electricity in the United States is 12.36 cents. Energy Information Administration. "*Average Price of Electricity to Ultimate Customers.*"

https://www.eia.gov/electricity/annual/html/epa_02_04.html.

⁴ A complete cost estimate of Scarcity Zero can be found via <https://scarcityzero.com/scarcity-zero/whitepaper/cost-estimate>

⁵ New York City is 302.6 mi², according to its Wikipedia entry -

https://en.wikipedia.org/wiki/New_York_City - which translates to ~8.44 billion square feet. We will assume that the aggregate surface area of all municipalities in America crosses the threshold of hundreds of billions, yet we estimate it is more likely past one trillion.

⁶ Wind turbines are more effective and have higher output as they increase in size. Nowakoski, G. A. , & Loomis, D. G. . (2023). The Power of Economies of Scale: A Wind Industry Case Study. Strategic Planning for Energy and the Environment, 42(03), 491–528. <https://doi.org/10.13052/spee1048-5236.4234>

⁷ International Electrotechnical Commission. "*Efficient Electrical Energy Transmission and Distribution.*" (2007). <https://basecamp.iec.ch/download/efficient-electrical-energy-transmission-and-distribution/#>

⁸ M. Brain, D. Roos, "How Power Grids Work."

<https://science.howstuffworks.com/environmental/energy/power4.htm>

Union of Concerned Scientists. "How the Electricity Grid Works." 17 February, 2015.

<https://www.ucsusa.org/resources/how-electricity-grid-works>

⁹ Electric Light & Power. "*Underground vs. Overhead: Power Line Installation-Cost Comparison and Mitigation.*" 2 January, 2013. http://www.elp.com/articles/powergrid_international/print/volume-18/issue-2/features/underground-vs-overhead-power-line-installation-cost-comparison-.html

¹⁰ Bloomberg CityLab. "*The Staggering Value of Urban Land.*" R. Florida. 2 November, 1917.

<https://www.bloomberg.com/news/articles/2017-11-02/america-s-urban-land-is-worth-a-staggering-amount>

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- ¹¹ Bloomberg CityLab. “The Staggering Value of Urban Land.” R. Florida. 2 November, 1917. <https://www.bloomberg.com/news/articles/2017-11-02/america-s-urban-land-is-worth-a-staggering-amount>
- ¹² Solar Window Power Model: <https://solarwindow.com/powermodel/>
- ¹³ Solar Window Power Model: <https://solarwindow.com/powermodel/>
- ¹⁴ Solar Window Power Model: <https://solarwindow.com/powermodel/>
- ¹⁵ If a single urban structure can annually generate 1.57 million kilowatt-hours annually, it would require only 637,000 buildings to generate one trillion kWh at similar generation capacity. New York City, alone, has more than one million buildings. <https://lastfiascorun.com/faq/often-asked-how-many-buildings-are-in-new-york-city.html>. We therefore operate under the assumption that nationwide there are many millions of buildings, thus exceeding the threshold to generate “trillions of kilowatt hours” in aggregate.
- ¹⁶ Washington Post. “Turns our wind and solar have a secret friend: Natural Gas.” C. Mooney. 11 August, 2016. <https://www.washingtonpost.com/news/energy-environment/wp/2016/08/11/turns-out-wind-and-solar-have-a-secret-friend-natural-gas/>
- ¹⁷ United States Government Accountability Office. “Electric Grid Cybersecurity: DOE needs to ensure its plans fully address risks to distribution systems.” 18 March, 2021. <https://www.gao.gov/products/gao-21-81>
- ¹⁸
- ¹⁹ EIA information on power plants nationwide. <https://www.eia.gov/tools/faqs/faq.php?id=65&t=2>
- ²⁰ Information on the number of Energy Utilities operating in the United States. <https://www.publicpower.org/system/files/documents/2018-Public-Power-Statistical-Report-Updated.pdf>
- ²¹ Energy.gov information on the number of power lines in the U.S. <http://energy.gov/articles/top-9-things-you-didnt-know-about-americas-power-grid>
- ²² CNBC. “Why America’s outdated energy grid is a climate problem.” C. Clifford. 17 February, 2023. <https://www.cnbc.com/2023/02/17/why-americas-outdated-energy-grid-is-a-climate-problem.html>
- ²³ American Society of Civil Engineers. “America’s Infrastructure Grades Remain Near Failing.” 9 March, 2017. <https://www.asce.org/templates/press-release-detail.aspx?id=24013>
- ²⁴ Wikipedia Entry on Miami-Dade County. https://en.wikipedia.org/wiki/Miami-Dade_County,_Florida
- ²⁵ Miami-Dade County. Energy outlook assessment. Page 2. https://www.miamidade.gov/greenprint/planning/library/milestone_one/energy.pdf#p2
- ²⁶ Solar panel output varies by sophistication, size, region and efficiency. We have therefore established assumptions based on the myriad solar options available. The SunPower E20 solar panel is an industry-leading solar panel available on the market today. With a nominal power output of 327 watts, it is 61.4

inches wide and 41.2 inches tall, coming to a surface area of about 17.5 square feet (as per <https://us.sunpower.com/sites/default/files/sunpower-e-series-commercial-solar-panels-e20-327-com-datasheet-505701-revh.pdf>). That translates to roughly 18.7 watts of power per square foot. Converting to energy, 18.7 watts of power exerted over an hour is measured as 18.7 watt-hours. Assuming five peak sun hours in a day, that totals 93.5-watt hours generated per day. Extrapolated over a calendar year, that totals 34,127.5 watt-hours.

Denoted in kilowatt-hours (the standard most energy is measured in), that comes to 34.12 kilowatt-hours of energy generated per square foot, per year. To account for anomalies, we'll reduce that figure by 10%, and estimate that one square foot of solar panel surface can reliably generate 30 kilowatt-hours per year. As there are 27.88 million square feet in one square mile, we will conclude that one square mile of solar panels would reliably generate 836.5 million kilowatt-hours in a year.

²⁷ American Society of Mechanical Engineers. "Entrepreneurs Look to Small-Scale Nuclear Reactors." M. Abrams. 2 March, 2021. <https://www.asme.org/topics-resources/content/entrepreneurs-look-to-small-scale-nuclear-reactors>

²⁸ Background reading on United States Navy Reactors - https://en.wikipedia.org/wiki/United_States_naval_reactors#:~:text=The%20U.S.%20Navy%20has%20never,are%20scheduled%20to%20be%20recycled.

²⁹ B.M. Elsheikh. "Safety assessment of molten salt reactors in comparison with light water reactors." Journal of Radiation Research and Applied Sciences. Volume 6, Issue 2. October, 2013, Pages 63-70. ISSN 1687-8507. <https://doi.org/10.1016/j.jrras.2013.10.008>.

³⁰ Multistage Flash is used in ~26% of desalinated water systems, second only to reverse osmosis due to energy cost. https://en.wikipedia.org/wiki/Multi-stage_flash_distillation

³¹ At 141.86 Megajoules per Kilogram (Higher Heating Value), Hydrogen has the highest specific energy of any practical chemical fuel. Energy Density Table (Chemical Reactions). https://en.wikipedia.org/wiki/Energy_density

³² Hydrogen combustion or use in fuel cells does not emit carbon. https://en.wikipedia.org/wiki/Hydrogen_fuel

³³ Most hydrogen today is produced by steam methane reforming of fossilized gas. https://en.wikipedia.org/wiki/Hydrogen_fuel / https://en.wikipedia.org/wiki/Steam_reforming#SMR

³⁴ Green Cars. "Different Types of Hydrogen Vehicles." L. Yap. July, 2023. <https://www.greencars.com/greencars-101/different-types-of-hydrogen-vehicles>

³⁵ United States Department of Energy. "Hydrogen and fuel cell technologies office." <https://www.energy.gov/eere/fuelcells/hydrogen-storage>

³⁶ Electric Vehicles have been commercially available since the late 2000's and market share has increased significantly over time. The same is true of electric aircraft (eVTOL), of which several startups have manufactured commercial models.

³⁷ "Next Generation Transportation" in this context refers to currently in-development projects such as the Hyperloop, Reaction Engine's SABRE, and Boeing's latest iteration of a man-piloted hypersonic aircraft. The following sources are for general background reading:

<https://virginhyperloop.com/>

<https://www.reactionengines.co.uk/beyond-possible/sabre>

<https://www.wired.com/story/boeing-hypersonic-mach-5-jet-concept/>

³⁸ International Energy Agency. "Direct Air Capture – more efforts needed." November, 2021.

<https://www.iea.org/reports/direct-air-capture>

³⁹ Carbon Engineering technical detail on diverting captured carbon to make specialized low-carbon fuels.

<https://carbonengineering.com/our-technology/>

For academic source: Noah McQueen et al 2021 Prog. Energy 3 032001. "A review of direct air capture (DAC): scaling up commercial technologies and innovating for the future." 16 April, 2021.

<https://iopscience.iop.org/article/10.1088/2516-1083/abf1ce>

⁴⁰ Scientific American. "The Discovery of Global Warming." S. Weart. 17 August, 2012.

<https://www.scientificamerican.com/article/discovery-of-global-warming/>

⁴¹ U.S. Department of Energy. National Energy Technology Laboratory (NETL). "Plasma Gasification." No author or date provided. <https://netl.doe.gov/research/Coal/energy-systems/gasification/gasifipedia/westinghouse>

⁴² Background reading on synthetic hydrocarbons / synthetic fuels.

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

Specific reading on hydrogenation:

https://en.wikipedia.org/wiki/Synthetic_fuel#Hydrogenation_processes

⁴³ A. Sanlisoy, M.O. Carpinlioglu. "A review on plasma gasification for solid waste disposal." International Journal of Hydrogen Energy. Volume 42, Issue 2, 2017. Pages 1361-1365. ISSN 0360-3199.

<https://doi.org/10.1016/j.ijhydene.2016.06.008>.

Background reading on Plasma Gasification: https://en.wikipedia.org/wiki/Plasma_gasification

⁴⁴ Power Technology Magazine. "Vogtle Electric Generating Plant, Burke County, Georgia." No author or date provided. <https://www.power-technology.com/projects/vogtle-electric-generating-plant-georgia/>

Georgia Power. Plate Vogtle 3 and 4: Project Update. <https://www.georgiapower.com/company/plant-vogtle.html>

⁴⁵ Power Technology Magazine. "Vogtle Electric Generating Plant, Burke County, Georgia." No author or date provided. <https://www.power-technology.com/projects/vogtle-electric-generating-plant-georgia/>

Georgia Power. Plate Vogtle 3 and 4: Project Update. <https://www.georgiapower.com/company/plate-vogtle.html>

⁴⁶ The USS Guardfish suffered a coolant leak in 1973 due to human error. No other accident from U.S.N reactors have occurred to public knowledge. [https://en.wikipedia.org/wiki/USS_Guardfish_\(SSN-612\)#1973_Reactor_Accident](https://en.wikipedia.org/wiki/USS_Guardfish_(SSN-612)#1973_Reactor_Accident)

⁴⁷ Commercial jets travel between 460-575mph at 36,000 feet. Flight Deck Friend. "How fast to passenger jets fly?" <https://www.flightdeckfriend.com/ask-a-pilot/how-fast-do-commercial-aeroplanes-fly>

⁴⁸ Airbus. "The A320 Family: the most successful aircraft family ever." January 2022. <https://www.airbus.com/sites/g/files/jlcbta136/files/2022-01/EN-Airbus-A320-Facts-and-Figures-January-2022.pdf>

⁴⁹ The Post and Courier. "Pace of 787 Dreamliner production quickens and Boeing's North Charleston campus." D. Wren. 1 April, 2018. https://www.postandcourier.com/business/pace-of-dreamliner-production-quickens-at-boeing-s-north-charleston/article_02b584ea-3384-11e8-a3d4-ff9ca36dc590.html

⁵⁰ According to Budweiser and several sources, it takes Anheuser-Busch approximately 30 days to brew a bottle of beer. <https://www.cnbc.com/2008/07/02/Brewing-the-King-of-Beers.html> /

⁵¹ National Geographic. "Great Pacific Garbage Patch." <https://education.nationalgeographic.org/resource/great-pacific-garbage-patch>

NOAA. "Garbage Patches: How Gyres Take Our Trash Out To Sea." <https://oceanservice.noaa.gov/podcast/mar18/nop14-ocean-garbage-patches.html>

⁵² The Ocean Cleanup Project is an organization attempting to clean oceans by way of floating sieves that collect ocean trash for disposal. <https://theoceancleanup.com/oceans/>

⁵³ Walton, Rod (9 August 2018). "Vogtle Cost Upgrade Causes Rethinking of \$25B Nuclear Plant's Future." Power Engineering. Retrieved 16 August 2018. \$25B for a 2300 MW reactor arrives at ~10.89MM per megawatt. Additional background reading here: https://en.wikipedia.org/wiki/Vogtle_Electric_Generating_Plant

⁵⁴ According to NuScale power, an SMR has an overnight cost of \$3.6MM per megawatt of generating capacity. NuScale Power. "NuScale's Affordable SMR Technology for All." <https://www.nuscalepower.com/newsletter/nucleus-spring-2020/featured-topic-cost-competitive>

This is within range of the University of Chicago's EPIC (Energy Policy Institute at Chicago)'s paper "Small Modular Reactors – Key to Future Nuclear Power Generation in the U.S.", R. Rosner, S. Goldberg, November 2011 (P.9), which was an addendum to the University of Chicago's *Economic Future Of Nuclear Power* report, 2004, which estimated SMR technology to be significantly lower, some 2,000/MW.

⁵⁵ Our World in Data. “*Leaning Curves: What does it mean for a technology to follow Wright’s law?*” M. Roser. 18 April, 2023. <https://ourworldindata.org/learning-curve>

⁵⁶ Background reading on the nuclear power debate.
https://en.wikipedia.org/wiki/Nuclear_power_debate

⁵⁷ Contemporary media has significant volumes of dis/misinformation in criticism of nuclear power, specifically that it is dangerous, that radioactive waste is pervasive and/or unmanageable, and nuclear power inherently carries a proliferation risk.

Nuclear Energy Agency. “*Addressing the challenges of misinformation.*” No date or author provided.
https://www.oecd-neo.org/jcms/pl_58232/addressing-the-challenges-of-misinformation

Forbes magazine. “*Natural gas industry blasts nuclear power with fake news.*” J. Conca. 15 June, 2017.
<https://www.forbes.com/sites/jamesconca/2017/06/15/natural-gas-industry-blasts-nuclear-power-with-fake-news/?sh=62bebe7f133b>

See also: https://en.wikipedia.org/wiki/Anti-nuclear_movement

⁵⁸ U.S. Department of Energy. “Quadrennial Technology Review.” Table 10.4: Range of materials requirements (fuel excluded) for various electricity generation technologies.” September, 2015.
<https://www.energy.gov/sites/prod/files/2017/03/f34/qtr-2015-chapter10.pdf> Hosted directly:
https://nextgiantleap.org/sites/default/files/source_files/quadrennial-technology-review-2015.pdf

⁵⁹ International Energy Agency. 2021 World Energy Outlook Special Report: *The Role of Critical Minerals in Clean Energy Transitions*, <https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions>

⁶⁰ U.S. Environmental Protection Agency. “*EPA Releases Briefing Paper on Renewable Energy Waste Management.*” 6 January, 2021. <https://www.epa.gov/newsreleases/epa-releases-briefing-paper-renewable-energy-waste-management>

⁶¹ On an annual basis, the United States consumes 1.4 billion gallons of diesel fuel (equivalent to 57 billion kWh) and 135 billion gallons of gasoline (equivalent to 5 trillion kWh). U.S. Energy Information Administration. “*How much gasoline does the United States consume?*”
<https://www.eia.gov/tools/faqs/faq.php?id=23&t=10>. “*Diesel fuel explained.*”
<https://www.eia.gov/energyexplained/diesel-fuel/use-of-diesel.php>

⁶² On an annual basis, the United States consumes 32.26 trillion cubic feet of natural gas (2022). Statista. “*Consumption of natural gas in the United States from 1995 to 2022.*”
<https://www.statista.com/statistics/184329/energy-consumption-from-natural-gas-in-the-us-from-1995/>

A cubic foot of natural gas is equivalent to 0.13 kilowatt-hours. Energy Information Administration. “*How much coal, natural gas, or petroleum is used to generate a kilowatt-hour of electricity?*”
<https://www.eia.gov/tools/faqs/faq.php?id=667&t=8>

32.26 trillion ft³ of natural gas, at 0.13kWh per ft³, translates to 4.194 trillion kWh.

⁶³ Statista. "Annual solar module production globally from 2000 to 2022."

<https://www.statista.com/statistics/668764/annual-solar-module-manufacturing-globally/>

⁶⁴ At 16,477 metric tons per terawatt-hour, the threshold of 4,050 TWh would be 66,731,850 metric tons per year. Over 20 years, this would derive a material throughput of 1.34 billion metric tons.

⁶⁵ At 16,477 metric tons per terawatt-hour, the threshold of 10,000 TWh would be 164,770,000 metric tons per year. Over 20 years, this would derive a material throughput of 3.3 billion metric tons.

⁶⁶ At 16,477 metric tons per terawatt-hour, the threshold of 14,000 TWh would be 230,678,000 metric tons. Over 20 years, this would derive a material throughput of 4.61 billion metric tons.

⁶⁷ Statista. "Cumulative installed wind power capacity worldwide from 2001 to 2022."

<https://www.statista.com/statistics/268363/installed-wind-power-capacity-worldwide/>

⁶⁸ Wind Turbines function at varying speeds of wind, typically around 30 to 50mph as per <https://www.wind-watch.org/faq-output.php>. According to this source: "At slower wind speeds, the production falls off dramatically. If the wind speed decreases by half, power production decreases by a factor of eight. On average, therefore, wind turbines do not generate near their capacity. Industry estimates project an annual output of 30-40%, but real-world experience shows that annual outputs of 15-30% of capacity are more typical.

With a 25% capacity factor, a 2-MW turbine would produce: $2 \text{ MW} \times 365 \text{ days} \times 24 \text{ hours} \times 25\% = 4,380 \text{ MWh} = 4,380,000 \text{ kWh}.$ "

To annually generate 4.05 trillion kWh, we would therefore need 924,657 turbines at this performance threshold.

At 10,260 tonnes per terawatt-hour, 4,050 TWh would present a material throughput of 41,553,000 metric tons. Over 20 years, this would derive a material throughput of 831,060,000 metric tons.

⁶⁹ Building off the figures in the prior citation, a generational threshold of 10,000 TWh would present the need for 2,283,105 wind turbines at this performance threshold. At 10,260 tonnes per terawatt-hour, this would present a material throughput of 102,600,000 metric tons. Over 20 years, this would derive a material throughput of 2.05 billion metric tons.

⁷⁰ Building off the figures in the prior citations, a generational threshold of 14,000 TWh would present the need for 3,196,347 wind turbines at this performance threshold. At 10,260 tonnes per terawatt-hour, this would present a material throughput of 143,640,000 metric tons. Over 20 years, this would derive a material throughput of 2.87 billion metric tons.

⁷¹ Visual Capitalist. *All the Metals we Mined In One Chart*. <https://elements.visualcapitalist.com/wp-content/uploads/2021/09/all-of-the-metals-one-visualization.html>

⁷² According to the DOE Quadrennial Technology Review 2015, Solar PV requires 850 metric tons (tonnes) of copper per TWh. At 4,050 TWh, this results in 3,442,500 metric tons. Over a 10 year timespan, this results in 34,425,000 metric tons.

⁷³ Statista. "Mine production of copper worldwide from 2010 to 2023." <https://www.statista.com/statistics/254839/copper-production-by-country/>

⁷⁴ Nature Journal. (Editorial). "Lithium-ion batteries need to be greener and more ethical." 29 June, 2021. doi: <https://doi.org/10.1038/d41586-021-01735-z>

Forbes Magazine. "If Solar Panels Are So Clean, Why Do They Produce So Much Toxic Waste?" M. Shellenberger, contributor. 23 May, 2018. <https://www.forbes.com/sites/michaelshellenberger/2018/05/23/if-solar-panels-are-so-clean-why-do-they-produce-so-much-toxic-waste/#175aff0e121c>

The Verge Magazine. "More solar panels mean more waste and there's no easy solution." A. Chen. 25 October, 2018. <https://www.theverge.com/2018/10/25/18018820/solar-panel-waste-chemicals-energy-environment-recycling>

⁷⁵ Council on Foreign Relations. "Why Cobalt Mining in the DRC Needs Urgent Attention." J. Campbell. 29 October, 2020. <https://www.cfr.org/blog/why-cobalt-mining-drc-needs-urgent-attention>

New Yorker Magazine. "The Dark Side of Congo's Cobalt Rush." Reporter at Large. 31 May, 2021. <https://www.newyorker.com/magazine/2021/05/31/the-dark-side-of-congos-cobalt-rush>

⁷⁶ Massachusetts Institute of Technology. "The Future of Strategic Natural Resources – Environmental Risks of Mining." No date or author provided. <https://web.mit.edu/12.000/www/m2016/finalwebsite/problems/mining.html>

Smithsonian Magazine. "The Environmental Disaster that is the Gold Industry." A. Bland. 14 February 2014. <https://www.smithsonianmag.com/science-nature/environmental-disaster-gold-industry-180949762/>

⁷⁷ Wind turbines have a lifetime of 20 years, as per U.S. Environmental Protection Agency "Renewable Energy Fact Sheet: Wind Turbines." (August, 2013).

Most commercially available solar panels have a lifetime of 25-30 years. GreenBiz "What will happen to solar panels after their useful lives are over?" N. Berg, 11 May, 2018. <https://www.greenbiz.com/article/what-will-happen-solar-panels-after-their-useful-lives-are-over>

⁷⁸ Forbes Magazine. "If Solar Panels Are So Clean, Why Do They Produce So Much Toxic Waste?" M. Shellenberger, contributor. 23 May, 2018. <https://www.forbes.com/sites/michaelshellenberger/2018/05/23/if-solar-panels-are-so-clean-why-do-they-produce-so-much-toxic-waste/#175aff0e121c>

The Verge Magazine. "More solar panels mean more waste and there's no easy solution." A. Chen. 25 October, 2018. <https://www.theverge.com/2018/10/25/18018820/solar-panel-waste-chemicals-energy-environment-recycling>

⁷⁹ Time Magazine. "The World has an E-Waste Problem." A. Semuels. 23 May, 2019. <https://time.com/5594380/world-electronic-waste-problem/>

⁸⁰ Nikkei Asia – Engineering & Construction. "Komatsu aims for lead in hydrogen-powered mining trucks." H. Yamanaka. 22 February, 2021. <https://asia.nikkei.com/Business/Engineering-Construction/Komatsu-aims-for-lead-in-hydrogen-powered-mining-trucks>

Mining Technology magazine. "Hydrogen-powered vehicles: innovations in the future of mining machinery?" JP Casey. 24 August, 2020. <https://www.mining-technology.com/features/hydrogen-powered-vehicles-innovations-in-the-future-of-mining-machinery/>

⁸¹ Background reading on passive nuclear safety systems: https://en.wikipedia.org/wiki/Passive_nuclear_safety

⁸² Control automation. "Automation could have prevented Chernobyl." B. Liptak. 9 January, 2013. <https://www.controlglobal.com/protect/safety-instrumented-systems/article/11380173/automation-could-have-prevented-chernobyl>

⁸³ World Nuclear Association. "Fukushima Daiichi Accident." <https://world-nuclear.org/information-library/safety-and-security/safety-of-plants/fukushima-daiichi-accident.aspx>

⁸⁴ World Nuclear Association. "Chernobyl Accident 1986." <https://world-nuclear.org/information-library/safety-and-security/safety-of-plants/chernobyl-accident.aspx#:~:text=It%20is%20estimated%20that%20all,was%20released%20in%20the%20accident.>

⁸⁵ Nuscale Power. "VOYGR Plant Models – Safety Features." <https://www.nuscalepower.com/en/products/voygr-smr-plants>

⁸⁶ Uranium-235 has an energy density of 79,390,000 MJ/kg. 4% of this is 3,175,600 MJ/kg. This figure multiplied by 192,000 is 609,715,200,000 Megajoules. 5% of this is 30,485,760,000 Megajoules.

⁸⁷ Discover Magazine. "Why Aren't we using thorium in nuclear reactors?" A. Hadhazy. 6 May, 2014. <https://www.discovermagazine.com/the-sciences/why-arent-we-using-thorium-in-nuclear-reactors>

110th Congress. (2008). S. 3680 (110th): Thorium energy independence and security act of 2008. Retrieved from website: <http://www.govtrack.us/congress/bills/110/s3680/text>

U.S. Department of Energy. "Closing the Circle on the Splitting of the Atom." January, 1996. https://www.energy.gov/sites/prod/files/2014/03/f8/Closing_the_Circle_Report.pdf

⁸⁸ Orano Group. “All about plutonium.” <https://www.orano.group/en/unpacking-nuclear/all-about-plutonium>

⁸⁹ Hargraves, Robert, and Ralph Moir. “Liquid Fluoride Thorium Reactors: An Old Idea in Nuclear Power Gets Reexamined.” *American Scientist*, vol. 98, no. 4, 2010, pp. 304–13. JSTOR, <http://www.jstor.org/stable/27859537>. Accessed 15 Feb. 2024.

⁹⁰ It is theoretically possible to weaponize the thorium-232 fuel cycle in abstract, as emphasized National Nuclear Laboratory, Government of the United Kingdom. “*The Thorium Fuel Cycle. An independent assessment by the UK National Nuclear Laboratory.*” August, 2010. https://www.nnl.co.uk/wp-content/uploads/2019/01/nnl_1314092891_thorium_cycle_position_paper.pdf#p6

However, successfully making a militarily deployable weapon from neptunium-237 or uranium-233 is significantly more difficult. This is due in part to their rare use in tests (where performance was considered sub-optimal), but more because both isotopes have significantly higher radioactive emissions. See: “*Neptunium 237 and Americium: World Inventories and Proliferation Concerns.*” D. Albright and K. Kramer. July 10, 2005. http://isis-online.org/uploads/isis-reports/documents/np_237_and_amerium.pdf#p14

The critical mass required to use either isotope in a device would quickly be lethal to humans, thus requiring high-exclusive use of remote/robotic equipment in most steps of assembly. The heightened radiation would also degrade the sensitive electronics necessary for precise detonation, forcing use of krytron tubes for implosion switches – which in addition to being highly controlled, would preclude miniaturization to warhead-size. In the case of uranium-233 (the superior of the two isotopes), its heightened radioactivity comes from a naturally occurring presence of uranium-232 – a strong gamma emitter. It has been theorized this U232 could be chemically removed, but beyond being an difficult process achievable only by state-level science programs, the level of purity necessary is extremely high. Even a 5PPM presence of uranium-232 within uranium-233 is hazardous. In general, most molten salt reactors carry a uranium-232 presence of ~220PPM.

See: “*The superior design advantages over all other nuclear reactor designs of the LFTR,*” SA LFTR Energy (Pty.) - <https://twugbcn.files.wordpress.com/2010/10/lftr-and-anti-proliferation.pdf>, as well as https://en.wikipedia.org/wiki/Uranium-233#Weapon_material.

In this context, it’s important to note that uranium-235 (standard weapons grade isotope) can be sourced from seawater, presenting a far easier pathway to access than weaponizing the thorium fuel cycle. (<https://www.forbes.com/sites/jamesconca/2016/07/01/uranium-seawater-extraction-makes-nuclear-power-completely-renewable/>). Simply stated: if a state-level entity has the capability to weaponize thorium, they could already have done so with easier methods at greater effect.

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