## Case Cards

Contention 1 is Leadership

We’re losing the nuclear race --- now is key.

Price 25 [Rowen Price, Senior Policy Advisor for Nuclear Energy, 1-31-2025; Trump Has Been a China Hawk on Nuclear Energy. But Congress Could Compromise That During Reconciliation, Third Way; <https://www.thirdway.org/memo/trump-has-been-a-china-hawk-on-nuclear-energy-but-congress-could-compromise-that-during-reconciliation>, Willie T. + AZ]

During the 117th Congress, IRA and the Bipartisan Infrastructure Law (BIL) created tax credits, grants, and loan programs to finance the research, development, demonstration, and even the deployment of emerging clean energy technologies, including nuclear. In a flurry of signals issued during the lame-duck period, the incoming administration and Republican Congressional leadership have made clear that many of these programs are on the chopping block in the first 100 days of the second Trump administration. In competition with state-backed civil nuclear programs such as China, the US needs to bolster its federal government funding for nuclear, not decrease it.

China is churning out large reactors at home, demonstrating (i.e., building and operating) advanced reactor technologies, and marketing advanced reactors cheaply along its “Belt and Road.” To stay relevant in this race for international market share, the US must rapidly finance the demonstration and subsequent commercialization of US nuclear small modular reactors (SMRs) and advanced nuclear reactors. The time is now, in the 2025 reconciliation process, to save this critical sector from opening its global market to China. Why? The decisions the US government makes this year will dictate whether US nuclear developers have the resources they need to keep pace and ground test these technologies. In the interest of national security and to ensure US competitiveness, Congress must robustly appropriate funding for advanced nuclear demonstrations and maintain federal programs critical to the scale-up of these technologies. The following programs are all essential to preserve or expand during budget reconciliation.

Affirming revitalizes US leadership.

Hiltibran 25 [Christel Hiltibran; Director of International Policy @ Third Way, MS in Environmental Science from Johns Hopkins University, BA in Political Science from Loyola University Maryland; 01-31-2025; “Trump Has Been a China Hawk on Nuclear Energy. But Congress Could Compromise That During Reconciliation”; Third Way; <https://www.thirdway.org/memo/trump-has-been-a-china-hawk-on-nuclear-energy-but-congress-could-compromise-that-during-reconciliation>; accessed 3-7-2025] tristan

Beyond bilateral trade barriers, the US must also dominate critical global industries to remain competitive. There is broad consensus that investments in national defense, space, artificial intelligence, and quantum computing will help make America more secure and more prosperous. The same is true of investments in nuclear energy. A robust domestic nuclear supply chain has corollary benefits, including reliable energy supply, that are foundational to our defense and technology sectors. Moreover, the strength of our nuclear industry directly supports our competitiveness abroad, which in turn affects our ability to uphold the highest global norms in nuclear security and nonproliferation. Failure to compete overseas will enable China, Russia, and other rivals to erode our influence on these international standards and cement century-long geostrategic partnerships around the world. Putting the US at the forefront of global civil nuclear markets will make us stronger, more secure, and more influential on the global stage.

Our adversaries understand the stakes. China and Russia have state-owned, heavily subsidized nuclear industries that are a key part of their efforts to gain allies and influence throughout the developing world. China and Russia view nuclear exports as a way to develop century long partnerships in Africa, Asia, and Eastern Europe. Their interest in advanced nuclear power is less about economics, and more about influence. The competition is well underway and the United States is losing. According to the International Atomic Energy Agency, 85% of all new reactors currently under construction in 2024 are Russian or PRC designs; 0% are US designs.

This year, President Trump and the new Republican Congress have an opportunity to do just that—through budget reconciliation.

Trump Could Cede Critical Geopolitical “Energy Dominance” to China in His First 100 Days by Compromising America’s Nuclear Industry—But It’s Not Too Late

Put simply, if we want to outcompete China, Congress needs to continue to prioritize clean energy.

The incoming Trump administration has made no secret of its hostility to the Inflation Reduction Act (IRA) and its clean energy provisions, especially its investments in wind and solar. But despite recent bipartisan alignment in support of nuclear energy, Trump’s agenda not only targets renewables but may also incidentally deal a significant blow to programs supporting nuclear development and demonstration in the US.

During the 117th Congress, IRA and the Bipartisan Infrastructure Law (BIL) created tax credits, grants, and loan programs to finance the research, development, demonstration, and even the deployment of emerging clean energy technologies, including nuclear. In a flurry of signals issued during the lame-duck period, the incoming administration and Republican Congressional leadership have made clear that many of these programs are on the chopping block in the first 100 days of the second Trump administration. In competition with state-backed civil nuclear programs such as China, the US needs to bolster its federal government funding for nuclear, not decrease it.

China is churning out large reactors at home, demonstrating (i.e., building and operating) advanced reactor technologies, and marketing advanced reactors cheaply along its “Belt and Road.” To stay relevant in this race for international market share, the US must rapidly finance the demonstration and subsequent commercialization of US nuclear small modular reactors (SMRs) and advanced nuclear reactors. The time is now, in the 2025 reconciliation process, to save this critical sector from opening its global market to China. Why? The decisions the US government makes this year will dictate whether US nuclear developers have the resources they need to keep pace and ground test these technologies. In the interest of national security and to ensure US competitiveness, Congress must robustly appropriate funding for advanced nuclear demonstrations and maintain federal programs critical to the scale-up of these technologies. The following programs are all essential to preserve or expand during budget reconciliation.

Programs we can’t afford to lose

Existing resources and upcoming reauthorizations can still go a long way toward making US nuclear deployments a reality. Congress must provide robust funding for these programs in FY25 to maintain the US’ competitive advantage.

Federal Program Mechanism Funding Available

Advanced Reactor Demonstration Funding Appropriations for the Advanced Reactor Demonstration Program BIL provided $2.5B; additional funding via annual appropriations is needed to complete the projects.

Loan Programs Office (LPO) Title 17 Programs Established under IRA: 1706: supports energy projects repurposing non-operational infrastructure and upgrading systems 1703: provides loan guarantees for innovative technologies. 1706: Up to $250B in loan guarantees, $5B credit subsidy appropriations. 1703: $40B in loan authority, most of $3.6B appropriations

Inflation Reduction Act 45Y and 48E Tax Credits Established under IRA: The production (45Y) and investment (48E) tax credits for clean electricity are tech neutral---thereby providing immense value for new nuclear projects. 45Y: 1.5 cents per kWh (adjusted for inflation) for facilities which meet prevailing wage and apprenticeship standards. 48E: Valued at 30% for projects which can demonstrate that they meet prevailing wage and apprenticeship standards.

Advanced Reactor Demonstration Funding

What it is: Appropriations for DOE’s Advanced Reactor Demonstration Program. This first-of-its-kind program provides multi-billion-dollar public-private partnerships for some of the US’s leading advanced nuclear power plants.

Why it’s essential: Very few foreign customers will buy American nuclear technology until that technology has been demonstrated at home. BIL provided $2.5B initial award funding for these programs. Since then, the two cost-share grants supported by this program have relied on annual appropriations. As of 2025, neither award has been fully funded yet. The successful and on-time completion of these projects requires robust annual appropriations. As such, the FY2025 Energy and Water Appropriations bills that have passed through the relevant committees contain significant funding for nuclear demonstrations. The Senate bill, drafted by Democratic Appropriations Chair Patty Murray (D-WA), makes up to $800M for nuclear demonstrations, and the House bill, drafted by GOP Chair Chuck Fleischmann (R-TN) contains $9B for nuclear demonstrations (although much of this funding comes from effectively eliminating loan programs that are important for nuclear energy). President Trump and Congress must ensure that the US fully funds both leading US advanced nuclear demonstrations and delivers on the bipartisan investments that lawmakers have made in the program.

Loan Programs Office (LPO) Title 17 Programs

What it is: Title 17 can finance a variety of projects across the nuclear industry, including nuclear reactor supply chain and manufacturing, new SMR and microreactor deployment, new large Gen III+ reactor deployment, and even nuclear fuel cycle projects.

Why it’s essential: Through the Energy Infrastructure Reinvestment Program (known as Section 1706) and Innovative Clean Energy Program (known as Section 1703), LPO can finance almost every type of new nuclear project from innovative greenfield plant builds to energy infrastructure retrofits, such as Holtec’s Palisades Plant restart. Indeed, the most recent new nuclear project in the United States, Units 3 and 4 at Plant Vogtle, were financed with over $12 billion in loan guarantees, awarded in both the Obama and Trump Administrations.

In September of 2024, LPO identified $65B in existing or incoming advanced nuclear project applications to be funded through the program's existing loan authority. This includes a suite of innovative projects, such as the restart of Constellation’s Three Mile Island, which could be one of the first nuclear projects brought online to serve America’s AI boom. Many other advanced nuclear developers, utilities, and data center developers are counting on LPO funding to finance the construction of nuclear projects in the next few years.  In addition to funding, Congress must commit to growing the US nuclear industry by extending LPO’s Title 17 authority lending authority, which is set to expire on September 31st, 2026.

Inflation Reduction Act 45Y and 48E Credits

What it is: Established under the IRA, the production (45Y) and investment (48E) tax credits for clean electricity are tech-neutral–thereby providing immense value for new nuclear projects.

Why it’s essential: These credits provide much needed value for new nuclear projects across the US, making them more attractive to private investors and even providing a financial hedge against inflated first-of-a-kind project costs. The 45Y production credit is 1.5 cents per kWh (adjusted for inflation) for facilities which meet prevailing wage and apprenticeship standards; the 48E investment credit is valued at 30% for projects which can demonstrate that they meet prevailing wage and apprenticeship standards.

Countries prefer US reactors.

Gattie 19 [David Gattie; Associate Professor of Engineering at the University of Georgia’s College of Engineering, Senior Fellow @ UGA’s Center for International Trade and Security; 05-22-2019; “Will the US lead? Or let China and Russia dominate nuclear energy”; The Hill; <https://thehill.com/opinion/energy-environment/444944-will-the-us-lead-or-let-china-and-russia-dominate-nuclear-energy/>; accessed 03-07-2025] tristan + leon

Moreover, with the UK, South Korea, Japan and France having shown signs of political uncertainty in their respective commitments to nuclear power, the global nuclear ecosystem is potentially vulnerable to domination by a country pursuing a role of top predator.

Meanwhile, the world is seeking U.S., Allied leadership in nuclear power — a clarion call that must be heard. At a minimum, there must be a viable non-authoritarian nuclear partner alternative committed to the rule of law, individual liberty, cooperative security, multilateral alliances and fair trade. However, while other countries waver, two countries show no signs of retreating from an aggressive nuclear power future — China and Russia. In fact, they are doubling down.

Agreements aren’t locked in yet.

Szulecki 23 [Kacper Szulecki; Research Professor in International Climate Governance @ NUPI, Professor @ the University of Oslo, Fellow @ the Centre for Socially Inclusive Energy Transitions; 02-27-2023; “Russian nuclear energy diplomacy and its implications for energy security in the context of the war in Ukraine”; Nature; <https://www.nature.com/articles/s41560-023-01228-5>; accessed 03-07-2025] tristan

While this is impressive, looking into the details of these agreements (particularly the NPP construction projects) reveals a more modest level of international engagement. Many of the projects have been stuck at the planning stage for several years or are merely visions laid out in non-committal MoUs. Competing offers might ultimately be chosen over those from Rosatom. For instance, the expansion of the Dukovany NPP in Czechia saw calls from opposition parties and the Czech secret service to exclude both Chinese and Russian companies from the tender, citing security concerns37, and Rosatom was explicitly excluded in 2021 following news of Russian intelligence involvement in a 2014 explosion at a Czech ammunition depot38. This happened despite Czechia’s relatively positive attitude towards Rosatom39 and the faith of the policymakers in nuclear energy as a foundation for energy security40,41. The Russian invasion of Ukraine triggered further cancellation of planned Russian-built nuclear power plants in Finland, Jordan and Slovakia.

Leadership determines hegemony.

Rodriguez 22 [Eric Rodriguez; Master's student in public administration; August 2022; "The Eastern Atomic Rise: Defining Nuclear Hegemony in a Multilateral World"; SIT Digital Collections; <https://digitalcollections.sit.edu/cgi/viewcontent.cgi?article=4303&context=capstones>; accessed 03-31-2025] colon + leon

This review of the existing literature has established that the academic framework to evaluate and study the utility of nuclear energy as a diplomatic and hegemonic tool does not exist. The geopolitical landscape continues to shift, most notably with the emergence of the BRICS (Brazil, Russia, India, China, South Africa) organization, which is challenging western hegemony. The hegemonic dynamic of nuclear power is also evolving as Russia (Geller, 2022) and China emerge as global leaders in nuclear energy development and exports. (Wang & Lee, 2022) To maintain global stability and security, compatible academic and policy tools must also be developed

Existing narratives born out of Cold War realism continue to frame the discourse in a profoundly different world order. Bin, for example, notes the alarmist view of nuclear weapons confrontation that frames much of the current discourse on U.S.-China nuclear relations. Ritchie notes a global nuclear “ordering anxiety” arising from the intersectionality of the mixed success of arms control initiatives and perceived renewed nuclear threats driven by the eroding “liberal international order”.

As long as realist Cold War and alarmist narratives continue to define the discourse on nuclear technology, leaders and academics, particularly in the west, will continue to look in the wrong direction by focusing on weapons when they should also be paying attention to Russia and China’s gains in nuclear energy. This has profound implications for foreign policy and the shaping of the emerging world order.

RESEARCH DESIGN AND METHODOLOGY

The over-arching phenomenon to be studied is the nuclear dimension of energy geopolitics. The hegemonic nature of nuclear power has changed over time with the simultaneous diminishing of Western dominance and the growing influence of the Global South. Therefore, Grounded Theory, which, according to Merriiam & Tisdell (2015), addresses “questions about process; that is, how something changes over time”, is the appropriate analytical framework for the study.

As Russia and China exercise hegemony through cooperation within the BRICS organization and in greater South-South relations, Cox’s Political-Economic Hegemony Theory is the most appropriate theoretical foundation upon which to base research for this paper. Since Russia and China’s emergence as nuclear energy hegemons within a governance context are relatively unstudied and overlooked, Critical Theory, which Bronner (2011) argues, “must respond to the new problems and the new possibilities for liberation that arise from changing historical circumstance”, is the appropriate framework under which to conduct research. At the same time, Grounded Theory, which Saldaña (2011) describes as “an analytic process of constantly comparing small data units” (in this case, case studies of Russian, Chinese, and American nuclear energy strategies), is the logical foundation for comparative analysis and is a practical approach to employ in building a definition of Nuclear Hegemony.

The primary methodology employed in this study consists of collecting and analyzing case studies under the Canonical Genre of qualitative research. (Marshall et al., 2021) Most contemporary literature about the philosophical and theoretical concepts of hegemony is oriented around Gramsci’s writings on power dynamics characterized by the transactions of socio-political groups as models to counter fascism, which modern scholars such as Hayes and Cox adapted and framed within geopolitical discourse. Considering that Gramsci was interested in alternate systems of governance (which is particularly relevant with the emergence of BRICS and other “counter-hegemonic” actors), his work and those of his modern counterparts are a logical foundation upon which to develop an appropriate concept of hegemony for the first phase of research for this paper.

The second phase consisted of case studies of Russian, Chinese, and American foreign policy and nuclear programs, encompassing analyses of government publications (where available) from all three states, as well as research and commentaries by western, Asian, and Eurasian academic institutions, think tanks, and media, who identified both the mechanisms by which these actors penetrated foreign nuclear markets, how their presence and capacity can and do affect how their client states behave, and to project how they may exercise their political, economic, and scientific advantages on the geopolitical stage.

During the third and final phase, the definition of Nuclear Hegemony is developed using Critical Genre approaches (Marshall et al.,) such as Critical Ethnography and Critical Discourse, based on Hayes’ Political-Economic Hegemony Theory. The hegemonic tools identified in the case studies were incorporated into traditional perceptions of hegemony and framed within international relations theories of Realism, Liberalism, and Constructivism.

DISCUSSION

Hegemony Conceived

We will proceed with a working conceptual idea of hegemony based on Hegemonic Stability Theory (Gilpin, Keohane), which attempts to explain how more endowed states leverage their political and economic advantage to influence the behavior of less endowed states. In simple terms, according to Joseph (2003), hegemony concerns the relationship between a dominant group’s leadership and a subordinate group’s consent.

Cox’s analysis of hegemony traces its modern origins to the work of Antonino Gramsci, former leader of the Italian Communist Party. While imprisoned in Italy, Gramsci wrote a series of papers that focused on defeating fascism and envisioned alternative models of the social fiber of the state based on Marxist concepts of an emergent working class that could exercise power in the state.

Contemporary scholars have struggled to define hegemony concretely. Ougaard (1988), for example, attempts to define hegemony first within the context of resource distribution in which hegemony represents “a preponderance of material power resources”, and second within the context of a state pursuing its own interests within an environment of conflict. Clingan (2013) attempts to define hegemony through economic indicators, suggesting, for example, that a state has achieved hegemony when its economy is larger than the next three combined. However, he notes that a definitive determination is a challenge because conventional measures such as GDP, GDP per capita, and output per worked hour, to name a few, yield different results. He also cites geography and distance as a limit on hegemony, noting that the ability to exert power diminishes proportionately with distance from power centers and resources.

Other scholars, such as Cox, focus on conditions conducive to achieving hegemonic capacity. He suggests that a prerequisite feature of a hegemon is the foundation and protection of a world order that originated with a social or economic revolution in the hegemonic state that then spilled over to other states. Consistent with Wallerstein’s Worldsystems theory, in which socially, politically, and economically advanced “core” states exert influence on less developed “semi-peripheral” and “peripheral” states, (Agnew, 2020) we can witness this phenomenon during the mid-nineteenth century British hegemonic expansion, the United States’ global position post World War II, and more recently during we are seeing the economic and political influence of the BRICS organization spreading to other states in the Global South. (Teslova, 2022)

Beyond these sources, there are few identifiable definitive factors that can be used to evaluate a state’s hegemonic status. Scholars of nuclear governance should not be discouraged by this but should instead see this as an opportunity to break new ground in this re-emerging field of study. Central to defining Nuclear Hegemony is the acknowledgment of the hegemon’s capacity to make the rules by which other players abide through “the elaboration of political projects, the articulation of interests, the construction of social alliances, the development of historical blocs, the deployment of state strategies and the initiating of passive revolutions.” (Joseph)

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International Relations Theory: Realism, Liberalism, and Constructivism¶ The three key international relations theories of Realism, Liberalism, and Constructivism seek to explain why and how sovereign states, who control all social, economic, and political activity within their borders, pursue their own interests and selfpreservation absent accountability to a prevailing institution (Mearsheimer, 1994) in a “competitive, often ruthless, Hobbesian domain” known as anarchy. (Gilpin, 2012; Glaser, 2019) Thomson (1995) defines sovereignty as the” recognition by internal and external actors that the state has the exclusive authority to intervene coercively in activities within its territory”.¶ Norwich University (n.d.) characterizes Realism as an environment in which a state acts to maximize its social, economic, and political power and influence in the interest of self-preservation. According to Donnelly (2014), “Realism emphasizes the constraints on politics imposed by human nature and the absence of international government. Together, they make international relations largely a realm of power and interests.”¶ Because states will almost always act in their own self-interest, (Gilpin, 2007) the state’s behavior is manifest through power. (Morgenthau & Thompson, 2018) Any action, including military action, is therefore justified in the interest of self-preservation(Schwarzenberger, 1964) as articulated by Schurmann’s Political-Military Hegemony theory, which is based on “direct political and military rule by one state over many aspects of the internal and important aspects of the external policies of other states” and is inherently coercive.¶ As one state acquires power, it diminishes other states’ relative power and influence. From a realist geopolitical perspective, hegemony can therefore be conceived as a global power system in which a state can exercise its economic and military dominance to “regularly get its way.” (Clingan) The subsequent system of winners and losers creates a perpetual state of competition for power and influence (Waltz, 2010), which inevitably leads to conflict.¶ Liberalism is defined by “an emphasis on international cooperation as a means of furthering each nation’s respective interests.” (Norwich University) The common market function of the European Union is an excellent articulation of liberal thought in which a capitalist, liberalized, integrated open market functions as the optimal mechanism to produce goods and services and ensure happiness and prosperity (Fukuyama, 1989) for its member states. It also creates a system of interdependence, in which states’ collective wellbeing depends on their ability to cooperate. (Paul, 2012) Interdependency, in theory, minimizes the likelihood of armed conflict, but it also requires states to relinquish their sovereignty, in certain policy areas, to a supranational authority. Liberal theory, therefore, aligns with Cox, Fenton’s (2018), and Mollakkattu’s (2009) concept of hegemonic power as based on the compatibility of interests between the hegemon and consenting states who willingly accept and (sometimes) actively participate in the supranational authority of the hegemon.¶ Constructivism “rests on the notion that rather than the outright pursuit of material interests, it is a nation’s belief systems—historical, cultural and social —that explain its foreign policy efforts and behavior”. (Norwich University) States are not the most important actors in international relations because international institutions and other non-state actors are valuable in influencing behavior through lobbying and acts of persuasion. (Norwich University) It could be argued that the emergence of the BRICS organization to challenge western hegemony and reshape western-dominated global institutions represents a nascent constructivist hegemonic order.¶ While a firm understanding of these IR theories is crucial to building a definition of Nuclear Hegemony, it is critically important to recognize that hegemony within a nuclear context is evolving and therefore contains elements of some or all three theories, which are often contradictory. Saull (2017), for example, balances liberal and realist approaches, describing hegemony as “international leadership by one political subject, be it the state or a “historical bloc” of particular social groupings(…)of other, weaker, less powerful parties.”¶ Alternately, while Hayes notes that nuclear geopolitics are “nuclear bloc” politics versus “balance-of-power” politics, suggesting that he views nuclear politics through a liberal lens versus a strict realist approach, Cox notes the applicability of Gramsci’s concept of hegemony to global governance because of the interplay of power groups and “alternate states” which is particularly relevant with the emergence of BRICS and other constructivist organizations.¶ Before we add the layer of nuclear technology to our analysis, two final points need to be made about hegemony and international relations: 1. While Realism and liberalism appear to be the dominant IR theories that arise when analyzing hegemony, it is important to remember that while these conventional concepts have shaped academic thought on the subject, we are venturing into a new political arena with newly emergent players and new concepts of world orders that are challenging these concepts. Therefore, we must be vigilantly mindful of the role that Constructivism and constructivist institutions can play in shaping contemporary concepts of hegemony; 2. That notwithstanding, it is equally important to be mindful that despite the cooperative and consensual verbiage of nuclear agreements, Cox warns us that when analyzing hegemony, coercion is always implied.¶ Perspectives on Nuclear Energy¶ Nuclear technology remains controversial in many parts of the world, particularly in the west. Many western countries have voiced strong opposition to nuclear energy, ranging from safety and security concerns to costs. Critics of nuclear energy, for example, warn of the potentially disastrous effects of reactor failure. The Union of Concerned Scientists (2013) list seven accidents associated with nuclear energy, including the melting of the Windscale 1 core in Cumbria, UK, in 1957 and the accidents at Three Mile Island in the United States, Chornobyl, Ukraine (former Soviet Union) in 1986, and most recently the Fukushima Daiichi reactor in Japan in 2011. The human casualties and environmental, structural, and capital damage that render affected areas indefinitely uninhabitable are sufficient reasons for many to oppose nuclear energy. Some critics, such as Muellner et al., (2021) also argue that nuclear power’s contribution to mitigating climate change will be minimal (although their argument comes from a “main source of future electricity generation” rather than its efficacy as part of a greater diversified production strategy).¶ In addition to the environmental, structural, and capital damage caused by reactor failures, the safe transportation and storage of radioactive nuclear waste, (Gardoni & Murphy, 2015; Jacoby, 2020; Saraç-Lesavre et al., 2021; Siegel, 2020) the weaponization of uranium, which is the main fuel that is enriched and used to power nuclear reactors, (World Nuclear Association, n. d.) and concerns of nuclear war between both major nuclear states and actors outside the nuclear regime such as North Korea, (Grove, 2022; Pazzanese, 2022) make nuclear technology unacceptable for many.¶ Finally, opponents argue that the upfront capital cost and build time of nuclear reactors make them economically unsound, particularly as the cost of renewable production continues to fall and with the (until recently) relatively low cost of natural gas. (Dunai & Clercq, 2019; Ferguson, 2011; Lovins, 2021)¶ Proponents of nuclear energy argue that it plays a unique role in energy security by providing carbon-free, reliable, cost-effective energy. Meserve (2009) argues that nuclear power is an attractive energy source, not only in combatting climate change but in providing energy reliably and relatively cheap. Hassan et al. (2020) point out that nuclear energy can 16 contribute significantly to “ensuring energy security” while also reducing carbon pollution in developing nations and economies, such as the BRICS countries, where reliable, carbon-free energy is crucial.¶ In terms of safety, proponents argue that enhanced safety standards implemented since the Fukushima accident will ensure the continued safe operations of nuclear reactors. According to the World Nuclear Association (2022b), these standards have been effective since there have been no further accidents since their implementation. They also argue that current facilities for the transportation and storage of nuclear waste are sufficient. (Nuclear Regulatory Commission, 2021) Finally, proponents argue that the weaponization of uranium is unlikely because few non-nuclear states or non-state actors have the facilities to enrich uranium, which is usually enriched to between 3 and 5% for power production, (Center for Arms Control and Non-Proliferation, n.d.) to weapons-grade at 90%. (World Nuclear Association, 2017)¶ Despite the substantial capital costs of conventional Nuclear Power Plants (NPPs), which critics argue are unwarranted compared to the lower costs of renewable energy and natural gas, institutions such as the World Nuclear Association (2021b), the Nuclear Energy Association (2021), and scholars such as Rhodes (2018), Swanek (2018), and Ulmer-Scholle (2022) argue that nuclear energy has an overall lower cost long-term.¶ With new technology on the horizon in the form of, among other promising technological developments, Small Modular Reactors (SMRs), nuclear energy has the potential flexibility and adaptability to be a significant “resource in humanity’s arsenal in the fight against climate change” (Siegel) reliably and more cost-effectively. SMRs, according to Budinger & Bauman, will mitigate many safety concerns raised by nuclear opponents because they do not need water or giant cooling towers. They can operate with minimal manpower, thus mitigating the lack of technical capacity in many developing countries. The 17 design is inherently safe and includes automatic shutdown mechanisms in the event of an overheat (Cho, 2019; Parshley, 2021). Because of their small design, SMRs can also be constructed onsite, reproduced, transported, and deployed more quickly, efficiently, and at a lower cost than conventional large-scale reactors. (Fitzpatrick, 2017; Iurshina et al., 2019)¶ The International Atomic Energy Agency: A Nuclear Hegemon?¶ As Cox notes, international organizations, such as the United Nations, and the Bretton Woods institutions, such as the World Bank and International Monetary Fund (IMF), are mechanisms “through which the universal norms of a world hegemony are expressed.” He notes five attributes of international organizations that “express their hegemonic role:¶ (1) They embody the rules which facilitate the expansion of hegemonic world order;¶ (2) they are themselves the product of the hegemonic world order; (3) they ideologically legitimate the norms of the world order; (4) they co-opt the elites from peripheral countries and (5) they absorb counter-hegemonic ideas.”¶ The International Atomic Energy Agency (IAEA) is an autonomous international organization within the United Nations (IAEA, 2016). Within the U.N. system, it works with over 12 U.N. agencies, including close coordination with the U.N. Security Council and the European Commission within the European Union. It officially came into being on 29 July, 1957 with President Dwight Eisenhower’s ratification of the U.S. Statute. (IAEA). According to the Statute (2014), its objectives are to “accelerate and enlarge” the capacity of nuclear energy to promote peace and prosperity worldwide, contribute to improvements in health and medicine, and ensure that it is not used for military purposes. It also aims to enable “countries that were not among the advanced nuclear powers to take advantage of the nuclear age for a variety of uses and ensuring that nuclear facilities were not diverted from civil to military uses.” (de Blasio & Nephew)¶ As an actor, The IAEA procures over one hundred million dollars annually in goods and services, most of which are delivered to member states worldwide. The list of services 18 includes construction services and upgrades for nuclear facilities, disposal of nuclear waste, supplies, and equipment related to nuclear technology, raw materials for production, and goods and services related to safety and security. It serves a crucial role as the international safeguards inspectorate, which verifies compliance by non-nuclear weapon states with international rules under the NPT. As a resource, the IAEA’s initiatives and programs, as well as research and publications, are utilized by member states to pursue their interests, which range from energy production to medicine, health and food production, and ultimately to weapons policy.¶ Brown (2015) argues that the IAEA has established itself as an international nuclear authority and is “an autonomous agent of global governance”, having managed to gain considerable compliance and cooperation from the international community on its rules and services implemented. It has also established legitimacy by utilizing a strong policy bias relative to other international organizations.¶ The IAEA wields authority through two sources of independent power in international governance which Barkin (2013) identifies as moral authority and political entrepreneurship. Moral authority, he maintains, can be manifest in two areas. The first area is the legitimacy of the IAEA to act as an “official voice” and to command the global community’s attention on nuclear technology issues. Secondly, as Brown notes, favorable assets such as the ability to leverage economies of scale in its projects and its perceived apolitical nature both also give weight to its moral authority, which can compel states to comply or consent in certain policy areas.¶ Political entrepreneurship, according to Barkin, is a process by which specific political positions are advanced through governance mechanisms. Thus, the IAEA is able to wield power by focusing international attention on issues that they deem important, as Secretary-General Mohamed El Baradei did through his initiative to prevent the militarization 19 of nuclear energy and ensure safety in peaceful applications (United Nations, 2005) for which he and the IAEA were awarded the 2005 Nobel Peace Prize.¶ Considering that the IAEA is funded mainly by Member State contributions as well as some voluntary contributions, its activities logically reflect the interests of its biggest contributors. Findlay (2012) maintains that international organizations’ budgets are “determined by a combination of politics, history, organizational inertia, competing priorities, and the health of member states’ finances.” Therefore, despite its moral authority, legitimized by its role in the NPT and Nobel prize, the IAEA is nonetheless asymmetrically dependent on funding from member states and represents the western global order that many non-aligned nations are now challenging.¶ Recalling Cox’s five hegemonic attributes of international organizations, it can be argued that the IAEA does embody rules that facilitate the expansion of the hegemonic world order. However, its activities are limited mainly to safety and security and therefore do not play a significant role in influencing states’ behavior in geopolitics. While it is a product of the hegemonic world order and legitimates its norms, those norms are still defined by western values that are informed in a decidedly unidirectional manner. By perpetuating what can be perceived as western values, it could be argued that the IAEA continues to promote western hegemonic ideas versus absorbing counter-hegemonic ideas. Based on Cox’s criteria and the IAEA’s limited capacity to influence and inform the geopolitical behavior of states beyond areas of nuclear safety and security, not to mention the internal challenges it faces to function properly in even this capacity, this work concludes that it is not a hegemon.¶ Russia: The World's One-stop Nuclear Shop¶ Over the last two decades, Russia has become the world's go-to supplier of nuclear technology, especially for countries new to the civilian nuclear market. She is deeply experienced in constructing and maintaining nuclear plants, has considerable industrial and scientific capacity, as well as market share of the global uranium supply, and has the capacity 20 to reclaim spent nuclear fuel from client states. By positioning itself as a one-stop-shop for reactors, fuel supply and reclamation, financing, and worker training, (Lovering & Halland, 2022) Russia embodies the Dependency dimension of Nuclear Hegemony.¶ Russia's rise as a nuclear energy player started in 2006 with the Kremlin's $55-billion plan to become a "leading global supplier of nuclear power". (Conant, 2013) By 2014 Russia had built 37 percent of all new nuclear reactors, compared to the US's 7 percent. (Lecavalier, 2015) Of the 439 nuclear reactors currently operating globally, 38 generate electricity in Russia. Additionally, 42 Russian-designed VVER reactors operate in Armenia, Bulgaria, Czech Republic, Finland, Hungary, India, Slovakia, and Ukraine, and an additional fifteen were under construction in Bangladesh, Belarus, China, Finland, Hungary, India, Iran, Slovakia, and Turkey as of 2021. (Bowen & Dabbar, 2022a) She has signed bilateral nuclear cooperation agreements with a total of 47 countries and has nuclear energy footprints in Africa, Asia, the Middle East, and South America. (Lovering & Halland, 2022)¶ According to the IAEA, (2021) Russia enjoys competitive strength in nuclear energy through its technological capacity, which includes intellectual property, manufacturing infrastructure, and workforce. Through its state-owned atomic energy corporation, Rosatom, Russia is able to "oversee and work at all stages of the nuclear fuel cycle and production chain, from uranium mining to decommissioning of nuclear facilities or management of spent nuclear fuel", which enables it to construct and operate nuclear reactors safely and economically. This makes it an attractive partner for energy-hungry states, especially developing states with limited capacity and financial resources.¶ She is also able to exercise considerable power in the nuclear Supply Chain through the considerable market share capture (Sallee, 2021) of many of the components of energy production. Through Rosatom, Russia controls key facilities in the mining, milling, conversion, and enrichment of uranium, as well as fuel fabrication and the manufacture and 21 distribution of "equipment, parts, and services for nuclear reactors." (Bowen & Dabbar, 2022b) According to Lovering & Halland, (2022) Russia controls nearly half of the global uranium enrichment capacity. Together with Kazakhstan and Uzbekistan, they supply half of the U.S.'s nuclear power imports and nearly 40 percent of Europe's.¶ Currently, Rosatom is the only nuclear supplier that can reclaim spent nuclear fuel from foreign clients to temporarily store and reprocess. (Kim, 2021; Schepers, 2019) Considering that most developing states and emerging economies lack the capacity to safely manage nuclear waste (which can potentially be weaponized) and considering that proper storage and management continue to challenge even developed states, the reclamation of spent fuel makes Russia not only an attractive supplier for "nuclear newcomer states", (Kerr, n.d.) but also offers a strong counter-narrative against criticism of her lax safety standards (Stulberg et al., 2021) and provides safeguard mechanism nuclear waste.¶ Since Rosatom is a state-owned enterprise (SOE), Russia can easily penetrate the nuclear export market by offering client states government subsidized loans with favorable terms that the U.S. cannot match. (Hayunga, 2020) Like China, this gives the Russian government direct and complete control over not only the construction of nuclear equipment and supply chains but also financing. This gives both countries a competitive advantage over the U.S., whose Export-Import Bank (EXIM) lending schemes are regulated by the Organization for Economic Cooperation and Development's (OECD) Arrangement on Officially Supported Export Credits which severely limited the financing of its nuclear exports until recently. (Nakano)¶ Ultimately, this means that Russia can establish a nuclear foothold in many client states efficiently and cheaply. In addition to financing 90% of the Rooppur Nuclear Power Plant in Bangladesh, and nearly 50% of the El Daaba reactor in Egypt (Schneider et al., 2018), Rosatom also offered to fund 100% of a nuclear project in Hungary, though Hungary 22 ultimately accepted a lesser amount. (Saha, 2017). Most Russian NPPs are built under EPC (Engineering, Procurement, and Construction) or "turnkey" contracts, (Lieu, 2020) where Rosatom designs and builds the reactors and then hands them over to the client state's utility company. (Schepers, 2019) However, the Akkuyu reactor in Turkey, which is currently under construction, was contracted under a "Build-Own-Operate" (BOO) agreement, where Rosatom will finance and retain ownership of the estimated $22 billion project (Schneider et al.) and sell electricity back to Turkey (Sallee, 2021) While the financial efficacy of the BOO remains to be seen, Russia's energy strategy is proving to be a reliable source of income. As Schepers notes, from Rosatom's 2017 "Performance of State Atomic Energy Corporation" report, more than one-third of Rosatom's international revenue came from NPP constriction.

<<LINE BREAKS CONTINUE>>

By establishing itself as a one-stop shop for nuclear energy production that includes "flexible financing options, training opportunities, and support with developing nuclear infrastructures related to safety, security, non-proliferation and export control requirements", (Schepers, 2019) Russia has ensured that its clients will remain dependent for all aspects of production and for a long time, considering the length of nuclear projects. It also ensures a steady income stream with the potential for parallel long-term partnerships in other areas of cooperation with its client states. It is, therefore, positioned to leverage its control of the supply chain to exert influence over its clients in the greater geopolitical environment over a long period of time. Given current events, this is concerning. As Russia controls a substantial supply of the world's natural gas, which it has been accused of politicizing and weaponizing. (Eddy & Stevis-Gridneff, 2022; Sabadus, 2022) the implication that it could employ a similar strategy with nuclear power is obvious. By controlling 40% of the global uranium conversion market and 46% of global uranium enrichment capacity, (Bowen & Dabbar; 2022b) Russia could easily disrupt the energy supply of any country dependent on it. This potential threat is not limited to prospective client states, as evident by the fact that despite its activities in Ukraine, Russia's uranium exports have yet to be sanctioned. (Arai & Hanawa, 2022; Freebairn, 2022; Hunnicutt & Scheyder, 2022; Wesolowsky, 2022)

Consequently, it can be concluded that Russia is exercising its Nuclear Hegemony by virtue of establishing a firm system of dependency through which it can exercise power over other states. While the cooperative nature of its bilateral agreements implies power by consent, the coercive, realist potential is nonetheless apparent.

China: Financing the Global Nuclear Belt

China's geopolitical nuclear power strategy is best conceived as a component of her Belt and Road Initiative (Ramana, 2022; Yi, 2018), which is branded as "a transcontinental long-term policy and investment program which aims at infrastructure development and acceleration of the economic integration of countries along the route of the historic Silk Road" (BRI, n.d.) that is intended to connect Asia, Europe, and Africa (Chatzky & McBride, 2020)

The BRI is a two-pronged initiative consisting of a land corridor, known as the Silk Road Economic Belt (SREB), and a sea corridor, known as the Maritime Silk Road (MRS), that will connect China with Europe and strategic sites in Africa through infrastructure projects related to energy, commerce, and transportation. (Kim, 2021) So far, 143 countries have agreed to participate in the BRI with about $8 trillion of announced investments. (Sandalow, 2019) When completed, the BRI will span over 70 countries, representing 60% of the global population and nearly 30% of the global GDP. (Sarwar, 2018)

The SREB has three main routes through Eurasia: the northern route from China to Northern Europe via the Eurasia land bridge through Russia to Germany; the middle route consisting of oil and gas pipelines running from Beijing to Paris via Afghanistan and Kazakhstan; and the southern route consisting of transnational highways running from Beijing through Southern Xinjiang, Pakistan, Iran, Iraq, Turkey, Italy, through to Spain. (Sarwar) The MRS meanwhile aims to establish a seabound network by developing, constructing, expanding, and operating ports, industrial parks, and special economic zones (SEZs) throughout the South China Sea and the Indian Ocean. (Ghiasy et al.,2018)

Sarwar argues that, unlike the original Silk Road, which facilitated trade and cultural exchanges between the east and west, the BRI is not only "an overt expression of China's power ambitions in the 21st century” but is also a geopolitical tool for China to counter the U.S.'s geopolitical pivot to Asia, and function as a foundation of a new global economy centered around China. Ayres, (2017) and Hillman & Sacks, (2021) and Zhang (2018) likewise caution about the political and economic threats that the BRI represents, not only to the west but also to BRI host countries.

Other scholars, such as Jin, (2017) suggest that China, BRI host countries, and even peripheral countries will benefit from the improved political and diplomatic relations that will be facilitated by the enhanced infrastructure connectivity, deepening economic cooperation, and person-to-person interactions facilitated by the BRI.

Kim (2021) conducted extensive research for the Wilson Center on the nuclear energy aspect of the BRI, which she notes is "important and understudied." China's global nuclear strategy, which aims at global dominance in high-tech sectors, was articulated in its 10-year "Made in China 2025" industrial policy in 2015. Through the BRI, she aims to build up to 30 overseas nuclear reactors by 2030, having (Reuters, 2019b) already built four nuclear reactors in Pakistan, with the goal to build 2 more. (Parameswaran, 2015; Tabeta, 2020) She is also in various stages of development of nuclear energy programs in Romania, Argentina, Brazil, the UK, Iran, Turkey, South Africa, Kenya, Egypt, Sudan, Armenia, The Philippines, Kazakhstan, and Saudi Arabia. (Rogers & Crow‐Miller, 2017; WNA, 2022b)

China's domestic nuclear market has grown substantially over the last three decades. Driven by increasingly poor air quality from coal-fired power plants in the 1970s, Beijing began to develop alternative energy sources. (Fairley, 2018; WNA) Therefore, Beijing began to invest heavily in domestic nuclear energy production.

Currently, China develops, constructs, and operates nuclear reactors through its three state-owned nuclear agencies: the Chinese National Nuclear Corporation (CNNC), the China General Nuclear Power Group (CGN), and the State Power Investment Corporation (SPIC) (WNA).

China's substantial investment in its nuclear industry (Baker et al., 2017) has enabled it to develop an array of domestically produced reactor models, such as the Hualong One (whose design is based on western technology) and is protected by intellectual property rights. (Reuters, 2019a) The first exported Hualong One reactor began construction in Pakistan in 2015 and commenced operation in May 2021. It is expected that China will ultimately construct a total of six nuclear reactors in that country. (ANS, 2021) According to Sallee, this homegrown reactor will give China access to new revenue streams and facilitate the building of stronger partnerships abroad. It is also representative of "China breaking the monopoly of foreign nuclear power technology and officially entering the technology's first batch of advanced countries."

Like Russia, China is able to penetrate the foreign nuclear market by offering generous and flexible financial terms, such as low-interest and concessionary loans with long grace periods (Chatzky & McBride; Mehta, 2020) to client states for whom nuclear reactors would otherwise be unaffordable. (American Security Project, 2019; Bastian, J.; 2021; Chatzky & McBride; Kim) Since these contracts often lack transparency, (Bastian, Gupta, and Hurley et al.) client states are likely not fully aware of what they are committing to.

According to Bing-Ming (2021), these financial arrangements, and the length of time of nuclear projects equate to a "marriage [that] is not easily dissolved." He goes on to explain that if a client state enters into a nuclear agreement with China and then decides to suspend the project in the pre-construction phase, it is liable for sizeable damages to China for breach of contract. Once reactor construction has begun, Bing-Ming continues, "the marriage is truly ironclad." This is because China, like Russia, has developed a supply chain that includes partnerships for uranium imports with BRI partners Namibia and Kazakhstan (WNA, 2021a), as well as control of equipment, technology, workforce, and waste disposal supplies and facilities by her state-owned nuclear utilities, rendering the client state dependent over a long time.

Some critics claim that China's financial strategies harm client states, leaving them vulnerable and dependent on China. (Ayres, 2017; Brattberg & Soula, 2018; Chatzky & McBride, 2020; Hurley et al., 2021) Others, such as Gupta (2020) and Mehta, suggest that they are a deliberate tactic to lure states into "debt traps" through which China can secure a long-term foothold in other countries and acquire control of their resources and strategic locations.

In any case, the debt crises in many of China's client states are causing concern. The situation is particularly dire in Africa, where China is the top lender. (Chaudhury, 2021) Despite denial by the Kenyan government, concern remains that Kenya could lose its port in Mombasa to China over its struggles to repay its $50 billion debt. (Chaudhury, 2019) Angola is likewise having to repay its debt in crude oil, (Pandey, 2018) leaving little for the country. Elsewhere, Tajikstan reportedly ceded 1,100 kilometers of disputed territory to China in exchange for debt forgiveness for an unspecified amount. (Gupta, 2020) China also assumed an 85% stake in the Hambantota Port in Sri Lanka under a 99-year concession for the $1.1 billion package for the construction of the port.

From a hegemonic standpoint, we could consider China's nuclear strategy as a synthesis of the liberal and constructivist approaches. Its nuclear programs consist of bilateral agreements based on consent that have the dual potential to fulfill client states' energy needs while affording China access to resources it needs to manage its domestic challenges. China is also incorporating new ideas and approaches by partnering with client states outside the traditional nuclear regime while embarking on one of the most ambitious infrastructure programs in history.

Throughout this analysis, we must heed our contemporaries' warning that in any hegemonic relationship, coercion is always implied. China is in various stages of nuclear cooperation with the Philippines, Thailand, Singapore, Cambodia, Sri Lanka, Sudan, Kenya, and Namibia, (WNA, 2022f) who are all participating in the BRI. (FSIF, 2021) Suppose we frame China's nuclear export strategy within the context of the BRI. In that case, it is easy to envision a coastal nuclear maritime route from China through the highly contested Malacca Strait (Greco, 2022) around the Indian Ocean and back.

Therefore, it could be argued that China is building hegemony in nuclear energy by establishing a supply chain that includes fuel, technological know-how, hardware, manpower, and disposal, similar to Russia. Driven by the aspirations of the BRI, it has been able to expand its hegemonic footprint by offering innovative and relatively affordable reactors with appealing financing terms that, while offering its client states cheap, reliable, and low-carbon energy could also render them not only dependent but also obligated for nearly a century if they default. Therefore, the latent coercive implications of hegemony are always there.

Hegemonic decline triggers adventurism and great power war.

Ero 25 [Comfort Ero; President and CEO of the International Crisis Group; Richard Atwood; Vice president of the International Crisis Group; 01-01-2025; "10 Conflicts to Watch in 2025"; Foreign Policy; <https://foreignpolicy.com/2025/01/01/conflicts-2025-syria-sudan-gaza-ukraine-iran-haiti-mexico-myanmar-korea-china/>; accessed 04-01-2025, leon + Willie T.]

Generalizing about what drives the turmoil is hard, given each conflict’s distinct roots.  China and Russia—and to some degree, North Korea—are challenging orders that were underpinned for decades by U.S. power in Asia and Europe. Elsewhere, absent a hegemon or concert of big powers acting in unity, more leaders sense constraints crumbling. More see opportunities to pursue ends by violent means or fear losing out if they hold back.

Most governments, of course, do not seek to crush rivals at home or sponsor proxies abroad, let alone annex neighbors or kill civilians en masse. But more are taking things into their own hands. Increasingly, the main check on their actions is how much fight their foes can put up.

If adventurism is on the rise, its knock-on effects—how rivals sensing the same loosened fetters might react—are harder to foresee. Interlinked conflicts make unintended consequences likelier. Yahya Sinwar, the Hamas leader who masterminded the Oct. 7 assault, surely underestimated the ruin that a largely unrestrained Israel would wreak on Gaza in response.

Even Israel, for all its spycraft, did not predict that its hammering of Hezbollah in Lebanon would help a reformed al Qaeda offshoot seize Damascus. (Syria’s new ruler, despite his jihadi past, says he’s not looking for a fight with Israel.)

Trump’s return brings fresh uncertainty. In Europe, the Asia-Pacific, and the Middle East, Trump’s promises are often contradictory, as are the views of his cabinet picks and loyalists. If he doubles down on confrontation, how much risk will he tolerate? If he seeks deals, what trade-offs might they entail, and what might the implications be for U.S. allies? Outside those arenas, if Washington is largely absent, how will others fill the space?

Trump’s admirers see virtue in impetuousness. Keeping rivals and allies on their toes can deter the former and extract concessions from the latter. Putin, they say, was shyer of acting up with Trump in office, and Trump’s ambiguity about NATO has shaken Europeans out of their complacency about the continent’s security just as much as the Kremlin’s aggression has.

But unpredictability could just as easily backfire. While no one wants all-out war, miscalculation is as much a risk along major-power fault lines as elsewhere. If Trump or top officials get too hawkish, a rival could respond in kind, aiming to reset a red line but crossing one of Washington’s own. Or a U.S. ally—the Philippines, say, or Taiwan or Israel—could overstep, prompting retaliation from China or Iran that risks dragging in the United States.

On the other hand, if Trump disparages Washington’s alliances, an adversary—Moscow, most likely, but plausibly Pyongyang or even Beijing—could decide to test Trump’s willingness to come to the aid of U.S. allies, prompting a political uproar in Washington that forces the president’s hand.

Extinction, nuclear winter. Starr 15

Steven Starr 15, 2/28/2015, Steven is an Associate member of the Nuclear Age Peace Foundation and has been published by the Bulletin of the Atomic Scientists. Starr is also an expert on the environmental consequences of nuclear war, Nuclear War: An Unrecognized Mass Extinction Event Waiting to Happen,  Symposium: The Dynamics of Possible Nuclear Extinction, [https://ratical.org/radiation/NuclearExtinction/StevenStarr022815.html)//](https://ratical.org/radiation/NuclearExtinction/StevenStarr022815.html)/) JZ

A war fought with 21st century strategic nuclear weapons would be more than just a great catastrophe in human history. If we allow it to happen, such a war would be a mass extinction event that ends human history. There is a profound difference between extinction and “an unprecedented disaster,” or even “the end of civilization,” because even after such an immense catastrophe, human life would go on. But extinction, by definition, is an event of utter finality, and a nuclear war that could cause human extinction should really be considered as the ultimate criminal act. It certainly would be the crime to end all crimes. The world’s leading climatologists now tell us that nuclear war threatens our continued existence as a species. Their studies predict that a large nuclear war, especially one fought with strategic nuclear weapons, would create a post-war environment in which for many years it would be too cold and dark to even grow food. Their findings make it clear that not only humans, but most large animals and many other forms of complex life would likely vanish forever in a nuclear darkness of our own making. The environmental consequences of nuclear war would attack the ecological support systems of life at every level. Radioactive fallout, produced not only by nuclear bombs, but also by the destruction of nuclear power plants and their spent fuel pools, would poison the biosphere. Millions of tons of smoke would act to destroy Earth’s protective ozone layer and block most sunlight from reaching Earth’s surface, creating Ice Age weather conditions that would last for decades. Yet the political and military leaders who control nuclear weapons strictly avoid any direct public discussion of the consequences of nuclear war. They do so by arguing that nuclear weapons are not intended to be used, but only to deter. Remarkably, the leaders of the Nuclear Weapon States have chosen to ignore the authoritative, long-standing scientific research done by the climatologists, research that predicts virtually any nuclear war, fought with even a fraction of the operational and deployed nuclear arsenals, will leave the Earth essentially uninhabitable.

Contention 2 is Transition

Clean energy transition is inevitable but must be faster.

Worland 21 [Justin Worland, Senior Correspondent @ Time & BA in History from Harvard University, 7-15-2021, The Energy Transition Is in Full Swing. It’s Not Happening Fast Enough, TIME, <https://time.com/6106341/green-energy-transition-iea/>, Willie T.]

Even if you follow these things closely, it can be hard to understand where the world’s fight against climate change stands. On the one hand, news abounds of the clean energy revolution, as wind farms and solar panels pop up in communities across the globe and automakers promise to go electric. On the other hand, scientists continue to warn that fossil fuels have placed the planet and everyone who lives on it on an unavoidable collision course with catastrophe.

A new report from the International Energy Agency (IEA) published Wednesday explains the dynamic in sharp detail: the world has begun a momentous shift in how we power the economy that will touch virtually every corner of human society, with investment in oil and gas slowing and spending on clean energy rising. But it’s not happening fast enough to avoid dangerous levels of warming.

“A new global energy economy is emerging,” IEA Executive Director Fatih Birol tells TIME. But when it comes to the necessary levels of investment in clean energy, there is “a gross mismatch.”

The IEA’s annual World Energy Outlook is designed to inform policymakers about the state of global energy markets as well as the emerging trends expected to define energy in the years to come. Its origins are undeniably wonky, but this year’s report takes on new significance with climate change on the rise in public consciousness and on the international stage. The agency released the 2021 report a month early to help inform talks among the delegates who will gather in Glasgow, Scotland, in early November for the biggest United Nations climate summit in years.

Perhaps nothing is more urgent than the report’s key message that countries need to dramatically accelerate their efforts to cut emissions for the world to have any hope of limiting temperature rise to 1.5°C, the level at which scientists say we might expect to see widespread catastrophic effects of climate change. Current pledges from countries to cut emissions only reduce carbon pollution by 20% of what’s necessary to avoid reaching that marker, according to the report’s analysis.

The report offers no shortage of solutions to make up the gap. Climate politics can often end up mired in debates about controversial topics like carbon capture and nuclear energy, but the report highlights four straightforward areas that would address the problem: electrification, energy efficiency, tackling methane emissions and advancing innovation. To make all of those happen, the world needs to grow annual investment in clean energy by close to $4 trillion by the end of the decade, according to the report. “Finance is the missing ingredient to accelerate,” says Birol.

Looming energy crises

The analytical work that underpins the report began long before the energy crunch gripping Europe and China and threatens to spread across the globe. Nonetheless, the report warns that the energy crisis—which the IEA attributes to a rise in energy demand amid the economic recovery from the pandemic, among other things—may presage future energy crises that could occur if governments fail to plan carefully.

At the heart of the agency’s concern is an underinvestment in clean energy. Investment in oil and gas has stalled in a way that is consistent with limiting warming to 1.5°C. At the same time, spending on clean energy infrastructure remains far below what it needs to be, creating the possibility of volatility and supply disruptions much like the world is facing today. “The longer this mismatch persists, the greater the risk for increased volatility,” says Birol. “What we need is very clear: to increase investment in clean energy technologies.”

Even as investment in oil and gas has slowed, the IEA warns that the economic recovery from the worst of the COVID-related downturn has failed to live up to the promises of a “green recovery” that was commonly touted as governments spent trillions to help prop up their economies in 2020. Just 2% of $16 trillion spent by countries around the world on COVID economic support was spent on clean energy, according to the report. As a result, the world is now experiencing the second largest uptick in carbon emissions in history, in large part as a result of growth of coal use to power the economic recovery. “We are now witnessing an unsustainable recovery,” says Birol.

Indeed,

Weise 24 [Zia Weise, senior reporter covering climate policy @ POLITICO & B.A. in journalism from Kingston University, 11-6-2024, Climate world absorbs a reality they’d hoped to avoid: Trump is back, POLITICO, <https://www.politico.eu/article/climate-world-diplomats-donald-trump-victory-clean-energy-fossil-fuels-greenhouse-emissions/>, Willie T. + sumzom]

The morning of his victory, however, officials and climate campaigners talked down Trump’s likely impact on plans to slow greenhouse gas emissions, hoping to calm nervous clean technology markets and present the transition as a fait accompli.

“Those investing in clean energy are already enjoying huge wins in terms of jobs and wealth, and cheaper, more secure energy. This is because the global energy transition is inevitable and gathering pace, making it among the greatest economic opportunities of our age,” said United Nations climate chief Simon Stiell.

The challenge is that the world isn’t moving quickly enough to prevent dangerous global warming, and any slowdown from the world’s second-largest emitter — itself a major driver of the global shift to clean energy — is bound to throw a wrench into global climate efforts.

Trump hinted at what was coming in his victory speech early Wednesday morning, touting America’s abundant supplies of “liquid gold.” Addressing Robert F. Kennedy Jr., the environmental lawyer who appears likely to bring his unorthodox views on healthcare to the heart of a Trump administration, Trump said: “Bobby, leave the oil to me.”

Only nuclear energy solves --- investment is key.

Grossi 24 [Rafael Mariano Grossi, PhD in History, International Relations and International Politics from the Graduate Institute of International Studies, 1-17-2024, 5 reasons we must embrace nuclear energy in the fight against climate change, World Economic Forum, <https://www.weforum.org/stories/2024/01/nuclear-energy-transistion-climate-change/>]

Globally, nuclear energy is also playing a key role in the transition to net zero. Fears about nuclear are slowly giving way to fact-based understanding. This year, for the first time, the document agreed at COP backed nuclear energy investment among low-emissions technologies.

One of nuclear’s key attributes is its energy intensity. A thimble-sized pellet of uranium produces as much energy as almost 3 barrels of oil, more than 350 cubic metres of natural gas and about half a tonne of coal.

5 reasons we cannot ignore nuclear energy

Nuclear power, which has 20,000 reactor years of experience across the world, has five distinct advantages.

1. From cradle to grave, nuclear energy has the lowest carbon footprint and needs fewer materials and less land than other electricity source. For example, to produce one unit of energy, solar needs more than 17 times as much material and 46 times as much land.

2. Uranium in the earth's crust and oceans is more abundant than gold, platinum and other rare metals. It is going to take us about 100 to 150 years to get through the uranium resources we deem economically recoverable today.

3. Nuclear power doesn’t rely on the weather. Well-run nuclear power plants, including for example those in the US, operate at least two to three times as reliably for two to three times as many years as intermittent low-carbon sources. As a flexible baseload for wind and solar that provides more energy when it is needed and less when it is not, nuclear power plants displace coal and enable renewables.

4. Each year, nuclear power plants produce a quarter of the world’s low-carbon electricity, saving many lives that would otherwise be cut short by the lethal pollution fossil fuels pump into the air. Nuclear energy is about as safe as solar. It is far safer than coal, gas and oil, and safer than almost every other alternative energy source.

5. It is true that spent fuel is highly radioactive and emits heat. But it is also relatively compact, and extremely carefully managed and regulated. Nuclear energy generation is so efficient that the amount of all spent fuel ever produced would — in theory — fit into 42 Olympic-sized swimming pools. Today, it is carefully stored in pools and dry storage systems or recycled. Countries like Finland and Sweden are close to putting into place deep geological repositories to dispose of spent fuel. France is also progressing in the implementation of a deep geological repository for high-level waste from spent fuel recycling.

Nuclear is one of the safest, cleanest, least environmentally burdensome and — ultimately, over the lifetime of a nuclear power plant — one of the cheapest sources of energy available.

But for all of nuclear energy’s positive attributes, there are hurdles to overcome. The accidents at Chernobyl and at the Fukushima Daiichi Nuclear Power Station left long shadows of mistrust and underinvestment. The upfront cost of building a nuclear power plant is considerable and budget overruns and long delays have made it more difficult to gain support for new construction.

Three levers to catalyze investment in nuclear energy

Three main levers will need to be pulled if we are to triple today’s investment levels and build the nuclear capacity that will help get us to net zero.

Lever 1: Nuclear must be acknowledged for what it is: a reliable, scalable, safe and highly affordable low-carbon source of energy. It must be treated that way when it comes to investment incentives. Today’s energy markets are not the same as those of the 1970s and 1980s. Nuclear needs private investment, even in markets where governments still take on much of the financing. Governments need to shoulder the risk of the high capital costs at the start. But that alone is not enough. They need to attract private financing through assured revenues and an enabling investment environment over the longer term. That means levelling the playing field nationally and internationally, including by changing the policies preventing investment in nuclear energy by many key international financial institutions and development banks.

The impact is Peak oil guarantees economic collapse --- only accelerated transition solves.

Ahmed 23 [Nafeez Ahmed, PhD in International Relations from the University of Sussex’s School of Global Studies, 3-29-2023, America’s Fossil Fuel Economy is Heading for Collapse – It Signals the End of the Oil Age, resilience, <https://www.resilience.org/stories/2023-03-29/americas-fossil-fuel-economy-is-heading-for-collapse-it-signals-the-end-of-the-oil-age/>, tristan]

US oil production is about to peak, but the world is unprepared for the tremendous economic and political consequences. The only path through is energy and economic transformation.

The global economy is currently teetering on the edge of a banking crisis. The IPCC has just released its final major report warning that global carbon emissions need to peak and decline immediately if we are to avoid plunging into dangerous global warming by breaching the 1.5C ‘safe limit’. And in recent weeks and months, industry leaders have announced that the US shale oil and gas revolution is over.

Yet few if anyone is talking about why these things are happening at the same time, and what they really mean.

One of our biggest problems is that we tend to think in silos and sectors. But in the real world, the sectors we assume operate separately are in fact fundamentally interconnected. We ignore and downplay these systemic interconnections at our peril.

The persistence of global inflation has taken many economists by surprise. While they recognise that the impact of Russia’s war in Ukraine on energy and food supplies has been the biggest driver, that silo-ed assumption has led to a failure to understand why inflation is unlikely to simply disappear anytime soon.

We have good reason to believe that the underlying drivers of inflation go beyond just the war in Ukraine. Although it’s extremely difficult to quantify, climate change and environmental degradation is driving inflation by eroding agricultural productivity leading to higher food costs. The impact of extreme weather events is also creating larger and larger damages to infrastructure which in turn is incurring greater costs. As these costs feed into the system, the supply of goods and services becomes more expensive.

Less difficult to quantify is the fact that inflation is historically linked to energy price hikes. And there is mounting evidence that the world is experiencing a major shift in the global fossil fuel system that entails rising costs and diminishing returns, which will end up having a major inflationary effect for far longer and deeper than conventionally assumed.

The end of the shale boom

Since late last year, there have been a growing number of reports pointing out that the US shale revolution is coming to an end. Yet the massive global consequences of this are not being discussed.

“US Shale Boom Shows Signs of Peaking as Big Oil Well Disappear” read one headline in the Wall Street Journal. “The aggressive growth era of US shale is over,” Scott Sheffield, CEO of top independent shale firm Pioneer told the Financial Times. “The shale model definitely is no longer a swing producer.” And according to Bloomberg: “The specter of peak oil that haunted global energy markets during the first decade of the 21st century is once again rearing its head”.

US industry executives are now openly acknowledging that US oil production is likely to peak within the next five or six years, or perhaps in 2030. But there is mounting evidence that the peak will come much earlier, with some industry observers pinpointing its arrival as early as within the next one or two years.

What’s extraordinary about these admissions is how little they are impacting public debate. The implications are seismic. They contradict bullish overinflated forecasts of the industry made two decades ago – in 2005, for instance, Washington DC think-tank RAND Corp was forecasting that the US had enough shale oil to last some 400 years; and in 2012, a senior ExxonMobil executive claimed that the US has “about 100 years of natural gas supply”.

These grand claims were often breathlessly reported as unimpeachable fact by some of the most respected media institutions in the world.

Naysayers (like myself) warning that shale oil and gas would offer at best a temporary boost that was bound to peak and decline in the near-term with major global economic consequences, were dismissed as ‘doomers’.

Now, it turns out, we were right all along.

Mistakes of forecasting

That’s not to say that the traditional ‘peak oilers’ at the time were spot on. They wrongly expected that following the plateauing of conventional oil around 2005, oil prices would rocket up permanently into triple digits as global oil production would go into terminal decline. That didn’t happen. Instead, global demand shifted to the more expensive forms of unconventional oil and gas – especially US shale – which made-up much of the short-fall as conventional oil production slowed down.

But this was a recessionary environment, so global demand was much lower than expected. The massive 2005-2008 global oil price spikes helped induce a banking collapse. After the 2008 financial crash, this meant that there was much less demand for oil – but as oil production projects are planned years in advance pegged to expectations of demand, the oil just kept pumping despite much lower demand due to economic recession.

The result was a glut of shale oil and gas on world markets that allowed oil prices to drop and fuelled widespread belief in a new era of ‘Made in America’ cheap oil.

The US shale boom had a good run, no doubt about it – but its ‘healthy’ lifespan appears to be around two decades. If US shale oil and gas is about to peak and decline in the next few years, what does this mean for the US and global economy?

Coming economic contraction

Given that the US shale revolution played the key role in keeping global oil prices down and lubricating the energy requirements of continued economic activity, the retraction of the US shale revolution will have massive economic impacts.

US production has accounted for around 70% of the total increase in global oil capacity since 2019, and 75% of growth in liquified gas supplies. So as US shale oil and gas peaks, plateaus and declines, global oil and gas production will do so too very shortly after.

Gulf oil and gas producers, however, will not be able to step-in to fill the shortfall. US oil production is currently averaging around 11 million barrels per day (mbd).

A 2022 analysis of production data among the Organisation of Petroleum Exporting Countries (OPEC) which include the biggest powerhouses such as Saudi Arabia and the UAE, suggests that the maximum OPEC could collectively increase production is around 4.5 mbd – that is, less than half of current US shale production.

It’s also not clear how long OPEC can deploy spare capacity to maintain maximum levels of production. This suggests that OPEC will not be able to meaningfully fill the supply gap as US shale declines, which is a clear indicator that total global oil production will eventually begin to peak and decline.

In 2017, I assessed these trends in Failing States, Collapsing Systems. I predicted that US oil and gas production would probably peak and plateau around 2025, and that major Middle East producers would peak and plateau around the 2030s. This scenario now appears to be unfolding before our eyes. Yet no one is talking about it.

The near-term economic and financial consequences will be devastating, and they could lead to permanent long-term consequences without significant transformative action. The impact on the US economy will be profound.

Shale production accounted for 10% of GDP growth in the United States from 2010-2015, which means that the next decade of shale’s plateauing and decline will gradually wipe this out. This will be experienced as a protracted inflationary economic crisis which, in turn, will contribute to volatility in global financial markets. Pundits will likely fail to understand these systemic interlinkages, focusing instead on failing banks, financial institutions and debt, without understanding its energetic triggers.

All this implies that we are sleepwalking into a global energy crisis that will, without accelerating the clean transformation of the energy system, create severe economic and financial consequences by undercutting the fundamental energetic basis of global economic flows. This will compound accumulated vulnerabilities in the banking system linked to unsustainable forms of debt.

The reverberations and bailouts seen in the cases of the Silicon Valley Bank, Credit Suisse and others are merely the opening cracks, that will become widening fissures in the absence of root-and-branch economic restructuring linked to the rapid development of a new energy system.

While that new system is still emerging, it is perhaps unavoidable that we will hit a number of bottlenecks. The danger is that instead of using these bottlenecks to restructure and adapt positively, we may end up regressing, with a loss of capital and energy that forestalls the full potential of transformation.

The window for action is extremely short: we need to act within this decade. Along the way, we need to be aware of the major trends which are likely to emerge as a result of the end of the US shale boom:

1. The illusion of cheap oil is evaporating

While we may still see fluctuating prices, it is becoming clearer that the glut of cheap oil this last decade was not a permanent feature of the energy system, but a temporary symptom of highly specific circumstances as the energy system moves deeper into a state of increasing inputs and diminishing returns. The immediate impact of the peak and plateau of US shale will be sustained high oil prices.

2. The near-term beneficiaries of this will be Gulf oil and gas producers

They currently appear to be the only fossil fuel energy suppliers with sufficient capacity to maintain production. They will therefore not only begin to dominate market share, they will also of course continue to reap higher profits from this more advantageous market position amidst high oil prices.

3. Some capital will move into OPEC for safety, but this is a mirage

Just as this last decade created the illusion of fossil fuel abundance due to the US shale boom, we may see that OPEC’s near-term ability to ramp up spare capacity as shale production declines perpetuates this illusion. We can expect to see lots of bullish statements from Gulf oil producers vindicating grand plans to expand their oil and gas production. Capital will move rapidly into OPEC countries, seen as a last safe space for investors looking for stability and growth. However, OPEC producers will also begin experiencing their twilight very shortly after the decline of US shale, which means that investors will begin to make serious losses as a result far sooner than they imagine.

4. Oil prices will fluctuate within a higher range as US shale peaks

While we can expect significant oil price volatility due to the recessionary impact of high oil prices which would lower demand and therefore allow prices to drop, as we move further into the era of plateau and decline across US and OPEC production, the overall decline in supply is likely to lead oil price fluctuations to narrow within a far higher range which will become a ‘new normal’ as long as oil demand remains high. This may also incentivise near-term conviction in the idea that new oil and gas investments are economical. That would be a colossal mistake, though, as we will see below due to coming reductions in oil demand in the latter half of this decade that will ameliorate high prices and make fossil fuel enterprises increasingly unprofitable.

5. We can expect heightened political polarisation

Incumbent industry ideology will likely blind many energy actors from recognising the writing on the wall – which explains the regressive self-defeating actions of the Biden administration in committing to Arctic drilling. This is like betting on the losing horse after being told it’s about to be overtaken by cars. It illustrates the power of America’s oil lobbies in their last ditch desperate attempt to stay alive on the back of taxpayer subsidies – flying in the face of hard economic realities (a few years ago I broke the story of the British military study which concluded that Arctic drilling was pointless for economic reasons because the costs are so high and returns so low as to make it commercially infeasible). That in turn suggests the political battleground between fossil fuel lobbies and clean energy advocates will become more fraught as the incumbency seeks to double-down in demanding more government subsidies. Millions of jobs will be at risk as the US shale industry declines, and this could create further negative economic and cultural consequences as the US returns to net import status.

6. Clean energy transformation will be critical to stabilise the global economy and restore prosperity

The only viable pathway through this crisis will be to accelerate the clean energy transformation focused on the deployment of exponentially improving technologies which are already scaling because they are cost-competitive with fossil fuels – namely, solar, wind and batteries. This will lay the groundwork for other potential applications such as e-fuels or green ammonia from green hydrogen. This transformation is already underway, and provides the opportunity for the US and others to produce larger quantities of energy at a fraction of the costs of fossil fuels. In Rethinking Climate Change, a RethinkX report for which I was contributing editor, we found that even in the absence of appropriate policy-decisions and major institutional barriers, economic factors will inevitably drive incumbent industries to collapse by 2040 as they are replaced by new solar, wind and battery systems. Unfortunately, while this is far faster than conventional analysts acknowledge, this is not fast enough to avoid dangerous climate change.

Damage is irreversible, and instant.

Towne 9 [Gorden Towne, Writer @ Boston University A&S Writing Program, 2009, Peak Oil: Priorities in Alternative Energy Development, Boston University, <https://www.bu.edu/writingprogram/files/2009/11/wrjournal1towne.pdf>, Willie T.]

As more oil is extracted from existing wells, it also becomes more difficult to locate the remaining oil deposits. Newly discovered oil fields generally contain significantly lower quantities of oil than past discoveries, based on the principle that the bigger deposits are easiest to find, and thus were found and harvested first. Thus, the problem of diminishing oil production from a single field over time is compounded by the fact that it becomes increasingly costly to locate progressively smaller oil deposits. Modern oil exploration is conducted using seismic detectors aboard large trucks or ocean-going ships.11 These oil-prospecting vehicles have high operating costs per unit area explored, so as oil becomes more scarce, the overhead cost for locating any one deposit increases. When oil becomes sufficiently scarce and expensive to locate and extract, the amount that can be produced will begin to decline year over year. The point of transition from increasing to decreasing production is known as the oil peak.

The economic, political, and sociocultural implications of peak oil, when it occurs, will be dramatic and pervasive. At the peak and immediately thereafter, burgeoning world oil demand will surpass the quantity that can possibly be supplied. This discrepancy will cause the cost of oil to skyrocket, which will be readily visible in the price at the pump. Because transportation is embedded in the cost of nearly all goods and services, rising fuel costs will place direct pressure on a broad range of businesses. This effect will manifest itself in increasing unemployment, along with rising consumer costs in everything from food to clothing and electronics. Domestically, the resulting ripple effect will be sufficient to set the economy on a cycle of stagflation, that is, simultaneous economic recession and monetary inflation. On its surface, this is not dissimilar from the effects of previous oil shortages, most notably that resulting from the OPEC embargo of the early 1970s.1213 In this instance, a temporary, artificial supply shortage was sufficient on its own to catalyze a cycle of stagflation, sending the U.S. economy into recession. In the case of peak oil, however, once this cycle begins, oil production will only continue a downward trend. In an unmitigated situation, this will cause the supply-and-demand discrepancy to grow ever wider. Where previous fluctuations in oil supply have triggered cyclic rises and falls in domestic economic health, problems spawned by falling oil supply will only worsen as production continues to decrease.

Nuclear energy insulates shocks.

Lee 10 [Chien-Chiang Lee, Professor of Finance @ National Sun Yat-sen University (Kaohsiung, Taiwan) & Ph.D. in International Economics @ Chung Cheng University, 6-24-2010, Nuclear energy consumption, oil prices, and economic growth: Evidence from highly industrialized countries, Energy Economics, <https://sci-hub.ru/10.1016/j.eneco.2010.07.001>, Willie T.]

This study utilizes the Johansen cointegration technique, the Granger non-causality test of Toda and Yamamoto (1995), the generalized impulse response function, and the generalized forecast error variance decomposition to examine the dynamic interrelationship among nuclear energy consumption, real oil price, oil consumption, and real income in six highly industrialized countries for the period 1965–2008. Our empirical results indicate that the relationships between nuclear energy consumption and oil are as substitutes in the U.S. and Canada, while they are complementary in France, Japan, and the U.K. Second, the long-run income elasticity of nuclear energy is larger than one, indicating that nuclear energy is a luxury good. Third, the results of the Granger causality test find evidence of unidirectional causality running from real income to nuclear energy consumption in Japan. A bidirectional relationship appears in Canada, Germany and the U.K., while no causality exists in France and the U.S. We also find evidence of causality running from real oil price to nuclear energy consumption, except for the U.S., and causality running from oil consumption to nuclear energy consumption in Canada, Japan, and the U.K., suggesting that changes in price and consumption of oil influence nuclear energy consumption. Finally, the results observe transitory initial impacts of innovations in real income and oil consumption on nuclear energy consumption. In the long run the impact of real oil price is relatively larger compared with that of real income on nuclear energy consumption in Canada, Germany, Japan, and the U.S.

1. Introduction

During the two energy crises in the 1970s, the price of oil doubled, even tripled in some countries, resulting in an increase of production cost and sharply reducing export competitiveness, which may have reduced imported-energy-dependent countries' economy performance and international competitiveness. Fossil fuels including coal, oil, and gas nowadays provide 85% of energy needs, and fossil-fuelled economic growth is the main factor for global warming through the release of carbon dioxide (CO2) into the atmosphere. In December 1997 the third session of the Conference of Parties to the United Nations Framework Convention on Climate Change (UNFCCC) in Kyoto, Japan adopted the Kyoto Protocol. Annex I countries agreed to reduce their collective greenhouse gas emissions by 5.2% from their 1990 level by 2008 to 2012. The U.S. President Obama's New Energy for America plans to reduce 10 million barrels of oil consumption per day by 2030 and to cut the country's collective greenhouse gas emissions by 80% from the 1990 level by 2050.

To combat these energy and environmental configurations, one of the important priorities of energy and environmental policy is to diversify the sources of energy and to find a secure, cheap, and nonGHG-emitting energy supply (Fiore, 2006; Vaillancourt et al., 2008; Wolde-Rufael, 2010). As noted by the International Energy Agency (IEA, 2008), nuclear energy may answer these conditions, as it reduces the instability of oil prices, the dependence on oil imports for many countries, and greenhouse gas emissions. Therefore, nuclear energy (non-carbon energy) may be a crucial substitute energy for oil, and whether imported-energy-dependent countries can adopt nuclear energy to replace the majority of fossil fuels in their economy has become an important issue

Absent action, world war ensues.

Bunzel 18 [Theodore Bunzel; Head of Lazard Geopolitical Advisory; 5-30-2018, "Do High Oil Prices Mean More International Conflict?", American Interest, <https://www.the-american-interest.com/2018/05/30/do-high-oil-prices-mean-more-international-conflict/>] sumzom

Does the relationship between oil prices and Russian behavior to which Bush alluded hold true? The higher the price of oil, the more aggressive Russia becomes? And what about other petrostates? Might it be true for those as well?

We may soon have more evidence for the proposition. Oil prices are brushing off 2016 lows and hitting three-year highs. Brent crude has been hovering above $70 a barrel since April, up from lows of around $30 in early 2016, fueled by OPEC production cuts and rising geopolitical tensions (over issues like the Iran deal). Though nuances, complications, and exceptions abound, the academic and historical evidence on balance tells us that, as we transition from a lower to a higher oil price regime, we can generally expect a darker geopolitical outlook. As rising oil revenues gives Russia, Saudi, Iran, and other oil-exporters an added sense of confidence, it may at least selectively inflame interstate tensions and lead to more aggressive behavior. That possibility, alongside an increasingly hawkish U.S. national security team and a President who appears to feel rather “unchained” of late, points to a potentially combustible mix just ahead.

It is generally taken for granted that aspects of geopolitics can function as a key input into oil prices. Trump’s mere threat of a U.S. strike in Syria, for example, caused oil to spike by 2 percent on April 11. In addition to short-term effects, geopolitical competition can influence prices in other ways. To give just one general example, as Soviet power spread into parts of the Third World after the independence era, some states felt safer nationalizing their oil industries to escape Western company control (Iraq in 1961, for example), and prices rose as a consequence.

But the relationship may also work the other way around: Oil prices can also be a key input into geopolitics. Many studies have demonstrated that oil prices have a direct effect on the domestic stability of petrostates. This makes ample intuitive sense: Higher prices fill public coffers, allowing governments to palliate needy populations and potential elite opposition groups by dispensing more largesse. Some regime elites may reason that a firmer grip on power may free them to carry out more assertive foreign policies without fear of being undermined at home.

There are, however, several complications to this general intuition. Some states already have sufficiently buoyant revenues relative to their small populations to satisfy their publics and feed clientelistic networks. Providing largesse can also backfire if prices drop; taking away something valuable that people have grown used to is a dangerous game, especially when elites aren’t ready to play it. And then of course there is the famed “oil curse”: For all sorts of reasons, from “Dutch disease” economic distortions to the derangement of normal citizen-state relationships, oil riches can in time undermine regimes, weakening and even destroying them.

That said, a more recent body of research has empirically demonstrated the intuitive twin of this conclusion: Higher prices cause greater interstate aggression by oil-producing countries. Why would this be the case? Greater oil revenue flushes petrostates with confidence and also cash that they can put toward military spending or foreign adventures. To take one obvious example, we need only look to Iran’s using its oil revenue to fund proxy groups such as Hamas and Hezbollah. Furthermore, military spending by one regional oil producer can beget spending by others, fueling regional arms races that can make aggression and conflict by miscalculation more likely. The onset of the Iran-Iraq War in September 1980 may be a prime example of that dynamic.

Most prominent among the empirical studies is Cullen S. Hendrix’s 2014 paper, which shows a statistically significant relationship between higher oil prices and “dispute behavior” (military actions short of actual war) by oil-exporters. (Hendrix also summed it up nicely in this Washington Post piece.) He found that “all things being equal, a one standard deviation ($18.60) increase in the price per barrel of oil from the sample mean ($33.81) is associated with a 13 percent increase in the frequency of [dispute behavior]” in oil-exporting states. He also found that, above $77 a barrel, oil-exporters are significantly more dispute prone than non-oil exporters.

Hendrix also explores the potential complication of reverse causality: Could dispute behavior by oil-exporting countries be driving prices higher, rather than the other way around? A key analytical consideration here is timing. We can all agree that geopolitical activity affects prices in the short-term (such as the Syria example mentioned above), but is this reverse causality true on a sustained basis? Parsing out long-term signal from short-term noise, Hendrix examines whether elevated aggregate dispute behavior affects oil prices at the yearly—rather than daily or weekly—level, and finds that this relationship does not hold. His explanation here is that other players typically step in to redress markets: “While dispute behavior may drive prices changes in the short term . . . the strategic significance of oil prices and oil-exporting states encourages major powers to act in ways that stabilize markets, either through market intervention . . . or direct, armed intervention.”

Jeff Colgan of Brown University has also touched on this topic, finding through his research that oil has fueled—in some way—one quarter to one half of interstate wars since 1973. He also notes that oil-producers are 50 percent more likely to engage in conflict than non-oil producers. Colgan identifies eight, non-mutually exclusive causal mechanisms for how oil fuels international conflict, most of which are implicitly exacerbated by higher prices. They are: “(1) resource wars, in which states try to acquire oil reserves by force; (2) petro-aggression, whereby oil insulates aggressive leaders such as Saddam Hussein or Ayatollah Ruhollah Khomeini from domestic opposition and therefore makes them more willing to engage in risky foreign policy adventurism; (3) the externalization of civil wars in oil-producing states (“petrostates”); (4) financing for insurgencies—for instance, Iran funneling oil money to Hezbollah; (5) conflicts triggered by the prospect of oil-market domination, such as the U.S. war with Iraq over Kuwait in 1991; (6) clashes over control of oil transit routes, such as shipping lanes and pipelines; (7) oil-related grievances, whereby the presence of foreign workers in petrostates helps extremist groups such as al-Qaeda recruit locals; and (8) oil-related obstacles to multilateral cooperation, such as when an importer’s attempt to curry favor with a petrostate prevents multilateral cooperation on security issues.”

Though he doesn’t substantiate statistically that higher prices lead to more conflict through these channels, he implies it heavily. For example, he writes that, “the low oil prices of the 1990s have given way to higher and more volatile prices, increasing the magnitude of the consequences one can expect from oil-conflict linkages.”

While the emerging academic evidence may validate the claim that higher oil prices lead to more aggression, the historical and anecdotal evidence is somewhat mixed, and understandably so. Oil price is clearly only one of many inputs into foreign policy decision-making, and an indirect one at that. No leader thinks, “Now that oil is at $X, I’m going to invade my neighbor.” Context obviously matters, too: No one imagines that Ecuador or Norway is going to invade or try to blackmail a neighbor just because spot prices rise 15 or 30 percent in a given six-month period. Price levels seep into decision-making more subtly, affecting interlocking beliefs about strategic behavior generally and specific cases more particularly; they may fuel self-confidence by shoring up budget outlooks and funding the tools of more aggressive behavior in contexts where such behavior could conceivably make sense.

Moreover, there are many contravening (and occasionally countervailing) complications. Prominent among these is the fact that low oil prices can incentivize states to “wave the flag” in order to distract from domestic difficulties—so the impact of low oil prices might lead to more aggressive behavior in some cases. That suggests that neither high nor low prices per se may be the trigger affecting behavior, but rather notable changes in price that become politically salient in one way or another.

And there’s also the tricky issue of timing: Over what timeframe does increased oil revenue fuel aggression? Is it in anticipation of higher prices, in direct response to the current pricing levels, or is there more of a lag in effect as oil revenue slowly shores up—or is expected to shore up—budgets and military spending over time? The answer might depend on specific cases and leadership cadres.

There is also a scaling problem. If a 20 percent rise in oil prices makes a more assertive foreign policy more likely in a given country, does a 40 percent rise make it twice as likely? Or put differently, how much of a difference in price, and presumably in expected revenues, does it take to cross a threshold where it might have an impact on decision-making? Are there multiple thresholds?

Russia exemplifies these issues. Taking the same long view as George W. Bush in his interview, it seems self-evident that rising oil prices and higher government revenues over the course of the 2000s gave Putin confidence, funded military expansion and modernization, and helped enable Russia’s most revanchist tendencies. Between 2003 and 2013, Russian military expenditure doubled as the price of Brent crude rose from a low of around $20 a barrel in 2001 to a high of more than $140 a barrel in 2008. Russia, as the saying goes, is a gas station with nuclear weapons; a higher pump price thus means more weapons, nuclear and otherwise.

But when you cross reference this conclusion with specific acts of Russian aggression over the past roughly twenty years, the picture gets much more complicated. When Russia invaded Georgia in August 2008, oil was above $100 a barrel. Same with Russia’s invasion of Crimea in 2014. But Russia also dramatically intervened in Syria in September 2015, when oil had dropped to around $50 a barrel and the economy was sputtering due to both low energy prices and Western sanctions. Here, many analysts plausibly described these interventions as a way of rallying Russians to the flag and distracting them from domestic hardship. More likely, Putin saw an emergency in Syria that simply had to be dealt with, no matter the cost or risk; the Assad regime was in danger of collapsing, and Syria is Russia’s only ally offering ports and bases in the Mediterranean basin. So Russia is a bit of a mixed bag, but on balance its behavior—especially over a long timeframe—appears to support the thesis.

Saudi Arabia’s role in the 1973 Yom Kippur war also illustrates the tricky question of timing. Saudi funding of the effort was enabled by a financial buffer created by a rise in revenues from the late 1960s, and was likely justified by an expected rise in revenues due to an oil price increase that was anticipated, in part, because of the very war it was in the process of financing. Its reserves had already grown so large that, for the first time, Saudi Arabia could ride out a supply (and revenue) disruption and still finance a war. But the Saudis helped finance a war that they themselves did not participate in. So if rising oil prices led to greater interstate aggression, it did so in this case in a particularly indirect way.

These are all interesting and important nuances that attenuate any direct causal connection one might be tempted to draw between oil prices and conflict. So it would be nice to know if historical studies have shown any significant statistical relationship between fluctuations in key sources of government revenue (and what memoirs and archives tell us about how those situations were perceived) and interstate behavior. It would be even nicer to drill down into such studies to find cases where specific lucrative commodities—for example, European colonial profits such as from British opium sales in China, or cotton grown in Egypt—made any difference in the behavior of the relevant governments. Alas, such studies do not exist.

But regardless of the timeframe and mechanism, academic and historical studies alike do suggest that higher oil prices have generally lead to more aggressive, or at least riskier, behavior in recent decades—whether in anticipation of higher prices, immediately in their wake, or only after sufficient revenue stores are built up.

So are we at a point in the energy price cycle where, all else equal, we should expect greater interstate conflict? We’re close to Hendrix’s $77 a barrel threshold, above which oil-exporters are significantly more dispute-prone than non-oil exporters. But given the nuances just described, this specific price threshold is probably too cute. The more realistic argument to make is about the effect of a higher-price vs. lower-price paradigm over a multi-year horizon (particularly in light of the timing issue and potential lag). And if the period of the past two years (when Brent largely hovered between $40 and $60) was a lower-price paradigm, 2018-19 is potentially gearing up to be a higher-price paradigm driven by continued supply cuts by OPEC, tight global inventories, and—in a coincidental way—heightened geopolitical risks. We’ll see how these factors play out, but if oil prices remain elevated we may begin to subtly feel their effects on behavior by Iran, Saudi Arabia, Russia, and perhaps others.

None of this is to say that oil prices are the most important factor in the geopolitical outlook over the near, medium, or long-term. The reputed hawkishness of Mike Pompeo and John Bolton, the effect of the upcoming mid-term elections on Trump’s decision-making, and reactions to potential exogenous shocks (for example, a major clash in Syria between U.S. or Israeli and Iranian or Russian forces) will play a much more direct and important role in shaping the geopolitical landscape. But a higher oil price regime (if it holds) could well make petrostates like Iran, Saudi, and Russia more aggressive—either in challenging the United States and Europe in the case of Russia, or by exacerbating ongoing proxy conflicts in and around the Middle East in the cases of Iran and Saudi Arabia. Given these and other dynamics, we should expect a bumpy ride ahead.

Contention 3 is Space

Mars is in sight.

Greenfieldboyce 25 [Nell Greenfieldboyce, NPR science correspondent & Masters of Arts degree in science writing, 2-12-2025, Is Trump the president who will truly set a course for Mars?, NPR, <https://www.npr.org/2025/02/13/nx-s1-5294575/president-trump-elon-musk-mars-moon>, Willie T.]

Back in 1969, Robert Zubrin remembers watching the first moon landing when he was a teenager. He says if someone back then had asked him to predict when astronauts would walk on Mars, "my guess would have been the early 1980's."

"And, in fact, NASA had plans to do that at that time, which were aborted by the Nixon administration," says Zubrin, an aerospace engineer who is president of the Mars Society and author of The Case for Mars.

Over the decades, as administrations have come and gone, presidents have repeatedly promised future missions to Mars, holding this up as a key goal for human space exploration.

Never before, though, has a president had such a close relationship with a would-be Mars colonizer, one who has transformed the world of rocketry.

Elon Musk, President Trump's ally who is shaking up government agencies, founded the company SpaceX with the goal of making humans a multiplanetary species. In addition to ferrying astronauts to orbit for NASA, this company is currently building and test flying a new space vehicle, Starship, that's designed to transport massive amounts of cargo—including people—and land on Mars.

"This is quite a singular moment for the prospects of getting to Mars," says Zubrin, who sees this as a time filled with both opportunity and peril.

"I think it actually is pretty clear right now that we're going to get a humans-to-Mars program started," he says.

But to succeed, any such plan would need broad political support, and he worries about Mars suddenly becoming a divisive, partisan issue.

"This is not going to work," says Zubrin, "if this is understood to be an Elon Musk hobbyhorse."

The presidents and Mars

In his inaugural address in January, President Trump got the attention of the space community when he said the United States would "pursue our manifest destiny into the stars, launching American astronauts to plant the Stars and Stripes on the planet Mars."

In some ways, a president inspirationally referring to Mars is nothing new.

Back in 1989, for example, President George H. W. Bush called for a return to the moon, to be followed by "a journey into tomorrow, a journey to another planet: a manned mission to Mars." He envisioned footprints in the Martian dirt by 2019, the 50th anniversary of the moon landing.

"Within a few short years after President Bush's Kennedy-esque announcement, however, the initiative had faded into history," one policy analyst wrote.

A decade and a half later, President George W. Bush refocused NASA on a return to the moon by 2020, adding that "with the experience and knowledge gained on the moon, we will then be ready to take the next steps of space exploration: human missions to Mars and to worlds beyond."

President Obama told NASA to forgo the moon, but did maintain Mars as a goal: "By the mid-2030s, I believe we can send humans to orbit Mars and return them safely to Earth," he said in a speech at NASA's Kennedy Space Center. "And a landing on Mars will follow."

First, the moon?

During President Trump's first administration, he issued a space policy directive that refocused NASA on a human moon landing, with missions to Mars added as a future goal.

That program, called Artemis, is what NASA has pursued ever since. It continued under President Biden, although it's been criticized as relying on a super-expensive rocket that rarely flies.

Despite delays and cost overruns, NASA says it is poised to send humans to orbit the moon next year. A landing is planned for the year after that.

Trump's reference to Mars, but not the moon, in his inaugural speech had some in the space community wondering if this was a result of Musk's influence.

The new Trump administration could kill Artemis and its lunar plans, but Casey Dreier, chief of space policy for the Planetary Society, says that would be "strange in the historical sweep of things" given that the first Trump administration basically created this program

"There's a lot of good reasons to still go to the moon, one of which is that the U.S. has made a commitment to not just its allies, but to the broader commercial space and business community here in the country," notes Dreier.

Still, he thinks that the current administration might challenge NASA to really nail down how the space agency will move from lunar exploration to a Mars mission.

More difficult than the moon

NASA has a "Moon to Mars Program Office," notes Dreier. He thinks, however, "there's no 'to Mars' part of it. It's all 'to moon.' "

He says NASA has constrained budgets, and there's always been concerns that the agency hasn't had enough resources to pursue both the moon and Mars.

"It's hard to express verbally, I think, how much harder Mars is than the moon and how different it is," says Dreier.

A trip to the moon takes just three days. Going to Mars, in contrast, takes months—one way.

Recently, a NASA program aimed at retrieving pristine rocks from the surface of Mars and bringing them back to Earth ran into real trouble, as costs ballooned by billions and the mission timeline slipped. One decision the Trump administration will have to make is whether, and how, to pursue this science mission.

Dreier says in terms of human exploration, NASA needs to lay out how its lunar activities will actually help get the agency closer to going to Mars.

"That is the key reframing that could help the long-term exploration program be more efficient and effective," he says.

President Trump's pick to lead NASA is Jared Isaacman, a private astronaut who flew to orbit twice in SpaceX vehicles and completed the first commercial extravehicular activity, or spacewalk. He has yet to be confirmed.

A NASA spokesperson told NPR in an email that the agency is "looking forward to hearing more about the Trump Administration's plans for our agency and expanding exploration for the benefit of all, including sending American astronauts on the first human mission to the Red Planet."

A non-partisan planet

Because of the way the planets align, potential launch windows to Mars open up in 2026 and 2028.

Musk has publicly stated that he's aiming to send Starship to Mars as soon as next year.

Starship has yet to reach orbit, but Zubrin thinks it's possible that an uncrewed Starship might land on Mars by 2028.

Reliable energy allows ensuing human settlement.

Pombo 21 [Daviel Vazquez Pombo, MSc in High Voltage Engineering from Aalborg University & PhD in Planning and Operation of Isolated Hybrid Power Systems from Technical University of Denmark, 4-7-2021, A Hybrid Power System for a Permanent Colony on Mars, Space: Science & Technology A Science Partner Journal, <https://spj.science.org/doi/10.34133/2021/9820546>, Willie T.]

Many are the reasons behind establishing a colony in Mars such as the possibility of discovering extraterrestrial life, ensuring the survival of our species after a massive extinction event, and improving quality of life, etc. However, there are only a few scientific publications regarding Mars colonisation. The few existing focus mostly on spacecraft concepts and design, at the expense of hardly mentioning or even neglecting basic day-to-day critical infrastructures like the power system. In fact, the relevant previous work starts mostly on the 70s, later in the 90s and 2000s; a couple of very high-level publications appear that mainly update some of the base assumptions due to the discoveries obtained by different unmanned missions sent to the red planet. In any case, establishing a permanent outpost in Mars requires a flexible, scalable, reliable, and safe power system. Therefore, this paper is aimed at analysing power sources, transmission/coupling possibilities, topology, etc. for a near-future Mars colony. This is addressed by reviewing all the excellent work developed since the 50s until the early 2000s and then updating it with present methods and technologies. Culminating with a proposal of a power system suitable for the task at hand, serious dialogues must start among the scientific community as it is its duty to serve humankind’s development [1–5].

There has not been much development specifically about the power system. Early documents like [6] proposed either a purely nuclear system or a combination with solar photovoltaic (PV) [7]; some others [8] suggested radioisotope but with a back-up role. However, most of the available work is superficial and undetailed. Recent development in energy technology obtained as a result of the energy transition demands a revision of the sources and storage system that might be used in the power systems of surface space missions. In addition, no document has proposed a balance of plant, a proper topology, or addressed the transmission system for the colony to name a few, not to mention how to address the particular effects of the Martian environment on electrical equipment [9]. Thus, studies focusing solely on the Martian environment and requirements are needed. Thus, this paper is aimed at reviewing the available technologies that will conform the power system of a near-future Martian colony and propose a suitable topology. This is done by reviewing the different proposed mission designs, concluding in a reasonable evolutionary scenario for the colony and its balance of plant suitable to satisfy its power and energy needs.

Then, the structure of the paper is as follows: Section 2 reviews the history of the most important documents published targeting manned missions to Mars, the interest behind establishing a permanent outpost, and it subsequently defines a dynamic architecture for the outpost. Thereafter, different power sources are analysed on Section 3 in order to choose a suitable combination conforming the Martian hybrid power system (HyPS). Then, whether the coupling should be in AC, DC, or mixed is discussed in Section 4. Afterwards, the resulting topology of the HyPS is presented and evaluated in Sections 5 and 6, respectively. Finally, the conclusions of this work are presented in Section 7, while also pointing out research paths that might continue this work.

2. Background, Motivation, and Mission Requirements

This section reviews the most important studies targeting Mars exploration in chronological order. This is aimed at illustrating the evolving concepts in certain areas while the stagnation in others such as power systems, while also helping to define the targeted mission. Despite the intention of providing an overview of all the developed science, there is a strong focus on NASA achievements until the 2000s, since Roscosmos public documents are written in Russian, a language sadly falling out of the knowledge base of the author.

The first formal approach to reach Mars was published in 1953 [10], where the flight systems and spacecraft are envisioned. A crew of 70 would be the first humans seeing the planet up-close as the arrival date was 1965 and precursor robotic missions were not considered. However, it was not until 1988 where a space agency such as NASA published a study with a similar aim [2], followed shortly by series of studies of human and robotic exploration beyond Low Earth Orbit and the Moon, Mars, Phobos, etc. [11, 12]. Then, [13] concludes that enough technological readiness would be achieved by 2000, starting the operations shortly afterwards; envisioning crews of 4 people, doubling two years after the first arrival and, also, suggesting several schedules ranging from 2011 to 2018 for the first mission and 2014 to 2027 to inaugurate the first permanent settlement.

In any case, [13] satisfies the power needs of the missions by means of SP-100, a nuclear fission reactor designed in 1989 for lunar missions easily adaptable for Mars [6]. It is worth mentioning that all the previous publications dismiss the possibility of using any locally available resources since there was no data available until the discoveries obtained by both Viking landers. Subsequently, in 1991, [14] further elaborates about a surface operating reactor, while [15] takes an extra step by coupling it with an in situ resource utilisation (ISRU) unit. A device capable of using local water, ice, and atmospheric CO2 as raw materials for fuel, air, water, plastics food, and other supplies. However, this concept will fall into oblivion for more than 10 years [16–18]. Afterwards, [19] points out the need for further research about the Martian environment before they could design landers, space suits, and other surface systems. After 1997, the approach taken by the studies changes trying to acquire a more holistic perspective, since previous attempts like [20] ended up focusing mostly or solely into flight and trajectory designs. Then, [9, 21] represent the most complete analyses until then, aiming to be used to drive R&D plans, understand mission requirements, open discussions, establish a baseline for future proposals, and stimulate further thought by also demanding improvement in certain aspects like the power system. A crew of 6 is envisioned in [9], no attention to surface power system is paid, and no ISRU is considered despite [15] being published 6 years prior.

After entering the new millennia, a high-level review of the Mars mission is published [3] stating that human arrival to Mars is so certain that a second revision will be necessary between 2015 and 2020 to account for the actual arrival. The book reviews concepts such as [10, 19] which never envisioned the role of robotic exploration. These unmanned missions helped discover unknown phenomena that would have ruined any manned mission developed with that time’s technology. It also points to the arrival delay caused by these discoveries as the reason for funding reduction in benefit of robotic exploration. The more was discovered, the least money available for a manned mission was available. Then, [16, 17] present concepts for self-sustaining Mars colonies by means of implementing ISRU. In [16], the 500 people colony site is selected in the North polar cap due to the water/ice available, while [17] focuses on obtaining water from the atmosphere, to avoid site dependency, envisioning a modular architecture capable of either 100, 1000, or 10000 crew scenarios. Following this trend, [18] is aimed at implementing an ISRU system to support propulsion and power systems for ground and flight vehicles in two scenarios, an Antarctica-inspired 100 people scenario and another terraforming scenario with a crew of 10000.

The first document from the European Space Agency (ESA) about a Mars mission is published in 2006 [22], which presents plans to study the Martian environment by using rovers. Then, [23] revives the interest of manned missions in three different sites, discussing mobility possibilities both on the surface and underground; the arrival is estimated between 2030 and 2040. Subsequently, in 2009, [7] suggests a framework aiming to facilitate reaching Mars as a multiagency effort. The document describes the systems and operations of a robotic precursor and the first three manned missions of 6 people each in different locations. This document stands out as the first time that the power system and energy management are highlighted as a key improvement needed. Subsequently, [24], a more completed version of [7], builds upon some of the aforementioned documents like [11–14, 21, 22] and others like [25, 26]. Among the conclusions of [24], the higher importance of robot-human partnership should be mentioned. Additionally, the selected crew of 6 must land prior to 2030; otherwise, a technology reassessment will be needed. Lastly, [24] contains the first proper section about the power system, which is envisioned as a combination of nuclear and PV for the main power while radioisotope power systems (RPSs) for backup needs. Thereafter, in 2014, [27] updates [7] with the latest developments, increasing again the role of robots and identifying solar power generation, nuclear fission, and active thermal control among the critical technologies. On the other hand, ESA and Roscosmos have a shared exploration agenda; however, no manned missions are foreseen [28, 29]. India and Japan have expressed that their targets do not include Martian exploration whatsoever, while China do it independently, targeting manned missions to the Moon in 2030 in collaboration with Russia as a prior step [30, 31]. Then, the Evolvable Mars Campaign is the current NASA mission seeking to enable crewed Mars missions in the mid-2030s timeframe [32]. Lastly, SpaceX is targeting the first manned mission to Mars in 2024 as preparation for a permanent settlement to be started shortly afterwards [5]. Nevertheless, why should we keep pursuing the dream of reaching Mars?

Many publications like [7–9, 33, 34] have reviewed the numerous reasons and objectives behind reaching Mars, which can be divided into 5 categories: planetology, humanistic, scientific, technological, and political. Ultimately, the goal is the integration of all the prior and acquired knowledge, which is referred in this work as holistic. This unification of knowledge will transcend any objectives established for the Mars colonisation and will push humanity forward. A summary of the possible reasons and objectives behind the conquest of Mars is presented in Figure 1Opens in image viewer. Nevertheless, the questions risen due to this endeavour might be even more valuable than the answers we hope to find [23].

Figure 1 Reasons to go to Mars.

Once the reasons behind getting humans into the red planet have been stated, the importance of establishing a permanent settlement instead of a temporary visit should be highlighted. The most important reason backing a sustained human presence in Mars is the increased cost-effectiveness of the mission. Research potential and discoveries escalate during sustained missions, while the cost does not increase significantly [23]. However, even disregarding the difficulty of reaching the planet safely, the particularities of engineering a robust system capable of operating under the Martian conditions will unequivocally translate in technological advancement for the general humanity. Examples of this process can be [35] where cross-disciplinary research is undertaken making use of the ISRU to propel an ascent vehicle in Mars, or [36] where a prototype for a greenhouse suitable for the Martian environment is presented, or [37] which is aimed at expanding the applications of ISRU units. Additionally, since one of the objectives is to avoid a massive extinction event, establishing permanent human settlements in other celestial bodies is a key. Then, terraformation of Mars, which consists of warming up the planet, in order to thicken its atmosphere, ultimately obtaining liquid water surface oceans on Mars [34], would only be interesting to achieve if there is a sustained human presence on the planet [38]. Lastly, Mars is not considered the end of the space exploration, but rather a step in it. Future missions aimed at more distant celestial objects will require longer stays before returning or continuing; thus, Mars represents a great training outpost.

At the end of the day, there are a variety of different envisioned manned missions, with crews ranging from 4 to 10000 depending on the length of stay and the ultimate exploration objectives. Barely no attention has been paid to the configuration and actual implementation of the power and energy management system (PEMS). Manned missions might still be decades down the road; however, complex robotic missions rather than individual rovers might be closer than ever due to latest developments in the field [39, 40]. Whatever the case, manned or unmanned, all the infrastructures depend on having a functional power system. Therefore, a reference architecture for the colony must be defined prior to sizing the necessary PEMS as it is needed in order to estimate the mission’s power and energy needs.

2.1. Architecture of the Colony

Even though there is no certainty as of this moment about the exact outlook of the colony, there are several strong candidates that can provide a rough approximation to be used as a starting point. Additionally, one of the self-imposed conditions of this work is that all systems must use current or near-future technology (technology readiness level of at least 6); no breakthrough technologies are assumed as following the recommendations of [22, 41]. Then, depending on the objective, any Mars surface mission can follow one of the coming strategies [7]:

(i)

Mobile home: all the structures are packed in a mobile, rover-based colony whose objective is long-duration exploration at great distances in a nomadic way

(ii)

Commuter: fixed, stable site for the colony with inclusion of both un- and pressurised rovers for mobility and science. The focus is on human exploration

(iii)

Telecommuter: similar to commuter, although most of the exploration is based on teleoperation of small robotic system from the local habitat

The focus of this work is on the commuter scenario as is the one that has received more attention and, also, it is the one best serving the purpose of a complex, permanent colony. One of the main reasons is the expected cost reduction of future missions by making use of the ISRU units and local manufacturing. While its concrete economic implications are tough to estimate and fall beyond the scope of this work, it is simple to understand how having a base in Mars will greatly reduce future mission costs. This is due basically to two reasons: launching satellites or other robotic missions manufactured directly on site and the possibility of providing support or maintenance [23].

In the commuter architecture, any planetary structure can be divided into 8 categories: habitats, laboratories, bioregenerative life support, ISRU, surface mobility (rovers), extravehicular mobility (eva suits), power system, and launch and landing area. All of them contain similar equipment such as windows, hatches, docking mechanisms, power distribution systems, life support, environmental control, safety features, stowage, waste management, communications, airlocks, and egress routes [9, 13, 17]. It is worth mentioning that rovers in this scenario are assumed to have a range of 100 km before needed resupply [7]; however, there is already available technology to get significantly larger ranges [42]. Disregarding the mobility range and the number of rovers, the habitats are always expected to keep a minimum of occupation due to safety measures [24]. Then, with an increasing population and expected duration of the colony, the number and purpose of the habitats change dramatically; if for a 6 people colony, habitats only include the bare minimum survival needs [7, 9]; a 100 people colony demands the existence of recreation facilities such as shops, open community spaces, parks, and public transportation [17].

2.2. Growing Stages of the Colony

After identifying the colony architecture as a commuter, the most influencing parameter affecting the power and energy demand is the foreseen population as it affects the required resources, habitats, etc. Since the aim of this work is to establish a permanent self-sustaining colony, its deployment is approached in stages.

Given the recent development in the field of robotics, it is reasonable to assume that the settlement will be founded by robots, which will select and prepare the terrain for the arrival of the first crew. Later, an initial crew of 6 will arrive, continuing the expansion of the colony and starting the scientific work. The next arrivals are expected shortly afterwards once the technology and structures have been tested, thus ramping the population in steps to 20, 50, and 100. This chain of arrivals and colony development is consistent with published work as [7, 10, 13, 17, 32, 41]; however, the robotic role has been considered, in general, higher. Then, even though there are already scenarios envisioning colonies up to 10000 people [16, 17], the author considers that scenario to be far enough in the future to require a technology and method reassessment specially including the lessons learned from the first years of the Martian colony.

Affirming is the best solution.

Nguyen 20 [Tien Nguyen, Ph.D. in Organic Chemistry & B.S in Chemistry with Minor in Physics, 5-15-2020, Why NASA thinks nuclear reactors could supply power for human colonies in space, Chemical & Engineering News, <https://cen.acs.org/energy/nuclear-power/NASA-thinks-nuclear-reactors-supply/98/i19>, Willie T.] \*\*brackets in original\*\*

The astronauts pass their days in darkness. After several months of living on the moon, they’re still adjusting to the endless night. The crew’s habitat at the lunar south pole sits in a shadowed crater—chosen for its promise of ice—that has not been touched by a single ray of sun for billions of years.

Fortunately, the nearby nuclear reactor is unfazed by the lack of light. Connected to the astronauts’ base camp by a kilometer of cables cautiously tracing the lunar surface, the reactor provides an uninterrupted supply of electricity for recharging rovers, running scientific instruments, and most importantly, powering the air and heating systems that keep the astronauts alive.

This is one vision of what human exploration could look like on the moon. In fact, NASA has plans to make some versionsof this scene a reality—and soon.

The agency aims to send a human mission to the moon by 2024 in an effort named the Artemis project. Congress has allocated more than $6 billion of NASA’s 2020 fiscal budget for space exploration programs including the Space Launch System rocket, the Orion spacecraft, exploration ground systems, and research and development. The agency estimates that it will cost $35 billion to land a crew on the lunar surface, including the first woman to step foot on the moon. After 2024, NASA hopes to move to launching one human mission each year and reach sustainable operations on the moon by 2028.

The lessons learned in that phase will be crucial in preparing for future trips to Mars. One major effort will involve figuring out which power systems—including ones that have never been tested on the lunar surface, such as nuclear power—would best support future settlements. Whether the necessary materials can be brought safely to the moon and whether systems such as nuclear fission can run reliably under such harsh conditions are central questions that must be answered as engineers weigh their options.

Going nuclear

Choosing a power source depends on the particular mission’s needs, says Michelle A. Rucker, an engineer at NASA’s Lyndon B. Johnson Space Center who has researched possible architectures for space settlements. Electricity may come from nuclear reactors, solar panels, batteries, fuel cells, or some combination of these technologies connected in a power grid, she says. “I’m a big fan of all the types of power.”

But each power source has distinct pros and cons to consider. Solar arrays have reliably delivered renewable power in space for decades but are useless in places that never get any light, like the potentially resource-rich craters on the moon. And on the windy, dusty surface of Mars, solar panels may struggle to collect enough light, making them a risky option for powering life support systems, Rucker says. Batteries and fuel cells have limited lifetimes for now, relegating them to supplementary power sources at best.

One type of nuclear device that has been used to power spacecraft is a radioisotope thermoelectric generator, which runs on the heat produced by the decay of plutonium-238. These generators have been used since the 1960s in Mars rovers and space probes sent to the outer edges of the solar system, such as the Voyager spacecraft and Cassini. Despite being the workhorses of scientific missions, the generators provide only several hundred watts of power, just enough to send radio signals back to Earth or power a camera.

On Earth, the nuclear technology used by power plants is nuclear fission, which splits uranium-235 atoms via bombardment with neutrons to generate heat that’s captured to produce electricity. Nuclear fission holds the potential to provide a continuous, reliable source of power for a small space settlement designed to last for several years.

In the 1960s, many scientists thought fission reactors for space would follow on the heels of radioisotope generators. In 1965, the US launched a small nuclear fission–powered satellite named SNAP-10A, but electrical issues caused it to fail a mere 43 days after launch; it’s still in orbit, now just another piece of space junk. The Soviet Union launched 31 nuclear fission–powered satellites over the next 2 decades.

But the development of new nuclear fission reactors for space stalled during that time because of design problems and ballooning budgets. Engineers wanted advanced performance from these systems right away, which led to complicated and expensive designs, says David Poston, a nuclear engineer at Los Alamos National Laboratory. He and Patrick McClure, who specializes in reactor safety at Los Alamos, have worked at the lab for the past 25 years and recall the days when nuclear fission had fallen out of favor.

“Pat and I were sitting around just kind of demoralized,” Poston says, “because we had gotten to the point where NASA wasn’t really interested anymore because the impression was that it was going to be too expensive and too hard to develop a fission reactor.” But the pair were convinced their team could come up with a design to dispel the funk that had settled around fission power for space.

In the early 2010s, they got their chance: researchers at Los Alamos and later the NASA Glenn Research Center and the US Department of Energy began work on a joint project called Kilopower, now renamed the Nuclear Fission Power Project. The goal is to develop a new nuclear fission power system for space that would be capable of producing 10 kW of electrical energy.

Designing the reactor

Four of these reactors could easily provide the 40 kW of power that Rucker estimates a six-member crew would need to live on Mars. The team’s modular, compact design is lightweight enough for space exploration, in which every kilogram counts. Previous hypothetical fission-power concepts required a payload of 12–14 metric tons (a 6–7 t reactor plus a backup), whereas a single Kilopower reactor would weigh an estimated 1.5 t, she says.

The team decided to approach the reactor design anew, putting one priority above all: simplicity. This meant not only maintaining a simple mechanical design but also looking for opportunities to simplify safety approvals and project management. As an example, McClure says, the team made a conscious choice to limit the size of the nuclear core to a container already being used to test nuclear materials instead of fabricating a new one.

“I hate to call it an innovation because it’s not that complicated. But it’s an innovation that we said, ‘Why don’t we just do it the simple way that we know is going to work?’ ” Poston says. “We knew it was going to work, but the world didn’t.”

The nuclear core, which is about the size of a paper towel roll and weighs 28 kg, comprises a solid alloy of about 8% molybdenum and 92% highly enriched uranium. The nuclear material is surrounded by a beryllium oxide reflector that bounces neutrons into the core to drive the fission reaction. Lodged inside the core is a rod of pure boron carbide that absorbs neutrons, quenching fission reactions.

When the boron carbide rod is slowly removed, neutrons start to strike uranium atoms, occasionally splitting them, creating more neutrons and releasing energy as heat. Once the number of neutrons lost equals the number of neutrons being produced, the reactor becomes self-sustaining. The fission-generated heat travels through sodium-filled heat pipes to a set of Stirling engines. Designed in the early 1800s, these simple piston-driven engines convert heat to electricity. Finally, the team’s reactor design includes a radiator to remove the excess heat, sloughing it off into space.

“We wanted to show not only the world but ourselves that we can still do something real because we had gotten away from actually testing real fission systems,” Poston says.

In a proof-of-concept test called DUFF, the team showed that the hardware worked to produce electricity. Then, in 2018, the team successfully tested a prototype of the reactor at the Nevada National Security Site. During the months-long KRUSTY experiment, researchers tested each of the reactor’s components and its ability to withstand various failures. (The experiment names were inspired by The Simpsons TV show.) The reactor also successfully passed a 28 h test, in which it ramped up to full power, peaking at about 5 kW, operated at a steady state, and then shut down safely.

The team hopes that with more optimization, such as by increasing the size of the nuclear core, it can meet its goal of producing 10 kW per reactor.

Of course, some people look at highly enriched uranium with skepticism, given its potential to harm humans and its role as a material for nuclear weapons. But McClure says transporting uranium to the moon and working alongside a reactor can be done safely. Uranium emits weak α particles, which can’t penetrate a piece of paper or skin, so the shielding that surrounds the nuclear core would prevent astronauts from any radiation exposure. Burying the reactor a few meters into the ground or putting it behind a big rock feature could also help keep astronauts safe from radiation when the reactor is on. Once the reactor has run its course, the radioactive waste will likely be shielded and left alone.

The worst-case scenario for such a system would involve the entire reactor blowing up midlaunch, aerosolizing and dispersing uranium particles. Even then, a person a kilometer away might receive a dose in the millirem range—less than the dose you get from solar radiation when you take a plane flight, McClure says.

Ultimately, the fission reactor’s future will depend on not only technical success but also sufficient funding. Dionne Hernández-Lugo of the NASA Glenn Research Center and deputy project manager of the Nuclear Fission Power Project says the proposed budget puts the team “on the path to build and send a surface power system to the moon.”

“It’ll be really exciting to test [the reactor] on the moon and get some experience under our belts before we go to Mars,” Rucker says. “On the moon, you’re close to home, so if something fails, it’s a fairly close trip to get back home, whereas on Mars, your system better be working.”

That enables lateral innovation.

West 20 [Darrell M. West, Senior Fellow in Governance Studies @ Center for Technology Innovation of Brookings, 8-18-2020, Five reasons to explore Mars, Brookings, <https://www.brookings.edu/articles/five-reasons-to-explore-mars/>]

The recent launch of the Mars rover Perseverance is the latest U.S. space mission seeking to understand our solar system. Its expected arrival at the Red Planet in mid-February 2021 has a number of objectives linked to science and innovation. The rover is equipped with sophisticated instruments designed to search for the remains of ancient microbial life, take pictures and videos of rocks, drill for soil and rock samples, and use a small helicopter to fly around the Jezero Crater landing spot.

Mars is a valuable place for exploration because it can be reached in 6 ½ months, is a major opportunity for scientific exploration, and has been mapped and studied for several decades. The mission represents the first step in a long-term effort to bring Martian samples back to Earth, where they can be analyzed for residues of microbial life. Beyond the study of life itself, there are a number of different benefits of Mars exploration.

UNDERSTAND THE ORIGINS AND UBIQUITY OF LIFE

The site where Perseverance is expected to land is the place where experts believe 3.5 billion years ago held a lake filled with water and flowing rivers. It is an ideal place to search for the residues of microbial life, test new technologies, and lay the groundwork for human exploration down the road.

The mission plans to investigate whether microbial life existed on Mars billions of years ago and therefore that life is not unique to Planet Earth. As noted by Chris McKay, a research scientist at NASA’s Ames Research Science Center, that would be an extraordinary discovery. “Right here in our solar system, if life started twice, that tells us some amazing things about our universe,” he pointed out. “It means the universe is full of life. Life becomes a natural feature of the universe, not just a quirk of this odd little planet around this star.”

The question of the origins of life and its ubiquity around the universe is central to science, religion, and philosophy. For much of our existence, humans have assumed that even primitive life was unique to Planet Earth and not present in the rest of the solar system, let alone the universe. We have constructed elaborate religious and philosophical narratives around this assumption and built our identity along the notion that life is unique to Earth.

If, as many scientists expect, future space missions cast doubt on that assumption or outright disprove it by finding remnants of microbial life on other planets, it will be both invigorating and illusion-shattering. It will force humans to confront their own myths and consider alternative narratives about the universe and the place of Earth in the overall scheme of things.

As noted in my Brookings book, Megachange, given the centrality of these issues for fundamental questions about human existence and the meaning of life, it would represent a far-reaching shift in existing human paradigms. As argued by scientist McKay, discovering evidence of ancient microbial life on Mars would lead experts to conclude that life likely is ubiquitous around the universe and not limited to Planet Earth. Humans would have to construct new theories about ourselves and our place in the universe.

DEVELOP NEW TECHNOLOGIES.

The U.S. space program has been an extraordinary catalyst for technology innovation. Everything from Global Positioning Systems and medical diagnostic tools to wireless technology and camera phones owe at least part of their creation to the space program. Space exploration required the National Aeronautics and Space Administration to learn how to communicate across wide distances, develop precise navigational tools, store, transmit, and process large amounts of data, deal with health issues through digital imaging and telemedicine, and develop collaborative tools that link scientists around the world. The space program has pioneered the miniaturization of scientific equipment and helped engineers figure out how to land and maneuver a rover from millions of miles away. Going to Mars requires similar inventiveness. Scientists have had to figure out how to search for life in ancient rocks, drill for rock samples, take high resolution videos, develop flying machines in a place with gravity that is 40 percent lower than on Earth, send detailed information back to Earth in a timely manner, and take off from another planet. In the future, we should expect large payoffs in commercial developments from Mars exploration and advances that bring new conveniences and inventions to people.

ENCOURAGE SPACE TOURISM

In the not too distant future, wealthy tourists likely will take trips around the Earth, visit space stations, orbit the Moon, and perhaps even take trips around Mars. For a substantial fee, they can experience weightlessness, take in the views of the entire planet, see the stars from outside the Earth’s atmosphere, and witness the wonders of other celestial bodies.

The Mars program will help with space tourism by improving engineering expertise with space docking, launches, and reentry and providing additional experience about the impact of space travel on the human body. Figuring out how weightlessness and low gravity situations alter human performance and how space radiation affects people represent just a couple areas where there are likely to be positive by-products for future travel.

The advent of space tourism will broaden human horizons in the same way international travel has exposed people to other lands and perspectives. It will show them that the Earth has a delicate ecosystem that deserves protecting and why it is important for people of differing countries to work together to solve global problems. Astronauts who have had this experience say it has altered their viewpoints and had a profound impact on their way of thinking.

FACILITATE SPACE MINING

zmany objects around the solar system are made of similar minerals and chemical compounds that exist on Earth. That means that some asteroids, moons, and planets could be rich in minerals and rare elements. Figuring out how to harvest those materials in a safe and responsible manner and bring them back to Earth represents a possible benefit of space exploration. Elements that are rare on Earth may exist elsewhere, and that could open new avenues for manufacturing, product design, and resource distribution. This mission could help resource utilization through advances gained with its Mars Oxygen Experiment (MOXIE) equipment that converts Martian carbon dioxide into oxygen. If MOXIE works as intended, it would help humans live and work on the Red Planet.

ADVANCE SCIENCE

One of the most crucial features of humanity is our curiosity about the life, the universe, and how things operate. Exploring space provides a means to satisfy our thirst for knowledge and improve our understanding of ourselves and our place in the universe. Space travel already has exploded centuries-old myths and promises to continue to confront our long-held assumptions about who we are and where we come from. The next decade promises to be an exciting period as scientists mine new data from space telescopes, space travel, and robotic exploration. Ten or twenty years from now, we may have answers to basic questions that have eluded humans for centuries, such as how ubiquitous life is outside of Earth, whether it is possible for humans to survive on other planets, and how planets evolve over time.

Either we successfully colonize or save humanity while trying.

HÉIgeartaigh 16 [Seán Ó HÉIgeartaigh, professor @ Cambridge + PhD in Genomics from Trinity College of Dublin, 10-5-2016, Technological Wild Cards: Existential Risk and a Changing Humanity, Centre for the Study of Existential Risk, <https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3446697>]

4. WORKING ON THE (DOOMSDAY) CLOCK

Technological progress now offers us a vision of a remarkable future. The advances that have brought us onto an unsustainable pathway have also raised the quality of life dramatically for many, and have unlocked scientific directions that can lead us to a safer, cleaner, more sustainable world. With the right developments and applications of technology, in concert with advances in social, democratic, and distributional processes globally, progress can be made on all of the challenges discussed here. Advances in renewable energy and related technologies, and more efficient energy use—advances that are likely to be accelerated by progress in technologies such as artificial intelligence—can bring us to a point of zero-carbon emissions. New manufacturing capabilities provided by synthetic biology may provide cleaner ways of producing products and degrading waste. A greater scientific understanding of our natural world and the ecosystem services on which we rely will aid us in plotting a trajectory whereby critical environmental systems are maintained while allowing human flourishing. Even advances in education and women’s rights globally, which will play a role in achieving a stable global population, can be aided specifically by the information, coordination, and education tools that technology provides, and more generally by growing prosperity in the relevant parts of the world.

There are catastrophic and existential risks that we will simply not be able to overcome without advances in science and technology. These include possible pandemic outbreaks, whether natural or engineered. The early identification of incoming asteroids, and approaches to shift their path, is a topic of active research at NASA and elsewhere. While currently there are no known techniques to prevent or mitigate a supervolcanic eruption, this may not be the case with the tools at our disposal a century from now. And in the longer run, a civilization that has spread permanently beyond the earth, enabled by advances in spaceflight, manufacturing, robotics, and terraforming, is one that is much more likely to endure. However, the breathtaking power of the tools we are developing is not to be taken lightly. We have been very lucky to muddle through the advent of nuclear weapons without a global catastrophe. And within this century, it is realistic to expect that we will be able to rewrite much of biology to our purposes, intervene deliberately and in a large-scale way in the workings of our global climate, and even develop agents with intelligence that is fundamentally alien to ours, and may vastly surpass our own in some or even most domains—a development that would have uniquely unpredictable consequences.

Every second matters.

Beckstead 14 [Nick Beckstead, research fellow at Oxford University's Future of Humanity Institute, 2014, Will we eventually be able to colonize other stars? Notes from a preliminary review, <https://www.fhi.ox.ac.uk/will-we-eventually-be-able-to-colonize-other-stars-notes-from-a-preliminary-review/>, Willie T.]

While this estimate is conservative in that it assumes only computational mechanisms whose implementation has been at least outlined in the literature, it is useful to have an even more conservative estimate that does not assume a non-biological instantiation of the potential persons. Suppose that about 10^10 biological humans could be sustained around an average star. Then the Virgo Supercluster could contain 10^23 biological humans. This corresponds to a loss of potential equal to about 10^14 potential human lives per second of delayed colonization.” Bostrom 2003, “Astronomical Waste.”

[2] “The lion’s share of the expected duration of our existence comes from the possibility that our descendants colonize planets outside our solar system. There are many stars that we may be able to reach with future technology (about 10^13 in our supercluster). Some of them will probably have planets that are hospitable to life, perhaps many of these planets could be made hospitable with appropriate technological developments. Some of these are near stars that will burn for much longer than our sun, some for as much as 100 trillion years (Adams, 2008, p. 39). If multiple locations were colonized, the risk of total destruction would dramatically decrease, since it would take independent global disasters, or a cosmological catastrophe, to destroy civilization. Because of this, it is possible that our descendants would survive until the very end, and that there could be extraordinarily large numbers of them.” Beckstead 2013, “On the Overwhelming Importance of Shaping the Far Future,” p. 57.

## Rebutall EV

1. T – Nuclear energy produces the least radiation AND no meltdown impact.

Rhodes 18 [Richard Rhodes, visiting scholar @ Harvard, MIT, and Stanford University, 7-19-2018, Why Nuclear Power Must Be Part of the Energy Solution, Yale e360, <https://e360.yale.edu/features/why-nuclear-power-must-be-part-of-the-energy-solution-environmentalists-climate>, Willie T.]

In the United States in 2016, nuclear power plants, which generated almost 20 percent of U.S. electricity, had an average capacity factor of 92.3 percent, meaning they operated at full power on 336 out of 365 days per year. (The other 29 days they were taken off the grid for maintenance.) In contrast, U.S. hydroelectric systems delivered power 38.2 percent of the time (138 days per year), wind turbines 34.5 percent of the time (127 days per year) and solar electricity arrays only 25.1 percent of the time (92 days per year). Even plants powered with coal or natural gas only generate electricity about half the time for reasons such as fuel costs and seasonal and nocturnal variations in demand. Nuclear is a clear winner on reliability.

Third, nuclear power releases less radiation into the environment than any other major energy source. This statement will seem paradoxical to many readers, since it’s not commonly known that non-nuclear energy sources release any radiation into the environment. They do. The worst offender is coal, a mineral of the earth’s crust that contains a substantial volume of the radioactive elements uranium and thorium. Burning coal gasifies its organic materials, concentrating its mineral components into the remaining waste, called fly ash. So much coal is burned in the world and so much fly ash produced that coal is actually the major source of radioactive releases into the environment.

In the early 1950s, when the U.S. Atomic Energy Commission believed high-grade uranium ores to be in short supply domestically, it considered extracting uranium for nuclear weapons from the abundant U.S. supply of fly ash from coal burning. In 2007, China began exploring such extraction, drawing on a pile of some 5.3 million metric tons of brown-coal fly ash at Xiaolongtang in Yunnan. The Chinese ash averages about 0.4 pounds of triuranium octoxide (U3O8), a uranium compound, per metric ton. Hungary and South Africa are also exploring uranium extraction from coal fly ash.

Studies indicate even the worst possible accident at a nuclear plant is less destructive than other major industrial accidents.

The partial meltdown of the Three-Mile Island reactor in March 1979, while a disaster for the owners of the Pennsylvania plant, released only a minimal quantity of radiation to the surrounding population. According to the U.S. Nuclear Regulatory Commission:

“The approximately 2 million people around TMI-2 during the accident are estimated to have received an average radiation dose of only about 1 millirem above the usual background dose. To put this into context, exposure from a chest X-ray is about 6 millirem and the area’s natural radioactive background dose is about 100-125 millirem per year… In spite of serious damage to the reactor, the actual release had negligible effects on the physical health of individuals or the environment.”

2. It’s statistically near-zero risk.

Ottoway ND [HJ Ottoway, No Date, IAEA, Nuclear Power Plant Safety, <https://www.iaea.org/sites/default/files/publications/magazines/bulletin/bull16-1/161_202007277.pdf>, Willie T.]

Early work in estimating the probability of large-scale accidents [4,6] summarized in WASH-1250, has indicated that the probability of a catastrophic accident in a nuclear power plant is very small — in the order of 10'9 to 10\*10 per year. (10-9/year means 1 chance in 1,000,000,000 per year of operation). Preliminary results from more thorough study in U.S.A. [3] appear to be in rather close agreement. Results of Refs. 4 and 6 have been interpreted in WASH-1250 to imply an average mortality risk to people living in the vicinity of a nuclear power plant of about 10'10 per person/year. In comparison with the relationship of Figure 1 this risk is seen to be trivial, even if there were no benefit involved — yet there is an obvious benefit provided in the form of electrical energy.

3. If poor oversight exists, then the impact happens anyways since existing reactors will just break down AND meltdowns have occurred with no impact --- Chernobyl, Fukushima, Three Mile Island all prove.

4. The companies that are using it will care and ensure safeguards because they want to avoid reputational and liability damage. Utilities companies also care about reliability, also they’ll ensure they only buy secure reactors AND it’s a competitive market, so if you’re safer than you’ll have more deals.

6. Companies self regulate  
Beaver 24:  
Beaver, W., 1-9-2024, Insurance and the public–private management of risk at US commercial nuclear power plants, Wiley Online Library, <https://onlinelibrary.wiley.com/doi/full/10.1111/rmir.12257>, //GP  
In the aftermath of the TMI-2 accident, sweeping changes occurred in the US nuclear industry. The accident created a public relations nightmare for nuclear utilities, increasing public fear and distrust, and threatening the continued existence of their plants and the future of US nuclear power generation. Under these circumstances, the utilities recognized the need for more self-regulation and better management of individual reactor risks. As a result, the utilities created several new institutions to develop safety standards, administer safety inspections, perform individual plant risk assessments and, when necessary investigate accidents. The Kemeny Commission recommended that the nuclear industry “establish a program that specifies appropriate safety standards including those for management, quality assurance, and operating procedures and practices, and that conducts independent evaluations” (Kemeny, [1979](https://onlinelibrary.wiley.com/doi/full/10.1111/rmir.12257?utm_source=chatgpt.com#rmir12257-bib-0026), p. 68). In response, the industry in December 1979 established the INPO with the mission to “promote the highest levels of safety and reliability—to promote excellence—in the operation of commercial nuclear power plants” (Institute of Nuclear Power Operations INPO, [2020](https://onlinelibrary.wiley.com/doi/full/10.1111/rmir.12257?utm_source=chatgpt.com#rmir12257-bib-0013)). After its formation, INPO developed performance indicators and began to conduct plant evaluations, visiting each plant about every 18 months. INPO conducted evaluations by sending teams of about 15 INPO personnel and peer evaluators to the plant for 2 weeks. As part of the evaluation, INPO assigns an index number for each reactor ranging from 0 (poor) to 100 (superior), and then ranks each reactor site from Category 1 (exemplary) to Category 5 (requires special attention and assistance) (US Department of Energy USDOE, [1986](https://onlinelibrary.wiley.com/doi/full/10.1111/rmir.12257?utm_source=chatgpt.com#rmir12257-bib-0054), pp. D4–5). The index is based on 10 performance indicators first reported on by utilities to INPO in 1985 (Pate, [1986](https://onlinelibrary.wiley.com/doi/full/10.1111/rmir.12257?utm_source=chatgpt.com#rmir12257-bib-0036), p. 61).

A2 Climate

Renewables aren’t enough and all implantation plans of a renewable grid are idealistic with flaws. Clack 17

Clack CTM, Qvist SA, Apt J, Bazilian M, Brandt AR, Caldeira K, Davis SJ, Diakov V, Handschy MA, Hines PDH, Jaramillo P, Kammen DM, Long JCS, Morgan MG, Reed A, Sivaram V, Sweeney J, Tynan GR, Victor DG, Weyant JP, Whitacre JF. Evaluation of a proposal for reliable low-cost grid power with 100% wind, water, and solar. Proc Natl Acad Sci U S A. 2017 Jun 27;114(26):6722-6727. doi: 10.1073/pnas.1610381114. Epub 2017 Jun 19. PMID: 28630353; PMCID: PMC5495221.

Anumber of studies, including a study by one of us, have concluded that an 80% decarbonization of the US electric grid could be achieved at reasonable cost ([1](https://www.pnas.org/doi/10.1073/pnas.1610381114?url_ver=Z39.88-2003&rfr_id=ori%3Arid%3Acrossref.org&rfr_dat=cr_pub++0pubmed#core-r1), [2](https://www.pnas.org/doi/10.1073/pnas.1610381114?url_ver=Z39.88-2003&rfr_id=ori%3Arid%3Acrossref.org&rfr_dat=cr_pub++0pubmed#core-r2)). The high level of decarbonization is facilitated by an optimally configured continental high-voltage transmission network. There seems to be some consensus that substantial amounts of greenhouse gas (GHG) emissions could be avoided with widespread deployment of solar and wind electric generation technologies along with supporting infrastructure. Furthermore, it is not in question that it would be theoretically possible to build a reliable energy system excluding all bioenergy, nuclear energy, and fossil fuel sources. Given unlimited resources to build variable energy production facilities, while expanding the transmission grid and accompanying energy storage capacity enormously, one would eventually be able to meet any conceivable load. However, in developing a strategy to effectively mitigate global energy-related CO2 emissions, it is critical that the scope of the challenge to achieve this in the real world is accurately defined and clearly communicated. Wind and solar are variable energy sources, and some way must be found to address the issue of how to provide energy if their immediate output cannot continuously meet instantaneous demand. The main options are to (i) curtail load (i.e., modify or fail to satisfy demand) at times when energy is not available, (ii) deploy very large amounts of energy storage, or (iii) provide supplemental energy sources that can be dispatched when needed. It is not yet clear how much it is possible to curtail loads, especially over long durations, without incurring large economic costs. There are no electric storage systems available today that canaffordably and dependably store the vast amounts of energy needed over weeks to reliably satisfy demand using expanded wind and solar power generation alone. These facts have led many US and global energy system analyses ([1](https://www.pnas.org/doi/10.1073/pnas.1610381114?url_ver=Z39.88-2003&rfr_id=ori%3Arid%3Acrossref.org&rfr_dat=cr_pub++0pubmed#core-r1) –[10](https://www.pnas.org/doi/10.1073/pnas.1610381114?url_ver=Z39.88-2003&rfr_id=ori%3Arid%3Acrossref.org&rfr_dat=cr_pub++0pubmed#core-r10)) to recognize the importance of a broad portfolio of electricity generation technologies, including sources that can be dispatched when needed. Faults with the Jacobson et al. Analyses Jacobson et al. ([11](https://www.pnas.org/doi/10.1073/pnas.1610381114?url_ver=Z39.88-2003&rfr_id=ori%3Arid%3Acrossref.org&rfr_dat=cr_pub++0pubmed#core-r11)) along with additional colleagues in a companion article ([12](https://www.pnas.org/doi/10.1073/pnas.1610381114?url_ver=Z39.88-2003&rfr_id=ori%3Arid%3Acrossref.org&rfr_dat=cr_pub++0pubmed#core-r12)) attempt to show the feasibility of supplying all energy end uses (in the continental United States) with almost exclusively wind, water, and solar (WWS) power (no coal, natural gas, bioenergy, or nuclear power), while meeting all loads, at reasonable cost. Ref. [11](https://www.pnas.org/doi/10.1073/pnas.1610381114?url_ver=Z39.88-2003&rfr_id=ori%3Arid%3Acrossref.org&rfr_dat=cr_pub++0pubmed#core-r11) does include 1.5% generation from geothermal, tidal, and wave energy. Throughout the remainder of the paper, we denote the scenarios in ref. [11](https://www.pnas.org/doi/10.1073/pnas.1610381114?url_ver=Z39.88-2003&rfr_id=ori%3Arid%3Acrossref.org&rfr_dat=cr_pub++0pubmed#core-r11) as 100% wind, solar, and hydroelectric power for simplicity. Such a scenario may be a useful way to explore the hypothesis that it is possible to meet the challenges associated with reliably supplying energy across all sectors almost exclusively with large quantities of a narrow range of variable energy resources. However, there is a difference between presenting such visions as thought experiments and asserting, as the authors do, that rapid and complete conversion to an almost 100% wind, solar, and hydroelectric power system is feasible with little downside ([12](https://www.pnas.org/doi/10.1073/pnas.1610381114?url_ver=Z39.88-2003&rfr_id=ori%3Arid%3Acrossref.org&rfr_dat=cr_pub++0pubmed#core-r12)). It is important to understand the distinction between physical possibility and feasibility in the real world. To be clear, the specific aim of the work by Jacobson et al. ([11](https://www.pnas.org/doi/10.1073/pnas.1610381114?url_ver=Z39.88-2003&rfr_id=ori%3Arid%3Acrossref.org&rfr_dat=cr_pub++0pubmed#core-r11)) is to provide “low-cost solutions to the grid reliability problem with 100% penetration of WWS [wind, water and solar power] across all energy sectors in the continental United States between 2050 and 2055.” Relying on 100% wind, solar, and hydroelectric power could make climate mitigation more difficult and more expensive than it needs to be. For example, the analyses by Jacobson et al. (11, 12) exclude from consideration several commercially available technologies, such as nuclear and bioenergy, that could potentially contribute to decarbonization of the global energy system, while also helping assure high levels of reliability in the power grid. Furthermore, Jacobson et al. (11, 12) exclude carbon capture and storage technologies for fossil fuel generation. An additional option not considered in the 100% wind, solar, and hydroelectric studies is bioenergy coupled with carbon capture and storage to create negative emissions within the system, which could help with emissions targets. With all available technologies at our disposal, achieving an 80% reduction in GHG emissions from the electricity sector at reasonable costs is extremely challenging, even using a new continental-scale high-voltage transmission grid. Decarbonizing the last 20% of the electricity sector as well as decarbonizing the rest of the economy that is difficult to electrify (e.g., cement manufacture and aviation) are even more challenging. These challenges are deepened by placing constraints on technological options. In our view, to show that a proposed energy system is technically and economically feasible, a study must, at a minimum, show, through transparent inputs, outputs, analysis, and validated modeling (13), that the required technologies have been commercially proven at scale at a cost comparable with alternatives; that the technologies can, at scale, provide adequate and reliable energy; that the deployment rate required of such technologies and their associated infrastructure is plausible and commensurate with other historical examples in the energy sector; and that the deployment and operation of the technologies do not violate environmental regulations. We show that refs. 11 and 12 do not meet these criteria and, accordingly, do not show the technical, practical, or economic feasibility of a 100% wind, solar, and hydroelectric energy vision. As we detail below and in SI Appendix, ref. 11 contains modeling errors; incorrect, implausible, and/or inadequately supported assumptions; and the application of methods inappropriate to the task. In short, the analysis performed in ref. 11 does not support the claim that such a system would perform at reasonable cost and provide reliable power. The vision proposed by the studies in refs. 11 and 12 narrows generation options but includes a wide range of currently uncosted innovations that would have to be deployed at large scale (e.g., replacement of our current aviation system with yetto-be-developed hydrogen-powered planes). The system in ref. 11 assumes the availability of multiweek energy storage systems that are not yet proven at scale and deploys them at a capacity twice that of the entire United States’ generating and storage capacity today. There would be underground thermal energy storage (UTES) systems deployed in nearly every community to provide services for every home, business, office building, hospital, school, and factory in the United States. However, the analysis does not include an accounting of the costs of the physical infrastructure (pipes and distribution lines) to support these systems. An analysis of district heating (14) showed that having existing infrastructure is key to effective deployment, because the high upfront costs of the infrastructure are prohibitive. It is not difficult to match instantaneous energy demands for all purposes with variable electricity generation sources in real time as needed to assure reliable power supply if one assumes, as the authors of the ref. 11 do, that there exists a nationally integrated grid, that most loads can be flexibly shifted in time, that large amounts of multiweek and seasonal energy storage will be readily available at low cost, and that the entire economy can easily be electrified or made to use hydrogen. However, adequate support for the validity of these assumptions is lacking. Furthermore, the conclusions in ref. 11 rely heavily on free, nonmodeled hydroelectric capacity expansion (adding turbines that are unlikely to be feasible without major reconstruction of existing facilities) at current reservoirs without consideration of hydrological constraints or the need for additional supporting infrastructure (penstocks, tunnels, and space); massive scale-up of hydrogen production and use; unconstrained, nonmodeled transmission expansion with only rough cost estimates; and free time-shifting of loads at large scale in response to variable energy provision. None of these are going to be achieved without cost. Some assumed expansions, such as the hydroelectric power output, imply operating facilities way beyond existing constraints that have been established for important environmental reasons. Without these elements, the costs of the energy system in ref. 11 would be substantially higher than claimed. In evaluating the 100% wind, solar, and hydroelectric power system (11), we focus on four major issues that are explored in

1.      Nuclear energy is better than renewables -- 3 warrants

Matthews 22 [Richard Matthews. Richard Matthews is a researcher, writer, journalist, consultant, and change activist. He has published thousands of articles and contributed to reports for policymakers including a United Nations Environment Program (UNEP) publication. His critical, interdisciplinary analyses have been cited by a wide array of academic publications. His research interests include carbon removal, nuclear power, and disinformation. He is currently spearheading Change Oracle’s Polycrisis Project (COPP). “Nuclear Power Versus Renewable Energy”. [changeoracle.com](http://changeoracle.com/). 07-20-2022. Accessed: 03-06-2025.

<https://changeoracle.com/2022/07/20/nuclear-power-versus-renewable-energy/#:~:text=Solar%20%26%20Wind%20Compared%20to%20Nuclear%20Energy&text=An%20analysis%20of%20the%20levelized,include%20storage%20and%20network%20costs>. //addy]

Nuclear is also one of the cleanest sources of energy. Recent research published in the Journal of Cleaner Production found that the emission of GHGs and natural resource use associated with nuclear power generation was similar to that of renewable energy.  An analysis by the European Commission indicates that in terms of full-cycle production, the emissions from nuclear are around the same as wind.  Other studies have concluded that nuclear may be even cleaner than solar. Orano claims that nuclear power generates four times fewer GHGs than solar.

Nuclear also requires substantially less land than wind and solar.  According to some assessments, nuclear requires 1/2,000th as much land as wind and 1/400th as much land as solar.  US government data indicates that a 1,000-megawatt wind farm requires 360 times more land than a similar-capacity nuclear facility, while a solar plant requires 75 times more area.

While there are valid concerns about nuclear waste, there are also legitimate issues with renewable waste.  Wind and solar generate a litany of chemical wastes including toxic heavy metals like cadmium, arsenic, chromium, and lead. While nuclear waste can remain radioactive for thousands of years, waste metals associated with renewables remain dangerous forever. Perhaps most importantly, the volume of nuclear waste is a tiny fraction of renewable waste. Nuclear waste is 1/10,000th of the waste generated by solar and 1/500th of the waste generated by wind.

Nuclear energy can be scaled up better than any renewable source and can put us on track for climate change progress. Empirical case studies and models prove Qvist 15

Staffan A. Qvist, "Potential for Worldwide Displacement of Fossil-Fuel Electricity by Nuclear Energy in Three Decades Based on Extrapolation of Regional Deployment Data," May 13, 2015 // Shah

<https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074>

Article Authors Metrics Comments Media Coverage Abstract Introduction Conclusion Supporting Information Author Contributions References Reader Comments Figures Abstract There is an ongoing debate about the deployment rates and composition of alternative energy plans that could feasibly displace fossil fuels globally by mid-century, as required to avoid the more extreme impacts of climate change. Here we demonstrate the potential for a large-scale expansion of global nuclear power to replace fossil-fuel electricity production, based on empirical data from the Swedish and French light water reactor programs of the 1960s to 1990s. Analysis of these historical deployments show that if the world built nuclear power at no more than the per capita rate of these exemplar nations during their national expansion, then coal- and gas-fired electricity could be replaced worldwide in less than a decade. Under more conservative projections that take into account probable constraints and uncertainties such as differing relative economic output across regions, current and past unit construction time and costs, future electricity demand growth forecasts and the retiring of existing aging nuclear plants, our modelling estimates that the global share of fossil-fuel-derived electricity could be replaced within 25–34 years. This would allow the world to meet the most stringent greenhouse-gas mitigation targets. Introduction Human industrial and agricultural activity is now the principal cause of changes in the Earth’s atmospheric composition of long-lived greenhouse gases, mainly carbon dioxide (CO2), and will be the driving force of climate change in the 21st century [[1](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone.0124074.ref001)]. More than 190 nations have agreed on the need to limit fossil-fuel emissions to mitigate anthropogenic climate change, as formalized in the 1992 Framework Convention on Climate Change [[2](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone.0124074.ref002)]. However, the competing global demand for low-cost and reliable energy and electricity to fuel the rapid economic development of countries like China and India has led to a large expansion of energy production capacity based predominantly on fossil fuels. Because of this, human-caused greenhouse-gas emissions continue to increase, even though the threat of climate change from the burning of fossil fuels is widely recognized [[3](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone.0124074.ref003)]. There is therefore an urgent need to assess what energy-generation technologies could allow for deep cuts in greenhouse-gas emissions and air pollution while simultaneously allowing for a rapid expansion of economic activity and prosperity in the poorer regions of the world. Much recent attention has been given to the potential of, and constraints on, renewable energy [[4](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone.0124074.ref004)]. Here we take a different tack, by making use of historical data from the Swedish nuclear program to model the feasibility of a massive expansion of nuclear power at a rate sufficient to largely replace the current electricity production from fossil fuel sources by mid-century—the time window for achieving the least-emissions pathway (representative concentration pathway 2.6 or lower) as set out in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [[5](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone.0124074.ref005)]. In a supporting analysis we also model France as a case study; the French example provides an excellent example of a significantly larger nation also pursuing an electricity production policy for a prolonged period based almost entirely on nuclear energy. As part of this analysis, we detail the impact nuclear power had on historical Swedish and French CO2 emissions, define the rate nuclear capacity was added, estimate the cost and construction time in these national nuclear programs, finally, show how they can be compared meaningfully to the current global situation. Why consider a large-scale nuclear scenario? The operation of a nuclear reactor does not emit greenhouse gases or other forms of particulate air pollution, and it is one of few base-load alternatives to fossil energy sources currently available that has been proven by historical experience to be able to be significantly expanded and scaled up [[6](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone.0124074.ref006)]. Large-hydro projects are geographically constrained and typical have widespread impacts on river basins [[7](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone.0124074.ref007)]. The land use [[8](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone.0124074.ref008)], and biodiversity [[9](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone.0124074.ref009)] aspects of a large-scale expansion of biomass for energy make its use as a sustainable global energy source questionable. Monetary values presented in this paper are, unless otherwise stated, reported in the value of the US dollar in 2005. When needed, inflation adjustments were done using data as provided by the U.S. Bureau of Labor Statistics. The year 2005 was chosen rather than 2014 because it is the current reference year for most major databases, including the World Bank data, and the reader can thus directly verify numbers appearing in this paper without the need for inflation adjustments. All gross domestic product (GDP) data are presented in the original form, not corrected by purchasing power parity (PPP) estimates. Using GDP-data that has not been PPP-adjusted gives more conservative results, since Swedish PPP-adjusted GDP is lower than the un-adjusted GDP for the entire time-span of interest [[10](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone.0124074.ref010)]. Source data and the calculations used for all numbers presented in this paper are provided in the [S1 Dataset](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone.0124074.s001). Nuclear capacity impact on CO2 emissions in Sweden Between 1960 and 1990 Sweden more than doubled its inflation-adjusted gross domestic product (GDP) per capita while reducing its per capita CO2 emissions through a rapid expansion of nuclear power production. The reduction in CO2 emissions was not an objective but rather a fortunate by-product, since the effect on the climate by greenhouse-gas emissions was not a factor in political discourse until much more recently. Nuclear power was introduced to reduce dependence on imported oil and to protect four major Swedish rivers from hydropower installations [[11](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone.0124074.ref011)]. As illustrated in [Fig 1](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone-0124074-g001), in the pre-nuclear era (1960–1972), the rise in Swedish CO2 emissions matched and even exceeded the relative increase in economic output. Once commercial nuclear power capacity was brought online, however, starting with the Oskarshamn-1 plant in 1972, emissions started to decline rapidly. By 1986, half of the electrical output of the country came from nuclear power plants, and total CO2 emissions per capita (from all sources) had been slashed by 75% from the peak level of 1970. Based on the data available in the World Bank database, this appears to be the most rapid installation of low-CO2 electricity capacity on a per capita basis of any nation in history (France and the U.S. installed more total nuclear capacity in the 1960 to 1980s, but less than Sweden on a per capita basis) [[12](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone.0124074.ref012)]. Thus Sweden provides a historical benchmark ‘best-case scenario’ on which to judge the potential for future nuclear expansion. Nuclear electricity costs in Sweden have always included a surcharge corresponding to the full estimated costs of researching, building and operating a final repository for all nuclear waste. At the end of the nuclear expansion period, Swedish electricity prices (including taxes and surcharges) were among the lowest in the world, and the running cost of the nuclear plants (per kilowatt hour [kWh] produced) were lower than all other sources except for existing hydropower installations [[13](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone.0124074.ref013)]. Emissions were reduced due to the closing of fossil power plants and the electrification (by nuclear power) of heating and industrial processes that were previously fossil powered. The total energy supply from crude oil and oil-derivative products dropped by 40% (from 350 terawatt hours per year [TWh/y] to 209 TWh/y) in the period 1970–1986. In the same time period, total electricity consumption doubled and the use of electricity for heating expanded by 5.5 times (from 4.7 TWh/y to 25.8 TWh/y) [[14](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone.0124074.ref014)]. The rate at which nuclear electricity production can be added Out of the 12 commercial reactors that were built in Sweden, nine were of completely indigenous designs that were developed without the use of foreign licenses [[11](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone.0124074.ref011)]. Another two reactors of indigenous design were exported to Finland and started operation during the same period (1979–1982). Research on commercial boiling water reactor (BWR) technology was initiated in Sweden in 1962. This means it took 24 years from the start of research until the technology provided a large proportion of the electricity output of the nation. The Swedish BWR development benefitted greatly from the fact that the US had already demonstrated the principles of the technology (the BORAX experiment series [[15](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone.0124074.ref015)]) and had started to put small BWRs of General Electric design online in the 1960s [[16](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone.0124074.ref016)]. The rate of addition of nuclear electricity in Sweden is presented in several different ways in [Table 1](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone-0124074-t001). The values represent the cumulative change in nuclear electricity production over the period, divided by the number of years and a normalization factor (either GDP/capita or population). For example the period 1975–1986 starts with the change in production between 1974 and 1975, and ends with the change in production between 1985 and 1986. The values are then divided by the total number of production years in the span, in this case 12 years. To put these numbers in a wider perspective, the number of years it would take to replace current global fossil fuel electricity production was calculated (weighted by population and economy) in the two right columns of the table. These estimates were based on current global data that is summarized in [Table 2](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone-0124074-t002). Although the range of values in [Table 1](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone-0124074-t001) is large, the analysis reveals that there is no way of selecting and weighing the available data that leads to an estimated replacement time for current fossil fuel electricity longer than two decades. These values should not be confused with the values given in Section 5, which also accounts for the replacement of the current nuclear fleet and the relative rates at which global energy consumption and GDP are growing. In order to build nuclear power plants at any of the rates of [Table 1](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone-0124074-t001) on a global scale, nearly all construction would have to occur in countries with an already established and experienced nuclear regulatory and licensing infrastructure in place, at least in the initial expansion period. This fact presents no major hurdle since virtually all major world energy consumers, encompassing over 90 percent of global CO2 emissions, are nuclear power producers with active regulatory institutions [[19](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone.0124074.ref019)]. Two features seen in all relatively rapidly expanding and successful nuclear programs were strong government involvement and support as well as some measure of technology standardization (indigenously designed PWRs in France, BWRs in Sweden). In this study we make no attempt at identifying and quantifying all the specific factors (societal, institutional, political, economical, technological) that enabled the rapid expansion of nuclear power in countries like Sweden and France. The question is highly complex and it is not clear whether the results of such a study are applicable globally. This study aims to show at what rate one can add nuclear production capacity in the “best case” scenarios as seen historically. Countries adopting or expanding their nuclear production capacity today have comparatively little need to develop indigenous designs and supply chains in the way Sweden did, since turn-key products are available from a number of vendors on an open competitive market. It is considerably easier to buy plants and nuclear fuel internationally today than it was in the early days of the Swedish nuclear program, with a larger number of mature, internationally marketed commercial designs on offer today compared to the situation of the mid 1960s. There is also a larger and more open fuel-supply market. Large collaborations such as the International Framework for Nuclear Energy Cooperation (formerly known as GNEP), with 64 participating and observing nations have recently been set up to facilitate the safe and efficient expansion of nuclear power globally [[20](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone.0124074.ref020)]. The historical data shows that as time progresses, the impact on the average addition rate caused by the initial time lag—where energy-generation installations are being planned, licensed and built but have not yet been put online (in the Swedish case; 1966–1972)—diminishes. Once the initial ramp-up period is over and the first installations begin to come online, the rate of addition will approach a steady state. By 1974/1975, Sweden had reached a steady-state rate of capacity addition that was essentially maintained for more than a decade, as seen in [Fig 2](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone-0124074-g002). The Swedish experience indicates that in steady-state phase of capacity expansion, nuclear power can be added at a rate of about 25 kWh/y/y/1k$-GDP, which, if multiplied by current global GDP ([Table 2](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone-0124074-t002)), amounts to ~1500 TWh/y/y (i.e., 10% of current global fossil-fuel electricity production when scaled to the worldwide economy). The peak annual addition rate per GDP in Sweden occurred 1980–1981 and corresponds to a GDP-weighted annual addition of 3000 TWh/y, or 20% of the current global fossil-fuel electricity production. Unit cost and construction time Despite the uncertainties on the economics and logistics of the recent nuclear expansion [[21](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone.0124074.ref021)], the current global unit cost and construction-time of nuclear reactors are actually quite comparable to the Swedish experience. The relevant Swedish historical and modern (last two years) of data are presented in [Table 3](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone-0124074-t003). With the exception of single first-of-a-kind projects like the highly delayed and poorly managed European Pressurized Reactor (EPR) at Olkilouto in Finland [[22](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone.0124074.ref022)] and Flamanville in France [[23](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone.0124074.ref023)], global data does not suggest that nuclear plants are necessarily significantly more expensive (as a fraction of the total economy) or time-consuming to build now than in the past, if efficiently managed. Recent studies by the European Commission report that new nuclear generation is economically favorable versus other generation sources, especially if all externalities of other generation sources as well would be internalized [[24](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone.0124074.ref024)]. In addition, recently published data suggest that cost escalations in the French nuclear program have been much smaller than previously stated, and that the cost escalation seen was caused to a large part by excessive scale-up of the reactor units [[25](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone.0124074.ref025)]. The recent global focus on small modular reactors (SMRs) has the potential to greatly reduce both complexity and uncertainty regarding construction times for new reactor projects. While historic construction time data is available and reliable [[16](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone.0124074.ref016)], cost-data is generally not clearly defined and in some cases not available at all. For the data of [Table 3](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone-0124074-t003), all cost data for the recently constructed reactors are taken from press-releases due to the lack of officially published source data. It is worth noting is that only three countries connected new reactors to the grid in 2012–2014: China, India and South Korea. Data from these countries (particularly China and India) are arguably most important to future global CO2 emissions reduction, because these populous and rapidly industrializing nations will constitute the bulk of energy demand and new production in the coming decades. While the cost of construction is currently stable or falling in these countries, a global expansion of nuclear power would mean increased operating costs as the price of uranium ore and fuel is driven up, at least until generation IV reactors that use recycled spent nuclear fuel and depleted uranium or thorium as their input, become widespread and economically competitive. The expansion of nuclear power production inevitably entails a proportional expansion of pressure-vessel fabrication capacity (large steel-forging presses) as well an expansion of the entire nuclear fuel cycle: mining, enrichment, fuel fabrication, recycling/reprocessing and disposal. A truly global and sustainable expansion of the type analyzed here would necessitate a transition to fast reactor systems before the turn of the century to ensure adequate fuel supply and near-complete recycling of long-lived actinide wastes [[26](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone.0124074.ref026)]. Implications, Caveats and the French Experience A surprising and encouraging result of our analysis is that the estimated time it would take the world to replace the fossil share of total electricity with nuclear power, based on Swedish experience, is less than two decades (see [Table 1](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone-0124074-t001) for details). Moreover, this projection is grounded in reality, being based on actual historical experience rather than speculation on future technological and cost developments. This number takes in to account both the relative difference in per capita GDP between the global average today and Sweden at the time (both adjusted for inflation to the 2005 level of USD), and it also includes the total planning and build time of all the reactors and the associated regulatory infrastructure. Replacing fossil-fuel electricity and heat production eliminates roughly half of the total source of anthropogenic CO2 emissions [[12](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone.0124074.ref012)]. Continued nuclear build-out at this demonstrably modest rate (Sweden was not, at that time, motivated by urgent concerns like climate-change mitigation), coupled with an electrification of the transportation systems (electric cars, increased high-speed rail use etc.) could reduce global CO2 emissions by ~70% well before 2050. However, global electricity production has grown at a more rapid rate than GDP/capita averaged over the last decade (+26% vs. +16% between 2000 and 2011) [[12](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone.0124074.ref012)]. The rapidly increasing demand for electricity in economically less-developed countries and the closing of aging existing nuclear installations built in the 1960s and 1970s makes the challenge of replacing the share of fossil electricity even larger than it would first appear. Further, as electricity goals are met progressively, the world will face the added task of replacing all final energy demand—including transportation and industrial processes—with synthetic fuels and chemical batteries, based on zero-carbon sources of heat and electricity [[27](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone.0124074.ref027)]. Balancing these factors, which act to increase the magnitude of the challenge, is the fact that today there is a mature world market with dozens of proven and licensed commercial nuclear power plant designs, almost half a century of engineering experience, and strong technology sharing and multilateral cooperation. There is thus no need for most countries in the 21st century to develop their own indigenous nuclear power plant designs (especially without the use of foreign licenses/patents), as was done in the 20th century Swedish program. GDP-weighted values of [Table 1](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone-0124074-t001) have been used to estimate a realistic value for the time it would take the world to replace current nuclear installations and all fossil fuel electricity by new nuclear. As a “low” estimate, we use the average nuclear production addition per $-GDP from start of research to the last grid connection (1962–1986); this provides an absolute upper bound for the time-to-replace estimation. An arguably more realistic estimate is the addition rate from the start of the first nuclear construction until the last grid connection (1966–1986). In this scenario, the first 6 years see no electricity production added at all. While [Table 1](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone-0124074-t001) shows addition rates have exceed 3 times this rate, it can be used as an upper bound for a worldwide nuclear expansion. Sweden was used as the example in this paper since it is the country that has done the most rapid and (relative to its size) largest nuclear expansion of any nation, and thus provides an empirical estimate for how quickly such an expansion can be done. However, since Sweden is a small nation, an additional analysis was performed that also includes an extrapolation based on the much larger nuclear program of France. The relevant input data for this analysis is summarized in [Table 4](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone-0124074-t004). Recent data has shown that electricity demand has outpaced GDP growth by about 10% averaged over the last decade. To remain cautious in our future projections, a 20% future lag between GDP growth and electricity demand was introduced as shown in [Table 4](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone-0124074-t004). This assumes a 20% increase in electricity production will need to be replaced per current-world GDP. The resulting time to replace the current global fossil-fuelled electricity production and the current nuclear fleet is given in [Table 5](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone-0124074-t005). Given this context, the low-rate estimate of the time for fossil electricity replacement based on Swedish data is 27.0 years and the high-rate estimate is 22.7 years. Averaging the high and low estimates, the conclusion is that nuclear power could replace fossil within a time span of approximately 25 ± 2 years. Using the data from the somewhat slower but larger-scale nuclear expansion in France in an identical way gives a best estimate time of replacement of 34 ± 4 years. Even a cautious extrapolation of real historic data of regional nuclear power expansion programs to a global scale, as shown in [Table 5](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0124074#pone-0124074-t005), indicate that new nuclear power could replace all fossil-fueled electricity production (including replacing all current nuclear electricity as well as the projected rise in total electricity demand) in 25–34 years—well before mid-century, if started soon. Conclusion Any climate change mitigation strategy will, due to the magnitude of the challenge, inevitably be based on extrapolation of existing data and assumptions about the future. This is true whether the technologies to displace the use of fossil fuel will be based on nuclear fission, fusion, wind, solar, waves, geothermal, biomass, pumped-hydro, energy efficiency, smart grids, electric cars or other technologies and any combination of the above. No renewable energy technology or energy efficiency approach has ever been implemented on a scale or pace which has resulted in the magnitude of reductions in CO2-emissions that is strictly required and implied in any climate change mitigation study—neither locally nor globally, normalized by population or GDP or any other normalization parameter. This paper makes an extrapolation of actual available historic data from regional expansions of a low GHG-emitting energy technology, rather than trying to speculate further on future potential deployment strategies. The results indicate that a replacement of current fossil-fuel electricity by nuclear fission at a pace which might limit the more severe effects of climate change is technologically and industrially possible—whether this will in fact happen depends primarily on political will, strategic economic planning, and public acceptance.