### Contention 1 is Subs

#### America’s SSBN fleet is aging out soon, new nuclear subs are needed.

**Carlin 24** [Maya Carlin, 9-13-2024, The Navy’s New Columbia-Class Missile Submarine Nightmare Is Here, National Interest, https://nationalinterest.org/blog/buzz/navys-new-columbia-class-missile-submarine-nightmare-here-211581, Willie T.]

Summary and 4 Points You Need to Know: The U.S. Navy’s Columbia-class submarines, designed to replace the aging Ohio-class vessels and maintain America’s sea-based nuclear deterrent, face significant delays and rising costs.

-Despite these challenges, the Columbia-class submarines, equipped with 16 missile tubes and advanced stealth technology, remain **critical for maintaining U.S. nuclear deterrence** in the face of growing adversarial threats.

$1.7 Billion Over Budget: The Columbia-Class Submarine’s Growing Price Tag

Considering the increasing hostility of America’s nuclear-armed adversaries, maintaining a technologically superior nuclear triad should be a **top priority** for policymakers. The ability to strike from land, air, and sea gives the U.S. the capability to respond to any nuclear attack with a barrage of its own nukes.

The U.S. Navy’s 14 Ohio-class submarines are currently responsible for America’s **sea-based nuclear deterrent**. Upcoming Columbia-class ships are designed to replace these **aging vessels**, and they are scheduled to enter service in the early 2030s.

Earlier this year, the Navy revealed that delivery of the first Columbia-class submarine is now expected to be delayed between 12 and 16 months. According to Bloomberg News and other outlets, delays affect the vessels’ bow section and power generators.

The Navy’s top civilian asserted in April that one of the **most significant drivers** of the delays is the slower delivery of a turbine generator constructed by Northrop Grumman. This news was detailed in a 45-day review conducted by Navy Secretary Carlos Del Toro.

An Overview of the Columbia-Class

Ohio-class submarines are the largest ships of their kind. Columbia-class boats will be even bigger. These vessels will measure 560 feet in length and displace nearly 21,000 tons, making them the largest and most complex submarines in history. The ships’ **nuclear reactors** will not require refueling during their planned lifetime service.

USS District of Columbia (SSBN-826) and USS Wisconsin (SSBN-827) are the only boats in this class ordered so far and will be followed by an additional 10 submarines. Electric Boat and Newport News Shipbuilding are constructing the ships from start to finish, as they are the **only manufacturers in the country** with the capacity to build nuclear-powered subs.

Few details about the Columbia class are unclassified, but some information has been shared. Each submarine in this class will be fitted with 16 missile tubes for launching Trident II D5 submarine-launched ballistic missiles. From boat nine onward, the remaining submarines will be equipped with an upgraded D5LE2 ballistic missile. Columbia-class submarines will boast enhanced acoustic performance and Mk 48 torpedoes. They will be extremely challenging for adversaries to detect.

What Is Hurting the Columbia-Class’s Prospects

While the Columbia class is built for the essential task to manage the Navy’s deterrent, the hefty price tag keeps growing. The Navy projected this fall that the lead ship of the class will cost around $1.7 billion more than projected. The Congressional Budget Office further warned that the rest of the ships will cost roughly $1.5 billion more than intended. “CBO estimates that total shipbuilding costs would average about $34 billion to $36 billion (in 2023 dollars) over the next 30 years, which is about 16 percent more than the Navy estimates. Compared with its estimates for the 2023 plan, CBO’s estimates increased by between 5 percent and 10 percent in real (inflation-adjusted) terms, depending on the alternative.”

These delays and cost increases are concerning, but falling behind the capabilities of **increasingly aggressive U.S. adversaries** would be a greater worry still. The timely introduction of the Columbia-class ships, along with the Navy’s other next-generation systems, is crucial.

#### BUT nuclear power issues have delayed Columbia --- we’ll miss the 2027 deadline.

**Lagrone 24** [Sam Lagrone, 4-10-2024, Late Turbines Have ‘Major Impact’ on Columbia Sub Delivery Schedule, Says SECNAV, USNI News, https://news.usni.org/2024/04/10/late-turbines-have-major-impact-on-columbia-sub-delivery-schedule-says-secnav, Willie T.]

This post has been updated with a statement from Northrop Grumman.

Late delivery of **steam turbines** for the under-construction District of Columbia (SSBN-826) is one of the main obstacles the Navy faces in delivering the nuclear ballistic missile submarine on time, Secretary of the Navy Carlos Del Toro told a House panel on Wednesday.

“One of the **most significant challenges** that we have with Columbia … is actually the late delivery of the turbine generator to Columbia by subcontractor Northrop Grumman,” Del Toro the House Appropriations subcommittee on defense.

“That has had a major impact on the Columbia.”

The turbines must be installed **before the submarine’s pressure hull is sealed** and the delay has had a **cascaded to the completion of other systems**, USNI News understands.

The new turbine design takes the steam generated from the **atomic reactors** to power the ship-wide electrical grid that makes the submarine quieter than the previous Ohio-class boomers. The turbines are government-furnished equipment and have been subcontracted to Northrop Grumman. USNI News reported on the turbine delay last month.

“Northrop Grumman is fully committed to the Columbia-class program, and is fully supportive of General Dynamics Electric Boat and the U.S. Navy as we work together to deliver this program,” the company said in a statement to USNI News.

The 12-boat, $136 billion class has repeatedly been called the **most important** Pentagon acquisition program. District of Columbia was to join the service as the first Ohio-class boomer –USS Henry M. Jackson (SSBN-730) is set to **decommission in 2027**.

#### Indeed,

**Seck this week** [Hope Hodge Seck, award-winning freelance reporter and editor who has covered the U.S. military and security issues since 2009, 4-9-2025, First Columbia-class Sub, Two Aircraft Carriers Face Delivery Delays, Navy Officials Tell Senate, USNI News, https://news.usni.org/2025/04/09/first-columbia-class-sub-two-aircraft-carriers-face-delivery-delays-navy-officials-tell-senate, Willie T.]

Likewise, nuclear aircraft carriers are facing delays as production on future Ford-class hulls are taking longer than anticipated, the officials told the Senate Armed Services seapower subcommittee.

For the Columbia-class submarines, set to replace the Ohio-class boats in the U.S. nuclear triad, lead ship District of Columbia (SSBN-826), is now set to deliver in **2029**, which is **12 to 18 months behind schedule**, said Rear Adm. Todd Weeks, program executive officer for strategic submarines. The next ships in the class, *Wisconsin* (SSBN-827) and *Groton (SSBN-828)*, are set to follow roughly on schedule in 2032 and 2034, he said.

#### Investment solves delays AND reassures suppliers.

**Field 22** [Benjamin R. Field, Master of Science in Program Management from the Naval Postgrad School & Nuclear Submarine Officer @ the US Navy, June 2022, ANALYSIS OF POSSIBLE SOLUTIONS TO SUPPORT THE TIMELY DELIVERY OF THE COLUMBIA CLASS SUBMARINE, Naval Postgraduate School, https://apps.dtic.mil/sti/trecms/pdf/AD1184869.pdf, Willie T.] \*\*brackets in original\*\*

In addition to seeking to alleviate the schedule strain, the CNO also thought that another avenue that should be pursued was accelerating the development of the Columbia class submarine. He assessed this could be accomplished by strengthening the submarine industrial base. A more robust industrial base would help to **alleviate material supply issues** which would assist in minimizing schedule delays. The larger industrial base can also increase the **quality of its workforce** which would minimize rework saving time, lowering costs, and increasing overall performance. One way the industrial base could be strengthened is by employing a targeted use of **Title III of the Defense Production Act** (DPA). According to 50 U.S.C, Title III of the DPA “provides the president a unique and broad authority to ensure the timely availability of essential domestic industrial resources to support national defense and homeland security requirements through the use of highly tailored **economic incentives**.” However, there were many different ways to utilize the DPA Title III. Should a purchase commitment be utilized to “create a guaranteed demand to reduce the risk for industry to make their own investments?” (Lehman, n.d.). Should a direct loan be made to help accommodate for the “**the risk tolerance** being [beyond that of] the commercial market?” (Lehman, n.d.). Are there any other provisions that should be considered? A final risk to schedule came from the new technologies that were being introduced on the Columbia-class. There were different opinions as to how mature the technology really is. Is conducting thorough operational testing to minimize the chance of any technical risk for major systems worth the time investment? If a flaw was discovered early, it could save large schedule delays in the future. And if minimizing technology risk was a primary consideration, would there be any interest in canceling the Columbia program and building new Ohio-class submarines? The Ohio-class are state-of-the-practice. This would likely come at the cost of performance in the competitive undersea domain, but a new line of Ohio-class submarines could certainly be created by 2031. Each of these possible solutions will come at some increased expense. Cost is another side of the triple constraint that could be optimized. How important is it to minimize the cost growth of the Columbia-class submarine program? Is it worth sacrificing schedule for cost? This option would likely only be possible if the CNO was able to alleviate schedule pressure created by the need identified in the JCIDS process by modifying the schedule in the APB. G. CONCLUSION In order to avoid the extremely undesirable outcome, the CNO knew he had to work with RADM Pappano to make some decisions. Time was ticking.

VI. CASE STUDY ANALYSIS AND CONCLUSIONS A. CASE STUDY ANALYSIS A strong acquisition case study analysis contains four vital parts: defining stakeholders, defining options and criteria, utilizing a decision matrix to make a logical decision, and presenting a final recommendation. 1. Stakeholder Analysis The Columbia-class submarine has a variety of stakeholders. The first step is to list all of the stakeholders and denote which aspects of the triple constraint they are the most concerned about. At most, each stakeholder can only choose to prioritize up to two concerns due to the limitations of the triple constraint. I have summarized the stakeholders and their concerns in Table 6

2. Define Options and Criteria Given the stakeholders and their primary concerns, the next step is to define options and decision criteria. Each option presented seeks to manage some aspect of the triple constraint. To clearly define criteria, an optimal schedule provides some type of sea-based strategic deterrent asset when it is needed such that a **strategic deterrence gap is avoided**, an optimal performance delivers a sea-based strategic deterrent asset that has all required capabilities to operate in a modern, competitive undersea-warfare environment while performing the mission of strategic deterrence, and an optimal cost minimizes cost to the taxpayer while still providing all planned capabilities. In addition to the criteria of the triple constraint, I have added technological risk as my piece of decision criteria. An optimal technological risk represents a highly improbable chance of any new technologies failing or any legacy technology being unavailable that would delay schedule.

Option One – Continue Columbia-class Program, Strengthen Industrial Base and Quality Assurance Programs (Schedule and Performance Optimization)

The DPA Title III should be used to improve/expand the state of the submarine industrial base. The goal of utilizing the DPA Title III is to incentivize existing suppliers to hire **new workers**, improve the **training programs** for their current workforce, purchase **new equipment** or **expand their facilities** which can aid in the production of submarine or submarine parts, and also to **attract new suppliers or sources of labor**. There are multiple ways of achieving this goal. Purchase commitments could reassure existing suppliers of the future **guaranteed demand** for their supplies and/or labor, thereby lowering their risk (Lehman, n.d.). This would increase the likelihood a supplier would spend their money to expand capabilities to support submarine production. Knowing that the government was offering purchase commitments could attract new suppliers or sources of labor who are seeking guaranteed future work. An in-rush of new suppliers would lessen the reliance on existing suppliers, helping to lower costs for future Columbia-class SSBNs. These new suppliers could provide quality, timely materials and bring experienced workers who would increase the quality of the work performed. The greater the quality of the industrial base, the less likely the Columbia program office will have to wait for parts or conduct rework, **improving the speed** at which the Columbia-class submarines will be delivered.

Outside of seeking to grow the industrial base, another way to minimize the probability of schedule delays for the Columbia class submarine is to increase the thoroughness of the quality assurance program. One obstacle to conducting “intrusive” supplier audits as required by a thorough quality assurance program was COVID-19 in 2020 (O’Rourke, 2022, p. 12). However, with the pandemic slowing down in early 2021, the quality assurance program must be brought back in full force. According to the Congressional Research Service, “documents from Electric Boat indicate that standard quality assurance activities early in the Columbia program were not sufficient to manage the diminished supplier base” (2022, p. 27). If the Navy can improve its quality assurance issues there is a much greater chance of catching a quality issue before it happens saving money by avoiding rework and, most importantly, avoiding additional schedule delays.

#### Failure kills sub-based nuclear deterrence and cedes ground to China/Russia.

**Sofrep 24** [No Author (cites Government Accountability Office), veteran owned media company that places an emphasis on reporting global affairs from the source, 10-2-2024, Columbia-Class Submarine Delays Leave America Vulnerable, Defense Budget in Peril, SOFREP, https://sofrep.com/news/us-columbia-class-sub-delay-issue/, Willie T.]

When we think about military defense, especially nuclear deterrence, we often picture massive submarines silently patrolling the world’s oceans, ready to defend the US at a moment’s notice.

One of the key players in this defense strategy is the Columbia-class submarine program, the Navy’s next generation of nuclear-powered ballistic missile submarines.

But the program is reportedly facing some serious challenges—delays and cost overruns that could have bigger consequences than most of us realize.

These delays aren’t just about getting a submarine ready in the water on time, as they could actually weaken our national security and seriously drain the defense budget at the same time. Here’s what’s going on and why it matters.

Concern #1: Impact on US National Security

The Columbia-class submarines are supposed to replace the aging Ohio-class submarines, which have been the backbone of the US Navy’s nuclear deterrent for decades.

These subs carry nuclear missiles, making them a critical part of the nation’s defense strategy—especially in a world we have today where rivals like Russia and China are ramping up their military capabilities.

Originally, the lead Columbia-class submarine was supposed to be delivered by October 2027, but that timeline has slipped due to difficult construction work and cost growth, among many others.

Now, according to the latest Government Accountability Office (GAO) report, we’re looking at a delay of up to 16 months, pushing the delivery back to February 2029.

What does that mean? Well, for starters, if the first Columbia-class sub isn’t operational by 2030, it could leave a gap in the US nuclear deterrent, which is a big deal in a world of growing geopolitical tensions—with Russia in the Atlantic and Arctic, China in the Pacific, and Iran’s influence in the Middle East.

The US Navy has a tough job ahead then, ensuring that these submarines are ready to go when needed.

Without these subs, the balance of power in undersea warfare could shift in favor of countries that don’t exactly have our best interests at heart.

Concern #2: The Ripple Effect on Defense Spending

Cost overruns are another massive issue for the Columbia-class program. I mean, we’re talking hundreds of millions of dollars here, which is beyond the original estimates.

Not to mention how, when you consider that the US plans to build 12 of these submarines, the numbers start to add up pretty quickly.

The total price tag for the program is hovering around $130 billion.

What’s more concerning is that these extra costs don’t just affect the submarine program. They could siphon money away from other critical defense projects.

It’s like when you blow your home renovation budget on one room, and suddenly, you can’t afford to fix the rest of the house.

The Navy has other modernization efforts to think about—fighter jets, ships, cybersecurity—and if the Columbia-class submarines keep eating up more and more funds, other parts of the military could be left high and dry.

Managing these kinds of large-scale projects is tough, no doubt about it. But the Navy has to figure out how to stay on budget without compromising the broader defense strategy.

Concern #3: Supplied Base Investment Efficiency

Here’s another problem: the Navy has already poured $2.6 billion into the submarine supplier base to make sure the Columbia-class construction stays on track.

These funds are meant to boost production, improve efficiency, and hopefully save some money in the long run. The catch? It’s not clear whether these investments are actually paying off.

According to the recent GAO report, the Navy hasn’t done a great job of tracking whether these investments are delivering results.

If the money being funneled into the supplier base isn’t leading to more efficient production or cost savings, then what’s the point?

Without clearer accountability, these investments could end up being a massive waste of resources.

Concern #4: Unmet Cost and Schedule Targets

Lastly, one of the most frustrating things about the Columbia-class program is that it consistently falls short of its cost and schedule targets.

Since 2022, the program has struggled with late materials, incomplete design products, and other production issues.

And these problems haven’t gotten any better.

This isn’t just an issue with submarines—it’s part of a broader pattern in US defense procurement.

Big defense projects often run over budget and behind schedule, and the Columbia-class submarines are no exception.

The Navy and its contractors need to start taking a hard look at why these projects keep missing their targets and how they can better manage risks moving forward.

Future Risks and Strategic Ramifications

Looking ahead, the risks aren’t just about what’s happening right now.

There’s real concern that delays and cost overruns could keep piling up, making the problem even worse. The longer these submarines take to build, the more expensive they become, and the harder it is to keep the project on track.

However, the bigger issue here is that America needs to stay ahead of rivals like China and Russia in undersea warfare. Both countries have been stepping up their submarine game, and the US can’t afford to fall behind.

If the Columbia-class subs are delayed further, it could give adversaries an edge in a part of military defense where the US has traditionally been dominant.

Nevertheless, the GAO has been all over this issue, and their recommendations are critical for getting the Columbia-class program back on track.

“GAO is making five recommendations, including that the Navy require the shipbuilder to revise its estimated cost at completion and include thorough analysis in its reporting; and that the program identify information it needs to determine whether investments in the supplier base support Columbia class construction goals,” the report recommendation reads.

GAO is calling for the Navy to revise its cost estimates and include a more detailed analysis of why these delays and cost overruns keep happening.

It’s also about holding contractors accountable.

The Navy needs to make sure that the companies building these submarines are doing everything they can to stay on time and on budget. Without that accountability, these kinds of defense projects will keep running into the same problems.

You can read the rest of the Columbia Class Submarine report by GAO here.

Final Thoughts on the Matter

The delays and cost overruns plaguing the Columbia-class submarine program aren’t just a headache for the Navy—they could have serious consequences for US national security and defense spending.

**If the Navy can’t get these submarines built on time, it risks weakening the country’s nuclear deterrent at a time when global threats are on the rise.** And with the costs spiraling, other parts of the defense budget could take a hit as well.

It’s time for the Navy to start addressing these challenges head-on, ensuring that this critical defense project doesn’t become another cautionary tale of mismanaged military spending.

The stakes are simply too high to let this one slip any further.

#### Nukes cause extinction

**Clare '23** [Stephen Clare; Effective Altruism Writer; June 2023; "Great power war"; 80000 Hours; https://80000hours.org/problem-profiles/great-power-conflict/; accessed 12-05-2024]

A modern **g**reat **p**ower **w**ar could see **nuclear weapons**, **bioweapons**, **autonomous weapons**, and other **destructive** new **technologies** deployed on an **unprecedented scale**.

It would **probably** be the **most destructive** event in **history**, **shattering** our **world**. It could **even threaten** us with **extinction**.

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We’ve come perilously close to just this kind of catastrophe before. On October 27, 1962 — near the peak of the Cuban Missile Crisis — an American U-2 reconnaissance plane set out on a routine mission to the Arctic to collect data on Soviet nuclear tests. But, while flying near the North Pole, with the stars obscured by the northern lights, the pilot made a navigation error and strayed into Soviet airspace.1 Soviet commanders sent fighter jets to intercept the American plane. The jets were picked up by American radar operators and nuclear-armed F-102 fighters took off to protect the U-2. Fortunately, the reconnaissance pilot realised his error with enough time to correct course before the Soviet and American fighters met. But the intrusion enraged Soviet Premier Nikita Khrushchev, who was already on high alert amidst the crisis in Cuba. “What is this, a provocation?” Khrushchev wrote to US President John F. Kennedy. “One of your planes violates our frontier during this anxious time when everything has been put into combat readiness.” If the U-2’s path had strayed further west, or the Soviet fighters had been fast enough to intercept it, this incident could have played out quite differently. Both the United States and the USSR had thousands of nuclear missiles ready to fire. Instead of a nearly-forgotten anecdote, the U-2 incident could have been a trigger for war, like the assassination of Franz Ferdinand.

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**Competition** among the world’s **most powerful** countries **shapes** our **world** today. And whether it’s through future incidents like the lost U-2, or something else entirely, it’s plausible that it could escalate and lead to a major, devastating war.

Is there anything you can do to help avoid such a terrible outcome? It is, of course, difficult to imagine how any one individual can hope to influence such world-historical events. Even the **most powerful** world **leaders** often **fail** to predict the **global consequences** of **their decisions**.

But I think the **likelihood** and **severity** of **g**reat **p**ower **w**ar makes this **among** the **most pressing** problems of **our time** — and that **some solutions** could be **impactful** enough that **working** on them may be one of the **highest-impact** things to do with **your career**.

By taking action, I think we **can create** a **future** where the **threat** of **g**reat **po**wer **w**ar is a **distant memory** rather than an **ever-present** danger.

Summary

**Economic growth** and **technological progress** have **bolstered** the **arsenals** of the world’s **most powerful** countries. That means the **next war** between **them** could be **far worse** than **W**orld **W**ar **II**, the **deadliest conflict** humanity has **yet experienced**.

Could **such** a war **actually occur**? We can’t rule out the possibility. **Technical accidents** or **diplomatic misunderstandings** could **spark** a **conflict** that **quickly escalates**. Or **international tension** could **cause leaders** to decide they’re **better off** fighting than **negotiating**.

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It seems hard to make progress on this problem. It’s also less neglected than some of the problems that we think are most pressing. There are certain issues, like making nuclear weapons or military artificial intelligence systems safer, which seem promising — although it may be more impactful to work on reducing risks from AI, bioweapons or nuclear weapons directly. You might also be able to reduce the chances of misunderstandings and miscalculations by developing expertise in one of the most important bilateral relationships (such as that between the United States and China). Finally, by making conflict less likely, reducing competitive pressures on the development of dangerous technology, and improving international cooperation, you might be helping to reduce other risks, like the chance of future pandemics. Our overall view Recommended Working on this issue seems to be among the best ways of improving the long-term future we know of, but all else equal, we think it’s less pressing than our highest priority areas (primarily because it seems less neglected and harder to solve). Scale There’s a significant chance that a new great power war occurs this century. Although the world’s most powerful countries haven’t fought directly since World War II, war has been a constant throughout human history. There have been numerous close calls, and several issues could cause diplomatic disputes in the years to come. These considerations, along with forecasts and statistical models, lead me to think there’s about a one-in-three chance that a new great power war breaks out in roughly the next 30 years. Few wars cause more than a million casualties and the next great power war would probably be smaller than that. However, there’s some chance it could escalate massively. Today the great powers have much larger economies, more powerful weapons, and bigger military budgets than they did in the past. An all-out war could kill far more people than even World War II, the worst war we’ve yet experienced. Could it become an existentially threatening war — one that could cause human extinction or significantly damage the prospects of the long-term future? It’s very difficult to say. But my best current guess is that the chance of an existential catastrophe due to war in the next century is somewhere between 0.05% and 2%. Neglectedness War is a lot less neglected than some of our other top problems. There are thousands of people in governments, think tanks, and universities already working on this problem. But some solutions or approaches remain neglected. One particularly promising approach is to develop expertise at the intersection of international conflict and another of our top problems. Experts who understand both geopolitical dynamics and risks from advanced artificial intelligence, for example, are sorely needed. Solvability Reducing the risk of great power war seems very difficult. But there are specific technical problems that can be solved to make weapons systems safer or less likely to trigger catastrophic outcomes. And in the best case, working on this problem can have a leverage effect, making the development of several dangerous technologies safer by improving international cooperation and making them less likely to be deployed in war. At the end of this profile, I suggest five issues which I’d be particularly excited to see people work on. These are: Developing expertise in the riskiest bilateral relationships Learning how to manage international crises quickly and effectively and ensuring the systems to do so are properly maintained Doing research to improve particularly important foreign policies, like strategies for sanctions and deterrence Improving how nuclear weapons and other weapons of mass destruction are governed at the international level Improving how such weapons are controlled at the national level Profile depth In-depth This is one of many profiles we've written to help people find the most pressing problems they can solve with their careers. Learn more about how we compare different problems, see how we try to score them numerically, and see how this problem compares to the others we've considered so far. Why might preventing great power war be an especially pressing problem? A modern great power war — an all-out conflict between the world’s most powerful countries — could be the worst thing to ever happen to humanity. Historically, such wars have been exceptionally destructive. Sixty-six million people died in World War II, likely the deadliest catastrophe humanity has experienced so far. Since World War II, the global population and world economy have continued to grow, nuclear weapons have proliferated, and military technology has continued to advance. This means the next world war could be even worse, just as World War II was much deadlier than World War I. It’s not guaranteed that such a war will break out. And if it does, it may not escalate to such a terrible extent. But the chance can’t be ignored. In fact, there are reasons to think that the odds of World War III breaking out this century are worryingly high. A modern great power war would be devastating for people alive today. But its effects could also persist long into the future. That’s because there is a substantial chance that this century proves to be particularly important. Technologies with the potential to cause a global catastrophe or radically reshape society are likely to be invented. How we choose to develop and deploy them could impact huge numbers of our descendants. And these choices would be affected by the outcomes of a major war. To be more specific, there are three main ways great power conflict could affect the long-term future: High international tension could increase other risks. Great power tensions could make the world more dangerous even if they don’t lead to war. During the Cold War, for example, the United States and the USSR never came into direct conflict but invested in bioweapons research and built up nuclear arsenals. This dynamic could return, with tension between great powers fueling races to develop and build new weapons, raising the risk of a disaster even before shots are fired. War could cause an existential catastrophe. If war does break out, it could escalate dramatically, with modern weapons (nuclear weapons, bioweapons, autonomous weapons, or other future technologies) deployed at unprecedented scale. The resulting destruction could irreparably damage humanity’s prospects. War could reshape international institutions and power balances. While such a catastrophic war is possible, it seems extremely unlikely. But even a less deadly war, such as another conflict on the scale of World War II, could have very long-lasting effects. For example, it could reshape international institutions and the global balance of power. In a pivotal century, different institutional arrangements and geopolitical balances could cause humanity to follow different long-term trajectories. The rest of this profile explores exactly how pressing a problem great power conflict is. In summary: Great power relations have become more tense. (More.) Partly as a result, a war is more likely than you might think. It’s reasonable to put the probability of such a conflict in the coming decades somewhere between 10% and 50%. (More.) If war breaks out, it would probably be hard to control escalation. The chance that it would become large enough to be an existential risk cannot be dismissed. (More.) This makes great power war one of the biggest threats our species currently faces. (More.) It seems hard to make progress on solving such a difficult problem (more) — but there are many things you can try if you want to help (more). International tension has risen and makes other problems worse Imagine we had a thermometer-like device which, instead of measuring temperature, measured the level of international tension.2 This ‘tension metre’ would max out during periods of all-out global war, like World War II. And it would be relatively low when the great powers3 were peaceful and cooperative. For much of the post-Napoleonic 1800s, for example, the powerful European nations instituted the Concert of Europe and mostly upheld a continental peace. The years following the fall of the USSR also seem like a time of relative calm, when the tension metre would have been quite low.4 How much more worried would you be about the coming decades if you knew the tension metre would be very high than if you knew it would be low? Probably quite a lot. In the worst case, of course, the great powers could come into direct conflict. But even if it doesn’t lead to war, a high level of tension between great powers could accelerate the development of new strategic technologies, make it harder to solve global problems like climate change, and undermine international institutions. During the Cold War, for instance, the United States and USSR avoided coming into direct conflict. But the tension metre would still have been pretty high. This led to some dangerous events: A nuclear arms race. The number of nuclear warheads in the world grew from just 300 in 1950 to over 64,000 in 1986. The development of new bioweapons. Despite signing the Biological Weapons Convention in 1972, the search for military advantages motivated Soviet decision makers to continue investing in bioweapon development for decades. Although never used in combat, biological agents were accidentally released from research facilities, resulting in dozens of deaths and threatening to cause a pandemic.5 Nuclear close calls. Military accidents and false alarms happened regularly, and top decision makers were more likely to interpret these events hostilely when tensions were high. On several occasions it seems the decision about whether or not to start a nuclear war came down to individuals acting under stress and with limited time. This makes international tension an existential risk factor. It’s connected to a number of other problems, which means reducing the level of international tension would lower the total amount of existential risk we face. The level of tension today Recently, international tension seems to have once again been rising. To highlight some of the most salient examples: China-United States relations have deteriorated, leading to harsh diplomatic rhetoric and protectionist trade policies that aim to reduce the countries’ economic interdependence. Russia’s invasion of Ukraine has killed about a hundred thousand people so far, raised the risk of nuclear war, and sent United States-Russia relations to their lowest point since the Cold War. Chinese and Indian soldiers fought deadly skirmishes along their countries’ disputed border in 2020–21. These dynamics raise an important question: how much more dangerous is the world given this higher tension than it would be in a world of low tension? I think the answer is quite a bit more dangerous — for several reasons. First, international tension seems likely to make technological progress more dangerous. There’s a good chance that, in the coming decades, humanity will make some major technological breakthroughs. We’ve discussed, for example, why one might worry about the effects of advanced artificial intelligence systems or biotechnology. The level of tension could strongly affect how these technologies are developed and governed. Tense relations could, for example, cause countries to neglect safety concerns in order to develop technology faster.6 Second, great power relations will strongly influence how nations do, or do not, cooperate to solve other global collective action problems. For example, in 2022, China withdrew from bilateral negotiations with the United States over climate action in protest of what it perceived as American diplomatic aggression in Taiwan. That same year, efforts to strengthen the Biological Weapons Convention were reportedly hampered by the Russian delegation after their country’s invasion of Ukraine raised tensions with the United States and other western countries. And third, if relations deteriorate severely, the great powers could fight a war. How likely is a war? Wars are destructive and risky for all countries involved. Modern weapons, especially nuclear warheads, make starting a great power war today seem like a suicidal undertaking. But factors like the prevalence of war throughout history, the chance that leaders make mistakes, conflicting ideologies, and commitment problems, make me think that conflict could break out anyway. On balance, I think such an event is somewhat unlikely but hardly unthinkable. To quantify this: I put the chance we experience some kind of war between great powers before 2050 at about one-in-three.7 War has occurred regularly in the past One reason to think a war is quite likely is that such conflicts have been so common in the past. Over the past 500 years, about two great power wars have occurred per century.8 Naively, this would mean that every year there’s a 2% chance such a war occurs, implying the chance of experiencing at least one great power war over the next 80 years — roughly until the end of the century — is about 80%.9 This is a very simple model. In reality, the risk is not constant over time and independent across years. But it shows that if past trends simply continue, the outcome is likely to be very bad. Has great power war become less likely? One of the most important criticisms of this model is that it assumes the risk is constant over time. Some researchers have argued instead that, especially since the end of World War II, major conflicts have become much less likely due to: Nuclear deterrence: Nuclear weapons are so powerful and destructive that it’s just too costly for nuclear-armed countries to start wars against each other.10 Democratisation: Democracies have almost never gone to war against each other, perhaps because democracies are more interconnected and their leaders are under more public pressure to peacefully resolve disputes with each other.11 The proportion of countries that are democratic has increased from under 10% in 1945 to about 50% today. Strong economic growth and global trade: Global economic growth accelerated following World War II and the value of global exports grew by a factor of almost 30 between 1950 and 2014. Since war disrupts economies and international trade, strong growth raises the costs of fighting.12 The spread of international institutions: Multilateral bodies like the United Nations General Assembly and Security Council promote diplomatic dialogue and facilitate coordination to punish transgressors.13 It is true that we are living through an unusually long period of great power peace. It’s been about 80 years since World War II. We just saw that a simple model using the historical frequency of great power wars suggests there was only a 20% chance of going that long without at least one more war breaking out. This is some evidence in favour of the idea that wars have become significantly less common. At the same time, we shouldn’t feel too optimistic. The numerous close calls during the Cold War suggest we were somewhat lucky to avoid a major war in that time. And a 20% chance of observing 80 years of peace is not that low.14 Structural changes might have dramatically reduced the likelihood of war. Or perhaps we’ve just been lucky. It could even be that technological advances have made war less likely to break out, but more deadly when it occurs, leaving the overall effect on the level of risk ambiguous. It just hasn’t been long enough to support a decisive view.15 So while the recent historical trend is somewhat encouraging, we don’t have nearly enough data to be confident that great power war is a thing of the past. To better predict the likelihood of future conflict, we should also consider distinctive features of our modern world.16 One might think that a modern great power war would simply be so destructive that no state leader would ever choose to start one. And some researchers do think that the destruction such a war would wreak globally makes it less likely to occur. But it would be hard to find anyone who claims this dynamic has driven the risk to zero. First, a war could be started by accident. Second, sometimes even prudent leaders may struggle to avoid a slide towards war. We could blunder into war An accidental war can occur if one side mistakes some event as an aggressive action by an adversary. This happened several times during the Cold War. The earlier example of the wayward American reconnaissance plane shows how routine military exercises carry some escalation risk. Similarly, throughout history, nervous pilots and captains have caused serious incidents by attacking civilian planes and ships.17 Nuclear weapons allow for massive retaliatory strikes to be launched quickly — potentially too quickly to allow for such situations to be explained and de-escalated. It is perhaps more likely, though, that an accidental war could be triggered by a technological malfunction. Faulty computers and satellites have previously triggered nuclear close calls. As monitoring systems have become more reliable, the rate at which such accidents have occurred has been going down. But it would be overconfident to think that technological malfunctions have become impossible. Future technological changes will likely raise new challenges for nuclear weapon control. There may be pressure to integrate artificial intelligence systems into nuclear command and control to allow for faster data processing and decision making. And AI systems are known to behave unexpectedly when deployed in new environments.18 New technologies will also create new accident risks of their own, even if they’re not connected to nuclear weapon systems. Although these risks are hard to predict, they seem significant. I’ll say more about how such technologies — including AI, nuclear, biological, and autonomous weapons — are likely to increase war risks later. Leaders could choose war All that said, most wars have not started by accident. If another great power war does break out in the coming decades, it is more likely to be an intentional decision made by a national leader. Explaining why someone might make such a costly, destructive, unpredictable, and risky decision has been called “the central puzzle about war.” It has motivated researchers to search for “rationalist” explanations for war. In his 2022 book Why We Fight, for example, economist Chris Blattman proposes five basic explanations: unchecked interests, intangible incentives, uncertainty, commitment problems, and misperceptions.19 Blattman's Five (Rationalist) Explanations for War This section discusses how great power tensions may escalate to war in the next few decades. It focuses on three potential conflicts in particular: war between the US and China, between the US and Russia, and between China and India. These are discussed because each of these countries are among the world’s largest economies and military spenders, and seem particularly likely to fight. At the end, I briefly touch on other potential large conflicts. Projected real GDP of the US, China, India and Russia according to a 2022 Goldman Sachs analysis Source: Author’s figure using data from: Kevin Daly and Tadas Gedminas, “Global Economics Paper The Path to 2075 — Slower Global Growth, But Convergence Remains Intact,” Global Economics Paper (Goldman Sachs, December 6, 2022), https://www.goldmansachs.com/intelligence/pages/gs-research/the-path-to-2075-slower-global-growth-but-convergence-remains-intact/report.pdf. United States-China The most worrying possibility is war between the United States and China. They are easily the world’s largest economies. They spend by far the most on their militaries. Their diplomatic relations are tense and have recently worsened. And their relationship has several of the characteristics that Blattman identifies as causes of war. At the core of the United States-China relationship is a commitment problem. China’s economy is growing faster than the United States’. By some metrics, it is already larger.20 If its differential growth continues, the gap will continue to widen between it and the United States. While economic power is not the sole determinant of military power, it is a key factor.21 The United States and China may be able to strike a fair deal today. But as China continues to grow faster, that deal may come to seem unbalanced. Historically, such commitment problems seem to have made these kinds of transition periods particularly dangerous.22 In practice, the United States and China may find it hard to agree on rules to guide their interactions, such as how to run international institutions or govern areas of the world where their interests overlap. The most obvious issue which could tip the United States-China relationship from tension into war is a conflict over Taiwan. Taiwan’s location and technology industries are valuable for both great powers. This issue is further complicated by intangible incentives. For the United States, it is also a conflict over democratic ideals and the United States’ reputation for defending its allies. For China, it is also a conflict about territorial integrity and addressing what are seen as past injustices. Still, forecasts suggest that while a conflict is certainly possible, it is far from inevitable. As of 8 June 2023, one aggregated forecast23 gives a 17% chance of a United States-China war breaking out before 2035.24 A related aggregated forecast of the chance that at least 100 deaths occur in conflict between China and Taiwan by 2050 gives it, as of 8 June 2023, a much higher 68% chance of occurring.25 United States-Russia Russia is the United States’ other major geopolitical rival. Unlike China, Russia is not a rival in economic terms: even after adjusting for purchasing power, its economy is only about one-fifth the size of the United States’. However, Russia devotes a substantial fraction of its economy to its military. Crucially, it has the world’s largest nuclear arsenal. And Russian leadership has shown a willingness to project power beyond their country’s borders. Country Military spending in 2021 (2020 USD, PPP adjusted) United States 801 billion China 293 billion India 76.6 billion United Kingdom 68.4 billion Russia 65.9 billion Top five countries by estimated military spending, 2021. Source: SIPRI Russia’s 2022 invasion of Ukraine demonstrated the dangers of renewed rivalry between Russia and the United States-led West. The war has already been hugely destructive: the largest war in Europe since World War II, with hundreds of thousands of casualties already and no end to the conflict in sight. And it could get much worse. Most notably, Russian officials have repeatedly refused to rule out the use of nuclear weapons. Unchecked interests and intangible incentives are again at play here. Vladimir Putin leads a highly-centralised government. He has spoken about how his desire to rebuild Russia’s reputation played in his decision to invade Ukraine. Given their ideological differences and history of rivalry, it is reasonable to expect that the United States and Russia will continue to experience dangerous disagreements in the future. As of 8 June 2023, an aggregated forecast gives a 20% chance that the United States and Russia will fight a war involving at least 1,000 battle deaths before 2050. China-India India is already the world’s third-largest economy. If national growth rates remain roughly constant, the size of the Indian economy will surpass that of the United States’ sometime this century. India also has nuclear weapons and is already the world’s third-largest military spender (albeit at a much lower level than China or the United States). One reason to worry that China and India could fight a war is that they already dispute territory along their border. Countries that share a border, especially when it is disputed, are more likely to go to war than countries that do not. By one count, 88% of the wars that occurred between 1816 and 1980 began as wars between neighbours.26 In fact, China and India already fought a brief but violent border war in 1962. Deadly skirmishes have continued since, resulting in deaths as recently as 2020. Forecasters agree that a China-India conflict seems relatively (though not absolutely) likely. An aggregated forecast gives a 19% chance of war before 2035. Other dangerous conflicts These three conflicts — United States-China, United States-Russia, and China-India — are not the only possible great power wars that could occur. Other potential conflicts could also pose existential risk, either because they drive dangerous arms races or see widespread deployment of dangerous weapons. We should keep in mind India-Pakistan as a particularly likely conflict between nuclear-armed states and China-Russia as a potential, though unlikely, conflict between great powers with a disputed border and history of war. Plus, new great powers may emerge or current great powers may fade in the years to come. While I think we should prioritise the three potential conflicts I’ve highlighted above, the future is highly uncertain. We should monitor geopolitical changes and be open to changing our priorities in the future. Overall predictions Below is a table listing relevant predictions from the forecasting platform Metaculus, including the number of predictions made, as of 10 March 2023. Note the different timescales and resolution criteria for each question; they may not be intuitively comparable. Prediction Resolution criteria Number of predictions Metaculus prediction World war by 2151 Either: A war killing >0.5% of global population, involving >50% of countries totalling >50% of global population from at least 4 continents. Or: A war killing at least >1% of global population, involving >10% of countries totalling >25% of global population 561 52% World War III before 2050 Involving countries >30% of world GDP OR >50% of world population AND >10M deaths 1640 20% Global thermonuclear war by 2070 EITHER: 3 countries each detonate at least 10 nuclear warheads of at least 10 kt yield outside of their territory OR 2 countries each detonate at least 50 nuclear warheads of at least 10 kt outside of their territory 337 11% When will be the next great power war? Any two of the top 10 nations by military spending are at war “At war” definition: EITHER Formal declaration OR Territory occupied AND at least 250 casualties OR Media sources describe them as “at war” 25th percentile: 2031 Median: 2048 75th percentile: 2088 Never (not before 2200): 8% No non-test nuclear detonations before 2035 No nuclear detonation other than controlled test [Note the negation in the question. It resolves negatively if a warhead is detonated] 321 69% At least 1 nuclear detonation in war by 2050 Resolves according to credible media reports 476 31% I have previously independently estimated the likelihood of seeing a World War III-like conflict this century. My calculation first adjusts historical base rates to allow for the possibility that major wars have become somewhat less likely, and uses the adjusted base rate to calculate the probability of seeing a war between now and 2100. This method gives a 45% chance of seeing a major great power war in the next 77 years. If the probability is constant over time then the cumulative probability between now and 2050 would be 22%. This is aligned with the Metaculus predictions above. We can also ask experts what they think. Unfortunately, there are surprisingly few expert predictions about the likelihood of major conflict. One survey was conducted by the Project for the Study of the 21st Century. The numbers were relatively aligned with the Metaculus forecasts, though slightly more pessimistic. However, it seems a mistake to put too much stock in this survey (see footnote).27 We now have at least a rough sense of a great power war’s probability. But how bad could it get if it occurred? A new great power war could be devastating At the time, the mechanised slaughter of World War I was a shocking step-change in the potential severity of warfare. But its severity was surpassed just 20 years later by the outbreak of World War II, which killed more than twice as many people. A modern great power war could be even worse. How bad have wars been in the past? The graph below shows how common wars of various sizes are, according to the Correlates of War’s Interstate War dataset.28 The x-axis here represents war size in terms of the logarithm of the number of battle deaths. The y-axis represents the logarithm of the proportion of wars in the dataset that are at least that large. Using logarithms means that each step to the right in the graph represents a war not one unit larger, but 10 times larger. And each step up represents a war that is not one unit more likely, but 10 times more likely. Cumulative frequency distribution of severity of interstate wars, 1816-2007 Source: Author’s figure. See the data here. Data source: Correlates of War Interwar dataset, v4.029 What the graph shows is that wars have a heavy tail. Most wars remain relatively small. But a few escalate greatly and become much worse than average. Of the 95 wars in the latest version of the database, the median battle death count is 8,000. But the heavy tail means the average is 334,000 battle deaths. And the worst war, World War II, had almost 17 million battle deaths.30 The number of battle deaths is only one way to measure the badness of wars. We could also consider the proportion of the population of the countries involved who were killed in battle. By this measure, the worst war since 1816 was not World War II. Instead, it’s the Paraguayan War of 1864–70. In that war, 30 soldiers died for every 1,000 citizens of the countries involved. It’s even worse if we also consider civilian deaths; while estimates are very uncertain, it’s plausible that about half of the men in Paraguay, or around a quarter of the entire population, was killed.31 What if instead we compared wars by the proportion of the global population killed? World War II is again the worst conflict since 1816 on this measure, having killed about 3% of the global population. Going further back in time, though, we can find worse wars. Ghengis Khan’s conquests likely killed about 9.5% of people in the world at the time. The heavy tail means that some wars will be shockingly large.32 The scale of World War I and World War II took people by surprise, including the leaders who initiated it. It’s also hard to know exactly how big wars could get. We haven’t seen many really large wars. So while we know there’s a heavy tail of potential outcomes, we don’t know what that tail looks like. That said, there are a few reasons to think that wars much worse than World War II are possible: We’re statistically unlikely to have brushed up against the end of the tail, even if the tail has an upper bound. Other wars have been deadlier on a per-capita basis. So unless wars involving countries with larger populations are systematically less intense, we should expect to see more intense wars involving as many people as World War II. Economic growth and technological progress are continually increasing humanity’s war-making capacity. This means that, once a war has started, we’re at greater risk of extremely bad outcomes than we were in the past. So how bad could it get? How bad could a modern great power war be? Over time, two related factors have greatly increased humanity’s capacity to make war. 33 First, scientific progress has led to the invention of more powerful weapons and improved military efficiency. Second, economic growth has allowed states to build larger armies and arsenals. Since World War II, the world economy has grown by a factor of more than 10 in real terms; the number of nuclear weapons in the world has grown from basically none to more than 9,000, and we’ve invented drones, missiles, satellites, and advanced planes, ships, and submarines. Ghengis Khan’s conquests killed about 10% of the world, but this took place over the course of two decades. Today that proportion may be killed in a matter of hours. First, nuclear weapons could be used. Today there are around 10,000 nuclear warheads globally.34 At the peak of nuclear competition between the United States and the USSR, though, there were 64,000. If arms control agreements break down and competition resurges among two or even three great powers, nuclear arsenals could expand. In fact, China’s arsenal is very likely to grow — though by how much remains uncertain. Many of the nuclear weapons in the arsenals of the great powers today are at least 10 times more powerful than the atomic bombs used in World War II.35 Should these weapons be used, the consequences would be catastrophic. Graph showing that early nuclear weapons are 1,000s of times more explosive than previous conventional explosives Source: AI Impacts, Effect of nuclear weapons on historic trends in explosives

<<LINE BREAKS CONTINUE>>

By any measure, **such** a **war** would be **by far** the **most destructive**, **dangerous event** in **human history**, with the potential to cause billions of deaths.

The probability that it would, on its own, lead to **humanity’s extinction** or unrecoverable **collapse**, is contested. But there seems to be some possibility — whether through a **famine** caused by **nuclear winter**, or by reducing **humanity’s resilience** enough that **something else**, like a **catastrophic pandemic**, would be far **more likely** to reach **extinction**-levels (read more in our problem profile on nuclear war).

**Nuclear weapons** are **complemented** and **amplified** by a **variety** of other **modern military** technologies, including **improved missiles**, **planes**, **submarines**, and **satellites**. They are **also not** the only **military technology** with the **potential** to cause a **global catastrophe** — **bioweapons**, too, have the potential to cause massive harm through accidents or unexpected effects.

#### AND Columbia subs cap nuclear escalation

**Osborn 25**, President and Editor in Chief of the Center for Military Modernization. Previously served at the Pentagon as a Highly Qualified Expert with the Office of the Assistant Secretary of the Army—Acquisition, Logistics & Technology. (Kris, Warrior Maven, “Why The Navy’s Columbia-Class Nuclear-Armed Submarine May Save The World,” Warrior Maven, https://warriormaven.com/uncategorized/25539#google\_vignette, accessed on 3-6-2025)

Why The Navy’s Columbia-Class Nuclear-Armed Submarine May **Save The World**

After years of science and technology, prototyping, and advanced design specs, the U.S. Navy is now building its first Columbia-class submarine, slated to arrive at the end of the decade.

Columbia-Class Submarine: What Do We Know? Lurking secretly in dark waters around the world and holding potential adversaries at risk of nuclear **destruction** from unknown locations, US **Navy’s** nuclear-armed ballistic missile **sub**marines offer the backbone of U.S. strategic deterrence.

**Undersea strategic deterrence** essentially **guarantees** second-strike retaliatory catastrophic destruction of any adversary who attacks the U.S. with nuclear weapons, thus **preventing war** by ensuring the complete annihilation of any country that attacks with nuclear weapons.

The promise of total destruction, somewhat paradoxically one might say, **keeps the peace**.

Columbia-Class Submarine – Lurking Threat

This conceptual premise is why, for many years now, the Pentagon has identified the now emerging **Columbia**-class nuclear-armed ballistic missile submarines as a **number one** DoD acquisition **priority**. After years of science and technology, prototyping, and advanced design specs, the U.S. Navy is now building its first Columbia-class submarine, slated to arrive at the end of the decade.

### Contention 2 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.

#### US is key.

**Harrison 24** [Todd Harrison, Senior fellow at American Enterprise Institute 5-8-2024, Building an Enduring Advantage in the Third Space Age, American Enterprise Institute - AEI, https://www.aei.org/research-products/report/building-an-enduring-advantage-in-the-third-space-age/, Willie T.]

Executive Summary The United States is leading the world into a new era of space activity known as the third space age. Unlike the militarization and exploration of the first space age (1957–90) and the diversification and stagnation of the second space age (1991–2015), the third space age (2016–present) is defined by rapid commercialization and proliferation. In this new era, US space capabilities and capacity are second to none, but China, Russia, and other nations are actively working to erode this advantage. This report provides quantitative insights and analysis of the trends in space launch, satellites, and space debris and makes recommendations for how to build an enduring advantage for the United States in space. The global annual launch rate hit an all-time high of 211 successful orbital launches in 2023, driven mainly by the **United States** and China, which each logged their highest launch rate ever at **103** and 66 **launches**, respectively. The US lead is even more stark considering that it comprised **81 percent of global effective launch capacity** in 2023—**four times the rest of the world combined**. The introduction of much **larger US launch vehicles, *particularly SpaceX’s Starship*** and Blue Origin’s New Glenn, and the higher **degree of reusability these** vehicles employ **will further increase the US lead**. These disruptive changes will give the United States a **unique ability to launch much larger payloads** at much **lower costs**, enabling new generations of satellites with designs unconstrained by size, weight, and power. The US **advantage in space also extends to satellite capabilities** and **production capacity**. Globally, more satellites were launched in the past five years (2019–23) than in all previous years combined. In 2023, 78 percent of satellites launched were US satellites, driven mainly by the deployment of SpaceX’s Starlink constellation. Commercial satellites comprise 84 percent of all satellites launched in the third space age, and market projections indicate that the satellite launch rate will remain high for the foreseeable future, driven by the deployment of highly proliferated commercial constellations, such as **Starlink and Amazon’**s Kuiper.

### Contention 3 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.

#### Repurposing ensures fast deployment.

**Abdussami 24** [Muhammad R. Abdussami, M.A. in Nuclear Engineering from Ontario Tech University & PhD from University of Michigan, June 2024, Investigation of potential sites for coal-to-nuclear energy transitions in the United States, Energy Reports, https://www.sciencedirect.com/science/article/pii/S2352484724002993, Willie T.]

1.2. Literature review

The U.S. government has undertaken various initiatives to assess the potential for coal-to-nuclear (C2N) transitions at coal sites across the country. Hansen et al. drafted an extensive report for the U.S. Department of Energy (DOE) that examined key factors influencing viable transitions for a hypothetical coal plant, considered the techno-economic aspects of C2N conversions, and evaluated the potential effects on local communities during this transition (Hansen et al., 2022). Similarly, Griffith et al. investigated different nuclear reactor technologies and provided **valuable insights** into the considerations for siting and replacing coal plants with nuclear alternatives (Griffith, 2021). A few technical studies have also been carried out in the field of C2N transitions. One investigation (“Gone with the Steam How new nuclear, 2021) discovered that repurposing coal plants with advanced reactors could offer economic advantages and benefits for host communities compared to renewable energy generation. A technical report published by NuScale SMR technology highlighted the capability of NuScale SMR technology to **repurpose retired coal plants** while **ensuring the economic stability** of communities and workers (“An Ideal Solution for Repurposing U.S, 2021). Bartela et al. conducted a case study on a 460 MWe supercritical coal-fired plant in Poland, demonstrating the techno-economic benefits of replacing it with a nuclear reactor incorporating thermal energy storage (Bartela et al., 2022), (Bartela et al., 2021). Furthermore, Lukowicz et al. performed a techno-economic analysis on the same Polish coal plant, proposing the replacement of the plant's steam cycle with a small-scale modular Pressurized Water Reactor (PWR) (Łukowicz et al., 2023). Simonian et al. evaluate the potential of C2N transition at the Limestone coal plant in Texas, comparing small modular, high-temperature gas-cooled, and molten salt nuclear reactor technologies. Each technology's pros and cons are weighed against cost, risk, and C2N integration complexity. The study concludes no one-size-fits-all solution exists for C2N transitions, and specific nuclear designs and transition schemes must be carefully considered for each project based on technical specifications and feasibility (Simonian and Kimber, 2023). Notably, although these studies focused on specific candidate coal plants, comprehensive siting analyses for C2N transitions were not addressed.

The potential for advanced nuclear reactors to replace coal plants has been discussed in (“Coal-to-Nuclear Transitions, 2024), **emphasizing their compatibility** with variable renewable technologies and their capability to provide both electricity and process heat. The document (“Coal-to-Nuclear Transitions, 2024) examines economic impacts, job creation, and revenue benefits in host communities, noting **significant increases in employment and income** following a coal-to-nuclear transition. It discusses workforce requirements, educational needs, and training for transitioning workers, outlining the overlap and distinct roles between coal and nuclear plants. Policy and funding aspects, including **tax incentives** and loans, are also addressed, with a focus on achieving net-zero emissions targets by 2050 and supporting disadvantaged communities. The document emphasizes the critical role of utilities in managing transitions and presents a comprehensive outlook on infrastructure reuse and community engagement strategies for successful coal-to-nuclear conversions. In another paper, the advantages of repurposing existing site infrastructure, including transmission infrastructure, environmental permits, and water usage rights, have been examined. Repowering coal plant sites with nuclear power offers **clean, reliable, and dispatchable energy**, addressing the twin challenges of decommissioning and transitioning to low-carbon energy sources. The paper guides utilities through the key considerations and steps involved in evaluating and repurposing coal plant sites for advanced nuclear generation, focusing on the potential to retain jobs, tax bases, and community support.

In contrast to the technoeconomic analyses described above, the siting of advanced nuclear reactors within operating or retired CPPs has received relatively little attention in the literature. Belles et al. conducted an analysis using the Oak Ridge Siting Analysis for Power Generation Expansion (OR-SAGE) tool to evaluate the suitability of 13 coal power plants in the Tennessee Valley Authority (TVA) service territory for the deployment of advanced nuclear reactors (Belles et al., 2013). A similar approach was adopted in another study (Belles et al., 2021), where OR-SAGE was utilized to assess the retrofitting of advanced nuclear reactors in existing or retired coal plants. Furthermore, Omitaomu et al. employed the OR-SAGE tool to investigate the siting of advanced nuclear reactors across the contiguous United States (Omitaomu et al., 2022). In a separate study, Toth et al. employed the Advanced Nuclear Site Locator (ANSL) tool to evaluate 304 coal sites in the U.S., identifying **79** potentially feasible sites for coal-to-nuclear transitions (Toth et al., 2021). However, they reported that state-level policies could pose challenges to the demonstration of advanced nuclear reactors. Therefore, a comprehensive assessment of all coal plants in the United States, encompassing operational and retired facilities, is necessary to gain an understanding of the most suitable coal sites for transitioning to nuclear power. While the existing literature provides some valuable insights into the siting potential of advanced nuclear reactors in coal plants, the number of studies on this subject remains limited.

1.3. Contribution

This paper aims to assess the feasibility of converting each operational coal site to nuclear power using a tool called Siting Tool for Advanced Nuclear Development (STAND). The studied coal plants are classified into two different groups (Group-01 and Group-02) based on their capacity. Since advanced nuclear reactors are divided into various classes, such as micro-reactors, medium-scale reactors, and Small Modular Reactors (SMRs), it is necessary to categorize coal plants accordingly to match their capacity for a smooth transition to nuclear power. Categorization will also help in presenting the research findings and data clearly, considering the substantial amount of data involved in the analysis. To conduct this analysis, our first step was to gather information on all operational coal sites in the U.S. until January 2023. The operational coal sites are the focus of this study to **take advantage** of the existing Balance of Plant (BOP) equipment, such as transmission lines and power system protection components, which can **reduce construction time and costs**. Analyzing operational coal plants will also guide policymakers, state-level governments, and energy modelers in determining the prioritization of coal plant retirements. Furthermore, we limit our study to operational coal sites in the U.S. as many retired coal sites lack the necessary technical infrastructure for an attractive coal-to-nuclear transition. Next, we classify all operational coal sites into two clusters based on their nameplate capacity. The CPPs located in non-contiguous states (e.g., Alaska and Hawaii) are not considered due to the lack of sufficient data in STAND. Each cluster is then individually simulated in STAND using selected attribute values, as mentioned in Section 2, specifically in Table 1, Table 2, Table 3. Section 3 discusses the clustering of CPPs. Section 4 provides additional information about the STAND tool. Section 5 presents the results of the study, while Section 6 concludes the study with discussion. This paper presents a comprehensive approach for utilizing STAND in evaluating the feasibility of transitioning from coal to nuclear energy across the U.S. The detailed results and investigation will provide a clear idea on which factors one should consider for a particular region/area to C2N transitions.

#### Scenario ONE is Climate Change.

**Nuclear energy is key for climate goals.**

**Matthew 22** [M.D. Matthew, Professor @ Saintgits College of Engineering (India), January 2022, Nuclear energy: A pathway towards mitigation of global warming, Progress in Nuclear Energy, https://aben.com.br/wp-content/uploads/2022/02/Nuclear-energy-a-pathway-towards-mitigation-of-global-warming.pdf] sumzom

The clean energy transition means shifting from fossil energy to energy resources that **release little or no greenhouse gases** such as nuclear power, hydro, wind and solar. About a **third of the world’s carbonfree electricity** comes from **nuclear energy.**

Nuclear power has a **great potential** to contribute to the 1.5 ◦C Paris climate change target. Nuclear power plants produce **no greenhouse gas** emissions during their operation; only very low emissions are produced over their full life cycle. Even after accounting for the entire life cycle from mining of nuclear fuel to spent fuel waste management, nuclear power is proven to be a low carbon electricity source. During operation and maintenance, nuclear power plants produce different levels of solid and liquid waste and are **treated and disposed-off safely**. While conventional fossil-fueled power plants cause emissions almost exclusively from the plant site, the majority of greenhouse gas emissions in the nuclear fuel cycle are caused in processing stages upstream (exploration and processing of the uranium ore, fuel fabrication etc.), and downstream from the plant (fuel reprocessing, spent fuel storage etc.). Over the course of its life-cycle, the amount of CO2-equivalent emissions per unit of electricity produced by nuclear power plants is comparable with that of wind power, and **only one-third** of the emissions by solar. The greenhouse gas emissions correspond to 10–15 gm of CO2 per kilowatt hour electricity produced in comparison with the emission from a fossil fueled plant of 600–900 gm, 15–25 gm from wind turbines and hydroelectricity, and around 90 g from solar power plants (Fig. 8) (Carbon Dioxide Emissions, 2021).

Nuclear power delivers reliable, affordable and clean energy to support economic growth and social development. **Without a larger role for nuclear energy, it would not be possible to combat climate change.**

Nuclear power can be **deployed on a large scale**. So, nuclear power plants can directly replace fossil fueled power plants. As of end December 2020, global nuclear power capacity was 393 GW(e) and accounted for around 11% of the world’s electricity and around 33% of global low carbon electricity. Currently, there are 442 nuclear power reactors in operation in 32 countries. There are 54 reactors under construction in 19 countries, including 4 countries that are building their first nuclear reactors according to the IAEA reports (Nuclear Power Proves its, 2021; Climate Change and Nuclea, 2020a, 2020b). Nuclear power is reducing CO2 emissions by about **two gigatons per year**. Therefore, nuclear power will be imperative for achieving the low carbon future. In France, nuclear power plants accounted for 70.6% of the total electricity generation in 2019, the largest nuclear share for any industrialized country. About 90% of France’s electricity comes from low carbon sources (nuclear and renewable combined). Nuclear power contributes 20% of electricity generation in the United States over the past two decades and it remains the single largest contributor of non-greenhouse-gas-emitting electric power generation out of 1,117, 475 MWe total electricity generating capacity of which 60% is from fossil fuel.

The second-largest source of low carbon energy in use today is nuclear power, after hydropower. Nuclear power plants provide **continuous and stable** energy to the grid whereas solar and wind energy require back-up power during their output gaps, such as at night or when the wind stops blowing. The International Panel on Climate Change (IPCC) has proposed at least doubling of nuclear power generation by 2050 to meet the Paris agreement. Nuclear power has compensated about 60 Gt of CO2 emissions over the past 50 years, nearly equal to **2 years** of global energy-related CO2 emissions and can help to conquer the challenges of climate change.

Existing reactors and future advanced nuclear technologies, like Small Modular Reactors (SMRs), can meet base load power needs and also **operate flexibly** to accommodate renewables and respond to demand. SMRs are a recent concept to accelerate the construction and commissioning of large nuclear power projects. By adopting the concept of modular manufacture of components, significant reduction in on-site construction time can be achieved. This can also help in reducing the capital costs. Several types of SMRs are currently under development and these offer improved economics, operational flexibility, enhanced safety, a wider range of plant sizes and the ability to meet the emerging needs of sustainable energy systems. Some of these reactors are designed to operate up to 700–950 ◦C (for gas cooled reactors) compared to LWRs, which operate at 280–325 ◦C. The electrical efficiency is higher and it can supply high temperature heat to industrial processes. High temperature SMRs can generate hydrogen through more energy efficient processes such as high temperature steam electrolysis or thermochemical cycles. Their smaller size and easier siting are expected to be a better fit for most non-electric applications, which require an energy output below 300 MWe.

#### Climate change is existential.

**Nogue 23** [Sandra; Lecturer in Paleoenvironmental Science @ the University of Southampton; 3-23-2023; OUP Academic; “Catastrophic climate change and the collapse of human societies,” https://academic.oup.com/nsr/article/10/6/nwad082/7085016; DOA: 3-24-2025] nikhil \*\*brackets in original\*\*

The scientific community has focused the agenda of studies of climate change on lower-end warming and simple risk analyses, because more realistic complex assessments of risk are more difficult, the benchmark of the international targets is the Paris Agreement goal of limiting warming to <2°C, and the culture of climate science is to try to avoid alarmism [1]. Current fires, prolonged droughts, floods and heat waves, together with the consequent **food insecurity**, **civil unrest** and **migrations**, however, are opening the eyes not only of most scientists but also of most people all over the world to the need for considering, at least, the potential catastrophic effects of the collapse of ecosystems and society due to the current **emergency** of climate change.

The projections for the climate of the coming decades are, as we all know, worrying. The worst-case scenarios in the 2022 Intergovernmental Panel on Climate Change (IPCC) report project temperatures by the next century that last occurred in the Early Eocene, reversing 50 million years of cooler climates within two centuries. The Pliocene and Eocene provide the best analogues for near-future climates [2]. Climates like those of the Pliocene are likely to prevail as soon as **2030** and unmitigated scenarios of emissions of greenhouse gases (GHGs) will produce climates like those of the **Eocene** for the coming decades. This situation is particularly alarming because human societies are locally adapted to a specific climatic niche with a mean annual temperature of ∼13°C [3]. We can thus logically expect that current and future warming may **easily overwhelm** societal adaptive capacity.

These climate projections could be even more detrimental if models would not neglect, as they currently do, **feedback in the carbon cycle** and potential **tipping points** that could generate higher GHG concentrations [4]. Examples include the apparent slowing of dampening feedbacks such as the natural carbon-sink capacity [5,6], the loss of carbon due to increasing frequencies and intensities of fire at northern latitudes [7], **droughts and fires** in the Amazon [8] or the thawing of Arctic permafrost that releases methane and CO2 [9]. This feedback is also likely not proportional to warming, as is sometimes assumed. Instead, abrupt and/or irreversible changes may be triggered at a temperature threshold [7]. Particularly worrying is a ‘tipping cascade’ in which **multiple tipping elements** interact in such a way that tipping one threshold increases the likelihood of **tipping another** [4,10].

Climate change also interacts with **other anthropogenic stressors** such as changes in **land use**, loss of **biod**iversity, **nutrient imbalances**, **pollution** and an **overuse** of available resources that are crossing the planetary safety boundary limits and operating as a possible **catastrophic** mix. This mix may exacerbate society vulnerabilities and cause multiple indirect stresses such as economic damage, loss of land and water, and food insecurity that can merge into system-wide synchronous failures. These cascading effects are not only biophysical or biogeochemical, but they also affect human society, generating **conflicts**, **political instability**, systemic financial risks, the spread of **infectious diseases** and the **risk of spillover**. For example, there is evidence that the 2007−10 drought contributed to the conflict in Syria [11].

Anthropogenic climate change interacting with these other stressors could thus cause a global catastrophe, in a **worldwide societal collapse**. Kemp et al. [1] have reminded us that although we have reasons to suspect it, such potential collapsing futures are rarely studied and poorly understood. The closest research is the search for evidence of tipping dynamics and estimating thresholds, timescales and impacts of potential tipping points [4]. We advocate for considering them while using the available knowledge acquired from historical and prehistorical examples of local and regional collapses, transformations and resilience of human societies also driven by climate and unsustainable use of resources (Fig. 1).

#### Scenario TWO is Peak Oil.

**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 cooperati**on, 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.

#### Cross Apply Clare --- GPW is existential.