Becoming Spacefaring: America's Path Forward in Space

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Abstract
Fundamental to a nation's national security is energy security. The United States is substantially energy insecure, and this energy insecurity is growing. A barrel of oil equivalent (BOE), representing the energy content of 42 US gallons of oil, is a convenient measure of energy resources, production, and consumption. In 2010, with a population of 309.3 million, the United States consumed 18 billion BOE of energy, with 85% coming from fossil fuels. By 2100, with a likely population of 617.5 million, the United States will need 31 billion BOE of energy. Fossil fuels cannot meet this demand. Hence, the United States must switch to sustainable energy. This will take decades and cost tens of trillions of dollars. The only practicable option is space-based solar and nuclear power, most likely from geostationary Earth orbit, and transmitted to ground receiving stations. To become energy secure with sustainable space-based power, the United States must begin a spacefaring industrial revolution and become a true, human, commercial spacefaring nation. A substantial, airline-like spacefaring infrastructure must be built throughout the Earth-Moon system to support this new and substantial space-based power industry. The presidential policy changes needed to pursue space-based power and the spacefaring industrial revolution are discussed.

Keywords: United States, energy security, immigration policy, technically recoverable fossil fuel resources, White's Law of Cultural Survival, standard of living, space-based power, space solar power, spacefaring, space policy

I. Introduction

America's energy security and national prosperity is in very serious jeopardy. As everyone understands, affordable supplies of oil, coal, and natural gas are the lifeblood of America's prosperity—providing about 85% of all the energy consumed in America. Yet, these are non-renewable energy sources, as everyone also understands. While the Earth has large amounts of these fuels, only that portion that can be recovered safely can be used. This technically recoverable portion is called the endowment—recognizing that it is a gift from nature. The US Geological Survey (USGS) has estimated the remaining technically recoverable endowment of known and yet-to-be-discovered oil, coal, and natural gas and this is far less than what is needed to sustain America through the end of this century.

This shortfall creates a serious American energy security crisis that is foolish to ignore. The era of affordable fossil fuels will end this century during the lifetimes of our children and grandchildren, placing their security and wellbeing at great risk. Despite a half-century of national political awareness of our fossil fuel insecurity, there is no rational national program underway to develop sufficient <u>practicable</u> sustainable energy replacements before affordable fossil fuel scarcity takes hold. This is alarming! Clearly, new sustainable energy sources must be found to replace fossil fuels. The cost will be in the tens of trillions of dollars. This is fundamentally a political issue regarding priorities, policies, and allocation of resources. America's political leaders largely do not even understand that there is an energy security issue with unavoidable serious consequences. In short, with respect to national energy security, America is dangerously in the dark.

Our ability to harvest fossil fuels is a function of technology and market price. When our technology is no longer able to extract fossil fuels at a price and in the quantities needed for a healthy economy, serious consequences follow because affordable electricity and fuels are the lifeblood of any modern civilization. The coming end of the era of affordable fossil fuels means that serious strife is in America's future unless we undertake significant steps to replace fossil fuels with new, sustainable energy sources and do this rapidly enough to have a smooth economic transition. Achieving this smooth transition will not be easy, quick, or inexpensive. It will take generations and will require a significant percentage of the gross domestic product throughout the remainder of this century. Most importantly, it will require that the United States become a true, commercial, human spacefaring nation, as the only practicable source of sustainable energy in sufficient quantities will be from space-based sustainable power systems.

The purpose of this article is to explain quantitatively why the era of affordable fossil fuels is ending, what the consequences will be if no effective transition plan is undertaken, why space-based power is the only real solution, and what initial policy steps should be undertaken by the next president to begin to resolve this crisis.

II. The Vital Importance of Affordable Energy Security

The abundance of energy in America, particularly inexpensive gasoline, has made Americans unappreciative of the importance of energy security. A reasonable person understands that ignoring vital needs has serious harmful consequences, but this is exactly what most people do with respect to energy security. They take for granted that they will have electricity, natural gas, and gasoline at prices they find affordable. Thus, the appropriate starting point to understand the need for space-based sustainable energy is to establish the importance of affordable energy security. Everyone understands the vital need for water security, food security, and shelter from the weather. Everyone now needs to understand firmly why energy security is also vital.

A. How Energy Influences How We Live

Anthropologists study how people live or have lived. They seek to find out what makes civilizations work or fail. This research now shows that the affordable availability of energy plays a major role in civilizations surviving or collapsing. Without sufficient food (human-consumed energy), the population will starve. Without sufficient electricity and fuels, a modern industrial society will collapse. White's Law of Cultural Survival is at the center of America's energy security crisis and its future cultural survival. Yet, few understand its significance or have even heard of it. Hence, to understand the central premise of this paper of the need for America to address its energy insecurity politically, it is very important to understand White's Law. Fortunately, it is easy to grasp.

Using his studies of ancient civilizations, the fundamental energy-related paradigm of modern civilization was defined by American anthropologist Leslie White in the 1940s. He defined what is referred to herein as While's Law of Cultural Survival. This law defines the paradigm—a society's rules for success—relating energy and technology to the society's standard of living.

The starting point is to understand clearly what White means by "culture". He defined culture as the "tools, implements, utensils, clothing, ornaments, customs, institutions, police, rituals, games, works of art, language, etc."[1] In other words, culture is our standard of living. A civilization ascending is increasing its standard of living; a civilization in decline is losing its standard of living. Think of the decline of the Roman civilization where, in a very short time, the Romans lost the "how to" knowledge and capacity to function in ways that they had developed over centuries.

Now for his use of "energy." Energy, as White uses this term, is "the capacity for performing work."[2] White uses this term in a very general way. For most of human history, the work he speaks of was derived from the muscles of humans and animals. Food was the source of this energy. Today, it is modern fuels and electricity.

White's research into ancient civilizations found a critical relationship between the level of culture of a civilization and the availability of affordable energy. He established that "Other factors remaining constant, culture evolves as the amount of energy harnessed per capita per year is increased, or as the efficiency of the instrumental means of putting the energy to work is increased."[3] "Instrumental means" is technology.

This is summarized in Wikipedia as:

1. Technology is an attempt to solve the problems of survival.
2. This attempt ultimately means capturing enough energy and diverting it for human needs.
3. Societies that capture more energy and use it more efficiently have an advantage over other societies.
4. Therefore, these different societies are more advanced in an evolutionary sense.

White's Law is expressed in the form of a symbolic relationship:

$$\textit{Energy}_{\textit{per capita}} \bullet \textit{Technology} \rightarrow \textit{Culture or standard of living}$$

White's Law is not a true mathematical relationship. The symbol "•" does not signify multiplication but only "interaction." The law indicates that the use of suitable forms of energy, using appropriate technologies, produces the civilization's culture. Especially in modern times, White's Law is essentially the law of cultural survival governing all modern

[1] Leslie White, *The Evolution of Culture: The Development of Civilization to the Fall of Rome* (New York: McGraw Hill, 1959), 3.
[2] Leslie White, "Energy and the Evolution of Culture," *American Anthropologist* 45, no. 3 (July-September, 1943): 335.
[3] White, *Energy and the Evolution of Culture* (New York: Grove Press, 1949), 111.

civilizations, including America. As will be discussed, it often determines if a nation goes to war.

As seen in White's definition, energy per capita—how much energy is used per person per year—is the proper metric to which attention must be paid. The standard of living is an expression of how well the average person lives. Hence, White's Law is related to how much energy is used directly and indirectly by the average person.

A good way to look at White's Law is by rewriting it incrementally, relating how changes in energy used per capita and changes in the technology available produce changes in the standard of living.

$$\Delta E_{per\ capita} \bullet \Delta T \rightarrow \Delta C_{standard\ of\ living}$$

Using White's Law, the relationship between energy, technology, and warfare can be examined.

B. Taking the Threat of Future Fossil Fuel Wars Seriously

Throughout most of human history, the ability of a civilization to ascend against its rivals was closely tied to its ability to produce sufficient excess food to sustain its army and, in times of peace, to undertake government construction efforts, increasing the standard of living. Egypt became a leading nation five thousand years ago as it harnessed the vast food production capability of the Nile River valley to provide food wealth to its rulers. This was used to develop a powerful nation, fielding strong armies and undertaking vast building programs. Later civilizations clearly understood the importance of having large, secure food resources by conquering Egypt first in order to use Egypt's grain production to feed their armies. Alexander the Great did this, as did the Romans. In those times, an army literally traveled on its stomach.

In the 1800s, the technology of steam power ushered in the industrial age. Steam power freed human civilization from the limits of muscle power or water power, enabling greater economic or military output per unit of human effort. After a fairly brief period where wood was the primary fuel, affordable supplies of wood fuel were soon exhausted and the world transitioned to fossil fuels to power the industrial age—first coal, then oil, and finally natural gas. Using White's Law, the increasing per-capita use of fossil fuels and improving mechanical powered technologies is expressed as:

$$\Delta E_{fossil\ fuels} \bullet \Delta T_{mechanical\ power} \rightarrow \Delta C_{standard\ of\ living/military\ capability}$$

Unfortunately, the distribution of fossil fuels is based on the growing conditions on continents hundreds of millions of years ago. What the transition to fossil fuels meant was that most of the world's developed nations—historically having existed in locations favorable to pre-industrial agrarian cultures—were suddenly in the wrong place. Nations wishing to modernize and industrialize found themselves domestically short of the modern energy and other natural resources necessary to become technological nations embracing the new ΔE and ΔT. What they needed, they soon realized, was to be elsewhere or, more accurately, to extend their political and military control elsewhere. In short, they needed empires. This situation became especially acute when oil became the primary fuel for transportation, making mechanized land and air warfare common in the early 1900s. Nations going to war on horses—as had been done for thousands of years—were easily dominated by nations having oil and mechanized warfare capabilities. Oil and mechanized warfare elevated the military culture of some nations while leaving the have-nots at their mercy.

As World War I (1914-1918) unfolded and the advantages of oil-fueled warfare became clear, those without oil quickly recognized their weakness. Beginning with World War II, the military control of oil has become the central theme of military hostilities. Control the oil and your military has its hand at the throat of all the other nations dependent on that oil supply. Germany, with limited domestic oil resources, understood this. Its military invasions of North Africa and Russia early in what became World War II were aimed at seizing the oil fields of the Middle East and southern Russia. By controlling the oil, Germany could have forced other nations, such as Britain and Russia, to suffer the consequences of dramatic ΔE decline, directly impacting their ability to wage war. Even though these nations still retained the mechanized warfare ΔT, this was just junk without oil. Germany tried to use White's Law of Cultural Survival as a tool of warfare. Millions of lives were lost in this attempt.

Japan, also with few domestic oil resources, as well as most other needed industrial natural resources, undertook military conquest of the Pacific to secure the needed oil and other resources. Japan, which did not begin to modernize until the 1860s, quickly recognized its natural resource shortcomings. By the early 1900s, to the surprise of many, it had become the preeminent modern military force in the western Pacific by defeating the Russian military in two decisive land and naval engagements.

Japan's attack on Pearl Harbor was directly tied to its need for oil. In the 1930s, the United States was the world's primary exporter of oil, supplying the bulk of Japan's oil. Cutting off Japan's oil was a measure used by President Roosevelt to try to force Japan to curtail its military conquests, especially after brutal attacks in China. Instead, what this oil embargo accomplished—most likely unavoidably—was an expansion of war in the Pacific, as the then highly militaristic Japan was unwilling to cede to these demands. Japan hoped that a quick strike on the US Navy, then stationed at Pearl Harbor, would cripple US military capability in the Pacific, giving Japan the upper hand. The attack failed because the US Navy's aircraft carriers were out to sea at the time of the attack. Millions died in the Pacific theater as Japan, driven by White's Law of Cultural Survival, tried to secure its vital oil and other vital industrial resources.

With the end of World War II, Middle East oil became a central focus of the Cold War between the United States/NATO and the former Soviet Union. By the end of World War II, the United States recognized that Middle East oil would be needed to replace declining domestic oil resources. The Soviet Union, even though it had substantial oil resources and is a major oil exporter today, also recognized that by controlling the Middle East politically it could control/influence the countries becoming increasingly dependent on these immense oil resources, including the United States. From the 1950s on, although often cloaked as religious conflicts, much of the turmoil in the Middle East has really been about the control of oil and the world political power this enables. Millions have died in the various wars and conflicts that have taken place in the Middle East. In a region of the world that has little industry, oil is the foundation of national and individual wealth and political power.

The anticipated US need for Middle East oil, dating back to World War II, came true in 1970. That was the year when domestic oil production peaked—as projected by American geochemist M. King Hubbard in the 1950s. He introduced the concept of "peak oil". This is when locating and exploiting new oil and gas deposits lags behind supplying a growing domestic oil demand due to an increasing population and an increasing oil-fueled standard of living—two-car households, suburban living, better cars, interstate highways, etc. Although the United States had been importing Middle East oil into some markets since the 1950s, domestic production was still then increasing. After domestic production peaked in 1970, the imported percentage of total oil consumed rose dramatically—from 9% <u>of total fossil fuel use</u> in 1970 to 18% in 1973, just three years later. For the first time in their history, Americans were substantially energy insecure, bringing White's Law quickly into play.

In 1973, as the third Arab-Israeli war broke out, Arab oil-producing countries used the growing US dependency on imported Middle East oil to punish the United States for supporting Israel following the surprise Arab attack. The United States initiated a massive arms airlift to replenish Israeli stocks of arms. Within two days, Arab oil producers, using the same rationale as did President Roosevelt when he embargoed oil to Japan, placed an embargo on exports of oil to the United States, creating a domestic oil supply crisis. It is now fairly well understood that the rapid response of the United States to support Israel, when it was suffering early heavy losses, was undertaken to prevent Israel from using its nuclear weapons in its defense. The Arab countries, perhaps not understanding the seriousness of the situation, attempted to use White's Law of Cultural Survival against the United States by creating a significant ΔE reduction to harm the US economy. This brought substantial oil price inflation in the United States, long gas lines, the threat of gas rationing, and a temporary recession <u>just four years</u> after the United States had been substantially energy secure! The awareness that the US president decided to have the United States endure this to prevent the likely use of nuclear weapons has only recently come to light.

In 1979, Iran again came to center stage as the monarchy, supported by the Western countries, was overthrown by revolutionary forces supported by the former Soviet Union. American hostages were taken at the US Embassy, precipitating hostilities between the US government and the new Iranian government that have continued ever since. One consequence of the revolution was that Iranian oil production fell dramatically. As Iran was then a major world oil supplier, this created a worldwide oil supply shortage. In 1978, imported oil provided 24% of the total US fossil fuel consumed. To counter domestic shortages, price controls on domestic oil were lifted. The market price of oil rose 250% within two years, creating a major recession, high unemployment, high inflation, and high interest rates. The economic impact of the recession lasted nearly a decade. At the bottom of the recession in 1982, imported oil had fallen to 11% of total fossil fuel use, while total fossil fuel energy use declined 13% from 1978 to 1982. US unemployment rose to 11% in 1982 from just under 6% at the start of the crisis in 1979. The impact of White's Law on the US standard of living and nearly all American families was very much evident.

It is very important to understand the US economy's sensitivity to market-driven price increases resulting from even modest per capita ΔE reductions as the era of affordable fossil fuels ends. The oil supply crisis of 1979, as well as that of 1973, showed that White's Law is clearly negatively impacting an energy-insecure America. US per-capita energy consumption historically peaked at the start of both the 1973 and the 1979 oil supply crises. Per-capita energy use—a measure of economic health—fell immediately after the 1973 crisis as the recession and higher prices took hold. As the economy came out of that first recession, per-capita energy use had climbed back to just above the 1973 level when the Iranian crisis started a second recession. By 1983, as the second recession dragged on, per-capita energy use had fallen 13% from the 1979 peak.

The two oil-supply crises in America in the 1970s and the severe economic recessions they triggered are now largely forgotten. Recent Middle East conflicts in which the United States directly and substantially engaged are now viewed from the perspective of war and anti-war and not about the central political conflict to control vital Middle East oil resources. Most Americans simply do not understand that nations engage in deadly serious conflict to obtain or preserve their control of oil and that the history of past conflicts is a harbinger of what is to come as all affordable fossil fuels, not just oil, are exhausted in the coming decades. History ignored is often history repeated. It is obvious that any future fossil fuel scarcity will trigger warfare—perhaps nuclear warfare—as nations scramble to be among the winners controlling what available fossil fuels remain. The need for a better energy security "Plan B" is obvious.

C. Immigration Policy and Energy Security

Modern humans began to migrate from Africa as long as 100,000 years ago by some estimates. Australia was reached around 45,000 years ago and, by current understanding, the Americas were first reached perhaps as long as 40,000 years ago. Except for some small part of southern Africa that is likely our ancestral home, humans everywhere else are immigrants or the decedents of immigrants.

While human migration certainly came from an urge to explore, most previous human migration was likely undertaken in search of better security—improved protection from the weather and threats, potable water, and, especially, reliable food sources. Too many humans in one area extracted food at a rate exceeding natural replenishment rates. Soon hunger set in and everyone then had to migrate anew seeking new food sources. Eventually, humans became territorial, forcing those outside their tribe to migrate elsewhere to protect the tribe's food supplies. Elbow room to live was a survival instinct.

Three fundamental food-producing ΔTs enabled an increased population density—fishing, food animal domestication, and plant cultivation. These increased the per-capita food supply (ΔE) per unit of human effort. The increased ΔE enabled greater numbers of humans to live off a given area of fertile land, enabling an improved ΔC in the form of increased permanence and growing population size. With a rising per-capita food energy availability and greater security against famine, humans had the time to create more ΔT, enabling even more ΔC.

The key to any society's long-term success is a family with the ability to give birth to and raise the next generation. The amount of land necessary per family established the acceptable population density. To the extent of available fertile land, migrants were likely welcomed as they strengthened the civilization by increasing the number of people, total land area in food production, and diversity of skills. And, of course, highly skilled migrants—merchants, artisans, healers, warriors, etc.—were also likely welcomed because the improved food ΔT produced excess food enabling these skilled migrants to be fed in payment for their skills.

The invention of steam power, followed by electricity and the internal combustion engine, transformed human civilization because they enabled far greater food production per unit of human effort. The result was that the percentage of the population required to produce food fell dramatically. However, the "price" was the creation of an entire new energy dependency—that of the non-renewable fossil fuels necessary to fuel the engines. During the time when human and animal food powered civilization, this energy supply was renewable. The low population density, established by the annual food-production capacity of the land, also meant that obtaining wood for fuel was not generally an issue. However, with the advent of steam power, wood fuel became scarce, forcing the industrializing nations to transition to coal as a replacement.[4] Oil, in the form of kerosene for lighting and gasoline for engines, and natural gas for lighting and heating followed. For modern civilizations, the critical "food" supply became non-renewable fossil fuels. As discussed above, a world war was largely fought to control the preeminent fossil fuel—oil.

D. Migration Now Has a Negative Impact on Modern Civilizations

This change in civilization's "food supply" from human and animal food to non-renewable industrial fuel changed how migration impacts a society. Migration now adds demand for energy to an economic unit, such as a nation, <u>without</u> adding capacity to expand the non-renewable fossil fuel resources being used. This is an important difference from when human and animal food was the primary energy source. In other words, a modern new immigrant, unlike our immigrant ancestors, does <u>not</u> add to the nation's fossil fuel resources, but only increases the drawdown of these resources, creating a negative impact on the nation's energy security. This change in circumstance is not well recognized.

A corollary is the drought now severely impacting the western United States. Nature supplies potable water through rainfall and snow melt. These western states have historically had droughts, both short-term and long-term, due to weather changes. Some droughts have lasted for hundreds of years well before humans occupied these areas in significant numbers and well before the use of fossil fuels. Water engineering projects undertaken nearly a century ago created reservoirs, dams on distant rivers, and pipelines

[4] Britain, as an island nation with an increasing population, was an exception, switching to coal in the 1500s because of shortages of wood fuel well before it industrialized with steam power.

to redistribute water to enable short-term droughts to be covered. However, regional population growth, primarily through migration into the region, has increased the drawdown rate of the available storage, while insufficient rainfall and snowfall has failed to correct this situation. Drought, and the famine it generally causes, is a historical reason why civilizations collapse. Immigration during good times, which increases the local population, also increases the likelihood of turning an otherwise moderate drought into one with severe consequences for everyone. Hence. significant net immigration into such drought-prone areas is very clearly a poor policy for the simple reason that these new immigrants do not bring new vital supplies of water with them.

E. The Negative Impact of Immigration on US Energy Security is Substantial

Just as the western United States is seeing the negative impact of net immigration-driven population growth on the sufficiency of its engineered water supplies, the same is happening to the United States overall with respect to the decrease in the longevity of its non-renewable fossil fuel endowment.

White's Law stated in terms of per-capita energy use is:

$$E_{per\ capita} \bullet T \rightarrow C_{standard\ of\ living}$$

The standard of living is a function of the available affordable energy per person (per capita) per year. Obviously, the greater the total population, the greater the total annual energy needed by the nation to sustain its standard of living.

$$E_{per\ capita} \times \text{population total} = \text{Annual energy needed by nation}$$

For any country dependent on fossil fuels, population growth due to immigration increases its total future energy needs. Thus, for a nation primarily utilizing domestic fossil fuels, immigration creates a faster drawdown of the remaining non-renewable fossil fuel endowment, advancing the time when fossil fuels are no longer affordable. This will decrease the standard of living of everyone. The conclusion is drawn that the transition from an agrarian society to an industrial society switched the impact of net immigration from positive to negative in terms of energy security. This makes US immigration policy a national security issue.

F. The United States Has Limited Useful Fossil Fuel Resources Remaining

The Earth has extensive remaining fossil fuel resources. However, only that portion able to be recovered safely, legally, and affordably using available technologies counts towards satisfying White's Law.

The USGS tracks US natural resources and makes projections of how much known and <u>yet-to-be-discovered</u> oil, coal, and natural gas resources are accessible for recovery using available technologies. This is known as the "technically recoverable resources." In simple terms, this projection constitutes the natural endowment of fossil fuels available to meet America's future White's Law of Cultural Survival needs.

What about those people on TV saying that the United States has lots of fossil fuel? Yes, the United States has lots of fossil fuels. What it does <u>not</u> have, as will be seen, is lots of technically recoverable resources.

What about discoveries of additional fossil fuel resources? The USGS includes an expert assessment of yet-to-be-discovered resources in its estimate of technically recoverable resources. Hence, even though new discoveries are made, these are included already in the remaining endowment estimate.

What about improvements in fossil fuel recovery ΔT? Certainly, improved recovery ΔT will increase the size of the technically recoverable resources. Take, for example, the hydraulic fracturing (fracking) of oil and natural gas shale deposits. This technology, now deployed for less than a decade, has substantially increased the size of technically recoverable US oil and, particularly, natural gas resources. The first fracking of oil wells began shortly after World War II, but it was not profitable. It took nearly fifty years of research and development to bring this ΔT out of the lab into profitable commercial use. Therefore, it is reasonable to conclude that a comparable technology being started today may not see substantial commercial use for many decades. From a strategic energy security planning perspective, while new fossil fuel recovery ΔT should be pursued, it is <u>not</u> reasonable to "bet the farm" on it. Sound energy security strategic planning must have a reasonable confidence of success and most certainly must avoid presumptions that things will just work out. California's drought shows that things do not just work out.

In 2011, the Congressional Research Service published the USGS 2010 projection of the size of the domestic technically recoverable fossil fuel resources or endowment. (As this does not include the affordability of the fuels brought to the market, this is an optimistic projection of the size of the <u>affordable</u> fossil fuel endowment.) Per the USGS, in 2011 the United States then had 1,366.8 billion BOE of technically recoverable fossil fuels—just about 1.4 trillion BOE.[5] While this sounds like an almost unlimited supply, for a growing nation of over 300 million, it is not.

A BOE is a simple measure of energy representing the amount of thermal energy in 42 US gallons of oil. All energy sources, not only coal and natural gas, but also wind, solar, hydroelectric, nuclear, etc., can be expressed in terms of how many equivalent BOE they supply to the consumer.

Currently, the United States is consuming about 18 billion BOE of energy each year with about 85% or about 15 billion BOE coming from fossil fuels. At the current rate of fossil fuel use, assuming that all of this is taken from domestic sources, the total endowment of US technically recoverable fossil fuel resources would last 89 years—only to the end of this century.

$$18 \text{ billion/year} \times 0.85 = 15.3 \text{ billion BOE/year of fossil fuels}$$

[5] Carl E. Behrens et al., *US Fossil Fuel Resources: Terminology, Reporting, and Summary*, 7-5700, December 28, 2011 (Washington, DC: Congressional Research Service, 2011), Table 4, pp. 15-16.

1,366.8 billion BOE ÷ 15.3 billion BOE/year = 89 years

Thus, the roughly 1.4 trillion BOE fossil fuel endowment—including resources not yet discovered and resources that are likely unaffordable to produce—will run out around 2100, provided the size of the US population does not increase and assuming the current standard of living is maintained. This is within the lifetime of today's children and grandchildren. Clearly, their future is **not** energy secure at today's standard of living and with a continued substantial reliance on fossil fuels. Assertions that the United States has lots of fossil fuels are clearly very misleading.

What about imports? As discussed above, the United States became substantially dependent on imported oil in the early 1970s and this has not benefited US national security. Fortunately, at least for a while fracking has substantially increased domestic oil and natural gas production, reducing natural gas and oil imports while lowering consumer prices. This has made the United States more energy secure. Why would it benefit the United States to increase its dependency on oil and gas imports in the future as the primary means of shoring up diminishing domestic supplies? Clearly, it would not.

G. Continued Immigration Will Dramatically Increase Energy Insecurity

In 1999, the US Census Bureau made several projections of the growth of the US population through 2100 based on various levels of immigration. Two cases are relevant to national energy security planning:

1. With the most likely fertility and mortality rates, but with zero immigration, starting at 274 million in 2000, the US population would likely climb to 377 million by 2100.

2. With the most likely fertility and mortality rates combined with the most likely net immigration using then current immigration policies, the US population would likely climb to 571 million by 2100.

The first case shows that the earlier ballpark estimate of an 89-year life of US technically recoverable fossil fuel resources is optimistic, because even with zero immigration, the US population will grow by about 27% by 2100. The second case is even more alarming. Likely net immigration substantially increases the population in 2100, making clear that America's fossil fuel endowment will last far less than a century. US immigration policy has a very significant impact on future US energy security and, consequently, US national security.

From 2008-2012 the Census Bureau updated its forecast, but only for 50 years. A private demographic analysis company used this data to create a model matching the Census Bureau projections and then used this model to extend the projections to 2100.[6] The starting point was the 309.3 million US population established in the 2010 census.

Six levels of net immigration were modeled with these results:

[6] Decision Demographics, Inc.

- With zero net immigration, the US population peaks in around 2050 at 358 million and declines to 343 million in 2100.

- With an annual net immigration of 500,000, the population in 2100 increases by 72 million to 415 million and continues to increase thereafter.

- With an annual net immigration of 1 million, the population in 2100 increases by 143 million to 486 million and continues to increase thereafter.

- With an annual net immigration of 1.5 million, the population in 2100 increases by 217 million to 560 million and continues to increase thereafter.

- With an annual net immigration of 2 million, the population in 2100 increases by 286 million to 629 million and continues to increase thereafter.

- With the Census Bureau's most likely level of immigration of just under 2 million per year, the population in 2100 increases by about 275 million to 617.5 million and continues to increase thereafter.

The Census Bureau's most likely 2100 population of 617.5 million is nearly twice the 2010 census of 309.3 million. This makes the average population from 2010-2100 1.5 times that of 2010. Thus, the corresponding increase in the rate of fossil fuel use means that the 1.4 trillion BOE of the US fossil fuel endowment will only last 60 years to 2070—a loss of 30 years—if today's standard of living is maintained.

$$(309.3 \text{ million in } 2010 + 617.5 \text{ million in } 2100) \div 2 = 463.4 \text{ million}$$

$$463.4 \text{ million} \div 309.3 \text{ million} = 1.5$$

$$1{,}366.8 \text{ billion BOE} \div (15.3 \text{ billion BOE/year} \times 1.5) = 60 \text{ years}$$

While not addressed so far in the public political debate on immigration policy, net immigration, both legal and illegal, significantly impacts the future population size of the United States and must, via White's Law of Cultural Survival, impact its future standard of living as the supply of affordable fossil fuels ends more quickly. In a free market, diminishing supply brings price inflation and economic recession as experienced in the 1973 and 1979 oil supply crises. *There is a price to be paid for irresponsible immigration policy and, with respect to energy security, that price is likely to be very costly and dangerous.*

H. The Impact of Energy Conservation is Likely to be Marginal

To keep from complicating the preceding calculations, the per-capita energy use was assumed to be constant through 2100. Measured in terms of BOE/year, US per-capita energy use peaked in 1979 at 62.1 BOE/year. From 2001-2007, when energy prices were fairly stable, just prior to the start of the current recession in 2008, the average was 58.1 BOE/year. At the 2010 population of 309.3 million, this comes to nearly 18 billion BOE/year of total energy consumption.

$$309.3 \text{ million population} \times 58.1 \text{ BOE/year} = 17.97 \text{ billion BOE/year}$$

The decline in per-capita energy use during times of economic prosperity has been slow. Over the nearly 30 years since 1979, the average per-capita energy use declined by only about 6% total—or only about 0.26% per year. This very minimal rate of reduction is especially noteworthy given the significant public and legal attention paid to energy conservation and improved energy use efficiency.

$$(62.1 – 58.1) \div 62.1 = 6.4\%$$

$$0.064 \div (2004\text{-}1979) = 0.26\%\text{/year}$$

While it is reasonable to expect further improvements in energy use efficiencies, at the same time the ΔT and ΔC of non-energy goods and services will require increases in per-capita energy use for larger cars, second cars, larger homes, second homes, travel, increased use of electronics and data handling, etc. Energy efficiency improvements are being converted into gains in the standard of living—exactly the same as has been happening since the start of the Industrial Age.[7]

With this in mind, per-capita energy use is optimistically assumed to decline steadily from 58 BOE/year in 2010 to 50 BOE/year in 2100. While there is uncertainty in this value, it must also be recognized that the Census Bureau's methodology-based projection of 617.5 million in 2100 is also uncertain. Both are, however, reasonable to use for this discussion.

I. Likely Net Immigration Will Double the Cost of Switching to Sustainable Energy

Modern civilization requires energy in two primary forms—electrical power generated to meet the immediate demand, called dispatched electricity, and a convenient and safe form of fuel for transportation, heating, and industrial processing. Thus, the new sustainable energy infrastructure replacing fossil fuels will need to provide on-demand dispatched electrical power and a fuel as well. The primary replacement for fossil fuels will be electrical power produced from sustainable solar and/or nuclear energy sources. Hydrogen, produced by the electrolysis of water using this sustainable electricity, will become the primary fuel.[8]

[7] The coming humanoid robotic revolution will likely substantially increase the human per-capita energy use. These robots will require energy for operation, transportation, housing, manufacturing, etc.

[8] Hydrogen is very difficult to store and handle in the general consumer market. It is quite likely that carbon will be extracted from the CO_2 in the atmosphere and combined with the hydrogen to produce methane, the primary component of natural gas. The technology for handling, storing, and using methane is well established. The carbon released into the atmosphere, from the combustion of this methane, will be recycled back into plants and more methane. It is quite possible that some of this artificial methane will be pumped back underground into depleted oil and gas wells for long-term storage, essentially returning to the

To help quantify this transition and the impact of immigration, a hypothetical all-nuclear energy infrastructure is modeled. A 1-GW nuclear power plant is typical of the size used by utilities. Such a 1-GW plant, operating 95% of the year, will generate 8,322 GW-hours (GWh) of electrical energy each year. This is equivalent to 5 million BOE/year.[9] This value is used to determine how many nuclear power plants would be needed to meet future US energy needs using only nuclear power.

$$\text{1-GW} \times \text{365 days/year} \times \text{24 hours/day} \times 0.95 = \text{8,322 GWh}$$

To establish a baseline, the US population in 2100 with zero net immigration will be used. With 343 million in 2100 using 50 BOE/year per capita, the gross energy need would be about 17 billion BOE/year. Note that this is less than the total US energy consumed in 2010.

$$\text{343 million population} \times \text{50 BOE/year} = \text{17.15 billion BOE/year}$$

In 2100, 3,430 1-GW nuclear power plants would be needed to sustain a standard of living comparable to today. Each 1-GW plant would meet the needs of 100,000 people.

$$\text{17.15 billion BOE/year} \div \text{5 million BOE/plant-year} = \text{3,430 1-GW plants}$$

Now, using the Census Bureau's most likely net immigration assumption, for a US population of 617.5 million in 2100, the total annual energy need would be almost twice as large at 31 billion BOE/yr. Hence, 6,180 1-GW nuclear power plants would need to be operating in 2100—of which 2,750 would be due to immigration-driven population growth.

$$\text{617.5 million population} \times \text{50 BOE/year} = \text{30.9 billion BOE/year}$$

$$\text{30.9 billion BOE/year} \div \text{5 million BOE/plant-year} = \text{6,180 1-GW plants}$$

$$\text{6,180 1-GW plants} - \text{3,430 1-GW plants} = \text{2,750 1-GW plants}$$

This most likely level of net immigration-driven population growth not only depletes the remaining US technically recoverable fossil fuels more rapidly, but it also nearly doubles, by 2100, the size of the sustainable energy infrastructure needed to replace these fossil fuels. This is another reason why US immigration policy is a key—but, currently missing—part of a national energy security planning.

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earth what was extracted this past century. In this manner, a substantial portion of the "excess" carbon currently in the atmosphere can be captured and removed from the atmosphere—provided sufficient sustainable electricity is available to produce the hydrogen.

[9] Currently, the gross thermal energy equivalent used by the United States is about 18 billion BOE/year. Of this total, historically about 40% has been used to generate electricity, with the remainder being carbon fuels used directly for transportation, heating, etc. In the all-nuclear energy infrastructure, to meet the historical 60% fuel needs, the hydrogen fuel must be produced using nuclear electricity. Using projected future electrolysis efficiencies, around 0.002443 GWh will be needed to produce one BOE of hydrogen. Thus, for providing both nuclear electricity (directly) and hydrogen fuel (indirectly), it works out that each 1-GW nuclear plant provides the equivalent of 5 million BOE of gross thermal energy. About 85% of the total nuclear electricity produced each year by the nuclear power plant would be used to produce hydrogen.

J. Immigration Will Cost about $240 Billion per Year on Average

In 2013, the US Department of Energy estimated that the overnight capital cost to build a new nuclear power plant was about $5.5 billion per GW. To this amount, $1.5 billion is added for land, construction financing, hydrogen electrolysis and storage, etc. The ballpark cost is then $7 billion per GW. To build an all-nuclear energy infrastructure for 617.5 million in 2100 would cost roughly $43 trillion. The portion of this cost that is due to new immigration is about $19 trillion through 2100 or an average annual immigration premium of $241 billion each year from 2020 through 2100.

$$6{,}180 \text{ 1-GW plants} \times \$7 \text{ billion/plant} = \$43.26 \text{ trillion}$$

$$2{,}750 \text{ 1-GW plants for immigration} \times \$7 \text{ billion/plant} = \$19.25 \text{ trillion}$$

$$\$19.25 \text{ trillion} \div (2100 - 2020) = \$241 \text{ billion/year}$$

K. Terrestrial Nuclear Energy Is Not a Viable Solution

Uranium U-235-based nuclear fission has been commercialized since the 1970s. While the above discussion described the US energy needs in terms of a hypothetical all-nuclear energy infrastructure, replacing fossil fuels with thousands of terrestrial nuclear power plants is not a viable option for these reasons:

- The US only has sufficient U-235 to fuel about 135 1-GW nuclear reactors for the typical 60-year life of a new plant.

- Breeding the fissile U-238 isotope into plutonium Pu-239 would provide almost an unlimited amount of fuel.[10] However, Pu-239 is the plutonium isotope used to make nuclear weapons. Thus, a domestic Pu-239-based nuclear industry opens the door to easy foreign nuclear weapon proliferation when foreign countries implement their own plutonium-based nuclear energy industries.

- Breeding thorium into U-233, the other fissionable uranium isotope, would also provide an almost unlimited amount of fuel. However, U-233 can also be used to make nuclear weapons, just as U-235 and Pu-239. Hence, this is also a path to nuclear proliferation.

- Nuclear power plants are thermal power plants, meaning that about 70% of the nuclear energy released ends up as waste heat dumped into the terrestrial environment. This requires a large river, a large lake, or the ocean to provide the necessary cooling. Also, nuclear power plants must be located away from areas prone to earthquakes and tsunamis and located away from populated areas. It is unlikely that the United States

[10] While many elements and many isotopes of these elements are radioactive—meaning that they undergo spontaneous nuclear decay—only three isotopes are capable of being used in a nuclear fission reactor or weapon. These are uranium-233, uranium-235, and plutonium-239. “Breeding” is where another isotope is artificially transmuted, in a nuclear reactor, into one of these three fissionable isotopes.

has sufficient locations for thousands of nuclear power plants. It has only 104 GW of nuclear energy today.

- No acceptable nuclear waste disposal method has yet been identified and put into practice.[11] The federal government's effort to build an underground waste burial site in Nevada has been stopped, leaving extremely hazardous nuclear waste in temporary storage. Many of the waste radioactive isotopes must be safely contained for tens of thousands of years. Building large numbers of additional nuclear power plants without a disposal solution does not appear reasonable.

- Fusion nuclear energy is a possible future replacement for fission nuclear energy. The practicality of fusion energy has not yet been demonstrated. Also, fusion plants would still be thermal power plants needing large rivers, lakes, or the ocean for cooling. Hence, locating thousands of large fusion power plants in the United States will be difficult.

L. Wind and Ground Solar Power Are Not Politically Acceptable Solutions

The current focus on sustainable energy is with building wind and ground solar farms. Many people have been misled to believe that using these terrestrial sustainable energy sources to replace fossil fuels is quite practical. In reality, as shown in the following, the substantial land area needed for solar and wind farms to produce sufficient energy to replace fossil fuels likely makes these politically unacceptable solutions.

Wind Energy

Current commercial wind farms use wind turbines that stand nearly 500 feet tall at the tip of the turbine blades. With good wind speeds, these turbines will each produce 2.5 MW (0.0025 GW) of electrical power—the turbine's nameplate output power. Of course, as everyone understands, wind conditions continually vary at any location minute-to-minute as well as seasonally, and even year-to-year. This variability means that wind electricity cannot be a primary source of on-demand dispatchable electricity to supply power to a utility's grid. The method that has been adopted by utilities is to use wind electricity when it is available to substitute for electricity generated by other means, such as natural gas-fueled generators. The key point is that wind power, as it is now implemented, is not a reliable means of producing on-demand electricity.

The "capacity factor", expressed as a percentage, is the percentage of the wind turbine's nameplate output power generally available during a given period of time such as a month or year. The US Department of Energy reports that from 2009-2013, the average capacity factor for wind farms was 32%. Wind turbine performance is still improving, so a capacity factor of 40% is reasonable to use for future projections. Using this value, a 2.5-MW wind turbine can be expected to produce 8.76 GWh of wind-electricity each year on average.

[11] Nuclear reactor designs using nuclear waste as fuel are being developed. These generally involve breeding U-233 or Pu-239. This technology is in a very early stage of development, with China leading much of this effort.

$$2.5 \text{ MW} \times 365 \text{ days} \times 24 \text{ hours/day} \times 0.40 = 8{,}760 \text{ MWh}$$

$$8{,}760 \text{ MWh} \div 1 \text{ GWh}/1000 \text{ MWh} = 8.76 \text{ GWh}$$

This wind-electricity, of course, is variable electricity produced whenever the wind blows, not necessarily when the customer needs the electricity. The necessary engineering solution to be able to produce on-demand dispatched electricity is first to convert all of the variable wind-electricity into hydrogen fuel using electrolysis. The hydrogen fuel is then used, as needed, directly by the end consumer as a replacement for oil and natural gas and by utilities to fuel gas turbine generators to provide dispatched electricity.

As calculated previously, the likely US population of 617.5 million in 2100 will require 31 billion BOE of energy each year. This gross energy is divided into dispatched electricity and fuels. In 2007, before the 2008 start of the current prolonged recession, the US used 17.42 billion BOE of energy. Of this, 40% was used to produce 4.16 million GWh of dispatched electricity. Scaling this up, in 2100 the United States will likely need 7.4 million GWh of dispatched electricity.

$$4.16 \text{ million GWh} \times (30.9 \div 17.42) = 7.4 \text{ million GWh}$$

Using projections of the future efficiency of large-scale electrolysis, the conversion of variable wind-electricity into utility-dispatched electricity is estimated to be 46% efficient.[12] This means that it eventually takes 2.17 GWh of variable wind-electricity to produce 1 GWh of dispatched electricity.

$$1 \div 0.46 = 2.17$$

In 2100, about 16 million GWh of wind-electricity will be needed to provide 7.4 million GWh of dispatched electricity.

$$7.4 \text{ million GWh of dispatched electricity} \div 0.46 = 16.1 \text{ million GWh of wind-electricity}$$

Of the 30.9 billion BOE of gross energy needed in 2100, from US historical data, 60% would be used as fuel. This equals 18.5 billion BOE of hydrogen.

$$30.9 \text{ billion BOE} \times 0.60 = 18.54 \text{ billion BOE of hydrogen}$$

In this hypothetical all-wind energy infrastructure, wind-electricity is also used to produce the needed hydrogen fuel. Producing 1 BOE of hydrogen fuel (lower heating value) from electricity, using projections of future electrolysis efficiencies, is estimated to require 2443 kWh (0.002443 GWh).

$$2443 \text{ kWh/BOE} \times 1 \text{ MWh}/1000 \text{ kWh} \times 1 \text{ GWh}/1000 \text{ MWh} = 0.002443 \text{ GWh/BOE}$$

[12] The overall 46% efficiency takes into account a loss of 5% for the transmission of the wind-electricity to the electrolysis plants, a 20% loss for the conversion of the wind-electricity into hydrogen fuel, and a 40% loss for the generation of electricity using the hydrogen: $(1 - .05) \times (1 - .20) \times (1 - .40) = 0.46$.

To produce 18.54 billion BOE of hydrogen will require 44.61 million GWh of wind-electricity.

$$18.54 \text{ billion BOE} \times 0.002443 \text{ GWh/BOE} = 45.29 \text{ million GWh of wind-electricity}$$

To meet the energy needs of 617.5 million in 2100, the wind-electricity required to provide dispatched electricity and hydrogen fuel are summed to yield the total GWh of variable wind electricity needed. To provide 30.9 billion BOE of energy using wind power will require about 61 million GWh of wind-electricity.

$$16.1 \text{ million GWh} + 45.29 \text{ million GWh} = 61.39 \text{ million GWh in 2100}$$

With each 2.5-MW wind turbines producing 8.76 GWh of wind-electricity per year, about 7 million of these 500-foot-tall wind turbines would need to be operating in 2100.

$$61.39 \text{ million GWh} \div 8.76 \text{ GWh per turbine} = 7 \text{ million turbines}$$

The physics of extracting power from the wind places a cap on how many megawatts of nameplate power can be placed per square mile. This means that crowding in more wind turbines does not proportionally increase the amount of wind-electricity produced per square mile.[13] When using 2.5-MW turbines, five turbines can be placed per square mile. Thus, 1.4 million square miles of wind farms would be needed to meet the energy needs of 617.5 million Americans in 2100. The land area required is just under one half of the land area of the entire continental United States

$$7 \text{ million turbines} \div 5 \text{ turbines/square mile} = 1.4 \text{ million square miles}$$

The total installed nameplate wind power in 2100 would be 17,500 GW compared with the 6,180 GW of nuclear power needed.

$$7 \text{ million turbines} \times 2.5 \text{ MW/turbine} \div 1 \text{ GW/1000 MW} = 17{,}500 \text{ GW}$$

As of 2013, the United States had 60.7 GW of nameplate wind power installed. While this sounds like a great deal, it is only 0.35% of what will be needed in 2100—less than 1%. Assuming a start in 2020 to build the necessary wind farms to reach 17,500 GW by 2100, each year 219 GW of new wind farms must be built. This means that a capacity equal to 3X the current total installed capacity must be added each year. Also, with an expected component life of 25-30 years, most of the early wind farms—turbines, electrical transmission system, etc.—must be replaced at least once by 2100. Finally, as the population continues to expand due to continued immigration, the building of new wind farms does not stop in 2100.

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[13] The wind's speed falls as it passes through the rotating blades of the wind turbine because the turbine is extracting power from the wind to turn the generator. As this happens, the wind picks up a rotational velocity that causes the lower-speed winds to mix with higher-speed winds at higher elevation. Due to this mixing, the wind's speed close to the ground increases back to its original speed. This occurs over a distance downwind of the turbine. Thus, if the next turbine is placed too close, the incoming wind speed is lower, producing less electrical power.

60.7 GW ÷ 17,500 GW = 0.35%

17,500 GW ÷ (2100 – 2020) = 219 GW/year of new wind farms

The large size of these turbines creates the impression that each will be able to meet the energy needs of a large number of people easily. This is not the case. In 2100, each wind turbine would provide the energy needed by around 88 people using the 50 BOE/year per-capita energy use assumed for 2100. In other words, a 500-foot-tall turbine would be needed for about every 40 homes. Each square mile of wind farms would provide for only 440 people. For comparison, a typical 1-GW nuclear power plant requires two square miles of land and provides the energy for 100,000 people.

30.9 billion BOE ÷ 7 million turbines = 4,414 BOE/turbine

4,414 BOE/turbine ÷ 50 BOE/person = 88 people/turbine

88 people/turbine × 5 turbines/square mile = 440 people served per square mile

To understand the impact of immigration, what happens if the population in 2100 stays at the zero net immigration value of 343 million people? Wind farms totaling 777,000 square miles would be needed in 2100.

343 million with zero immigration ÷ 617.5 million with likely immigration = 0.555

1.4 million square miles × 0.555 = 777,000 square miles (for 343 million)

Even with the lower population level, wind power is an impractical energy source. The primary reason is that the best areas of the continental United States for wind farms are the central states from north Texas to the Canadian border. This is America's breadbasket. Installing nearly 800,000 square miles of 500-foot-tall wind turbines would place wind farms on virtually all land between the Mississippi River and the Rocky Mountains. This would severely impact agriculture, the rural environment and standard of living, general aviation, and many forms of wildlife.

Ground Solar Energy

Ground solar energy is the other highly touted form of sustainable energy. Like wind energy, it also produces variable solar-electricity. In this case the variability is due to the day-night cycle as well as seasonal variations in the length of the available daylight and, of course, weather. Thus, the variable electricity from solar farms must be handled the same as wind-electricity—first converting the solar-electricity to hydrogen using electrolysis and then using the hydrogen for end consumer fuel and for generating dispatchable electricity at the utilities.

While the US Department of Energy identified a capacity factor of 40% as being a reasonable target for wind energy, the corresponding value for ground solar farms is only 20%, primarily due to the day-night cycle. The amount of solar-electricity needed to meet the 2100 energy needs of 617.5 million people is the same as that for wind-electricity—61.39 million GWh. However, due to the lower capacity factor, the installed nameplate power must be twice that of wind farms—35,000 GW of ground solar nameplate AC power.[14]

$$17{,}500 \text{ GW of wind power} \times (0.40 \div 0.20) = 35{,}000 \text{ GW of nameplate solar power}$$

To estimate how many square miles of ground solar farms will be needed, the starting point is to establish a baseline using large solar farms built in recent years in the American Southwest where the available ground insolation is the best in the country. These solar farms are averaging 81 MW per square mile of nameplate AC power. For comparison, wind farms have about 12.5 MW per square mile of nameplate AC power.

As the location of solar farms expands beyond these best insolation areas to meet the 2100 energy needs, the available average insolation will decrease primarily due to increased weather losses, e.g., cloud cover. Taking this into account, a value of 72.5 MW AC (0.0725 GW) per square mile is a reasonable value to use for calculating how many square miles of solar farms will be needed.

To meet the 2100 energy needs of 617.5 million people, 483,000 sq. mi. of land, primarily in the southwestern United States, must be leveled, scraped clean of vegetation, covered in gravel to control erosion and weeds/brush, and planted with solar photovoltaic arrays. The comparable area for a zero net immigration population of 343 million people in 2100 is 268,000 square miles. For comparison, the area of Texas is 269,000 square miles.

$$35{,}000 \text{ GW} \div 0.0725 \text{ GW/square miles} = 482{,}759 \text{ square miles (for 617.5 million)}$$

$$482{,}759 \text{ square miles} \times 0.555 = 267{,}931 \text{ square miles (for 343 million)}$$

Due to the terrain of many of the southwestern states, only about 20-25% of the land is suitable for solar farms. Hence, virtually all flat land in southern California, New Mexico, Arizona, Nevada, Utah, and western Texas would need to be covered with solar farms regardless of the land's current use. It is unlikely this would be politically or environmentally acceptable.

To install 483,000 square miles of solar farms by 2100, starting in 2020, an average of about 6,000 square miles of new solar farms must be built each and every year through 2020. With an expected lifetime of 30 years, much of this solar infrastructure will need to be rebuilt one or more times before 2100. It is also important to understand that, with immigration, the size of the US population does not level off by 2100, but continues to expand meaning more land must be converted to solar farms in the 22nd century.

$$482{,}759 \text{ square miles} \div (2100 - 2020) = 6{,}034 \text{ square miles per year}$$

[14] By their design, wind turbines produce alternating current or AC electrical power. Ground solar photovoltaic panels produce direct current or DC power. This must be converted to AC power before sending the electricity into the power grid. This DC-AC conversion is about 78% efficient. Thus, the nameplate power rating of solar farms must be stated in terms of the AC power produced.

M. Terrestrial Renewable Energy Sources Are Simply Not Practical to Replace Fossil Fuels

From these estimates of the size of ground solar and wind farms needed to power America in 2100, two more terrestrial sustainable energy options can be scratched from the list as being impractical. Conventional fission nuclear energy has already been shown as impractical. In the same vein, expanded hydroelectricity, geothermal-electricity, biomass, wave-electricity, and tidal-electricity will have little measurable impact. There are no plausible terrestrial solutions to replace fossil fuels especially if immigration continues. Yet, the clock is ticking on when the remaining US technically recoverable fossil fuels will be exhausted.

White's Law of Cultural Survival shows that to preserve American culture, economic prosperity, and national security, America's energy infrastructure must provide 50-58 BOE/year of affordable energy. Only about 15% or about 9 BOE/year now come from renewable and nuclear energy. America's standard of living will fall as the level of affordable energy per capita falls. Hence, if terrestrial renewable and nuclear options cannot be counted on to replace diminishing supplies of affordable fossil fuels, then America's cultural collapse is inevitable without a viable political and engineering solution. Plan A—the political naiveté of presuming that terrestrial renewable and nuclear energy can be counted on to replace fossil fuels—is a failure. Plan B must now kick in. While this is hard for some to comprehend, when all terrestrial potential solutions have been eliminated as being impractical, attention must focus on the one remaining doable engineering solution—space-based power.

N. Space-Based Power is the Remaining Solution to Make America Energy Secure

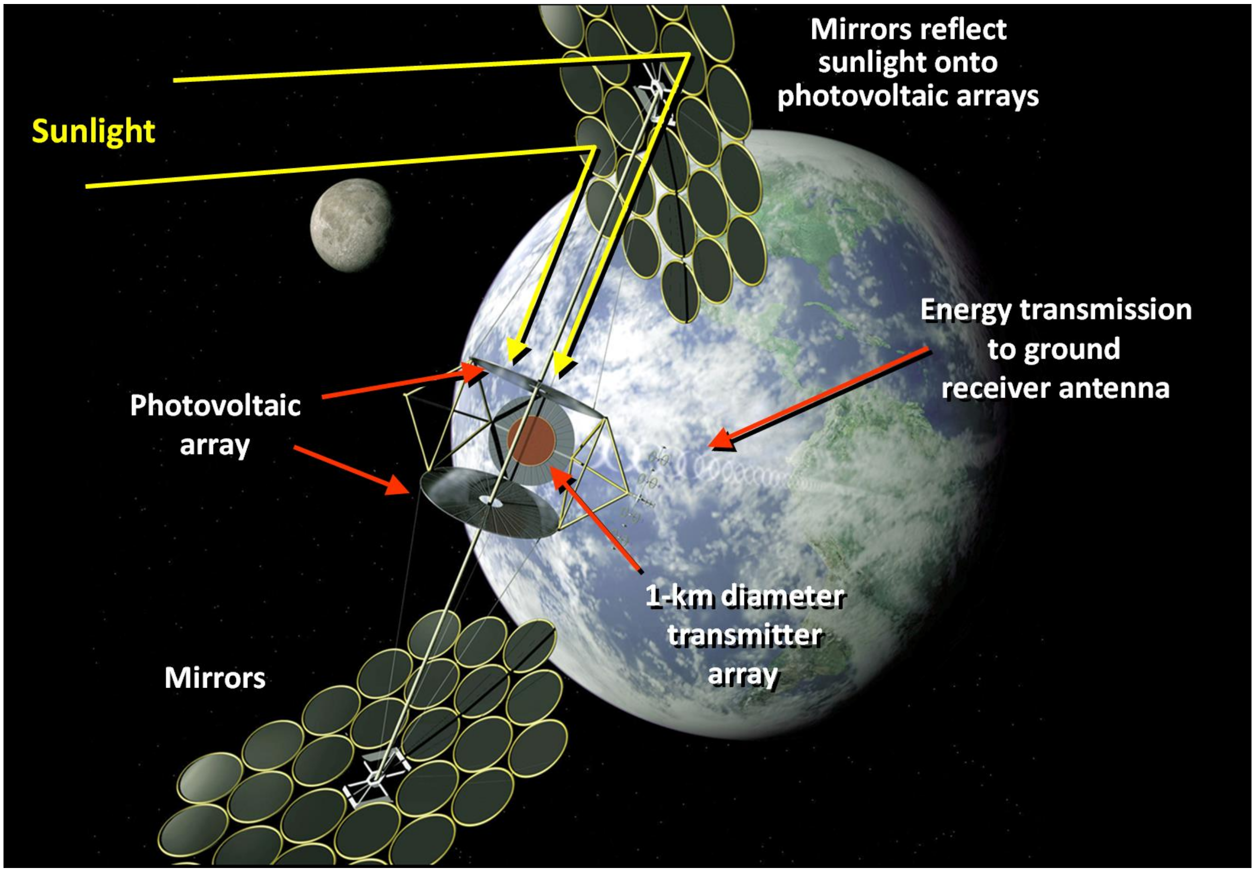

Figure 1. Notional illustration of a space-based solar power station. Source – NASA.

Space-based power is where solar energy is collected or nuclear energy is generated in space, most likely in geostationary Earth orbit (GEO), and transmitted to large ground receiving stations using microwave radio transmission. This space-based power would be generated almost continuously.[15] Ground receiving stations collect this transmitted power, convert it into AC power, and send it to the utilities' power grids. This would be baseload electrical power equivalent to what is generated by coal-fired and nuclear power plants today. This space-based electrical power can also be used to produce hydrogen fuel for transportation, heating, and industrial processing. Stored hydrogen fuel would provide a strategic reserve for backup gas turbine electricity generation should a receiving station go offline.

The design of the transmission system keeps the peak power level in the transmission beam at about one third of the equatorial noonday insolation. With this design, about 10 square miles of land of the ground receiving station is required for each 1 GW of output AC power. Thus, about 60,000 square miles of ground receiving stations would be

[15] The space-based solar arrays will be in continuous sunlight 365 days a year, 24 hours a day, except when these arrays pass into the Earth's shadow. This only happens near the spring and fall equinoxes and happens for only a couple of hours a day at local midnight, at a time when power demand is reduced. Gas turbine generators would provide electricity during this period.

required to deliver roughly 6,000 GW of AC power to the power grids. This is far less than the 483,000 square miles needed for ground solar energy or the 1.4 million square miles needed for wind farms. Also, these receiving stations can be located in parts of the country where the land use and environmental impact is suitable for this use.

Each space-based solar power station in GEO will likely generate 5 GW of electrical power. If this is done with large flat photovoltaic solar arrays, each GW of output power at the ground station requires about 1.7 square miles of space solar arrays in GEO. To obtain 5 GW of output on the ground, the space solar power platform will require about 8.5 square miles of solar arrays. To provide 6,180 GW, for a population of 617.5 million in 2100, would require 1,200 5-GW platforms totaling about 10,500 square miles of space solar arrays. This falls to about 5,800 square miles of space solar arrays needed for a 2100 population of 343 million.

$$5 \text{ GW} \times 1.7 \text{ square miles/GW} = 8.5 \text{ square miles of space solar arrays}$$

$$6{,}180 \text{ GW} \times 1.7 \text{ square miles/GW} = 10{,}506 \text{ square miles of solar arrays}$$

$$10{,}506 \text{ platforms} \times 0.555 = 5{,}831 \text{ square miles (for 343 million)}$$

O. Space-Based Power will be a Significant National Undertaking

Clearly, undertaking space-based power will require a revolution in space industrialization to build and operate, before the end of this century, up to 1,200 space power platforms, each the size of Manhattan. (The world’s energy needs will require 5-6 times this number.) The current approach of launching satellites to GEO and hoping that they deploy and function properly and never require hands-on repair will obviously not work. The size, complexity, and, especially, the need for assured space-based power will make this very much a human undertaking. While this is contrary to the thinking of many now working to make space-based power practical—focusing on robotic, self-assembly, and human telepresence approaches—there are no terrestrial analogs of such a human-designed system functioning in this manner. Certainly, substantial robotic and telepresence will be used, but to achieve assured space-based power, humans will be living and working throughout the Earth-Moon system in large numbers. This is the proven way to get critical tasks properly done.

As the reality of space-based power being the only practicable solution to replacing fossil fuels and maintaining America’s standard of living becomes understood, without doubt the American public will become excited about becoming a true human commercial spacefaring nation building and operating this new space-based power industry. Just as the 19th century was the age of steamships and railroads and the 20th century was the age of aeronautical flight—both ages bringing substantial technological and social changes—the 21st century will be the start of the age of true human spaceflight of the kind Americans have dreamed about since the 1950s. Not only will we build a substantial space-based power industry, but we will also then use a portion of this renewable power literally to power the expansion of human civilization throughout the central solar system and provide for the defense of the planet against asteroid impacts.

III. Building a New Spacefaring Logistics Infrastructure Will Be the First Step

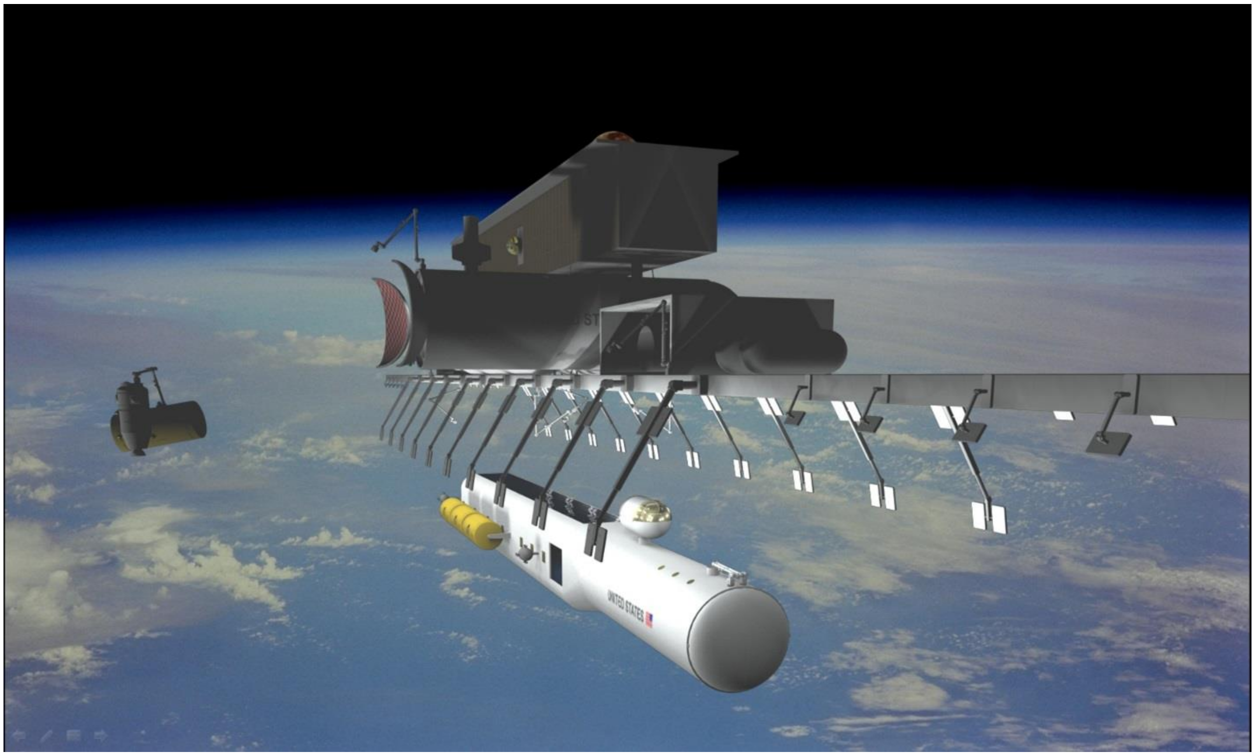

Figure 2. Low Earth orbit space base/space dock with spaceship departing. Source – US Government.

In this exciting future, tens of thousands of Americans will travel to, live, and work throughout the Earth-Moon system to build and operate this space-based power industry. When opening any frontier, the first enabling step is to build infrastructure providing safe, routine, and frequent access to and movement within the new frontier. The initial—repeat, initial—new spacefaring infrastructure will involve:

- Airline-like passenger transport to and from Earth orbit and throughout the Earth-Moon system using airworthiness-certified, fully reusable space transportation systems.

- Medium-class payload and freight transport to Earth orbit using fully reusable or expendable space transportation systems. The fully reusable systems will likely be space cargo versions of the airworthiness-certified, fully reusable passenger space transportation systems. (These will be similar to the air cargo versions of passenger airliners.)

- Heavy and oversize unmanned transport to Earth orbit using the new expendable Space Launch System being developed by NASA. Payloads can include large components for space power stations, entire small and medium-class spaceships (e.g., Space Guard cutters), and large components of large spaceships and space habitats assembled at the low Earth orbit (LEO) space dock.

- Space logistics bases/space docks, space habitats/hotels, and space fuel depots in LEO. These will be the primary destinations for passenger and payload traveling from the terrestrial spaceports to LEO.

- Space tugs to provide cargo and passenger transport between LEO facilities and to provide auxiliary transport at other locations in the Earth-Moon system (e.g., GEO, the Lagrangian points, lunar orbit).

- Space ferries to transport passengers and cargo from LEO to GEO, the Lagrangian points, and lunar orbit.

- Space Guard cutters to provide law enforcement and emergency support throughout the Earth-Moon system.

- Space logistics support bases in GEO and lunar orbit to support industrial operations on the lunar surface.

- Lunar landers for cargo and passengers.

- Lunar hoppers to move about the Moon.

- Large logistics support spaceships providing payload and passenger transport and on-site logistics services at GEO, the Lagrangian points, and lunar orbit.

- Lunar bases to support lunar resource extraction, processing, and transport.

A. The Feasibility of Building This New Infrastructure Is Right above Your Head

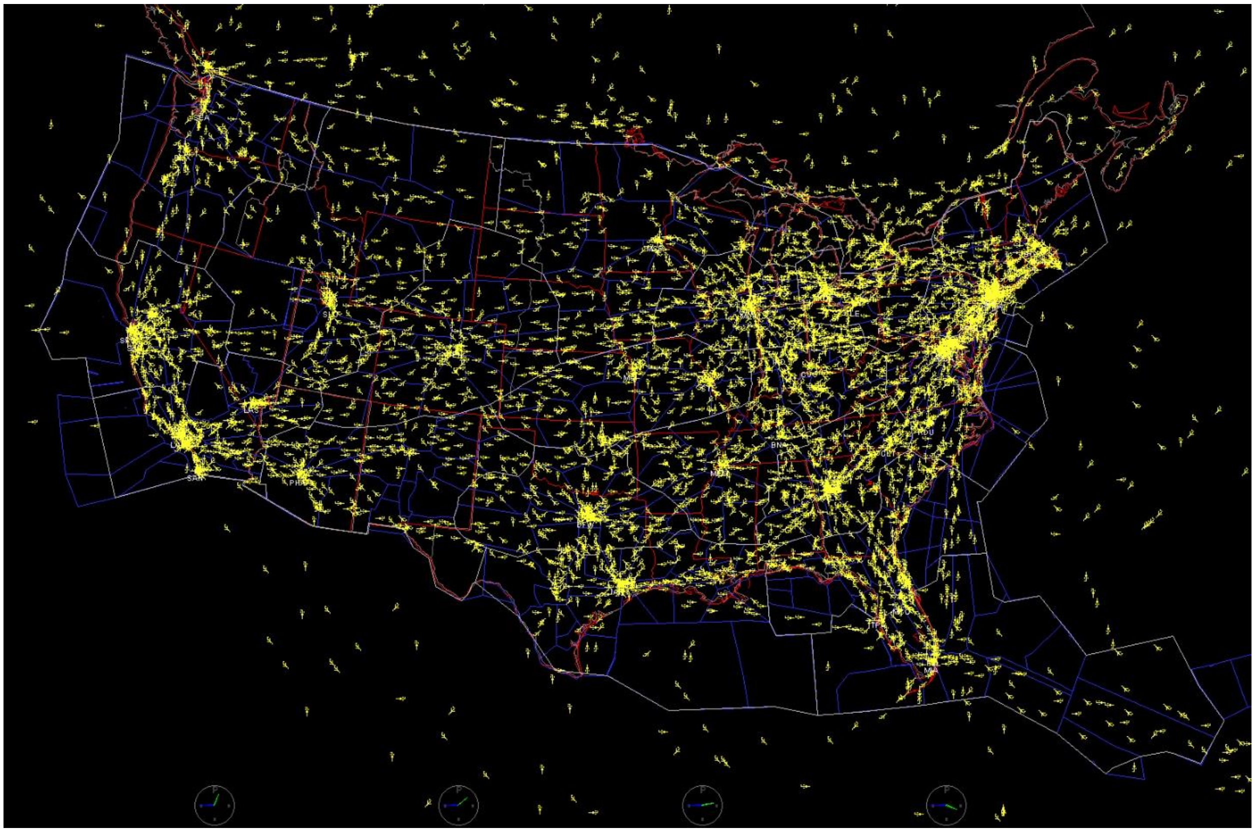

Figure 3. Snapshot of the airliners flying the sky above America. Source – NASA.

While many will express doubt about the feasibility of building this new spacefaring infrastructure, consider that on any typical morning or afternoon several thousand commercial airliners are flying above America carrying roughly a half million passengers and quite plainly demonstrating what America is capable of achieving. Think of what someone would have thought a century ago in 1916 of airliners capable of flying at near the speed of sound for thousands of miles carrying hundreds of passengers and of having thousands of these flying every day. If you time traveled back to that time, what would you have said to try to convince them that this is possible?

The reality is that the technical depth of the American aerospace industry is quite strong and everything listed above can be achieved using available technologies—yes, available technologies. Certainly, the initial spacefaring operational capabilities will later appear to be primitive, just as aircraft a century ago were primitive compared to those built today. But, it is important to understand that getting started with building a substantial initial capability does not require any major technical hurdles to be overcome. In other words, the American aerospace industry is primed and ready to proceed with the engineering development of the initial capabilities—most importantly, the fully reusable space access systems, the Space Launch System, and the LEO space base.

B. Putting some financial numbers to this undertaking

Establishing a new space-based power industry capable of delivering, with needed reliability and security, 6000+ GW of electrical power will not only be a significant technological undertaking, but also a major economic undertaking. From the previous discussion of a hypothetical all-nuclear terrestrial energy infrastructure to replace fossil fuels, 6,180 1-GW nuclear power plants would need to be operating in 2100 to meet the energy needs of 617.5 million. The ballpark cost of this is $7 billion per GW for a total cost of about $43 trillion through 2100.[16] Starting in 2020, the average annual cost of this is $541 billion each year.

$$6{,}180 \text{ 1-GW plants} \times \$7 \text{ billion/plant} = \$43.26 \text{ trillion}$$

$$\$43.26 \text{ trillion} \div (2100\text{-}2080) = \$541 \text{ billion/year}$$

A reasonable expectation is that this ballpark cost estimate is at the low end of the cost of building 1200 space-based power stations and 60,000 square miles of ground receiving stations. Hence, at least $500 billion to $1 trillion will likely be needed each year for the rest of the century, on average, to establish and build out this industry to meet the energy security needs of America in 2100.[17]

How does this compare to other federal expenditures? NASA's current entire annual budget is in the range of $18 billion, while the Department of Defense's budget is in the range of $600 billion. The NASA budget, at its peak during the Apollo program, was roughly $44 billion a year in current dollars. Thus, the effort to undertake space-based power will require annual expenditures, for the rest of the century, in the range of 10 to 20 times the Apollo program. It is apparent that a substantial percentage of the US GDP will become directly engaged in building and operating this new space-based power industry.

While these substantial expenditures at first appear alarming, in reality they offer a substantial new economic opportunity for America. Not only will America become energy secure with sustainable energy, thereby decreasing trade losses, but America's national security obligations related to imported oil imports will diminish. Properly undertaken, this program of space industrialization can have a broad beneficial national economic impact leading to a resurgence of domestic manufacturing. At the same time, the new spacefaring industrial technological revolution will bring broad ΔT advances across the board as improved technologies "invade" other industries, increasing America's industrial and commercial competitiveness.[18]

[16] This is the cost of building 6,180 new plants. With a projected nuclear plant lifetime of 60 years, about 1000 early plants would need to be replaced by 2100. This replacement cost is not included. Also, plant maintenance, fueling, nuclear waste disposal, and other such costs are not included.
[17] The rest of the world will likely need to expend $5-6 trillion each year to have their space-based power systems built—a substantial percentage of this could be undertaken by US companies.
[18] Building and operating this new spacefaring enterprise will require a significant step forward in design sophistication and standardization, product quality, manufacturing, robotic and tele-presence capabilities, software, etc. This new engineering expertise will filter into everything else as it sets the new standard.

From White's Law of Cultural Survival, it is clear that this investment in space-based power is a fundamental war-avoidance undertaking. There is no choice but to do this as space-based power is what will be required to transition to sufficient sustainable energy to replace fossil fuels and ensure America's energy security without either resorting to war or sliding backward in terms of the standard of living. Thus, the cost of building this new industry is America's anti-energy war cost. The cost of energy wars, likely with nuclear-armed adversaries, will certainly be far higher.

IV. Becoming spacefaring will be a new public-private enterprise

The depletion of America's technically recoverable fossil fuel endowment began in the mid-1800s and has been accelerating ever since due to population growth and an increasing energy need per capita. The previous calculations showed that with the most likely level of immigration, the remaining fossil fuel endowment will be depleted within 60 years. White's Law of Cultural Survival, buttressed by historical precedent, indicates that the consequences of this on America will be devastating unless sufficient replacement sustainable energy sources are built in time. With space-based power being the only practicable sustainable energy solution with the capacity to meet US 2100 energy needs, building an effective space-based power industry is a matter of national security of the highest importance.

National security needs transcend the commercial marketplace because the Federal Government—not private enterprise—bears the final responsibility for assuring national security. This does not, however, mean that the Federal Government would or should itself undertake this transition to space-based power. What it means is that private enterprise will undertake building this new space-based power industry and enabling spacefaring logistics infrastructure within a framework of public-private partnerships defined by national policy and federal legislation.

A. The Benefit of New Grand National Energy Engineering Projects

Americans have not been exposed to a grand national engineering project with a definitive goal since the Apollo program of the 1960s. Throughout American history, such projects have inspired the nation—the Erie Canal, the Transcontinental Railroad, the Panama Canal, the Hoover Dam, nuclear-powered submarine *Nautilus*, etc. America is a country with substantial, often world-leading, scientific, engineering, and technological industrial capabilities that have largely been underused since the 1960s—nearly three generations ago. Other countries now build the biggest dams. Other countries are erecting the largest buildings—ironically often designed by American companies. Other countries are digging the longest tunnels. Other countries build the biggest aircraft, the biggest ships, and the most modern cities. Far too many Americans now appear to be socially conditioned to ignore, if not outright deny, America's technological strengths and to be content with America's increasing national insignificance. This social trend is dangerous to America's future, as it creates a national sense of indifference leading to political hesitation in addressing key problems requiring technological solutions. When addressing America's current and growing energy insecurity, hesitation will bring disaster.

Building the vitally needed space-based power industry and the enabling spacefaring logistics infrastructure will require grand new national engineering projects surpassing all undertaken previously. Assume, for this discussion, that each 5-GW space power station in GEO is equivalent to a new aircraft carrier—the most complex military weapon system built in the world. The United States builds these aircraft carriers at a rate of about two per decade. Now imagine needing to build 1,200 of these by the end of century—delivering 15 each and every year—and having to assemble these at the top of a mountain 26,000 miles tall. This is but the tip of the iceberg of what will be undertaken as America becomes a true human commercial spacefaring nation to secure its sustainable energy future. This grand undertaking will define the 21st century for America.

B. America's Current Space Enterprise is Obsolete

Insignificance has overtaken America's government human space enterprise. With only a few exceptions, it has become technologically timid, focused on job self-preservation rather than bold but sound technological advancement. Inexplicably, for the first time in US history, a major national infrastructure—the Space Shuttle—ended operations in 2011 without a new and far better replacement coming into existence. As a consequence, NASA now has to depend on Russia to fly our astronauts into space on Russian expendable launch vehicles first designed in the 1960s. Now, embarrassed and trying for a quick fix, the federally funded solution is to go backwards to 1960s-era space capsules in an attempt to recapture the faded glory of the Apollo program.

On the aerospace commercial side, startup space companies are finding that there is no shortcut to safe human spaceflight. It really does take careful design, experienced engineering, a sound systems architecting and engineering approach from the beginning, lots of testing and evaluation, and lots of money to make complex aerospace systems function with acceptable operability, economics, and human safety. It has been more than ten years since SpaceShipOne won the suborbital Ansari X-Prize. Immediately after that success, the public was led, with great fanfare, to believe that only a few years would be needed to start commercial suborbital passenger spaceflight. Experienced engineers knew better, and were ignored, but have been proven right. Human flight systems are never easy, quick, or inexpensive. This is why effective public-private collaboration will be needed to achieve safe commercial human spaceflight.

C. Effective Public-Private Collaboration Will Be the Key to Success

For important national programs, collaboration and, quite often, formal partnerships of the government and private industry have been required to produce a successful outcome. Private industry brings competition, design creativity, industrial capability, customer engagement, and product-focused technical skills and experience to the partnership. Government brings broad scientific expertise, multi-program system engineering experience, substantial unique test capabilities, and anchor funding to the partnership. This partnership arrangement has been used to make operational, for example, jet-powered aircraft, nuclear energy, interstate highways, major ports and airports, large hydroelectric power plants, the first satellite-based telecommunications, and the entire manned orbital space program. In many of these areas, as the technical risk subsided and the experience and expertise of private industry grew, future efforts became completely private as the level of risk fell to be within the range suitable for private funding. Government, at that point, steps back to maintain only regulatory oversight if this is needed. This historically successful public-private model now needs to be used to start building the spacefaring logistics infrastructure and the new space power industry.

Many in the pro-commercial space movement deny the need for such public-private partnerships. They believe that dogged determination will get it done. To counter this view, the emergence of the commercial jet aviation industry in the 1950s is a very pertinent example. Jet engines, originating in the late 1930s, were integrated into aircraft in the latter years of World War II. The thermodynamic operation of jet engines optimizes their flight for high subsonic speeds at high altitudes. Quickly, aeronautical engineers determined that fundamental design changes were needed including swept wings, pylon-mounted engines, and pressurized fuselages.

Immediately after the war, new types of jet fighters quickly entered service at a rate that today would appear truly amazing. The key advancement, however, was the need for a new jet-powered bomber. Piston-powered, propeller-driven bombers were simply too slow to survive encounters with jet fighters. Bombers needed to fly higher and faster. To achieve this, aerodynamics called for swept wings while propulsion engineers found that they needed to put the jet engines on pylons hanging below the wing. The reasons were the need for easy access to the jet engine for maintenance and the need to prevent a seized jet engine or engine fire from damaging the wing's structure.

While these sound like fairly easy changes, they were quite complex, especially given the analytical capabilities of the time. The key engineering advancements were made during the development of the Boeing B-47 and Boeing B-52 jet bombers. These two military programs gave Boeing the engineering and manufacturing capabilities to develop its jet-powered transport prototype with swept wings, pylon-mounted engines, and a pressurized fuselage. Boeing offered this prototype to the military as the basis for a new jet tanker to keep up with the new jet bombers. This became the KC-135 tanker that is still flying today. As the KC-135 entered production, Boeing built on its design experience to produce the similar Boeing 707, one of the first successful commercial jet airliners. So successful was this design, compared to propeller-driven airliners, that the first operational Boeing 707, flying the 8-hour London-New York route, did not fly with an empty seat for the first six months. Everyone loved to fly jets and they still do. America took the lead in commercial jet aviation in the 1950s and 1960s because of the public-private partnership that enabled the needed technological advancements to be achieved. Done well, public-private partnerships accelerate the fielding of new capabilities—exactly what is now needed to begin to field the initial spacefaring logistics infrastructure.

D. The Space Industrial Boom is about to Begin

The United States is about to embark on industrializing outer space because of the need to develop space-based sustainable power to preserve its national security, economic prosperity, and standard of living. As the scale of the effort grows to be in the ballpark of $1 trillion a year of economic activity, this new industry will be employing around 13 million people, at an average annual wage of $75,000, just to meet US needs. Secondary employment will multiply this by a factor of 2-3. Thus, just as the steam power revolution enabled substantial new commercial enterprises to be formed in the 1800s, America's embarking on creating a new space-based sustainable power industry will bring comparable economic benefits throughout the 21st century. The proper descriptive word to use is “boom.”

The public’s “awakening” to the economic potential of space industrialization will reshape American politics. The public will come to understand the tremendous economic opportunity for technological creativity, entrepreneurship, business formation and expansion, job creation, and career development needed to build space-based power systems, a spacefaring infrastructure throughout the Earth-Moon system, and the many new enterprises making use of both of these. Further, the American public will quickly realize that much of this job creation will call for employees with critical science, math, engineering, technology, and vocational skills—the sort of jobs that create solid middle-class prosperity.

E. The Proven Path to Opening New Frontiers—Build New Infrastructure

The initial focus of this spacefaring industrial revolution will be establishing the permanent infrastructure to reach and work within space routinely and safely. Many, even in the pro-space movement, do not recognize the profound change that will occur as this spacefaring logistics infrastructure is established. Space is now difficult, costly, and unsafe to reach. This forms the current paradigm of how space operations are undertaken. To understand why this paradigm will soon be obsolete, we need to go back to the early 1800s on the Ohio frontier to help envision the changes that will unfold this century in space.

Following the Revolutionary War, Americans moved in large numbers into the Ohio frontier along the Ohio River and its tributaries. Many had earned land in exchange for service during that war. Others bought land from the Federal Government. The land was rich in terms of the needs of an agrarian society—fertile soil, plentiful rain, moderate climate, extensive forests of wood for construction and fuel, and navigable rivers for reaching deep into the frontier.

The one major disadvantage for early settlers was the lack of an established transportation infrastructure beyond Pittsburgh at the head of the Ohio River. There were no roads and the land was primarily dense forest, making cross-country travel difficult. River travel was the only practical means of movement within the frontier. Fortunately, the Ohio River and many of its tributaries were navigable much of the yea. However, trying to move cargo upriver to Pittsburgh and then back across land to the eastern cities was extremely difficult and generally unprofitable.

With the plentiful supply of timber, the primary means of travel was to construct a river raft called a flatboat. This was then floated downstream with St. Louis or New Orleans being the primary destination for selling farm produce. As a consequence of the impracticability of upriver travel, the flatboats were considered expendable, generally being used only once to reach a downriver destination and then sold for lumber or firewood. People, after completing their business and purchasing needed dry goods and farming supplies, simply walked home, perhaps over a thousand miles, carrying what they could on their backs or on pack mules.

There was some two-way passenger river travel, but with a high cost and long travel times. A round trip by keelboat in the early 1800s between Cincinnati and New Orleans took 78 days and cost $160, or about half a year's earnings for a worker. To go upriver, men used long poles to push or ropes to pull the boat upstream. More prosperous people would sail from New Orleans to an eastern port, go cross-country to Pittsburgh by coach, and then float back down the Ohio River to reach their home. The difficulty of expanding the territory economically beyond subsistence farming, due to this primitive and difficult one-way logistics infrastructure, was obvious to everyone. This prevented the vast wealth potential of the western territories from being realized.

In 1807, just four years after the Louisiana Purchase, Robert Fulton commercialized the first steamboat on New York's Hudson River, demonstrating the commercial profitability of fully reusable, two-way river transport of passengers and cargo. In 1811, a prosperous engineer, Nicholas Roosevelt, in partnership with Fulton, used this technology to build the first steamboat on western waters in the Pittsburgh area. This was a significant vessel of about 150 feet in length, displacing 371 tons, and having accommodations for 60 passengers in below-deck cabins. With Roosevelt at the helm, it departed Pittsburgh and traveled roughly 2,000 miles downriver to New Orleans over the 1811-1812 winter. Beginning in April, 1812, the steamboat—named the "New Orleans"—began two-way travel up and down the lower Mississippi, focusing on the growing cotton trade. It quickly became one of the most prosperous enterprises in America by making two-way river travel safe, comfortable, dependable, and affordable. The old paradigm of one-way, expendable river vehicle travel was destroyed with the new paradigm of fully reusable, two-way travel.

Competition adapted quickly to the new paradigm. Over 60 steamboats were operating within only two years—surprisingly, during the War of 1812. Some helped in the defense of New Orleans in 1814. By 1826, 143 steamboats were operating all along the major western rivers. Commerce and settlement exploded as new settlers and their equipment could be safely and affordably transported throughout the Midwest and farm products could be transported into markets serving the world. In the 1850s, 3 million passengers and 8 million tons of cargo were transported annually on just the Ohio River. In that same decade, railroads reached the Ohio valley. Passenger and freight began to switch to this newer form of transportation. By 1900, over 200,000 miles of track were laid, up from only 9,500 in 1850—about 4,000 miles were added each year on average. The paradigm shift from one-way, expendable transportation to two-way, fully reusable transportation made the Ohio-Mississippi River valleys the heartland of a rapidly growing, rapidly industrializing America in the 19th and early 20th centuries. This prepared the United States for the trials of the two 20th-century world wars as this heartland was at the center of building America's military capabilities.

History teaches that creating significant new infrastructure gives a shot of adrenalin to a nation's economy. For engineers and entrepreneurs, the decision to build significant new infrastructure opens the door to applying their imagination to building the initial infrastructure, figuring out how to make it better to build market share, and figuring out how to make use of it in new wealth-producing ways. For example, consider the digital information infrastructure called the Internet. It started with simple e-mail with no conception of what was to come. Two generations later, how much of the vast wealth created by this digital information sharing infrastructure has come from e-mail? Very little.

While the objective of the coming American industrialization of space will be to build a space-based power industry, the critical initial operational advancements will be in building an integrated human spacefaring logistics infrastructure extending throughout the Earth-Moon system. Building this infrastructure will, in itself, not only create substantial new jobs and companies, it will also foster an explosion of new products and services making use of this new infrastructure. Space-based power generation will be only one of these. Today, we can no better predict what the others will be than those who saw the first e-mail had any inkling of what was coming. All we know is that major new infrastructure leads to substantially increased prosperity, large job creation, company formation and IPOs, intellectual property, and lots of new fun. Building major new—repeat, new—national infrastructure is one thing government can do that creates true opportunity and progress. For anyone understanding America's current energy insecurity and the vital need for space-based power, the need to build a national integrated human spacefaring infrastructure should now be plainly obvious. The public will be asking why this has not already started.

V. Where the United States Stands Today in Terms of Commercial Spaceflight Passenger Transport

A. The Importance of Airworthiness-Certified Passenger Spaceflight Systems

Explorers explore and settlers settle. Consequently, exploration and settlement each have their own rules for safety. The early stages of space settlement will occur as the space industrial revolution unfolds. For space settlement to proceed, an acceptable level of operational safety must be achieved. This means that human operations in this new frontier will undergo a paradigm shift in safety from the higher level of risk inherent in exploration to the low level of risk associated with and expected for normal living activities.

Passenger transport safety highlights this distinction. Legally a passenger is a person who has hired a business to transport him or her to a destination by paying a fare. When hiring the business, the passenger surrenders the responsibility for his or her safety to the business owners and operators. In accepting the fare for the transportation, the business also accepts a "duty to care" obligation for the passenger's safety. If the business owner or operator is negligent and harm comes to the passenger, then the owner or operator may be sued to recover damages. If the negligence is severe, then criminal charges may also be brought. The duty to care obligation is part of common law, indicating that this is a normally expected legal obligation that the owner and operators accept when the business begins to operate.

Starting in the 1800s, as steamboats and railroads became a common form of passenger transportation, the increasing mechanical complexity of the systems exceeded the ability of the passengers to ascertain their safety by normal visual inspection. This was especially true for components such as the boilers, brakes, rails, and bridges, whose proper functioning were critical to safety. Regulation, independent inspection, and certification became the way the duty to care obligation was met. Regulations, usually involving design and manufacturing standards, were implemented by law, as were inspections by qualified independent experts. When the system being inspected was found to comply with the regulations, a certificate was issued. This protected the owners from unwarranted lawsuits claiming negligence and provided the basis for allowing the business to operate with the public's confidence.

For commercial aircraft, airworthiness certification is used to meet the duty to care obligation. This involves two parts. First, a new aircraft design or type must be shown by analysis, inspection, and ground and flight test to be safe—to be airworthy. This necessarily involves building and flying prototype and early production aircraft of the new type. When the new design is demonstrated to be airworthy, a "type certificate" is issued, freezing the design. Then the new design goes into serial production. Each production aircraft is (a) individually inspected to show that it was built per the approved design and (b) ground and flight tested to demonstrate that it was properly built—the controls work, all the cables are properly connected, the software is loaded correctly, the landing gear retracts and extends, etc. When this is demonstrated, each individual aircraft is issued an airworthiness certificate giving the owner who buys the aircraft the legal ability to transport passengers on that particular aircraft. Only then does that aircraft enter service and begin to carry passengers.

Undertaking the airworthiness certification process, while required by law, also demonstrates the builder's commitment to passenger safety as this is a carefully regulated process. Having the airworthiness certification process enables the builder to demonstrate the safety of the new design in a manner that the public accepts as being adequate to protect safety reasonably. Having an airworthiness certificate for each operational system—and maintaining it through proper inspections, maintenance, and repairs—enables the operator to demonstrate that its duty to care obligation is being met.

The key to making the airworthiness process work is that it is regulating fully reusable flight systems. Prototype and early production aircraft must be flown repeatedly to gather flight test data to support the type certificate. Each production aircraft must be test flown prior to receiving its airworthiness certificate and entering passenger service. This same safety-assurance rationale carries over into all other forms of passenger transport—certify, then operate. And, of course, this certification process cannot be applied to an expendable or partially expendable flight system, which is why public transportation systems are not expendable or partially expendable.

Obviously, for the commercial transportation of passengers to and from earth orbit and within the Earth-Moon system, only fully reusable flight systems will be able to be used in order to achieve the airworthiness certification necessary to meet the operator's duty to care obligation. Hence, to open space to commercial human operations, fully reusable spaceflight systems need to be developed, type certified, and, then, have each operational system be airworthiness certified before becoming operational. Current or planned human expendable or partially expendable spaceflight systems cannot be airworthiness certified and are, therefore, not useable for passenger transportation.

It is important to differentiate a certificated fully reusable space access system from the "reusable" concept of recovering and reusing a stage or major component, such as the engines, of an otherwise expendable launch vehicle. If any normal fight safety components of the flight system are expendable, then the system cannot be certified. Hence, reusing a recovered component is an economic choice only. While this may be important for decreasing the overall launch costs for these expendable systems, simply being reusable, but without formal airworthiness certification, says nothing about the safety of the system.

B. America's Interest in Fully Reusable Space Access Dates Back to the 1950s

The American dream to become a true human spacefaring nation has been widely evident with the American public since the mid-1950s, when Wernher von Braun, in cooperation with Walt Disney, introduced this spacefaring future to the public. Von Braun, an early pioneer in expendable rockets, understood the need to move to a more conventional logistics infrastructure. His view of the future involved reusable space access systems, orbiting space stations, and reusable spaceships to reach the Moon.

By the late 1950s, stimulated by Sputnik and the initial race to launch orbiting satellites, the American dream of human spaceflight evolved into operational intent within the US Government.[19] The US Air Force started a number of programs, including the original aerospaceplane studies for fully reusable, single- and two-stage space access systems, the hypersonic X-planes to explore the aerothermal environment of hypersonic flight (e.g., the X-15), and the orbital manned reusable spaceplane, DynaSoar (X-20).[20] When President Kennedy made his fateful decision to pursue expendable launch vehicles and space capsules to beat the Soviets to the Moon in the civilian space race, progress in the development of more aircraft-like reusable operational capabilities continued through military R&D.[21] Even after the military's DynaSoar program was cancelled in 1963, largely due to the rapid maturation of military surveillance satellite technologies and ballistic missiles, significant research continued into lifting body designs, advanced materials and structures, and advanced propulsion.

The second opportunity to pursue the spacefaring path began with the start of the Space Transportation System, better known by its popular name, the Space Shuttle. As the name implies, it was originally intended to provide frequent and routine civil access to LEO. It was conceived in the early 1970s as a fully reusable, two-stage system design to

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[19] That the Soviet Union launched the first satellite was an intentional US foreign policy objective. By letting the Soviets launch first, they established, rather than opposed, the legal precedent of the freedom of orbiting satellites to pass over another country. They reinforced this with the first orbiting manned mission.

[20] The manned DynaSoar reusable spaceplane—about the size of small fighter jet—was to be launched on an expendable launch vehicle. This is being done today, although unmanned, with the Boeing X-40 spaceplane.

[21] President Kennedy was first and foremost a politician. He had no particular interest in space. The manned lunar landing goal was a 1961 political response to the Soviet Union's then lead in manned space operations coupled with the failure of the American CIA's Bay of Pigs invasion of Cuba just weeks earlier. After the Cuban Missile crisis that almost brought nuclear war, and shortly before he was killed in 1963, Kennedy appeared to be ready to roll back the lunar landing goal. In a speech at the United Nations he proposed a joint expedition to the Moon with the Soviet Union and was having policy analysts evaluate the projected costs of the Apollo Program. The key point is that the Apollo Program was pursuing political goals, not spacefaring operational goals. After Kennedy's death, it became his legacy. This is why this program left little useful post-Apollo spacefaring infrastructure. The need for America to become energy secure with sustainable space-based power is a clear operational goal rather than merely a "feel good" political goal.

be used in conjunction with an orbiting space station—reflecting the common sense fact that a reusable space access system needs someplace to go to in orbit in order to deliver passengers and cargo. Unfortunately, by 1972, politics and funding constraints changed this into the partially expendable system that we know as the Space Shuttle. Also, the space station was dropped. Safety concerns were addressed by presuming that production and pre-flight quality control of the expendable components would suffice. These changes subverted its original mission goal to operate frequently and routinely, with airline-like safety, because each new flight required the untested use of new and rebuilt components—the external tank and the solid rocket boosters.

Over the course of its 30 years of operation, the Space Shuttle only flew 135 times while unfortunately having two catastrophic failures with loss of crew—failures originating in the new/rebuilt expendable components. Thus, the proven risk of mission failure was about 1:60—far, far less than what is acceptable for public transportation.[22] Expendability prevents knowing for certain that a system is safe to operate prior to being used in regular service. This elevates the risk substantially, making this form of space travel unacceptable for spaceflight passengers.[23]

C. The US Aerospace Industry Has Been Able to Build Fully Reusable Space Access Systems since the 1980s

This engineering common sense need for full reusability in space access was recognized in the 1950s. The first aerospaceplane design studies, started in the late 1950s, were focused on trying to find a fully reusable technological solution to space access. After the Apollo program—and its use of expendables as a politically expedient way of beating the Soviet Union—the focus returned to fully reusable space access when the Space Shuttle requirements were initially defined. It was intended to be a fully reusable, two-stage-to-orbit (TSTO) spaceflight system with airline-like operations. This was a very ambitious objective given the fact that the entire preceding operational and industrial experience was with high-risk expendable launch systems. The requisite political support for the funding necessary to substantially advance the state of the art in a system development program did not exist. The political compromise of the partially expendable Shuttle, with a much larger capacity to accommodate military payloads, was implemented.[24]

With the decision to not pursue full reusability with NASA's Space Shuttle, the pursuit of this approach returned to the military. At the same time the Space Shuttle was about to begin flight operations in the early 1980s, the US Air Force was evaluating military applications of fully reusable military aerospaceplanes. There was common agreement

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[22] A safety risk assessment performed by NASA after Space Shuttle operations ended, using safety assessment tools not available 30 years ago, found that the early Shuttle flights had a likely probability of failure of about 1:12. By the end of the program, this had only improved to about 1:100.

[23] An employee of a company traveling to a destination on a company-owned system is not a passenger in the legal sense of the word. Employees accept the safety risk of the transportation used by willingly being employees. Employee safety is governed by other laws and regulations. NASA astronauts, as employees, are not passengers when they travel on NASA-provided spaceflight systems like the Space Shuttle. However, when the company sends the employee on a trip using a commercial carrier with a purchased fare, the employee becomes a passenger.

[24] These decisions were made prior to the first oil supply crisis—an important event in triggering the initial interest in space-based power undertaken in the late 1970s and early 1980s.

that, to be operationally effective, the system had to be aircraft-like and not some version of an expendable launch vehicle. This moved the intended user of the system from the launch community to the aircraft operations community, meaning that the system would be based at airfields and not at launch facilities. For this reason, the concept studies focused on horizontal takeoff and landing approaches on runways using quasi-single-stage-to-orbit (SSTO) and TSTO systems.[25] A new name was invented—TransAtmospheric Vehicle (TAV)—to separate this concept politically from NASA's Space Shuttle and the military's expendable launch vehicles (ELV). Multiple concepts were studied under contract.[26] A baseline study objective was to define concepts employing 1980s technologies so that a formal program start decision could be pursued.

In 1985, at the conclusion of the TAV conceptual design evaluation, the Air Force decided not to pursue gaining Department of Defense approval to start the formal engineering and manufacturing development of a TAV military system. This decision was based on changing mission needs and funding priorities. Instead, attention turned to developing a revolutionary airbreathing propulsion solution for an SSTO approach. The TAV decision was <u>not</u> a decision based on a determination of inadequate technology or inadequate industrial readiness needed to proceed into formal system development.[27] What the TAV studies showed was that since the start of the Space Shuttle development in the early 1970s, the US aerospace industry had acquired the necessary industrial capability to begin the development of fully reusable, two-stage, rocket-powered space access systems with acceptable program risk.

For the future of the American human spaceflight program, the failure to proceed with the TAV development was another fateful decision, just as was the decision not to pursue full reusability for the Space Shuttle. The military's development of new flight technologies and systems generally precedes commercial adoption, because this provides a proven path to overcome the inevitable technical obstacles and achieve the necessary technical and operational maturity necessary to enable commercial operations. The Air Force's KC-135 jet tanker, developed in the early 1950s by Boeing, gave rise to Boeing's B-707 commercial jet airliner that helped to jumpstart the commercial aviation industry in the late 1950s. The same has been true for advanced materials and structures, engines, digital flight controls, etc.

Had the TAV program been pursued, a military TAV TSTO system would have likely become operational by the late 1990s.[28] This would have opened the door to commercial

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[25] A quasi-SSTO approach used some form of launch assistance such as droppable rocket packs.

[26] A decision to start the conceptual assessment of a new military weapon system follows the preparation and approval of a formal statement of need, citing a military mission deficiency and the lack of an existing solution. This is how the military TAV studies began.

[27] One quasi-SSTO approach was the Boeing Reusable Aerospace Vehicle (RASV). This concept emerged in the late 1970s from Air Force studies. It used then-available rocket, structures, and materials concepts. In 1982, the chairman of Boeing gave the internal company go-ahead to propose to the Air Force building a prototype RASV. This indicates the level of maturity of these primarily rocket-powered systems in the 1980s was sufficient for a major aerospace contractor to support program initiation. The RASV was one of several TAV concepts studied as part of the TAV studies.

[28] See Boeing's patent, US4802639, Horizontal-takeoff transatmospheric launch system, originally filed on September 28, 1984, during the time the Air Force TAV studies were underway. This patent was granted

TSTO derivatives, especially given the 1986 Space Shuttle Challenger failure that exposed the substantial safety and operational inadequacies of the entire US space access infrastructure. A civilian passenger version of such a TSTO TAV system could easily have transported 20 or more passengers to LEO. A civilian cargo version could have transported medium-sized payloads. Think of the impact this would have had on the course of US manned space operations, both civil and commercial, versus where the American human space program stand's today.

It is very important to recognize that from the mid-1980s, America's commercial aerospace industry had signaled that it had the capability to develop fully reusable space access systems—most likely TSTO systems. Yet, for more than a generation, normal commercial market forces/constraints have prevented industry from pursuing this approach, even when the termination of the Space Shuttle and the consequences of this became apparent. Hence, there is a clear need for an effective public-private partnership to initiate this capability as industry will not do this itself.

Within months of the decision not to pursue the military's TSTO TAV, the Federal Government instead chose to pursue the goal of demonstrating a fully reusable SSTO system capable of taking off and landing on a runway. This became the National Aerospace Plane (NASP/X-30) program as part of a national effort to reinvigorate aerospace science and engineering. The technical path chosen was to maximize the use of airbreathing propulsion, employing scramjets capable of operating to Mach 12 and above.[29]

To put this into perspective, the NASP program was initiated in 1985 when the first personal computers were just becoming available. A typical laptop PC today has more computing power than the supercomputers of that time. While exciting, NASP was the point where the nation's intended reach exceeded its technical grasp. While the US aerospace industry had the technical ability to execute a rocket-powered TSTO system development with acceptable risk, the X-30 SSTO program was very high risk. This became quite evident by the end of the 1980s as the projected gross takeoff weight of the flight system grew substantially as design closure—the predicted ability to achieve orbit—became increasingly uncertain.[30]

Consequently, with the NASP program floundering, with the military's TAV not being pursued, with the military doubling-down on ELVs in the wake of the Challenger failure in 1986 and not seeing any need for human military operations in space, and with NASA doubling-down on the Space Shuttle after the Challenger failure, the US aerospace

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in 1989. This patent is for a fully reusable, two-stage, horizontal takeoff and landing manned space access system.

[29] The concept of a scramjet-powered SSTO came out of the first aerospaceplane studies of the early 1960s.

[30] To achieve a stable LEO, the space flight system must reach the required orbital velocity—a function of orbital altitude—which is not dependent on the design of the flight system. Whether the system is one-stage or two-stage, is rocket-powered or uses airbreathing propulsion, the necessary orbital velocity is the same. Design closure is when a design is predicted to be able to reach this orbital velocity. Only designs that close, with reasonable margins for shortfalls in design and performance, are considered viable.

industry began to dismantle its then-impressive manned fully reusable spaceflight development capabilities. The practical reason was that there was no likely near-term return on their investments to be prepared for a government development contract for a fully reusable system.

The final fling at SSTO was the ill-conceived X-33 program in the 1990s. This started as a follow-on to the earlier rocket-powered studies that produced the Boeing RASV concept in the 1970s. In the 1980s, the military began to address the need for ballistic missile defense seriously. Placing platforms into Earth orbit to detect, track, and destroy launched ballistic missiles was one approach being considered. For this to be practical, the means to place military payloads into orbit at costs substantially lower than ELVs was needed. Drawing on efforts originating in the 1970s, an all-rocket, vertical-takeoff and vertical-landing (VTVL), subscale demonstrator program was proposed. Focusing on demonstrating VTVL capability and aircraft-like reusability, the Delta Clipper Experimental (DC-X) effort was started in 1991 under contract to the military. The 39-foot tall, 42,000 pound, unmanned, fully reusable DC-X experimental vehicle made eight test flights, demonstrating that such rocket-powered systems could be built and operated. As the first phase of the DC-X program ended with several successful fully reusable flights, a 1995 revision to the National Space Transportation Policy placed responsibility for developing fully reusable space access capabilities under NASA. Once again, the military, even though making significant progress, was taken out of the picture by national political priorities.

This policy change placed developing fully reusable space access into political conflict with NASA's jobs- and budget-heavy "800-pound gorilla" called the Space Shuttle. If the fully reusable space access approach had become successful, then the Shuttle program would have ended. The only political path forward for the fully reusable approach was to try again for an SSTO solution. Such a technically demanding approach would protect its development funding in the budget process, because politicians would view the potential of it really threatening the Shuttle program as very unlikely.

Like the NASP program before, the guiding national policy was flawed in that preference was given to the Space Shuttle and ELVs. The common sense next step of developing a fully reusable TSTO system, even as a demonstrator to prepare for the future, was pushed aside in favor of another high-risk, but politically safe, SSTO approach. What was most unfortunate with the X-33 program was that it did not reach flight testing because an inadequate technical design was selected from the competing designs. (The design selected was not from the company that had done the DC-X effort.) Even if the X-33 had not reached orbit, the technical information gained would have been very useful for future programs. Unfortunately, the X-33 program was cancelled after the propellant tank's ground structural test article failed prematurely, casting doubt on the overall airframe design approach, since the SSTO airframe is essentially a large propellant tank.

The one good aspect of these past 30 years has been the growing competence of the US aerospace industry in on-orbit operations. The International Space Station (ISS) program has kept this segment of the industry engaged developing capabilities that will now be needed to undertake building the LEO component of the integrated spacefaring logistics infrastructure. However, manned space access of the type needed by a true human spacefaring nation has been withering for over a generation and this must be rebuilt.

VI. Where to Start to Become Spacefaring and Energy Secure

Politics is how a society establishes priorities and allocates resources to achieve these priorities. While it would be nice if this happened in a logical and amiable manner, this is not how real life works. Emotion and passion establish priorities among many competing issues. Political leaders exercise the public's passion to elevate some issues onto the warning radar screen of the body politic to become an issue of serious concern warranting attention to resolve. Elected officials then, using their legal and political powers, reallocate resources to address the issue. For the critical issue of America's now inadequate future energy security, who first should be waving the red flag of warning of a serious national policy issue needing to be addressed? Engineers, as this is why the profession exists—to protect the public.

A. Engineering Societies Must Take the Lead

As previously discussed, White's Law is expressed generally as:

$$\textit{Energy} \bullet \textit{Technology} \rightarrow \textit{Standard of Living}$$

At the very heart of White's Law is technology. Technology is the instrument of true progress elevating the standard of living and the instrument of problem resolution when the standard of living is threatened, as it is now by the end of affordable fossil fuels.

The earlier calculations clearly show that the domestic endowment of technically recoverable fossil fuels will be depleted this century. The science and technology needed to build replacement sustainable energy sources exists, so the resolution of this critical issue is <u>not</u> a fundamental scientific research problem but is an engineering challenge. Hence, what is now needed is the detailed engineering work necessary to deploy known science and technology into the specific hardware and software designs and industry that will build the new space-based power industry and the enabling spacefaring logistics infrastructure.

Unlike the 1800s and early 1900s, when engineers like Robert Fulton and Nicholas Roosevelt, John and Washington Roebling, and the Wright Brothers were well known to the public, no prominent engineers have an effective political voice in America at this time. Today, engineering societies speak to the public on matters of national technological importance—or, at least, they should. On the strength of the quantitative data available, America's engineering societies should be taking on the task of elevating American energy insecurity onto the radar warning screen of the body politic and, through letters, testimony, and presentations, educate the American public and its elected representatives on the seriousness of this issue and its needed solution.

B. Presidential Leadership Is Critical

The need for America to become energy secure has existed since the 1970s without any effective presidential political leadership to make this happen. It will not happen without committed presidential leadership. Hence, the commitment for America to become a true human commercial spacefaring nation must start at the very top with a clear presidential policy to have America become energy secure using sustainable space-based power. Obtaining this commitment will be a significant challenge, because of the ignorance of political leaders in recognizing national energy insecurity as an issue needing immediate national political attention. Only the election of a president in 2016 who acknowledges this will make this politically possible for the next eight years. Otherwise this issue will be in conflict with everything promised during the campaign—priorities, funding, and legislation.

C. With Such a New President, the Starting Point Is Policy

As the nation's chief executive, each president promulgates the execution of the president's constitutional duties by issuing executive orders. One form of an executive order is a formal statement of national security or foreign policy. These are generally referred to as Presidential Decision Directives, with the subject of each directive being a statement of policy on a particular topic or a tasking to undertake a particular action. If a national security topic believed to be of national significance is not addressed by a Presidential Decision Directive, it is unlikely to warrant much attention by that administration.

With the new presidential administration in 2017, the starting point to address America's energy insecurity is to establish or revise these four national policies:

- National Energy Security Policy
    - National Space-Based Power Policy
- National Space Policy rewritten as the National Spacefaring Policy
    - National Space Transportation Policy rewritten as the National Spacefaring Infrastructure Policy

D. New National Energy Security Policy

The United States has fought wars and continues to deploy significant military forces overseas, at great human and monetary cost, to protect its oil supplies. Also, it has invested billions, often foolishly, in sustainable energy technologies that lack practical scalability. All of this has been done in the absence of a formal national energy security policy. No president has yet said that the United States should be energy secure or has clearly defined how this is to be accomplished.

A formal policy commitment by the next president to US energy security is necessary to focus the nation's resources on making the United States energy secure. *The primary policy objective should be for America to become energy secure with affordable sustainable energy sources, under its legal control and military protection, to replace fossil fuels by a year established by the president.* The president would make clear that the policy is needed to maintain America's national security, economic prosperity, and standard of living as the era of affordable fossil fuels unavoidably ends.

E. New National Space-Based Power Policy

Subordinate to the National Energy Security Policy would be a new National Space-Based Power Policy. This policy would establish the goal for the United States to replace fossil fuels with reliable and secure space-based power production delivered to America and delivered to US spacefaring enterprises in space by electromagnetic power transmission. The policy would guide the establishment of a new National Space Power Agency to oversee the private sector's development, construction, and demonstration of US-owned space-based power production systems and to develop an integrated private space-based power industry. The policy would also establish appropriate national defense responsibilities for the protection and defense of the new space-based power industry.

F. National Space Policy → National Spacefaring Policy

Each new administration releases an updated National Space Policy. The current policy, released in 2010, has these goals: energize competitive domestic industries, expand international cooperation, strengthen stability in space, increase assurance and resilience of mission-essential functions, pursue human and robotic initiatives, and improve space-based Earth and solar observation. These bland goals are obviously intended to maintain the current American paradigm of limited space operations primarily focused on robotic science programs and only infrequent government human operations.

To be fair, there are important elements of the current policy, such as the use of nuclear power in space and radiofrequency spectrum protection. However, the entire policy needs to be refocused, starting with the title. "Space" is merely a place. Policies guide activity and should be appropriately named.

Undertaking space-based power will clearly be a spacefaring undertaking. *The revised and renamed National Spacefaring Policy should make clear that a fundamental transformation in US operations throughout the Earth-Moon system will begin.* To the current categories of military/intelligence, government human operations at the ISS, commercial satellite operations, and government robotic science and exploration projects, *will be added the establishment of routine and continuous government and commercial human operations throughout the Earth-Moon system*. This will include, but not be limited to, transportation and logistics; research and development; fabrication, assembly, maintenance, and operation; commercial resource exploration; natural resource recovery and extraction; settlement; protection and defense; and emergency services. This revised policy will guide the paradigm shift from the past focus on limited human operations in space to the new normal of extensive human operations in space.

G. National Space Transportation Policy → National Spacefaring Logistics Policy

The National Space Transportation Policy is subordinate to the National Space Policy. The National Space Transportation Policy has been where specific directions regarding space transportation systems and organizational ownership have been defined. Consistent with the expansion of the National Space Policy into the National Spacefaring Policy, the National Space Transportation Policy must expand in name and scope to address the national needs for creating an integrated spacefaring logistics infrastructure extending throughout the Earth-Moon system. The National Space Transportation Policy should become the National Spacefaring Logistics Policy.

The name change emphasizes to the public the paradigm shift in human spacefaring operations that must now be undertaken to enable America's energy security to be achieved through space-based power. Earth-to-orbit space transportation is, after all, just one part of what it will take logistically to open the Earth-Moon system to routine, frequent, and safe government and commercial human operations. Hence, the name change will help to emphasize that the age of human space exploration, within the Earth-Moon system, is transitioning into the age of human spacefaring commercialization. Of course, human space exploration will not end, but will, in fact, expand as the new spacefaring logistics and space-based power transmission capabilities make human exploration far more affordable and safe.

A key part of the updated policy will be to integrate the first initial government and commercial spacefaring logistics operations. Routine, frequent, and safe operations of Americans throughout the Earth-Moon system will be necessary for companies to undertake developing, building, and operating space-based power systems. This requires that a substantial and almost entirely new spacefaring logistics infrastructure, operating throughout the Earth-Moon system, be established. The policy should make clear that the Federal Government will lead this effort in a manner that will foster substantial new entrepreneurship within America and will engage all sectors of America, economically and geographically, in this spacefaring transformational effort.

In this rewritten policy, specific direction should be established to:

- Implement a National Spacefaring Logistics Agency to oversee the implementation of this policy in an effective and integrated manner and undertake the government responsibilities defined in this policy.

- Extend aviation airworthiness certification to human spaceflight. To maintain independence, this should be undertaken by the Federal Aviation Administration.

- Develop, and bring into operation, airworthiness-certified, commercial, fully reusable, TSTO space access systems capable of transporting passengers and cargo to and from LEO. Establish a Civil Reserve Space Fleet, under the control of the Department of Defense, and incorporate these new systems into this fleet.

- Develop and bring into operational status the Space Launch System to be used for transporting large and oversize cargo and payloads to LEO and for use in launching payloads into higher Earth orbits or on Earth-escape trajectories.

- Build and bring into operational status an initial Space Logistics Base—with a space dock and co-orbiting space propellant depot—in an LEO "logistics" orbit at an orbital inclination close to 30 degrees.
- Upgrade and extend the Kennedy Space Center to accommodate the terrestrial spaceport needs for implementing the new National Spacefaring Policy and National Spacefaring Logistics Policy.
- Upgrade and extend the Johnson Space Center to train the government and commercial space operators necessary to undertake these new logistics capabilities.
- Utilize the manned spaceflight capabilities developed under the NASA Commercial Crew Program to transport government and contractor personnel to LEO to undertake the assembly and initial operation of the Space Logistics Base.
- Utilize competitive commercial launch capabilities to transport freight and small-medium payloads to LEO to support the assembly and initial operation of the Space Logistics Base.
- Direct NASA and the USGS to survey lunar and asteroidal natural resources to support future commercial spacefaring operations.
- Deploy the initial US Space Guard capabilities.

VII. Conclusion – What This All Means

The future national security of the United States depends on having sufficient and affordable sustainable energy supplies. Current efforts to achieve this through haphazard, non-integrated attempts at ground-based renewable energy are inadequate. Quantitative analyses, shown herein, establish that the current approaches will simply not work. Energy security is certainly one area where ignorance of the facts will only bring disaster and waste.

Space-based power transmitted to ground receiving stations is the only approach to sustainable energy that is capable of being scaled up to meet US energy needs. This, however, requires that a spacefaring industrial revolution be undertaken to transform America into a true human commercial spacefaring nation. The scope and favorable impact of this transformation on American society will be immense.

The starting point of this transformation is to do what government typically does best—build new infrastructure. At the same time the research and development of the approaches to be used to actually design and build the space-based power industry are being developed, the Federal Government, in partnership with private industry, must first build the enabling spacefaring logistics infrastructure. In doing this, America must pursue the common sense path of creating a new spacefaring logistics infrastructure comparable in safety and operational effectiveness to the commercial airline industry.

The bottom line that every American needs to understand is that time is not on our side. The rapidly growing American population, driven by immigration, is depleting America's remaining technically recoverable fossil fuel endowment at an increasing rate. Drawing on White's Law of Cultural Survival, our increasing fossil fuel energy demand is bringing the end of the era of affordable fossil fuels dangerously close—perhaps only 60 years—without any sound sustainable energy security plan to replace these fossil fuels. The only way to characterize this is cultural suicide.

The need to bring the critical issue of national energy security to the public's attention is obvious. The only groups positioned within American society to do this effectively are the national engineering societies. It is time for these societies to promote national energy security with sustainable energy and identify space-based power as the only practicable way to achieve this.

America has faced an energy security crisis before when coal rescued an economy faced with diminishing wood fuel supplies. In the process, the American economy and prosperity soared as per-capita supplies of affordable energy increased through the use of domestic fossil fuels. Becoming energy secure with sustainable space-based power will bring the American dream of becoming a true spacefaring nation into reality. It will be technologically challenging and costly, no doubt, but it will also be a lot of fun!

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About the Author: James M. (Mike) Snead has wide-ranging systems and structural engineering experience from a variety of significant projects including the X-30 National Aerospace Plane, Delta Clipper Experimental (DC-X), and USAF Transatmospheric Vehicle (TAV). He holds an MS in Aerospace Engineering from the US Air Force Institute of Technology and a BS in Aerospace Engineering from the University of Cincinnati. He is a registered professional engineer in the State of Ohio and a graduate of the Department of Defense's Advanced Program Management program (in residence). He has chaired the AIAA Space Logistics Technical Committee and is an Associate Fellow of the AIAA.

Mike was the Project Engineer for the Air Force TAV Project Office where he led the technology readiness assessment for a fully-reusable, manned, space access system. Following establishment of the National Aerospace Plane Program (X-30), he was the Chief Flight Systems Engineer (Phase I) and Lead Structures Engineer (Phase II) in the X-30 Joint Program Office Systems Engineering Division. Later, he was a name-requested Government Technical Consultant for the DC-X Program – supporting this program through the fourth flight test – and served on the X-33 source selection. He developed systems engineering concepts for an integrated spacefaring logistics infrastructure focusing on fully-reusable to-space and in-space transportation capable of achieving the equivalent of airworthiness certification for safety. His primary efforts were developing fully-reusable, rocket-powered, TSTO system concepts using current technologies as well as concepts using advanced airbreathing propulsion.

Prior to his focus on space systems, Mike worked in the Air Force Aeronautical Systems Center's Engineering Directorate doing both original engineering and contractor structural engineering oversight on a diverse range of aircraft including the F-4, F-111, C-141, and Saudi AWACS. He served on the Executive Independent Review Team assessing first flight readiness for the YF-22 and YF-23 Advanced Tactical Fighters and on the F-22 independent cost team. While working in the Air Force Research Laboratory, He served as Lead for Agile Combat Support where, in addition to focusing on future space logistics, he co-developed the Configurable Air Transport (CAT) tanker and air mobility concept. He also initiated and led a wide-ranging futures wargaming effort, reporting to the Air Force Chief Scientist, focusing on advanced military weapons system conceptualization.

In addition, he established and leads the Spacefaring Institute LLC with a special focus on space solar power and the integrated spacefaring logistics capabilities needed to make space solar power a primary sustainable energy supply capability. In this effort, Mike has published several papers and a YouTube video on space solar power and the enabling spacefaring logistics capabilities.

Editors' Notes: Mike Snead is one of the world's leading energy researchers and a frequent publisher in the Journal of Space Philosophy. In this article he broadens his scope to the macro issue of the United States becoming a Spacefaring nation and resolving Space Faring logistics, Space leadership and policy, social problems like immigration and culture along with energy security which will translate to overall national security, He states that the Space industrial boom is about to begin and tells readers how the financing for these revolutionary changes can be managed. ***Bob Krone and Gordon Arthur.***