Trends in Chemical Engineering
Vol. 18, 2020

Review

The Goldilocks policy and the transition to a sustainable energy mix

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ABSTRACT

Society is in the midst of a transition from dependence on fossil fuels to a sustainable energy mix. This paper describes an energy policy that recognizes the need to protect the environment from the combustion of fossil fuels while protecting national and global economies during the transition from fossil fuels to sustainable energy. It is shown here that historical energy transitions can be used to determine a reasonable duration for making an orderly transition to a sustainable energy portfolio. The policy is referred to as the Goldilocks Policy and is proposed as the basis for a grand energy bargain.

KEYWORDS: energy transition, energy policy, future of fossil energy.

1. Introduction

Nonrenewable fossil fuels [1, 2] account for over 80% of energy consumption in the modern world. Most of the global energy infrastructure is designed to produce, refine, and distribute fossil fuels. There is concern that the consumption of combustible fuels is driving undesirable climate change. Many people are working to replace fossil fuels – coal, oil and gas – with renewable sources of energy by the end of the 21st century in an effort to mitigate the environmental impact of combustible fuel consumption. This effort is having an impact on the demand for fossil fuels. In this section the motivation to replace fossil fuels is discussed. The impact on fossil fuel demand is considered in Section 2.

The transition to a future energy mix and the components of a future energy portfolio depend on competing political interests. These competing visions are outlined in Section 3. A key difference between the competing visions in Section 3 is the length of time they are proposing to achieve the transition to a sustainable energy economy. A realistic duration of time to make the transition from one energy source to another is justified in Section 4.

The Goldilocks policy: The basis for a Grand Energy Bargain is introduced in Section 5. The Goldilocks policy is a roadmap for making an orderly transition from non-renewable, combustible, carbon-based energy sources to a sustainable energy mix. The Goldilocks policy is used to demonstrate how to achieve a sustainable energy mix by 2100. Conclusions are presented in Section 6.

2. Do fossil fuels need to be replaced?

Two key issues that are motivating the replacement of fossil fuels are discussed in this section: Anthropogenic climate change (ACC), and peak oil demand. The term anthropogenic climate change is used to describe climate change due to human activity and is discussed first. Climate change is a broad topic, so the discussion here is limited to the importance of climate change as a motivating event. More discussion of

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climate change is provided by [3] and references therein. Peak oil demand is then considered.

Climate change

The scientific basis for understanding climate includes earth-based and satellite observations of changes in the earth's climate, and computer programs known as global climate models that are designed to analyze climate data. An example of an earth-based observation is the measurement of carbon dioxide concentration in the atmosphere.

Combustion of fossil fuels and animal exhalation are two key mechanisms for the emission of carbon dioxide (CO_2) into the atmosphere. Charles David Keeling and colleagues performed measurements of atmospheric CO_2 at Mauna Loa, Hawaii. They observed that CO_2 concentration varied from approximately 310 ppm in the late 1950s to 400 ppm on May 11, 2013.

The Keeling method has been used at locations around the world and the United States National Oceanographic and Atmospheric Administration (NOAA) has released the data to the public [4]. Figure 1 presents an overlay of CO_2 concentration data from relatively isolated monitoring stations at Mauna Loa, Hawaii; Barrow, Alaska; Summit, Greenland; Tutuila, American Samoa; and South Pole, Antarctica. The overlay of data shows annual variations of CO_2 concentration and a steadily increasing average similar to the Mauna Loa Keeling curve. This reinforces other measurements of atmospheric CO_2 concentration that indicate an increase in atmospheric greenhouse gas concentrations during the past two centuries. The increase in atmospheric CO_2 concentration is concurrent with increases in carbon-based fuel consumption, and a significant growth in global population.

Observations of carbon dioxide (CO_2) concentration in the atmosphere show that the amount of CO_2 in the atmosphere is increasing. This is a significant observation because CO_2 is a greenhouse gas and a by-product of fossil fuel combustion. Fossil fuel represents over 80% of global energy consumption.

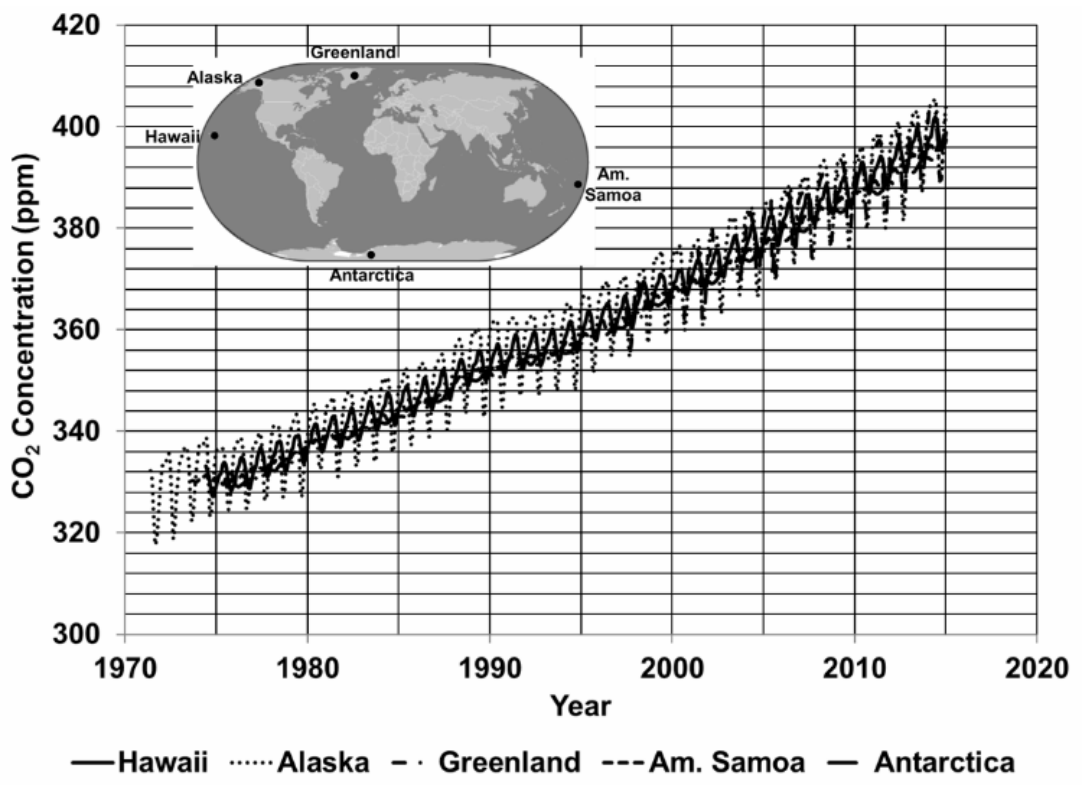

Figure 1. Overlay of CO_2 concentration from different parts of the world [3, 4].

It fuels the global fleet of vehicles powered by internal combustion engines (ICE) and is used to provide heat and electricity. The replacement of fossil fuels, a leading source of atmospheric CO_2, will have a significant impact on national economies. How should society proceed?

The United Nations Intergovernmental Panel on Climate Change (UN IPCC) provides the mainstream view of climate change. The IPCC was "established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) in 1988 to provide the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts. In the same year, the UN General Assembly endorsed the action by WMO and UNEP in jointly establishing the IPCC." [5] Yergin identified the establishment of the UN IPCC as the decisive step "that would frame how the world sees climate change today" ([6], page 461). According to Yergin, the UN IPCC "was not an organization in any familiar sense. Rather it was a self-regulating, self-governing organism, a coordinated network of research scientists who worked across borders, facilitated by cheaper and better communications." ([6], page 461). The UN IPCC was charged with reviewing and assessing "the most recent scientific, technical and socio-economic information produced worldwide relevant to the understanding of climate change. It does not conduct any research nor does it monitor climate related data or parameters" [5].

Reports by the UN IPCC exerted substantial influence on government policy around the world, as well as public controversy. The historical role of the environment in government is reviewed by Fanchi [3]. A second group called the Nongovernmental International Panel on Climate Change (NIPCC) was formed to independently evaluate the impact of increasing atmospheric carbon dioxide on the earth's biosphere. The NIPCC was designed to provide an educated, independent assessment of the conclusions and recommendations made by the UN IPCC. Both groups include reputable scientists and engineers with credentials in science and technology.

A comparison of UN IPCC and NIPCC reports shows that the two groups agree that climate is changing, but disagree on the impact of human activity. The UN IPCC argues that global climate models support the idea that human activity is adversely affecting the climate. Human activity, especially fossil fuel combustion, is altering the temperature of the atmosphere, increasing the rate of glacier melting, causing sea levels to rise, and increasing the acidity of ocean water.

By contrast, the NIPCC says that observed climate change is a natural variation of climate. The NIPCC argues that global climate models do not adequately represent all of the mechanisms that affect climate. Attempts to validate global climate models by replicating historical observations of climate change have shown that the models have limitations [7]. Model limitations raise questions about the reliability of model forecasts. It is worth noting that governments continue to provide substantial funding for the study of climate change, which suggests that some issues still need to be resolved.

John Hofmeister spent 25 years in energy consuming companies before serving as president of Shell Oil Company from 2005 to 2008. He looked at the climate change debate and concluded that ([8], page 64): "debating climate change is a fantastic waste of time and human energy. There is no agreement on what it is or isn't. There is no set of measures accurate enough to be credible to present a clear and present danger. There is no rebuttal for the argument that we have always had cycles of global warming and global cooling, and Earth has adjusted accordingly."

Steven Koonin expressed another view. Koonin had experience as a physics professor and provost at Caltech before eventually working as Undersecretary for Science in the United States Department of Energy during President Barack Obama's first term. Koonin wrote in an opinion piece in the Wall Street Journal (Sep 19, 2014) that "We are very far from the knowledge needed to make good climate policy." He observed that "the idea that climate science is settled" is misguided, may have distorted policy discussions, and hindered the resolution of scientific issues.

The 21st United Nations Framework Convention on Climate Change (UNFCCC) Conference of Parties known as COP21 was convened in Paris in

late 2015. The purpose of COP21 was to seek an international agreement to reduce the impact of human activity on climate. United States Secretary of State John Kerry spoke on behalf of the Obama Administration on December 9, 2015. Kerry pointed out the need for global cooperation by explaining that "even if every American citizen biked to work, carpooled to school, used only solar panels to power their homes, if we each planted a dozen trees, if we somehow eliminated all of our domestic greenhouse gas emissions, guess what – that still wouldn't be enough to offset the carbon pollution coming from the rest of the world.

"If all the industrial nations went down to zero emissions – remember what I just said, all the industrial emissions went down to zero emissions – it wouldn't be enough, not when more than 65 percent of the world's carbon pollution comes from the developing world."

The COP21 Paris Climate Agreement was adopted by 195 countries, including the United States, on December 12, 2015 [9]. The agreement is "a global action plan to put the world on track to avoid dangerous climate change by limiting global warming to well below 2°C".

The United States withdrew from the COP21 Paris Climate Agreement in June 2017 after Donald Trump became President. The Trump Administration expressed concern that the agreement was unfair to American workers and taxpayers, and that the negative impact on the United States economy would exceed the positive impact on the global environment.

Ten members of the oil and gas industry responded to concerns about anthropogenic climate change by launching the Oil and Gas Climate Initiative (OGCI) in 2014. According to the OGCI website [10], "OGCI is a voluntary, CEO-led initiative which aims to lead the industry response to climate change." The purpose of OGCI is to "pool expert knowledge and collaborate on action to reduce greenhouse gas emissions." The ten founding companies were BP (Britain), CNPC (China National Petroleum Corporation), Eni (Italy), Equinor (formerly Statoil of Norway), Pemex (Mexico), Petrobras (Brazil), Repsol (Spain), Saudi Aramco (Saudi Arabia), Shell (The Netherlands) and Total (France). None of the founding companies was headquartered in the United States.

OGCI founding members adopted the policy that "We, the leaders of the ten major oil and gas companies, are committed to the direction set out by the Paris Agreement on climate change. We support its agenda for global action and the need for urgency. Through our collaboration in Oil and Gas Climate Initiative (OGCI), we can be a catalyst for change in our industry and more widely."

"OGCI aims to increase the ambition, speed and scale of the initiatives we undertake as individual companies to reduce the greenhouse gas footprint of our core oil and gas business – and to explore new businesses and technologies." Notice that OGCI was not abandoning its core oil and gas business; instead, OGCI was implementing a strategy that would focus its resources on mitigating the negative effects of fossil fuel consumption.

Three major oil companies headquartered in the United States – Chevron, ExxonMobil, and Occidental Petroleum – joined the ten founding members [11] in September 2018.

Peak oil demand

Fossil fuels exist in finite amounts and are nonrenewable, yet they are the primary energy source for the modern world. Many people were concerned that peak oil production predicted by M. King Hubbert [12] would occur at the beginning of the 21st century. The development of directional drilling, hydraulic fracturing, and favorable economics made it possible to economically produce shale gas and shale oil. This allayed concerns that the supply of oil would peak in the first half of the 21st century. It is now more likely that the demand for oil and gas may peak before peak oil production occurs.

Until recently, peak oil referred to the supply of oil. Growth of the renewable energy sector has raised the possibility that peak oil consumption will occur when peak oil demand occurs. Demand for oil will be significantly impacted when electric vehicles replace internal combustion engines.

Jeremy Rifkin [13] expressed the urgency felt by many that society needs to replace fossil fuels

as soon as possible based on climate models: "We are facing a global emergency. Our scientists tell us that human-induced climate change brought on by the burning of fossil fuels has taken the human race and our fellow species into the sixth mass extinction event of life on Earth" ([13], page 1). Rifkin went on to say that the IPCC ([5], page 6), "a scientific body of the United Nations, issued a dire warning in October 2018 that global warming emissions are accelerating and that we are on the verge of a series of escalating climatic events, imperiling life on the planet". Rifkin argued that we only have twelve years to make the transition to a sustainable energy portfolio. According to Rifkin, ([13], page 1) the IPCC concluded that "to avoid the environmental abyss we would have to cut the emission of global warming gases 45 percent from 2010 levels – and we only have twelve years to make this happen" ([5], page 14).

Rifkin pointed out that a Green New Deal has been proposed and is receiving significant political support from the political left. Proponents of the Green New Deal argue that we need to replace fossil fuels by 2030 based on the IPCC report. IPCC reported a range of results (model pathways) to illustrate uncertainty. The IPCC case referenced by Rifkin could be considered a possible but unlikely scenario based on available models. It is an example of a short transition period (12 years from 2018 to 2030) when compared to a transition period of approximately 60 years based on historical data in the United States.

Rifkin described the EU and China as leaders in what he called the Third Industrial Revolution [13]. The EU Supergrid is an example of an attempt to replace carbon-based economies in the EU with economies based on renewable energy by 2050 [1]. The EU energy transition period was expected to take between 40 and 50 years beginning in the 21st century. Proponents of the EU energy transition have identified several key factors that they consider desirable: security of supply, economic competitiveness, and environmental objectives (e.g. mitigating anthropogenic climate change).

Rifkin provides a competitor's view of the energy industry future based on a specific climate modeling scenario. In a Chapter entitled "The Tipping Point: The Collapse of the Fossil Fuel Civilization, circa 2028", Rifkin [13] presented the view of an energy transition that reaches peak fossil fuel demand (not Hubbert's peak oil supply) by 2030. The chapter discusses timing and duration of an energy transition, comparative energy economics, and carbon capture and storage.

Rifkin pointed out that the fossil fuel industry needs to be concerned about stranded assets. He defined stranded assets as "assets that have been prematurely written down before their expected life cycle runs its normal course" ([13], page 51). He observed that stranded fossil fuel assets "are all the fossil fuels that will remain in the ground because of falling demand as well as the abandonment of pipelines, ocean platforms, storage facilities, energy generation plants, backup power plants, petrochemical processing facilities, and industries tightly coupled to the fossil fuel culture" ([13], page 8).

The financial community has shown concern that there will be considerable stranded assets in fossil-fuel related sectors. Lazard's Power, Energy, and Infrastructure Group have studied the issue and concluded "We have reached an inflection point where, in some cases, it is more cost-effective to build and operate new alternative energy projects than to maintain existing conventional generation plants" ([13], footnote 53).

Eberhart [14] challenged the view that peak oil demand was imminent. However, a pandemic [15] that slowed the global economy and reduced demand for fossil fuels in 2020 motivated some participants in the oil and gas industry to reconsider their energy transition strategy. For example, Bousso and Zhdannikov [16] reported that major oil and gas company BP was "poised to sell 'stranded assets' even if oil prices rally." A November 2020 oil and gas industry conference on upstream finance and investments sought to discuss the industry's ability to lead the energy transition and to re-attract investment in the oil and gas sector.

3. Competing visions

Advocates of the political left want to replace fossil fuels with renewable energy sources as soon as possible and believe human activity drives

climate change. Former Vice President and Democratic Presidential candidate Al Gore embraced the science that raised concerns about the anthropogenic climate changes and became a leading proponent of Climate Change. He won a Nobel Peace Prize in 2007 for his work on Global Warming. He once said, "The turning point came in 2009…with the inauguration of a new President [Obama] in the United States, who immediately shifted priorities to focus on building the foundation for a new low-carbon economy" [17]. Democratic energy policy supports a significant investment in renewable energy such as wind energy and nuclear energy, as they already have a strong history of energy production. The Obama Administration made significant investments in solar energy and electric vehicles; imposed regulations that have had an adverse impact on fossil energy production in the United States; and allowed development of a new nuclear fission reactor.

Left wing supporters argue that money currently in oil and gas subsidies should be used to improve alternative energy sources. The new Biden Administration (installed January 2021) is expected to support a transition to sustainable energy as soon as possible to help mitigate anthropogenic climate change. They argue that this will make a safer, cleaner society.

Advocates of the political right argue that the economic benefits of low energy prices outweigh potentially damaging climate effects. By contrast, the Goldilocks policy states that the best way to achieve an efficient transition to sustainable energy is by basing the transition on historical data to reduce regulatory uncertainty and use natural gas as transition fuel.

The Trump Administration reduced support for the large-scale development of a renewable energy infrastructure begun under the Obama Administration; allowed the free market to determine when an energy technology is ready to become part of the national energy mix; supported traditional fossil fuel production and consumption but was willing to provide R&D funds for further developing renewable energy sources.

Right wing supporters argue that the adoption and implementation of sustainable energy technology will occur soon enough to mitigate long term damage to the climate. They argue that a rapid transition to sustainable energy can significantly damage the economy.

Former Shell Oil Company President John Hofmeister noted that both major political parties in the United States have called for energy independence, but there has been "no meaningful continuity of political leadership for sufficient sustained periods of time to deliver on the many, many promises of energy independence" ([8], page 27).

Advocates of both competing visions have expressed concern about anthropogenic climate change (ACC). Is ACC an urgent concern that requires government disruption of the private sector as in the Green New Deal, or is there time to implement a managed transition? The Goldilocks Policy for energy transition has been proposed [3] as a policy that recognizes a need for urgency to protect the environment while endorsing a plan to implement a predictable rate of energy transition. The Goldilocks Policy is discussed in more detail in Section 5. In the next section we identify a realistic time frame for implementing the energy transition.

4. How much time do we have?

Time is needed to make the transition from one energy source to another. How long has it taken in the past to achieve an energy transition? Historical energy consumption in the United States is used to illustrate energy consumption and energy transition periods in the developed world.

The per cent contribution of different energy sources to the United States energy mix during the period from 1750 to 2015 is shown in Figure 2. The energy category labeled "Nuclear Electric" refers to electricity generation by nuclear fission reactors. The energy category labeled "Other Renewable" includes conventional hydroelectric power, geothermal, solar thermal, photovoltaic, and wind.

Figure 2 highlights the periods when energy transitions occurred in the United States. The primary energy source in 1750 was the combustible biomass wood. Wood continued as the primary energy source until coal was discovered and adopted as a combustible fuel in the mid-1800s.

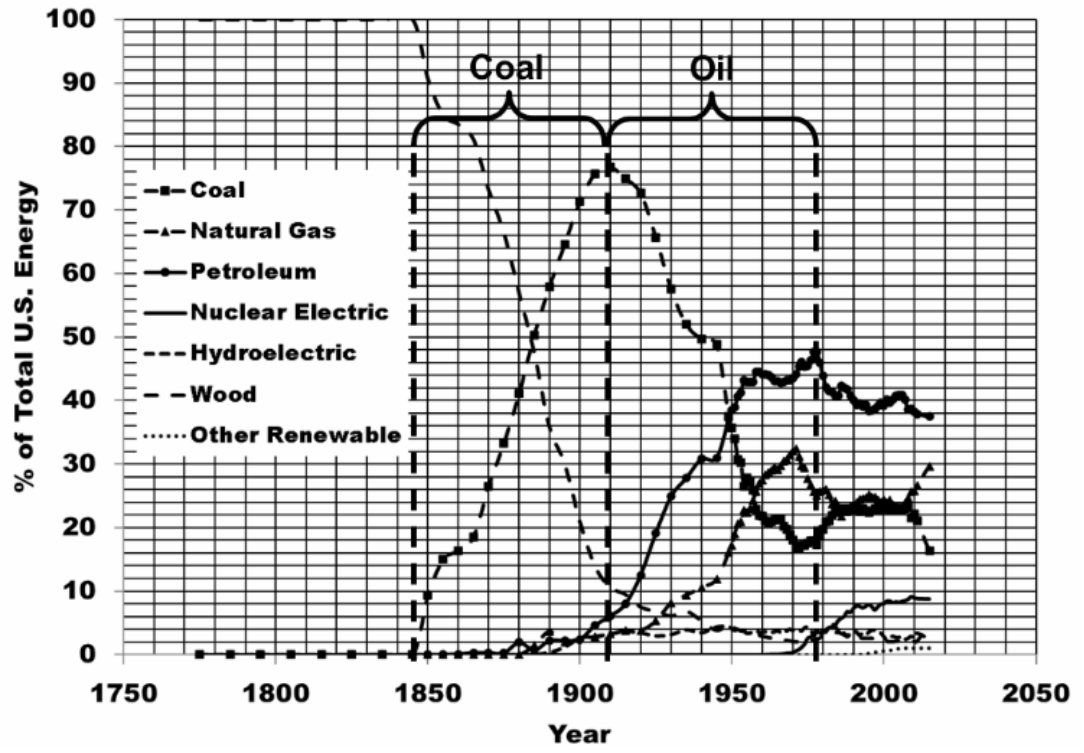

Figure 2. Coal and oil transition periods based on U.S. energy consumption by source, 1750-2015 (%), data from [2].

Coal began to replace wood around 1850 and peaked in the early 1900s. Petroleum began to replace coal in the early 1900s and peaked in the latter half of the 20th century. The transition from wood to coal and then from coal to oil each took about 60-70 years to complete. This suggests that the time to achieve an energy transition from one primary energy source to another has historically required 60-70 years.

In a 2018 interview with Paul Voosen, energy scholar Vaclav Smil expressed his belief that we should be less reliant on fossil fuels to help mitigate climate change [18]. In his 2003 book **Energy at the Crossroads**, Smil wrote that the "transition from societies energized overwhelmingly by fossil fuels to a global system based predominantly on conversions of renewable energies will take most of the twenty-first century" ([19], page 363). A technological breakthrough such as the development of cheap energy storage could shorten the transition period.

Energy expert and economic historian Daniel Yergin agreed with Smil that energy transitions can take decades. The future energy mix will depend on factors such as price, value delivered, and government policy. An example of a government policy is to enact a law that requires utilities to generate electricity from renewable energy sources by a specified date [20, 21]. Yergin also noted that older energy sources do not necessarily disappear after the transition, but can co-exist with newer energy sources.

5. The Goldilocks policy

The Goldilocks policy [22] calls for a gradual transition to a sustainable energy mix. Three of the most important goals of an energy policy are to sustain economic growth, secure energy supply, and achieve a clean and safe environment. Factors that can be used to achieve these goals are technical feasibility, economic viability and government policy. Technical feasibility refers to available technology that minimizes safety concerns to society or the environment.

Economic feasibility recognizes that most of the global energy infrastructure is designed to use

fossil energy. The cost of transforming the energy infrastructure is a significant factor in determining the rate of transition to a new energy mix.

Government policy should seek to optimize the rate of transition to a sustainable energy portfolio, but there are many options about what constitutes the rate of transition. One option is to implement a sustainable energy portfolio by utilizing the abundance of natural gas in shale. Another option is to expand the availability of wind and solar power to provide enough electricity to support an electric vehicle fleet and replacement of the internal combustion engine. Improvements in energy storage technology can facilitate the widespread adoption of electric vehicles. A third option is to combine use of natural gas as a transition fuel with a renewable energy infrastructure.

5.1. A Grand Energy Bargain

Concerns about European dependence on Russian fossil fuels and Russian adventurism in Ukraine in 2014 motivated columnist Thomas L. Friedman of the New York Times to suggest adopting a Grand Energy Bargain advocated by Hal Harvey of Energy Innovation [23]. The Harvey-Friedman Grand Energy Bargain would be a compromise between competing political visions of the energy transition discussed in Section 3. Implementation of the Harvey-Friedman Grand Energy Bargain would advance economic growth, provide for national security, and recognize environmental concerns. The Harvey-Friedman Grand Energy Bargain would

- simultaneously optimize energy affordability, reliability and environmental compatibility;
- use modern technology to provide affordable, reliable and clean energy; and
- rely on the government to ensure that natural gas resources are used to usher in a secure, clean-energy future.

Table 1 presents four objectives of the Harvey-Friedman Grand Energy Bargain.

Details of the Harvey-Friedman Grand Energy Bargain would have to be negotiated. For example, Hofmeister proposed a Federal Energy Regulation Board that could implement some of the Harvey-Friedman Grand Energy Bargain steps, but Hofmeister preferred a cap-and-trade system to a carbon tax [8]. Furthermore, advocates for limited government might object to some details, such as imposing a carbon tax or adopting a cap-and-trade system, or creating a federal agency with extensive regulatory power (the FERB).

5.2. The 2% solution

We can forecast energy consumption based on the Goldilocks policy given a few assumptions. As an example, it is reasonable to assume that energy consumption will continue the linear growth shown in this century, and that the consumption of nuclear fission energy will not change. The Goldilocks policy calls for increasing the consumption of alternative energy by 2% per year to match the reduction in fossil fuel consumption. If we neglect the effect of the pandemic [15] in this example,

Table 1. Harvey-Friedman Grand Energy Bargain.

Step	Objective (see [23] for quotes)
1	Adopt “national rules for extracting natural gas based on known best practices, including strategies that eliminate the leakage of methane, which is so much more potent a greenhouse gas than carbon dioxide”
2	Set “a national clean energy standard for electricity. One popular approach is to require utilities to raise the fraction of their electricity from zero-carbon sources — such as wind, solar or nuclear — by, say, 2 percent per year”
3	Accelerate “energy efficiency and clean power technologies by building up our research and development programs”
4	Impose “a revenue-neutral carbon tax … that would replace payroll and corporate taxes”

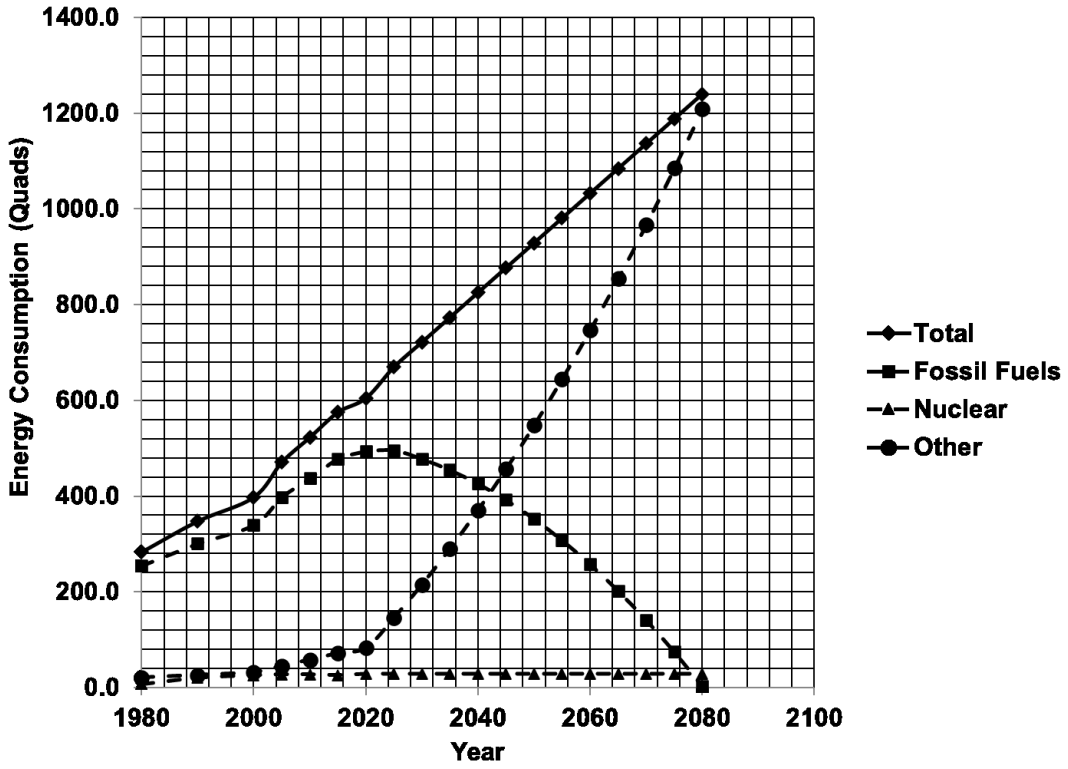

Figure 3. Forecast of energy consumption based on the 2% solution of the Goldilocks policy [3].

we obtain the energy consumption forecast shown in Figure 3. According to this forecast, fossil fuel consumption will end by 2080.

Technological advances could significantly change the forecast. For example, several countries are sponsoring the International Thermonuclear Experimental Reactor (ITER) being built in Southern France. ITER is a nuclear fusion reactor based on a tokamak design. It is expected to produce 500 MW fusion power from 50 MW input power. Other nuclear fusion reactor concepts are being developed. For example, researchers at the Max Planck Institute are attempting to design a nuclear fusion reactor using the Wendelstein 7-X stellarator. Nuclear fusion power could provide an environmentally benign, virtually inexhaustible source of energy if it can be successfully commercialized.

6. Conclusions

This paper describes an energy policy called the Goldilocks policy: The Basis for a Grand Energy Bargain. The Goldilocks policy is a roadmap that will allow us to make an orderly transition from non-renewable, combustible, carbon-based energy sources to a sustainable energy mix. If adopted, the Goldilocks policy will require discipline and patience to implement. There are many obstacles that can impede or change the Goldilocks policy. Some of the obstacles have arisen as the result of historical trends and are discussed in more detail by Fanchi [3].

A review of climate data shows that the question of anthropogenic climate change is still unsettled, but enough is known to motivate a transition away from fossil fuels. Several competing visions have been proposed for reaching a sustainable energy mix. The Goldilocks policy is based on a vision that recognizes the need to protect the environment from the combustion of fossil fuels while protecting national and global economies during the transition from fossil fuels to sustainable energy. We show that the transition to a sustainable energy mix does not have to be abrupt and catastrophic. If domestic and global obstacles can be overcome, historical energy

transitions can be used to establish a reasonable duration for making an orderly transition to a sustainable energy portfolio.

CONFLICT OF INTEREST STATEMENT

There are no conflicts of interest in this article.

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