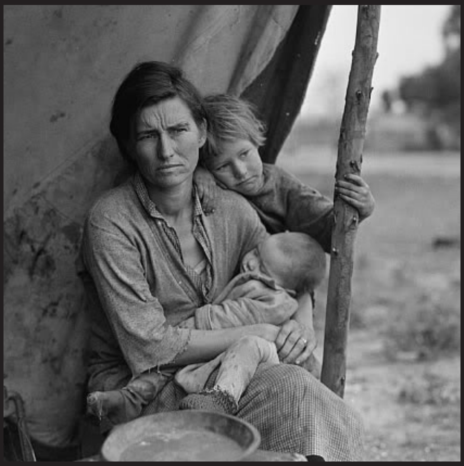
TEXAS PUBLIC POLICY FOUNDATION

Fossil Fuels: The Moral Case



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by Kathleen Hartnett White

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Fossil Fuels: The Moral Case

by Kathleen Hartnett White

Preface

Current policies to supplant fossil fuels with inferior energy sources need to incorporate a deeper understanding of the transformative role of energy in human society lest they jettison the wellsprings of mankind's greatest advance.

The thesis of this paper is that fossil fuels, as a necessary condition of the Industrial Revolution, made modern living standards possible and vastly improved living conditions across the world. Humanity's use of fossil fuels has released whole populations from abject poverty. Throughout human history, elites, of course, have enjoyed comfortable wealth. No more than 200 years ago, however, the lives of the bulk of humanity were "poor, nasty, brutish and short," in the words memorably used by Thomas Hobbes.[1]

This paper aims to articulate and explain some startling, but rarely acknowledged, facts about the role of energy in human history. Energy is so intimately connected to life itself that it is almost equivalent to physical life. Virtually everything needed to sustain the life of a human individual—food, heat, clothing, shelter—depends upon access to and conversion of energy. Modern, prosperous nations now access a seemingly limitless supply of energy. This cornucopia, however, is a very recent advance in mankind's history. Fossil fuels, methodically harnessed for the first time in the English Industrial Revolution, beginning in the 18th century and taking off in the 19th century, have been a necessary condition of prosperous societies and of fundamental improvements in human well-being.

Adequate treatment of this topic is a daunting task for anyone. The unprecedented stakes in today's contentious energy policy debates about carbon, however, make it a morally necessary topic. As a former final decision-maker in a large environmental regulatory agency, I urge current officials and concerned citizens to reflect on energy policies within a broad but fundamental context: human history and the physics of material lives.

My research was initially inspired by a comprehensively researched monograph by Indur Goklany titled "Humanity Unbound."[2] His paper took me to a dozen books and twice as many academic papers. With gratitude, I acknowledge the books listed below as the most enlightening, persuasive guides on the topic. And I highly recommend them for more thorough analysis than allowed by the confines of this paper. May those policymakers entrusted with the authority to make binding decisions about energy consider these books as "a look before an unreflective leap" that could unravel mankind's greatest achievement—the potential enjoyment of long, comfortable, healthy lives without the gnawing hunger of subsistence poverty.

The Improving State of the World, Indur Goklany.
Energy and the English Revolution, E.A. Wrigley.
Farewell to Alms, Gregory Clark.
The Rational Optimist, Matt Ridley.
The Great Divergence, Kenneth Pomeranz.
The Bottomless Well, Peter W. Huber and Mark P. Mills.
Knowledge and Power, George Gilder.
Energy and Society, Fred Cottrel.
Energy Transitions, Vaclav Smil.

A Story

In his book, *The Rational Optimist*, Matt Ridley tells a stirring story about the phenomenal improvements in human living standards achieved over only the last two centuries of mankind's long history.

> Imagine that it is 1800, somewhere in Western Europe or eastern North America. The family is gathering around the hearth in the simple timber-framed house. … The baby boy is being comforted by one of his sisters … His elder sister is feeding the horse in the stable. Outside there is no noise of traffic, there are no drug dealers and neither dioxins nor radioactive fall-out have been found in the cow's milk. …
>
> Though this is one of the better-off families in the village, father's Scripture reading is interrupted by a bronchitic cough that presages the pneumonia that will kill him at 53—not helped by the wood smoke of the fire. … The baby will die of the smallpox that is now causing him to cry; his sister will soon be the chattel of a drunken husband. … Toothache tortures the mother. … The stew is grey and gristly yet meat is a rare change from gruel; there is no fruit or salad at this season. … Candles cost too much, so firelight is all there is to see by. Nobody in the family has ever seen a play, painted a picture or heard a piano. School is a few years of dull Latin taught by a bigoted martinet at the vicarage. Father visited the city once, but the travel cost him a week's wages and the others have never travelled more than 15 miles from home. Father's jacket cost him a month's wages but is now infested with lice. The children sleep two to a bed on straw mattresses on the floor.
>
> Since 1800, the population of the world has more than doubled and real incomes have risen more than nine times. Taking a shorter perspective, in 2005, compared to 1955, the average human being on Planet Earth earned nearly three times as much money (corrected for inflation), ate one-third more calories of food, buried one-third as many of her children and could expect to live one-third longer. She was less likely to die as a result of war, murder, childbirth, accidents, tornadoes, flooding, famine, whooping cough, tuberculosis, malaria, diphtheria, typhus, typhoid, measles, small pox, scurvy, or polio. She was less likely, at any given age, to get cancer, heart disease, or stroke. She was more likely to be literate and to have finished school. She was more likely to own a telephone, a flush-toilet, a refrigerator, and a bicycle. All this during a half century when the world population more than doubled, so that far from being rationed by population pressure, the goods and services available to the people of the world have expanded. *It is, by any standard, an astonishing human achievement.*[3] (Emphasis added.)

Introduction: Mankind's Fossil-Fueled Energy Breakthrough

Sorely missing from current policy debates about carbon-rich energy is recognition of the inestimable *human* benefits of fossil fuels. Before any use of the newly minted metric called the social cost of carbon (SCC), consider the profound societal benefits of which fossil fuel are a necessary condition. Too few recall that the relatively recent Industrial Revolution of the 18th and 19th centuries—dependent on fossil fuels—was one of the two greatest advances in human society since humans lived in caves and hunted for food. The other turning point was the Neolithic agricultural revolution when human groups began cultivating crops and domesticating animals.[4]

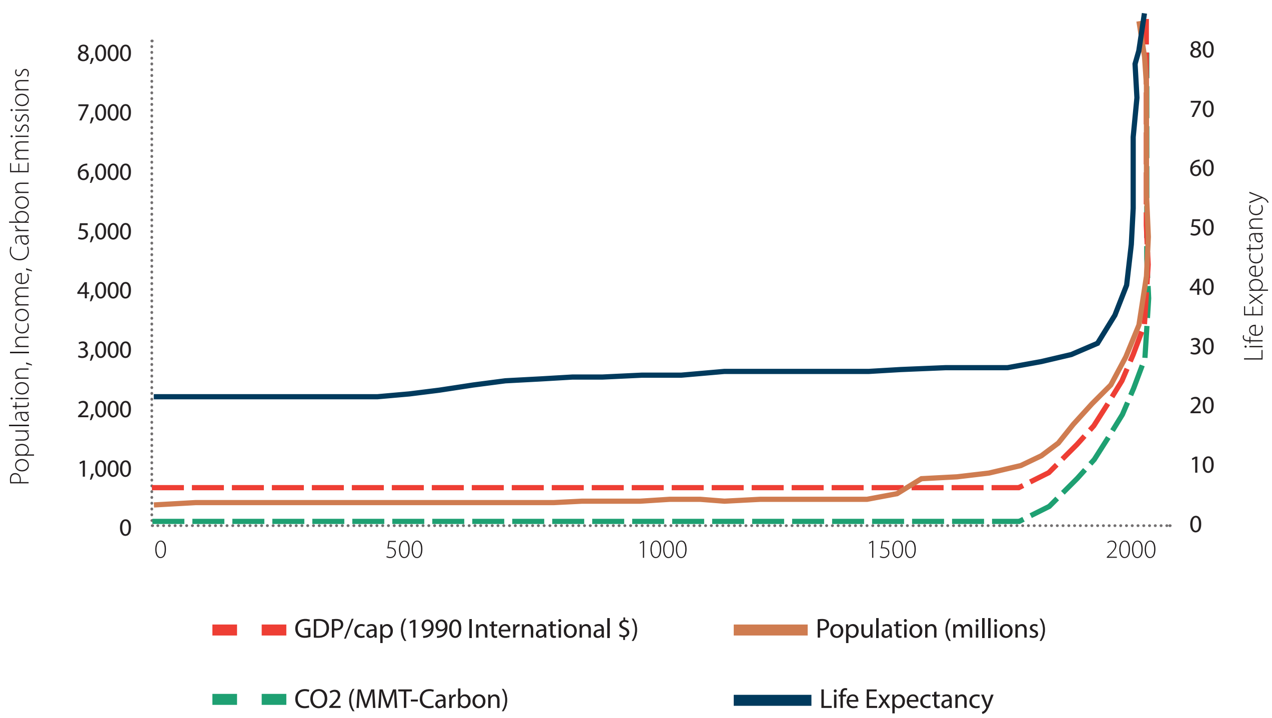
This paper highlights the role of energy in the English Industrial Revolution to focus on the role of energy in the unprecedented economic growth spawned by the Industrial Revolution. Questions of what caused the revolution or why it occurred where and when it did are beyond the scope of this analysis.

Of course, many inter-related factors led to the Industrial Revolution and the prodigious economic growth in its wake. England's democratic legal institutions which protected private property rights and contractual transactions were and remain paramount, as does capital accumulation. Fossil fuel energy, however, was a necessary condition of industrialization's beginning and perhaps even more so, of its continued growth which has freed billions of human beings from poverty.[5] The breakthrough known as the Industrial Revolution took off and continued when England methodically tapped the energy in fossil fuels.

Harnessing the vast store of concentrated energy in fossil fuels allowed mankind, for the first time, to escape the natural world's energy limits—intractable constraints that had kept human lives of all but the most privileged in subsistence poverty.[6] Before the Industrial Revolution, all societies were dependent on the limited flow of solar energy captured in living plants for subsistence needs such as food, fuel, and shelter. Physical living conditions differed across societies and eras, but there was no sustained upward trend.

The fixed supply of land on which to raise food and harvest timber was regularly diminished by natural disasters and political upheaval, or overstretched by increasing population. As historian E.A. Wrigley documents: "The energy flow was insufficient to underwrite the increased output on the scale associated with an 'industrial revolution.' Only by gaining access to a vast *store* rather than a limited *flow* of energy could this problem be solved."[7] In England, coal first provided this vast store of concentrated energy. Natural gas derived from coal soon followed. Crude oil's first commercial use began in the mid 19th century.[8]

Figure 1: Global Progress, 1 A.D. - 2009 A.D.



Sources: Indur Goklany, *Humanity Unbound*, p. 3. Updated from Indur Goklany, "Have Increases in Population, Affluence and Technology Worsened Human and Environmental Well-being?" *Electronic Journal of Sustainable Development* 1. no. 3 (2009); based on Angus Maddison, *Statistics on World Population, GDP and Per Capita GDP, 1-2008 AD*, University of Groningen, 2010; World Bank, *World Development indicators, 2011*; T.A. Boden, G. Marland, and R.J. Andrews, *Global, Regional, and Nationasl Fossil-Fuel CO_2 Emissions*.

Notes: Data are sporadic until 1960. This figure assumes that trends between adjacent data points are linear.*

*Angus Maddison (1926-2010) was a British economist and a prominent world scholar on quantitative macroeconomic history including the measurement and analysis of economic growth and development. He did most of his research and writing at the University of Groningen. The historical data compiled by Maddison on income per capita, population, lifespan and other demographic factors is widely used across the world including by the Organization for Economic Co-operation and Development (OECD), Harvard Center for International Affairs, and World Bank for which he was a consultant. Maddison's data is the basis for most of the historical claims and "startling facts" in this paper. The data bases he developed are regarded as one of the most important sources for the analysis of long term economic growth and are widely used across the world. His data used in this paper is also available in his "The World Economy: Historical Statistics" and "Contours of the World Economy 1-2030 AD: Essays in Macroeconomic History" among his long list of publications on this topic.

Use of the energy in fossil fuels unleashed economic productivity on a scale previously unimaginable. When innovative minds developed a steam engine which could convert the stored heat energy in coal into mechanical energy, the economic limits under which all human societies had formerly existed were blown apart. A life of back-breaking drudgery was no longer the inescapable condition of the overwhelming majority of mankind. **Figure 1** (previous page) depicts the dramatic upward trend.

Life expectancy had changed little throughout all human history until the Industrial Revolution; it thereafter tripled. Income per capita has since increased 11-fold. Not coincidentally, man-made emissions of carbon dioxide have risen three-fold since the beginning of the Industrial Revolution. Fossil-fuel powered mechanization revolutionized economic productivity, increased incomes, population, and life expectancy across all classes.

Matt Ridley, author of *The Rational Optimist*, captures the magnitude of the breakthrough: "By 1870, the burning of coal in Britain was generating as many calories as would have been expended by 850 million labourers. It was as if each worker had 20 servants at his beck and call. The capacity of the country's steam engines alone was equivalent to six million horses. … That is how much energy had been harnessed to the application of the division of labor. That is how impossible the task of Britain's 19th century miracle would have been without fossil fuels."[9]

Fossil fuel use and the consequent anthropogenic emissions of carbon dioxide (CO_2) also have greatly expanded the global food supply. Fertilizer derived from natural gas has increased agricultural productivity by 40-60 percent.[10] Fossil fuel-based fertilizers have saved vast natural ecosystems from conversion to cropland. Although combustion of fossil fuels releases pollutants, those emissions can be dramatically reduced far quicker through technological controls than can the reversion of cropland to natural ecosystems be achieved. Rather than ravaging the natural world as environmentalists assume, fossil fuels have allowed industrial civilizations to shrink the human footprint. And the increased atmospheric concentration of man-made CO_2 has enhanced plant growth and thus the world's food supply.

Synthetic fibers derived from fossil fuels now account for 60 percent of all fibers.[11] Basic materials such as plastic, vinyl, and fiberglass constitute the raw material in thousands of products in daily use. The prosperity supported by abundant fossil fuel energy allows investment in effective technologies to eliminate harmful pollution.

Renewable energy still provides only a sliver of energy supply. In spite of the billions of dollars in subsidies, retail prices for renewables are still far higher than prices for fossil fuels.[12] In European countries which rushed too quickly to embrace renewable energy, families regress to burning wood for heat and cooking because electricity is unaffordable. German officials warn that soaring energy costs risk "dramatic deindustrialization."[13]

At any cost, renewable energy from wind, solar, and biomass remains diffuse, unreliable, and parasitic, in that those intermittent sources rely on fossil fuels for back-up. And while nuclear fission provides energy comparable or superior to fossil fuels, it cannot provide the versatile benefits mentioned above. Additionally, the public remains resistant to broad deployment of nuclear generation.

Energy-dense, abundant, versatile, reliable, portable, and affordable, fossil fuels provide over 80 percent of the world's energy because they are superior to the current alternatives. Until energy sources fully comparable or superior to fossil fuels are securely available, policies to reduce emissions of CO_2 should proceed with caution lest they prematurely exhaust the well-springs of mankind's greatest advance.

Energy Fundamentals: A Question of the Sun with a Dash of Physics

High energy use is the *sine qua non* of life in modern, prosperous societies. And it is only the population born after World War II that has reaped the full energy bounty now assumed in U.S. lifestyles. Abundant energy is so imbedded in every moment of our personal and working lives that its presence, action, and value go unnoticed. Far beyond the energy contained in the overflowing food in our grocery stores, consider the abundant energy in cooling, heating, transportation, appliances, clothing, medical devices, materials, and our omnipresent electronic devices. Bundles of concentrated energy are interwoven in almost every action we take and every physical object we use.

Compared to the limited discretionary time enjoyed by our ancestors, the time we have left after feeding, clothing, sheltering, and financially supporting our families reflects the amount of work done—not by human muscle—but by stored energy. A single example of the profound benefits of energy: Imagine life without the indoor and outdoor illumination we enjoy 24 hours a day. More than two billion of the world's population still has no access to electricity.

Energy: Definition and Metrics

The term "energy" is commonly used, but with varied meanings, as elusive to the physicist as to the man on the street. The most common definition is "the capacity to do work."[14] In physics, "work" is defined as force multiplied by the distance through which it acts. The English word "energy" derives from the Greek words "er" meaning "at" or "in" and "ergon" meaning "work." "Power" in physics is defined as energy in motion or more precisely, the rate at which work is done.[15]

Europe measures energy in joules or newton-meters. In the U.S., work and energy are measured in units of foot-pounds. Unlike most other countries, the standard measure of energy most broadly used in the U.S. remains the British thermal unit (Btu). A Btu represents the amount of thermal energy (heat) necessary to raise the temperature of one pound of water by one degree Fahrenheit. Btus, foot-pounds, joules, and calories are all convertible to one another. Watts, a measure of electric energy, is defined as one joule per second.

The most telling measures are energy density and power density. Energy density is a measure of the amount of energy per unit of weight or volume. "Power density refers to the energy flow that can be harnessed from a given unit of volume, area, or mass."[16] Measurement of the power density of energy sources in watts per square meter (W/m2) reveals the comparative weakness of energy derived from so-called renewable sources such as wind, solar, plants or wood. The power density of wind is about 1.2 W/m2, whereas a natural gas well producing only 60,000 cubic feet of gas per day has a power density of 28 W/m2.[17]

The most familiar measure of energy is the calorie, which measures the amount of heat energy in food. For example, one loaf of bread contains roughly 1,400 calories or 5,714 Btus. As a measure of energy understood as "the capacity to do work," one person would have to eat 22 loaves of bread to complete the same work as a car engine burning one gallon of gasoline, which contains 126,000 Btus.[18]

The Human Energy Equation

A truth so basic that it is widely overlooked is that human life and all material production rely on the consumption of heat or mechanical energy. Photosynthesis, made possible by the sun, is the source of this energy. The American Heritage Dictionary briefly explains the process:

> Almost all life on earth depends on food made by organisms that can perform photosynthesis, such as green plants, algae and certain bacteria. These organisms make carbohydrates from carbon dioxide and water using light energy from the sun … Almost all of the oxygen in the earth's atmosphere was produced as waste by photosynthetic organisms….[19]

A lucky planet, the earth is the only planet in our solar system with enough atmospheric oxygen to support human and animal life.

On the most fundamental physical level, life depends on food energy, without which human, animal, and plant life all cease. The sun provides 99.98 percent of the energy of the world's climate.[20] The source of life-sustaining energy on this planet is the radiant energy of the sun. Through the chemical process of photosynthesis, plants convert a minute portion of the massive amount of radiant energy that the sun daily showers on the earth. The amount of radiant—or light—energy continuously flowing from the sun may average the energy equivalent of 20 million calories a day per acre surface of the earth. Through photosynthesis, plants convert to organic matter (carbohydrates) perhaps only 0.18 percent of the solar energy.[21]

Thus, the human body depends upon daily consumption of what was originally solar energy stored in food to sustain life. A masterful chemical reactor, the human body turns the solar energy stored in plants (as a result of photosynthesis), as well as the meats from animals nourished by plants, into chemical, heat, and mechanical forms of energy necessary for bodily function and locomotion. Even at complete rest or in a comatose state, the human body depends on a minimal consumption of energy to sustain bodily function known as "the basic metabolic rate."

The same solar energy captured in human food, in a vastly more concentrated form, is stored in fossil fuels. Coal, crude oil, and natural gas are composed of the residue of once-living plants and animals, highly concentrated through geological compression for millions of years. Peat is a younger fossil fuel compressed over thousands of years.

Fossil fuels can be characterized as a form of "ancient nature" because they originate from living nature—the products of recent photosynthesis. Not unlike the combustion of fossil fuel in a car, the human body chemically "burns" the energy in food—the gift of solar energy captured through photosynthesis in living plants. The growing plants viewed out the window and in our own bodies may become fossil fuels 300 million years from now.

Energy in the Pre-Industrial World

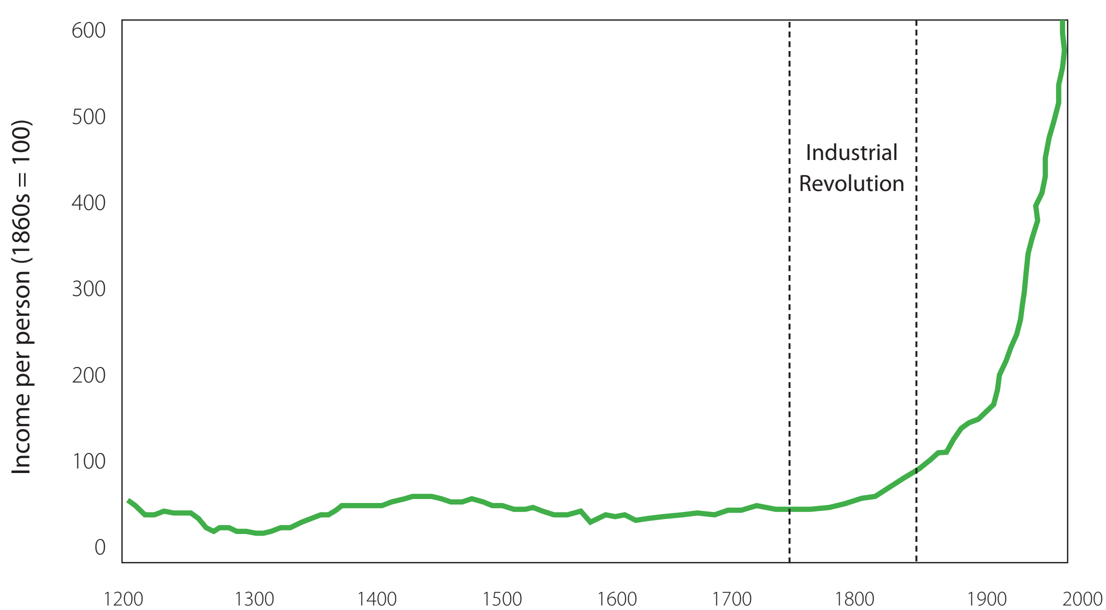
Prior to actively harnessing the energy stored in fossil fuels little more than 200 years ago, human societies depended on the limited and variable supply of energy annually captured in recent plant growth. Fuel was almost entirely derived from trees and woody plants. Food, clothing, shelter, and materials still depended on plant growth and animals dependent on plant growth that humans cannot digest.* Unavoidably subject to nature's destructive whims such as drought, flood, and pestilence or to human foibles such as war, human subsistence was a precarious and often lost gambit particularly for children and the infirm. Thirty percent of children died before reaching 15 years of age.[22]

In England, real income per person was relatively static from 1200 until around 1850 when income rose sharply and steadily as shown in Clark's graph in **Figure 2**.

Mankind's Energy History

Obviously, the length of mankind's history is imprecise and is based on wide ranging definitions of "human." Yet, for all but the last 200-250 years of that history, mankind lived under physical strictures comparable to animals. Humanity made its first energy advance around 8000 B.C., when human groups began to cultivate crops and raise livestock instead of hunting and gathering what unassisted nature might provide.[23] This Neolithic agricultural revolution augmented the supply of food and materials needed for human survival, but the gains were marginal and fleeting—inad-

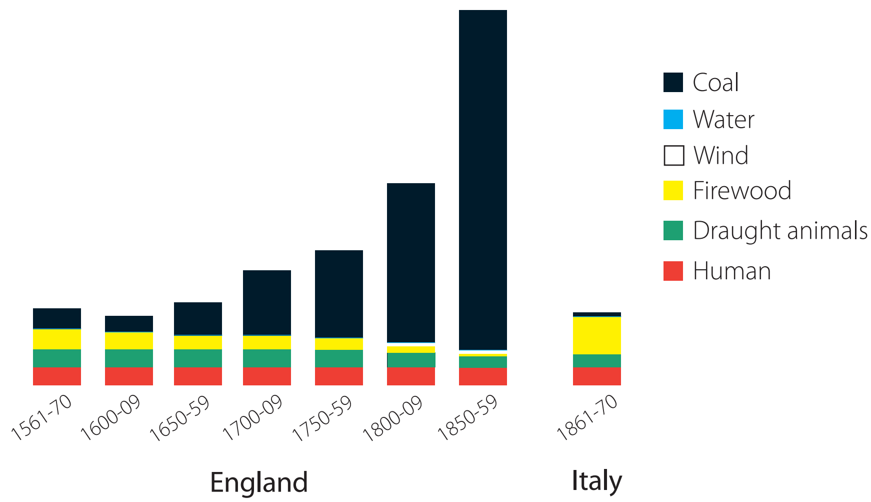
Figure 2: Real Income Per Person in England (1200-2000)



Source: Gregory Clark, *A Farewell to Alms*, p. 195.

* The large classes of mammals known as ungulates are herbivores that can convert grasses—indigestible to humans—into meat tissue.

Figure 3: Energy Consumption in England and Wales (1561-70) Compared with Italy (1861-70)



Source: E.A. Wrigley, *Energy and the English Industrial Revolution,* p. 95.

equate to support a continuously increasing population while improving living standards for the bulk of that population.

Before England methodically tapped into coal, plant photosynthesis remained the dominant source of all energy as it had been for the hunter gatherers thousands of years earlier. Wind and water mills, although plentiful, did not significantly augment the energy supply.[24]

Until the onset of the Industrial Revolution, human and animal muscle supplied mechanical power, and combustion of woody plants supplied almost all heat energy. At various times and in various societies, coal, natural gas, or crude oil was used when it was readily accessible near, or through outcrops on, the surface of the earth.[25] The Netherlands made highly productive use of peat—a relatively much younger fossil fuel and with far less energy density. And then peat became scarce.

As the Industrial Revolution neared, fossil fuel use began to increase. In the latter decades of the 17th century, England increased use of coal for heat energy but wood, draught animals and human muscle still provided the majority of energy consumed. By the middle of the 18th century coal had become the predominant source for energy consumed in England.[26] Fossil fuel use, however, was never converted to mechanical energy on a large scale until the Industrial Revolution in the 18th and 19th centuries. (**Figure 3**).

Natural gas (mostly derived from coal) also was put to commercial use in the early stages of industrialization in England.* The commercial use of natural gas is relatively recent although natural gas seeping from the ground had been recognized in ancient Greece and Rome. Around 1785, England began to use the natural gas produced from coal to light houses and streets. In 1816, Baltimore, Maryland became the first city to light its streets with manufactured natural gas. Robert Bunsen's invention of the Bunsen burner in 1885 opened many opportunities for this versatile fossil fuel.

Although Herodotus described oil pits near Babylon and Marco Polo described oil being collected near the Persian city of Baku in the 13th century, the first sustained commercial applications of petroleum did not occur until the mid-

*A full treatment of the productive roles played by natural gas and petroleum in the Industrial Revolution is beyond the scope of this paper. Suffice it to say that coal in England led the early portion of the energy breakthrough, but diverse uses of natural gas and petroleum also supported the phenomenal economic growth and energy benefits of the later 19th and 20th centuries.

19th century in the United States—also the period when the internal combustion engine was invented. Petroleum is an extraordinarily versatile energy source. When refined, crude oil can be separated into different parts called fractions. From those fractions come propane, butane, multiple petrochemicals, gasoline, kerosene, diesel, jet fuel, home heating oil, ship fuel, lubricating oils, and asphalt. Perhaps 6,000 different products in daily use derive from petrochemicals.[27]

Wrigley explains the energy factor implicitly recognized by the classical economists but not so named: "As long as supplies of both mechanical and heat energy were conditioned by the annual quantum of insolation and the efficiency of plant photosynthesis in capturing incoming solar radiation, it was idle to expect a radical improvement in the material conditions of the bulk of mankind."[28]* Wrigley also points out that the importance of coal in the Industrial Revolution was not that it caused a breakthrough at any one point in time, but that coal enabled increased productivity to continue.

"The quantity of energy needed," Wrigley concludes "to underwrite the scale of material production reached in England by the middle decades of the 19th century would have been far beyond attainment in an organic economy and, in the absence of coal, this would have prevented growth on a comparable scale."[29] In other words, the many technological changes occurring during the 18th century in England are conceivable without coal but the sustained and rapid growth of the economy in the 19th century would have been impossible without coal. In this sense, coal was a necessary condition of the Industrial Revolution viewed in its sweep through three centuries.

According to historian Gregory Clark: "The basic outline of world economic history is surprisingly simple. Indeed it can be summarized in one diagram … Before 1800, income per person—the food, clothing, heat, light, and housing available per head—varied across societies and epochs. But there was no upward trend. A simple but powerful mechanism … [known as] the Malthusian Trap, ensured that short-term gains in income through technological advances were inevitably lost through population growth."[30]

Clark paints a startling picture: "The average person in the world of 1800 was no better off than the average person in 100,000 B.C. … Before 1800 there was no fundamental distinction between the economies of humans and those of other animal and plant species."[31] Clark's dramatic statement may seem an offensive oversimplification of global economic history, but recall that it only refers to the physical parameters of human life. In this context income means the amount of food, clothing, shelter, and materials available to the average person. Of course the wealthy elites in many societies enjoyed a higher standard of living, but the overwhelming majority of people did not.

Certain societies over various periods in human history made significant gains in income per capita, technological innovation, commerce, and population as well as the arts and letters. Two fascinating examples include the great trading cultures of Italian city states between the 9th and 15th centuries and the ancient Phoenician city states between 1200 and 900 B.C. Yet, these societies ultimately waned and did not achieve sustained economic growth on the scale of the English Industrial Revolution which benefited the bulk of population. Both the Italian and Phoenician city states relied on slave labor to perform much of the work that mechanization in the Industrial Revolution spared workers.

Since the historical breakthrough known as the Industrial Revolution, man's ability to harness the energy of fossil fuels has secured unprecedented improvements in health, wealth, and living standards. Current policies to supplant the fossil fuels undervalue the magnitude of human improvement made possible by fossil fuels and overvalue current alternatives to fossil fuels. As Matt Ridley's story of energy shows, although mankind developed new sources and uses for energy, the gains were marginal until fossil fuels were tapped to provide mechanical energy.

The Malthusian Trap

The "Malthusian Trap" encapsulates the theory articulated by the Rev. Thomas Malthus in his "Essay on the Principles of Population" published in 1798.[32] Ironically, Malthus wrote this essay in the early stages of the English Industrial Revolution—a revolution in economic growth that his

* The term "insolation" broadly refers to the amount of solar radiation received by the earth. Specifically, the term refers to the rate of delivery of solar radiant energy per unit of a horizontal surface.

theory precluded. At the core of his theory is the assumption that mankind's only portal to energy is circumscribed by the fixed extent of tillable land and timber. "Elevated as man is above all other animals by his intellectual faculties," Malthus wrote, "it is not to be supposed that the physical laws to which he is subjected should be essentially different from those which are observed to prevail in other parts of animated nature."[33] How soon after he wrote that statement did inventive humans develop technologies to transcend what previously appeared to be the physical world's intractable limits!

According to Malthus, when good harvests increased the food supply, income per capita would temporarily rise, only to be brought back down by increases in population. When drought or pestilence ravaged the supply of food and heat energy, famine would "cruelly" check growth. Incomes would decline; malnutrition would inevitably decrease fertility or shorten lifespan, and the population would decrease. In a Malthusian world, mankind is trapped by the same natural laws that apply to animal populations.

According to Malthus, birth rate must match death rate. If it does not, nature inevitably will check growth by reducing the standard of living. As he argued, population expands geometrically (e.g. 1, 2, 4, 16, 32, 64, 128, etc.) while food supply can only increase arithmetically acre by acre on an assumed fixed area of land (e.g. 1, 2, 3, 4, 5, 6, etc.). "The power of population is indefinitely greater than the power of the earth to produce subsistence for man."[34]

In other words, increasing human numbers will inevitably outstrip the maximum productivity of a fixed extent of land. The huge gains in agricultural productivity later made possible by fossil fuel-based fertilizer, transportation and refrigeration were understandably unfathomable to Thomas Malthus.

Although Malthus did not explain the "trap" in terms of energy, he was accurately describing the energy limits for societies before humans methodically tapped the vast store of concentrated energy found in fossil fuels. As such, human society, like animal societies, was still subject to the intractable constraints of mercurial nature and thus to a limited and variable supply of food and heat energy. As educated and culturally refined were the elites of 17th and 18th century England and other European countries, their lives remained governed by an extremely limited flow of energy captured in recent photosynthesis in plants.

The energy breakthrough that literally fueled the productivity for which the Industrial Revolution is known, of course, did not occur at a certain time, decade or even century. England and other countries, particularly in Europe had been using coal for heat energy from the late 16th century onward. But the energy contributed by coal dwarfed energy delivered by human muscle, draught animals, and firewood combined by 1800 onward. (See Appendix I for breakdown of energy consumption by source from 1560-1860).

Stretching the Energy Limits

Human living standards, especially in European countries, had made incremental gains in some areas centuries before the Industrial Revolution. Improved agricultural methods applied to larger areas of land increased food supply and thus supported increasing population. More roads, canals, and ships were built which facilitated greater commerce and trade. Development of the printing press enhanced the accumulation and transmission of knowledge, and spurred inventive technologies. Universities were established. The arts flourished but were inaccessible to the bulk of the population.

Critically, legal institutions which uphold the rule of law, private property rights, contractual transactions, competitive free markets, and the inalienable rights of each individual took form before 1800—the most common date for the beginning of the Industrial Revolution.

Select European countries, especially England, achieved some gains in agricultural productivity and thus a growth in population well before the Industrial Revolution. But the rate of population growth did not take off until 1850 as shown in **Table 1** below.

In 1750, England had one of the longest life expectancies at 35 years. Global average life expectancy, however, only rose from 24 to 25 years from 1000 to 1750—the period in which the world population tripled to 760 million. Income did not rise as rapidly as population. Global average income increased to $640 by 1750, only 0.05 percent higher than in 1000 A.D. In contrast, average income in England increased annually at a rate of 0.36 percent during the 18th century according to Angus Maddison's *Statistics on World Population*. In food supply, population, lifespan, and a vast store of energy, England had progressed farther than any other country except the Netherlands and was primed to lead the Industrial Revolution.[35]

Mankind's Release from the Malthusian Trap

Historian E.A. Wrigley's "Energy and the English Industrial Revolution" documents the necessary role of fossil fuels in mankind's second-most momentous advance. "Around 1800, in northwestern Europe and North America, man's long sojourn in the Malthusian world ended… Between 1770 and 1860… the English population tripled. Yet, real incomes, instead of plummeting, rose… A new era dawned."[36]

Table 1: Population Totals of Selected European Countries 1600-2000 and Related Growth Rates

	England	The Netherlands	France	Germany	Sweden	Italy	Spain
1600	4.2	1.5	19.6			13.5	6.7
1650	5.3	1.9	20.3			11.7	7.0
1700	5.2	1.9	22.6	16.0	1.4	13.6	7.4
1750	5.9	1.9	24.6	17.0	1.8	15.8	8.6
1800	8.7	2.1	29.3	24.5	2.4	18.3	10.6
1850	16.7	3.1	36.3	35.4	3.5	24.7	14.8
2000	49.0	15.9	58.9	82.2	8.9	57.8	39.5
Percentage annual growth rate							
1600-50	0.49	0.47	0.07			-0.29	0.08
1650-1700	-0.04	0.00	0.21			0.30	0.11
1700-50	0.25	0.00	0.17	0.12	0.55	0.30	0.30
1750-1800	0.77	0.20	0.35	0.73	0.56	0.29	0.42
1800-50	1.32	0.78	0.43	0.76	0.79	0.60	0.67
1850-2000	0.72	1.10	0.32	0.56	0.62	0.56	0.66
Relative size of national populations England = 100							
1600	100	37	471			325	161
1650	100	36	382			220	132
1700	100	36	434	307	26	261	142
1750	100	32	416	287	30	267	145
1800	100	24	338	283	27	211	122
1850	100	19	217	212	21	148	88
2000	100	32	120	168	18	118	81

Source: E.A. Wrigley, *Energy and the English Industrial Revolution,* p. 155.

The Simple Story of Energy According to Matt Ridley

"The story of energy is simple. Once upon a time all work was done by people for themselves using their own muscles. Then there came a time when some people got other people [aka slaves] to do the work for them, and the result was pyramids and leisure for a few, drudgery and exhaustion for the many. Then there was a gradual progression from one source of energy to another: human to animal to water to wind to fossil fuel. In each case, the amount of work one man could do for another was amplified by the animal or machine. The Roman Empire was built largely on human muscle power; in the shape of slaves…The European early Middle Ages were the age of the ox…With the invention of the horse collar, oxen then gave way to horses, which can plough nearly twice the speed of an ox, thus doubling the productivity of a man…

"In turn oxen and horses were soon being replaced by inanimate power. The watermill … became so common … that by the time of the Doomsday Book (1086), there was one for every 50 people in southern England … The windmill appeared first in the 12th century and spread rapidly … But it was peat, rather than wind, that gave the Dutch the power to become the world's workshop in the 1600s…

Hay, water and wind are ways of drawing upon the sun's energy: the sun powers plants, rain and wind. Timber is a way of drawing on a store of the sun's energy laid down in previous decades—on solar capital, as it were. Peat is an older store of the sunlight—solar capital laid down over millennia. And coal, whose high energy content enabled the British to overtake the Dutch, is still older sunlight, mostly captured around 300 million years before. *"The secret of the industrial revolution was shifting from current solar power to stored solar power."* (Emphasis added)

Source: Matt Ridley, *Rational Optimist*, pp. 214-216.

Neo-Malthusian Perspectives

Although the Industrial Revolution and the sustained growth it spawned disproved Malthus' predictions, Malthusian perspectives remain appealing to the pessimists among us. In spite of the continual growth in global population, food supply, energy resources, and income per capita, pessimists continue to predict resource depletion, world famine, increased poverty and now apocalyptic global warming. Modern Neo-Malthusians such as Paul Ehrlich and Lester Brown persist in their claim that the world's population will overcome food supply and natural resources.[37] The many predictions of mass starvation and "peak oil," voiced by Ehrlich and his ilk, have repeatedly failed to occur in spite of increased consumption by a growing world population. As economist Julian Simon and others have shown, human creativity is the ultimate resource capable of continually expanding the bounds of the master resource called energy.[38]

Fossil Fuels: A Necessary Condition of the Industrial Revolution

Wrigley and others persuasively regard fossil fuels as a necessary condition of the Industrial Revolution. How could the Industrial Revolution, which began in England around 1800, spread to three continents? How could it now be growing in China and India, and still improving human-well-being throughout the developing world? All this without the kind of energy held in fossil fuels? Coal, however, cannot be construed as a "sufficient condition" or a cause of the English Industrial Revolution. Historians still debate the multiple, reinforcing, and inter-related factors that led to the Industrial Revolution. Other factors include greater literacy, accumulation of knowledge, inventive technologies, efficiency gains, and legal institutions that protect property rights and contractual transactions that promote capital accumulation.

Yet, without access to the vast store of dense and versatile energy in fossil fuels, the economic growth and human well-being rising since the early 1800s likely could not have occurred. If mankind's first major advance was the Neolithic Agricultural Revolution, then the second major advance known as the Industrial Revolution was at root an energy revolution for heat and mechanical energy. "[T]apping into the new energy source changed the production horizon in a fundamental fashion that had happened only once previously in human history, at the time of the Neolithic food revolution."[39]

Throughout human history, various societies developed technologies to enhance the supply of the energy provided by nature. But the progress was halting or temporary. All too often it regressed. The Neolithic food revolution made wealth and high culture possible for the elite, but grinding poverty remained the common lot of mankind.

Productivity Unleashed

"The Industrial Revolution is unique in world history," writes historian Gregory Clark, "owing to the sudden appearance of a more rapid rate of efficiency advance than had been witnessed over sustained period by any earlier economy."[40]

Thomas Malthus, whatever the defects of his analysis, was one of the three men credited with articulating the structure of classical economics, the other two being Adam Smith and David Ricardo. The lives of these men coincided with the early decades of the Industrial Revolution although they were unaware of the game-changing nature of the economic breakthrough going on around them. Malthus, Ricardo, and Smith agreed that an Industrial Revolution which could indefinitely sustain increasing population and income per capita was physically and economically impossible.[41]

The Puzzle of the Industrial Revolution: Sustained Growth

Most economists remain puzzled that the economic growth started by the Industrial Revolution has never stopped. In his recent book *Knowledge and Power*, George Gilder reflects on the perplexing magnitude of the growth. "The central scandal of traditional economics," he writes, "has long been its inability to explain the scale of per capita economic growth over the last several centuries. It is no small thing. The seven-fold rise in world population since 1800 should have attenuated growth per capita. Yet the conventional gauges of per capita income soared some 17-fold, meaning a 119-fold absolute increase in output in 212 years."[42]

Although economists struggle to explain the continually expanding growth, the events of this energy and industrial revolution are widely recognized. The hallmark of the revolution was, as Clark states above, a rapid and radical expansion of the productive powers of an economy. Efficiency is here understood as the ratio between the cost per unit of input and the cost per unit of output. Efficient and profitable enterprises produce more output per unit of input and thus can generate profit. The magic of fossil fuels is that their input can exponentially increase output, and thus overall efficiency.

Prodigious Gains in Productive Efficiency

Consider textiles. According to Clark and Wrigley, the textile industry accounted for over 50 percent of the increased productivity, and thus growth, in England during the entire 19th century. "Efficiency in converting raw cotton to cloth increased 14-fold from the 1760s to the 1860s, a growth rate of 2.4 percent per year, faster than productivity growth in most modern economies."[43] In 1760, transforming a pound of cotton into woven cloth took approximately 18 man-hours. By 1860, the same work was completed in 1.5 man-hours.[44] Similar rate of gains were achieved across many industries.

England first used coal to overcome the island's chronically limited supply of heat energy available from wood. During the 18th century, coal was increasingly used in homes and handicraft industries. Coal was also used to mine more coal, providing heat energy for the crude pumps used to extract the coal. "And once it had become clear that coal could provide heat energy on a scale and at a price which had no previous precedent, it was not surprising that attention turned to parallel problem with mechanical energy."[45]

The Core of the Industrial Revolution: Mechanical Energy

The steam engine, which translated heat energy into mechanical energy, unleashed the seemingly unlimited productivity and inventiveness for which the Industrial Revolution is known. Thomas Newcomen's first steam engine converted only 1 percent of the heat energy from burning coal. James Watt's later engine—the symbol of the English Industrial Revolution—converted 10 percent of the heat energy and was much faster.[46] Not long after the development of Watt's steam engines, inventors translated the vertical movement of the pistons into rotary motion.

This advance made possible the application of fossil fuels to a huge range of devices and machines that increased manufacturing productivity by leaps and bounds and reduced hard labor. The steam engine and derivative devices mechanized production that previously was the hard labor of human or animal muscle. With mechanization, productive efficiency soared, and so did energy efficiency.[47]

Unprecedented Growth

In contrast with Malthus, Ricardo, and Smith, some English economists fully grasped the energy equation in England's industrialization. William Jevons, whose life spanned the gathering speed of the English Industrial Revolution in the mid-19th century, correctly assessed the magnitude of the energy revolution taking place around him—mankind's liberation from the Malthusian trap. Jevons writes in *The Coal Question*: "With coal almost any feat is possible or easy; without it we are thrown back into the laborious poverty of earlier times."[48] As England used more and more coal, Jevons was concerned that eventual depletion of England's coal supply would drive up the price of coal and thus arrest the phenomenal growth. Coal, however, did not become scarce or more expensive. Indeed, using coal-fired energy begat more energy, productivity, and income.

Every other boom in human history eventually hit a wall and then declined because resources dwindled—whether timber, cropland, pasture, labor, water, or peat. These resources, unlike coal, are renewable and so replenish themselves but at a pace far too slow to meet ongoing demand. Coal in the English Industrial Revolution was a different story. As England used more and more coal, it actually became more abundant and cheaper. Although not in principle renewable (save for another 300 million years of geological compression) fossil fuels remain abundant enough to sustain economic growth for at least centuries until fully comparable or superior energy sources are genuinely available at scale.

More output from less input remains the inherent dynamic of economic growth from fossil fuels. Modern societies get increasingly more work out of each ton of fossil fuel. According to recent EIA data, the carbon intensity of the U.S. economy has been declining since 1949.[49] (*See Figure 5*) The U.S. now uses 50 percent less energy per unit of GDP than it did in 1950.[50]

Less than 250 years ago, England was the first country to transcend what had been universal constraints on accessible energy and thus universal constraints on economic growth. Rapid growth no longer meant an inevitable regression. Mankind's Malthusian shackles were torn apart.

"A Farewell to Alms"

The greatest gift of the energy breakthrough, on which the Industrial Revolution still relies, is the release of entire populations from abject poverty. Unlike any previous economic boom, the poorest—not the already wealthy—were the greatest beneficiaries. "The plain fact is that the mechanization of production in the Industrial Revolution raised incomes across all classes," remarks Matt Ridley.[51]

Princeton historian Gregory Clark titled his global economic history, *A Farewell to Alms*—a word-play on Ernest Hemingway's *A Farewell to Arms.* Both titles evoke the primal hope of mankind for a world without poverty or war. At the beginning of his history of the Industrial Revolution, Clark underlines his theme in startling terms:

> The Industrial Revolution, a mere 200 years ago, changed forever the possibilities for material consumption. Incomes per person began to undergo sustained growth in a favored group of countries. … Moreover the biggest beneficiary of the Industrial Revolution has so far been the unskilled."[52*]

Indur Goklany in **Table 2** shows the barely measurable increase in global income per capita (as well as life expectancy) from 1 A.D. until 1750 A.D., around the dawn of the Industrial Revolution. Note that the dramatic increase from 1750-2009 is strongly correlated with what is the first sizeable increase in man-made emissions of CO_2 in human history.

* Although Clark's claims may seem overwrought, note that his point is about the physical parameters or material conditions of life for the majority of people. His empirical data derives from the macroeconomic historical data significantly compiled by the late Angus Maddison.

Table 2: Average Annual Rate of Increase for Various Time Periods

	1 A.D. -1000 A.D. %	1000 A.D. - 1750 A.D. %	1750 A.D. - 2009 A.D. %
Life Expectancy	0.01	0.00	0.41
Income	0.00	0.05	0.98
Population	0.02	0.14	0.88
Carbon Dioxide Emissions			3.23

Source: Indur Goklany, *Humanity Unbound*, p. 6.

Clark's figures for England in Figure 2 (page 8) show what he characterizes as "the unprecedented, inexorable, all-pervading rise in incomes per person since 1800. The lifestyle of the average person in modern economies was not unknown in earlier economies: it is that of the rich in ancient Egypt or ancient Rome. What is different is that now paupers live like princes and princes live like emperors."[53] As Goklany summarizes these numbers: "Never in human history had indicators of human well-being advanced so rapidly."[54]

Industrialization of the more pervasively agrarian United States took off a little later than the English Industrial Revolution. Raw materials and foodstuffs from the U.S. significantly supplemented the needs of England's industries and growing population. Without these "ghost acres," many historians question whether England's comprehensive industrialization would have been as successful. The U.S. story, however, is quite the same as England's: dramatic rises in life expectancy, population, GDP per capita and CO_2 emissions.[55]

Greatest Gains to the Poor

Income per capita calculated as an average may be highly misleading. But the most distinctive feature of the economic boom fueled by the Industrial Revolution is that the income gains accrued more to the poorest and the average worker than to the wealthy. The average English income headed upward around 1800. By 1850, it was 50 percent above the level in 1750 in spite of the fact that the population tripled. As Matt Ridley notes: "The rise was steepest for unskilled workers … The share of national income captured by labour rose … Real wages rose faster than real output throughout the 19th century, meaning that the benefit of cheaper goods was being garnered by the workers as consumers, not by bosses and landlords."[56]

The most distinctive feature of the economic boom fueled by the Industrial Revolution is that the income gains accrued more to the poorest and the average worker than to the wealthy.

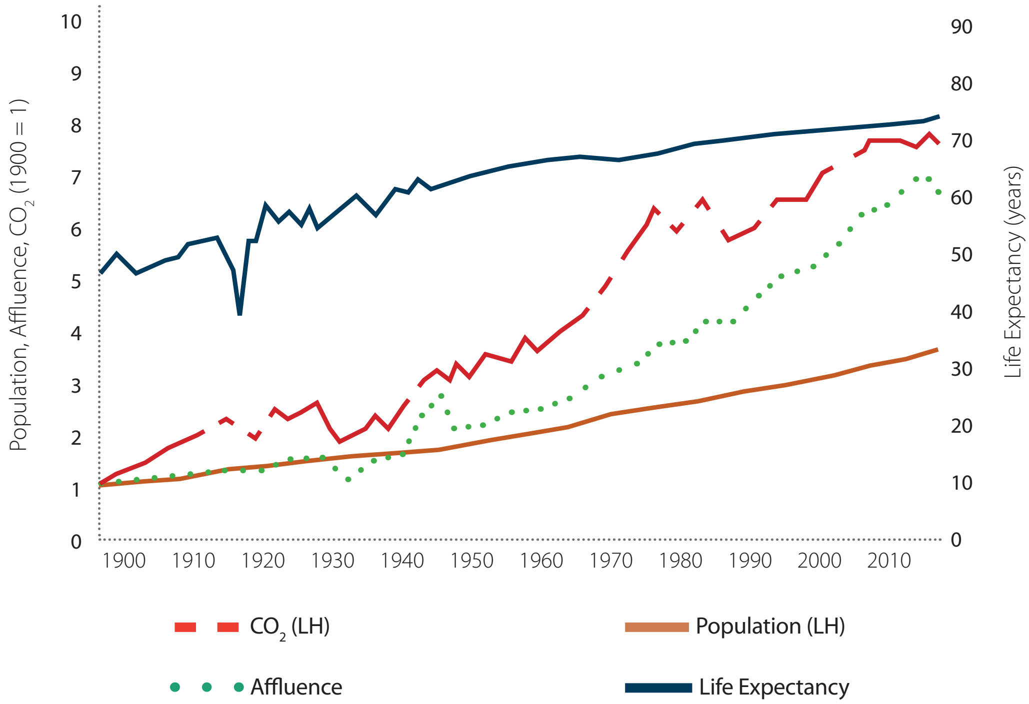
As the abundant heat and mechanical energy supplied by coal increased productivity, the supply of goods increased while the price declined. The winter jacket mentioned in Ridley's vignette at the beginning of this paper, which cost a month's wages, may have cost only a week's wages by 1850. As productivity increased, factory workers were better able to afford to buy the products they helped produce. A middle class emerged.

Satanic Mills?

The prevalent views of living conditions of workers during the first century of England's Industrial Revolution are grim. Perhaps the most memorable is Blake's poem lamenting the "dark Satanic Mills."[57] Karl Marx, Charles Dickens, and other writers decried the pollution, filth, and general squalor in the new factories and urban apartments. Later writers, however, point out that worse poverty, disease, pollution, and child labor certainly existed in England before the Industrial Revolution. Rural poverty may have been worse than urban poverty.

Matt Ridley says, "In Gregory King's survey of the British population in 1688, 1.2 million laborers lived on four pounds/year and 1.3 million 'cottagers'—peasants—lived on two pounds/year. That is to say, half the entire nation lived in abject poverty; without charity they would starve.

Figure 4: U.S. Carbon Dioxide Emissions, Population, GDP, and Life Expectancy (1900-2009)



Source: Indur Goklany, *Humanity Unbound*, p. 8.

During the Industrial Revolution, there was plenty of poverty but not nearly as much as this nor nearly as severe."[58] The violent protests of the 19th century textile workers—known as the Luddites—against the labor-saving machines were short-lived. Although factory workers in early stages of the Industrial Revolution may have worked, by modern standards, in dangerous and dirty work places, they lived lives better than their tenant farming ancestors, which is why they flocked to the factories from the farms.[59]

The poverty of early industrial England may be so memorable because it was the first time politicians and writers expressed concern. The prosperity that industrial growth made possible indeed increased and institutionalized compassion. In 1807, the British Parliament at last passed William Wilberforce's legislation to abolish the slave trade. About the same time, the world's largest factory complex opened in Manchester, powered by coal and illuminated through steam and gas lights.

The Great Divergence

The farewell to alms, however, has not spread to all countries. "Material consumption, in some countries, mainly in sub-Saharan Africa, is now well below the pre-industrial norm. … Just as the Industrial Revolution reduced income inequalities *within* societies, it has increased them *between* societies," as Clark notes. The historical factors leading to this "Great Divergence" are analyzed in a book by that name written by Kenneth Pomeranz. The gap in incomes between the poorest and richest countries is now of the order of 50:1."[60]

In the developing world, foreign aid and increased access to basic modern medicine have increased population without engendering a foundation for the legal institutions, capital accumulation, or affordable energy on which modern economic growth rests. By conditioning financing for energy infrastructure in developing countries on use of renewable energy, the U.S., the European Union, the International Monetary Fund, and World Bank immorally consign these populations to energy poverty.

Fossil Fuels and the Modern Agricultural Revolution

Fossil fuels are extraordinarily versatile energy sources. The most revealing example is the role that natural gas has played in increasing the food supply for a growing world population.

Paul Ehrlich's Dire Predictions Were So Wrong

Since 1800, agricultural productivity has increased by as much as the rest of the economy. The doom-saying predictions of Malthus, and in recent times of Paul Ehrlich and Lester Brown, of mass starvation by the end of the 20th century have not occurred. Thomas Malthus made his prediction of impending famine in 1798. Global population then doubled by 1923 and doubled again by 1973 without fulfilling Malthus' prediction. The most well-known neo-Malthusian, Paul Ehrlich, in his 1968 best-selling book *The Population Bomb*, said "India couldn't possibly feed two hundred million more people by 1980," and, further, that "Hundreds of millions of people will starve to death in spite of any crash programs."[61] Ehrlich's predictions did not materialize.

In 1974, India became a net exporter of wheat.[62] In the 1960s, India produced about two tons of rice per hectare, a quantity that tripled by the mid-1990s. And the price of rice fell from about $550 per ton in the 1970s to about $200 per ton in 2001. India is now a major rice producer and exported almost 4.5 million tons in 2006.

Of course, millions of people in developing countries—and most harshly in sub-Saharan Africa—remain undernourished or malnourished. The international Food and Agricultural Organization (FAO) estimates that over 870 million human beings are chronically undernourished.[63] Food supply per person, however, has increased as the world's population increased. Also known as the Green Revolution, the Agricultural Revolution of the 20th century could not have occurred without abundant, affordable fossil fuels.[64] Indeed, the modern agricultural upsurge can be considered a later chapter of the energy revolution on which the 19th century Industrial Revolution relied.

Natural Gas Derived Fertilizer and Fossil Fuel Inputs

The dramatic increase in agricultural yield began in the 1920s with the commercial development of fertilizer made from synthesized nitrogen. "This energy intensive process fixes nitrogen from the air by reacting it under very intensive pressure with hydrogen (obtained from natural gas), generally over an iron catalyst."[65]

Abundant, affordable fossil fuels are essential to the productivity of 20th century agriculture. The fertilizers, pesticides, machinery, refrigeration, and efficient transport responsible for expanding and distributing food supply all rely on fossil fuels. And the elevated atmospheric concentrations of CO_2, resulting from the use of fossil fuels, have significantly increased plant productivity and drought resistance.

Colossal Agricultural Productivity through Fossil Fuels

Fossil fuels, indeed, have made the planet greener. Global warming alarmists refuse to acknowledge these fundamental facts about CO_2. In stunningly exaggerated rhetoric, U.S. Secretary of State John Kerry recently characterized man-made emissions of CO_2 as "perhaps even … the world's most fearsome of weapons of mass destruction."[66] In shrinking man's footprint on the natural world and at the same time increasing the world's food supply, man's use of fossil fuels provides benefits of profound and far-reaching value.

The numbers are staggering but totally ignored by President Barack Obama and his most senior policymakers. Without fossil fuels, the amount of land needed to grow crops to meet current global food demand would have to increase by 150 percent.[67] From 1961-2007, the world population doubled from 3.1 billion to 6.7 billion, but food supply per person increased by 27 percent. The amount of cultivated cropland, however, increased by only 11 percent.[68] "In effect, in 2007, the global food and agricultural system delivered, on average, two-and-a-half times as much food per acre of cropland as in 1961."[69]

Fertilizers derived from natural gas have vastly improved agricultural yield. The *Agronomy Journal* reports: "The average percentage of yield attributable to [natural gas-derived] fertilizer generally ranged from 40-60 percent in the USA and England and tended to be much higher in the tropics."[70] A study in Nature Geosciences found in 2008 that this same type of fertilizer so increased the productivity of cropland that it fed 48 percent of the world's population.[71]

Pesticides are another energy-intensive input to high-yield farming. Agronomist E.C. Oerke estimates 50-77 percent of wheat, rice, corn, potatoes, and soybeans would have been lost over 2001-2003 without the use of pesticides. Pesticides, according to Dr. Oerke, reduce the loss to 26-40 percent.[72]

Constant movement of cereal grains, fresh produce, dairy products and meats across countries and across continents also extends the food supply and provides the rich diversity of fresh foods available 365 days of the year in affluent countries like the U.S. More importantly, transport by air and road allows rapid movement of foodstuffs from areas of surplus to areas of scarcity and famine. Affordable fossil fuels make this transportation system possible.

Refrigeration, packaging, and containers reduce food waste that can otherwise eliminate around one-third of food supply.[73] Whether providing fuel for cooling and freezing or raw material for packaging, fossil fuels reduce loss of the food supply.

Increased Atmospheric Concentrations of CO2 Increases Agricultural Yield

Carbon dioxide has been recognized as a plant food for more than two centuries and was first so recognized by the Swiss chemist Nicolas T. de Saussure.[74] This should come as no surprise when the process of photosynthesis is understood. CO_2 is the chemical compound used by plants to construct their tissues—the food source of animals and humans. The EPA may call CO_2 a dirty pollutant, but it remains the "gas of life" for living plants and likewise for humans, who depend upon plant growth for food.

Human use of fossil fuels has increased the atmospheric concentration of CO_2 from approximately 280 parts per million (ppm) at the beginning of the Industrial Revolution to approximately 393 ppm in 2013. According to hundreds of studies, this increased concentration of CO_2 has enhanced plant productivity, growth, moisture retention and resistance to pests. "For a 300 ppm increase in the air's CO_2 content … herbaceous plant biomass is typically enhanced by 25 to 55 percent."[75]

A workshop on Anticipated Plant Responses to Global Carbon Dioxide Enrichment at Duke University in 1977 included a bibliography of 590 studies concerning CO_2 effects on plants.[76] The CO_2 benefits reported in this research included: increases in plant photosynthesis, less water loss, greater leaf area, increase in plant branch and fruit. Another conference in 1992 concluded that a doubling of the atmospheric level of CO_2 would increase photosynthesis in plants by 50 percent.[77]

Ethanol: The Folly of Food as Fuel

The wealthy elite of the world may not have a keen interest in the global supply of basic cereal grains such as rice, corn, and wheat, but these are the basic foodstuff of the majority of the human beings with whom we share life. Work in one of the poorest countries of the world is a vivid reminder of what a life of constant hunger would be like. Using a vitally needed global food grain, such as corn, for the transportation fuel known as ethanol literally takes food from the mouths of hungry millions.

The ethanol policies of the United States, which transform a basic food into an optional fuel, have led to food riots in several countries over the last few years and have been widely condemned by international institutions devoted to eliminating hunger. How blitheringly fast the human condition has changed in affluent countries. Both the current U.S. Surgeon General and First Lady Michelle Obama consider obesity the greatest public health threat in this country. And obesity is more prevalent in lower than in higher income groups. How rapidly the poor in the United States' greatest health threat has changed from too little food to too much food!

Sources: Marco Lagi, Karla Z. Bertrand and Yaneer Bar-Yam, "The Food Crises and Political Instability in North Africa and the Middle East," New England Complex Systems Institute (Aug. 2011); Kim, D. & Leigh, J. P. (2010). "Estimating the effects of wages on obesity," *Journal of Occupational and Environmental Medicine*, 52(5) 495-500.

Although fertilizer, pesticides, irrigation and new plant varieties spurred the 20th century's Agricultural Revolution, significant credit may be attributed to the addition of man-made CO_2 to the atmosphere. This dramatic benefit is ignored in recent methodologies developed to estimate the social cost—meaning the social harm—of carbon. Surely, the value of increasing food supply on the same amount of land is of high societal value.

The Versatility of Fossil Fuels: Synthetic Materials

Versatility is one of the distinctive advantages of oil, coal, and natural gas. The use of these minerals as the combustion fuel for transportation, industrial process, and electricity absorbs a huge volume of energy. Yet this is the tip of the iceberg. Supplanting fossil fuels with nuclear power or with renewable fuels like wind and solar is an imaginable (if currently impracticable) energy alternative. But with what materials would modern societies replace fossil fuels in the thousands and thousands of products of constant use in homes, business, industry, and medicine? Plastics, synthetic fibers, chemicals, pharmaceuticals, road and construction materials, steel, and a host of other materials are derived from fossil fuels.

Plastic, Asphalt, and So Much More

From petroleum or crude oil, when refined and separated, gasoline, kerosene, asphalt, chemical feed stocks, and pharmaceuticals can be made. The last two categories of uses cover almost all consumer products. Everything "plastic" derives from petroleum or natural gas. Consider a list of over 400 common products derived from petroleum by-products.[78] A miscellaneous selection from this list includes: scotch tape, shotgun shells, soccer balls, guitar strings, pacifiers, aspirin, rubbing alcohol, artificial limbs, fabric softener, hair color, lipstick, shaving cream, electric tape, and Plexiglas. Coal is a vital source of carbon in more than 70 percent of steel production today.

Textiles

The majority of all textiles and clothing are now made of synthetic fibers derived from fossil fuels. Synthetic alternatives to natural materials are the primary reason for the mind-boggling abundance of consumer goods. Clothing and household furnishings—the most personal consumer goods—are a compelling example. Until the late 1800s, all clothing and textiles were made from natural materials such as plant fiber (cotton), wool from sheep, goats, or wild animals, animal skins, and silk from worms. Synthetic fibers derived from fossil fuels currently account for 60 percent of global fibers.[79]

Polyester is the raw material for 80 percent of synthetic fibers, while vinyl, nylon, and acrylic account for 18 percent of synthetics.[80] All these fibers, derived from petroleum, have reduced the cost of clothing across the world and improved the warmth and affordability of winter clothing. For specific uses such as insulation, water repellency, and lighter weight material, synthetic fibers are stronger than natural materials.

Environmental Benefits of Fossil Fuels

Global warming alarmists are misleading the public about CO_2 emissions. Whether emitted from the human use of fossil fuels or as a natural (and necessary) gas in the atmosphere surrounding the earth, carbon dioxide has none of the attributes of a pollutant. The Environmental Protection Agency (EPA)'s increasing characterization of man-made CO_2 as "dirty carbon pollution" is absurd.

CO_2 Differs from Genuine Pollutants

In contrast to the genuine pollutants enumerated in the Clean Air Act, current CO_2 levels in the ambient atmosphere have no direct effects on human health. A remarkable number of highly educated people even who question the IPCC science behind anthropogenic global warming alarmism (GWA), nonetheless, regard "carbon" or CO_2 as a dirty harmful pollutant. They evidently conflate genuine pollutants such as sulfur dioxide, nitrogen oxides, and benzene and mercury, etc., emitted in uncontrolled combustion of fossil fuels with CO_2.

In December 2009, EPA issued an "Endangerment Finding" regarding greenhouse gases.[81] The Endangerment Finding concluded that CO_2 (and five other greenhouse gases) endanger human health and welfare, and are thus subject to regulation as "pollutants" under the Clean Air Act. In reaching this conclusion, the EPA relied on modeled predictions of warmer temperatures decades in the future. Yet both the EPA and President Obama assert that "dirty carbon pollution" is harming human health right now, as a lethal inhalant could. This assertion is flatly wrong.

Consider that the federal Occupational Safety and Health Administration (OSHA) sets a health effect level for CO_2 concentrations in an enclosed space at 5,000 ppm.[82] Current atmospheric concentrations of CO_2 are slightly less than 400 ppm—12.5 times lower.

Fossil Fuel Use Shrinks Human Footprint on Natural World

Fossil fuel use has substantially reduced the human footprint on the earth's glorious natural ecosystems and the animal and plant species which draw life from those natural systems. Human use of land for food, fuel, and materials always has been the greatest encroachment on our natural world. As a form of highly concentrated solar energy stored underground, fossil fuels have checked human interference with the biodiversity of the natural world.

This powerful benefit of fossil fuels has been entirely dismissed by organized environmentalism during the last four decades.* Policies to replace fossil fuel based electric generation with wind and solar generation necessitate significant land modification, habitat destruction, and harm to protected wildlife species.

Since the late 1960s, the environmental left has vilified fossil fuels for their potentially harmful—but eminently reversible—impacts on air and water quality. As noted earlier, global cropland would have to increase by 150 percent without fossil fuel input.[83] "This means that to maintain the current level of food production, at least another 2.3 billion hectares of habitat would have had to be converted to cropland. This is equivalent to the total land area of the United States, Canada, and India combined."[84] Agriculture now has converted 1.5 billion hectares of the surface of the earth to cropland. Without the productivity achieved through natural gas derived fertilizer, pesticides, and other modern agricultural machinery dependent on fossil fuels, the amount of land devoted to cropland would be as much as 3.8 billion hectares.[85]

Replacing animal power with fossil fuel driven mechanical power also confers environmental benefit. Almost 30 percent of the U.S. crop harvest in 1910 was devoted to feeding 27.5 million horses used for animal power on the farm and for transportation.[86] Although U.S. food demand has grown with population over the last 100 years, the number of acres of American land devoted to agricultural crops has not increased since 1910. Had animal power not been replaced by fossil fuel-based power, the amount of cropland necessary to feed a population more than three times larger than that of 1910 would give environmental purists grave indigestion.

Renewables Increase Human Footprint on Natural World

Current wind and solar installations use much more land than coal, natural gas, or nuclear power plants. In spite of rapid development over the last five years, possible only through billions spent in federal subsidies, solar installations generate a mere two-tenths of 1 percent (0.2%) of electric power.[87] For solar to meet total U.S. electric demand, 10,000 square miles of land would have to be given over to solar panels.[88]

Consider the Ivanpah installation—the world's largest solar generating station, located in the Mojave Desert of southern California. This recently opened 377 megawatt (MW) facility occupies 3,500 acres. Wind farms also create a far larger human footprint than fossil fuel or nuclear fired power plants. Wind requires a land area roughly 2,000 times larger than a nuclear plant comparable in generating capacity.

Moreover, fossil fuels have been particularly kind to trees—the original source of almost all heat energy. The amount of timber needed to replace the volume of coal used by England in 1850 would have covered 150 percent of "England's green and pleasant land" (again to evoke William Blake).[89] Today's carbon emissions per unit of economic output are modest when compared to those of pre-industrial societies.

Remarkable Environmental Improvement

If not controlled, of course, the combustion of fossil fuels releases potentially harmful pollutants. Over the last 30 years, innovative emission control technologies have achieved enormous reductions of those pollutants. Although the EPA rarely acknowledges this environmental success, data on the Agency's own website documents the remarkable environmental improvement. (See Table 3, next page).

* A rare exception has been Indur Goklany, who deserves praise for the attention he has brought to these issues.

Emissions from cars and trucks, now the predominant source of particulate matter and precursor emissions for ozone, have been reduced over 90 percent at the same time vehicle miles traveled have almost doubled.[90] Emissions of lead have declined by 97 percent.[91] Additionally, the EPA's Toxic Release Inventory documents a 65 percent reduction since 1988. New power plants emit 90 percent less sulfur dioxide than plants built in the 1940s.[92] The adverse environmental impacts associated with fossil fuels can be reversed and have already been arrested. Reversing the ecological loss occasioned by conversion of natural ecosystems to cropland is typically far more difficult.

Fossil fuel use, ironically, expedited development of the technologies which have so dramatically abated the pollution associated with fossil fuel use. The emission control technologies typically utilize considerable energy to operate. If energy was not abundant and affordable, use of these technologies would be limited. Additionally, the ever-increasing efficiency made possible by fossil fuel-generated prosperity has allowed businesses and consumers to absorb the steep cost of comprehensive environmental controls now used in prosperous countries.

Environmental Improvements: A Luxury for the Developing World

Environmental quality remains an unaffordable luxury for much of the developing world. The most polluted cities in the world, according to the World Bank's list, are in developing countries and not in prosperous countries consuming huge volumes of fossil fuels.[93] In the World Health Organization's list of 89 of the world's cities most polluted by sulfur dioxide (SO_2), consider that Guiyang, China—the first city on the list—has SO_2 levels 45 times higher than Los Angeles—the last city on the list. Environmental protection has taken a back seat to rapid economic development in countries like China, where release from severe poverty has understandably been the first priority.

China and India have begun to abate their air and water pollution. But to claim that China is launching significant initiatives to cap carbon, as President Obama asserts, is misleading. China's environmental priority is to cut genuine pollution that actually impairs human health from high ambient concentrations of contaminants such as smog and soot. China is not shuttering coal-fired power plants as is occurring in the U.S. due to EPA regulation.

Matt Ridley reminds us that two billion people in the world have never seen an electric switch.[94] Policies now implemented by the World Bank, the International Monetary Fund, and by the U.S. government, to prohibit financing of affordable fossil fuel-fired electric generation in developing countries, cruelly delay and deny the world's poorest families light, heat, and cooling. The greatest environmental killers are contaminated water and uncontrolled sewage. Clean water and safe waste disposal require treatment systems that depend upon abundant electric power.

Table 3: Air Quality Improvement 1980-2010

	Ambient 1980-2008	Ambient 1980-2010	Emissions 1980-2008	Emissions 1980-2010
Carbon Monoxide (CO)	-79%	-82%	-58%	-71%
Ozone (O3)	-25%	-28%	-49%	NCD
Lead (Pb)	-92%	-90%	-96%	-97%
Nitrogen Dioxide (NO2)	-46%	-52%	-40%	-52%
Particulates (PM10)*	-31%	-38%	-46%	-983%
Fine Particulates (PM2.5)**	-21%	-27%	-36%	-55%
Sulfur Dioxides (SO2)	-71%	-76%	-56%	-69%

NCD-No Current Data, *1990-2010, **2000-2010

Source: U.S. Environmental Protection Agency, "Air Quality Trends" (Jan. 2012).

U.S. Reduces CO_2 Emissions Without Mandates Through Market Driven Efficiency

Reduced emission of CO_2 is another coincidental result of highly efficient industrial processes. Still dependent on fossil fuels for 80 percent of energy consumed, the U.S. is actually reducing emissions of CO_2 more than are many countries which have imposed carbon reduction mandates. On October 2013, the EIA announced that energy-related emissions of CO_2 had decreased 3.7 percent in 2012, to the lowest level since 1994.[95]

And if carbon dioxide is considered a "dirty pollutant" instead of the "gas of life," consider the graph below, which depicts the decreasing carbon intensity of the U.S. economy since 1949. As a measure of the amount of CO_2 generated per dollar of economic output, the carbon intensity of the U.S. declined 6.5 percent in 2012.

Energy-rich, steady-state, controllable fossil fuels have made possible the increasing productive efficiency that scarce wood, as well as inherently intermittent wind or solar, cannot.

Human Benefits of Fossil Fuels

This paper has attempted to demonstrate how fossil fuels, first harnessed in the English Industrial Revolution and still supporting economic growth across the world, vastly improved the basic physical conditions of humanity and helped release whole populations from subsistence poverty. Although the developed world has enjoyed higher rates of economic growth, the most impoverished people in the developing world are significantly better off than they were in 1950. According to Goklany, "The poor in the developing world grew their consumption twice as fast as the world as a whole between 1980 and 2000. The Chinese are 10 times as rich … 28 years longer lived than they were 50 years ago. … The United Nations estimates that poverty was reduced more in the last 50 years than in the previous 500."[96]

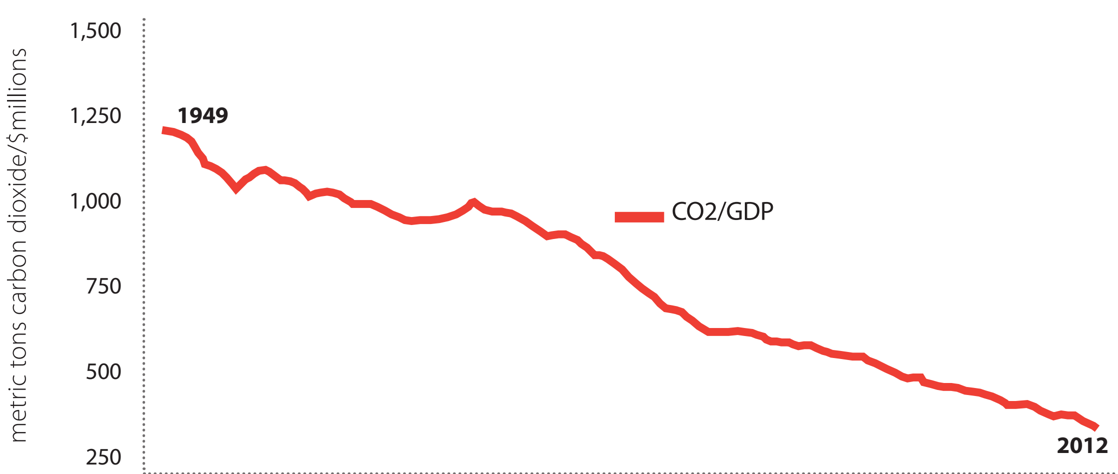
Major Improvement in Basic Indicators of Human Well-Being Across the World

Widely used indicators of living standards show the dramatic increase in life expectancy, income per capita, population, and caloric intake per person since fossil fuel supplanted woody plants as almost the sole source of energy. Figures in earlier sections of this paper chart the scale of improvements in living conditions and well-being.

To review:

- Life expectancy was 20-25 years (largely as a result of high rates of infant and childhood mortality) for most of human history.[97] During the middle of the 18th century, life expectancy in England was 35 years, much higher than in other countries. From that point, the world began to catch up. By 2009, life expectancy around the world was 69 years—and in the U.S., 79 years.

Figure 5: Carbon Intensity of the U.S. Economy, 1949-2012



Source: U.S. Energy Information Administration (Oct. 2013).

- The world's population increased from 760 million people in 1750 to 6.8 billion people in 2009. Over the same period, emissions of CO_2 as a result of fossil fuel increased from 3 million metric tons to 8.4 billion metric tons. In contrast to Malthus' and Ehrlich's predictions of mass starvation, income and nutrition improved.

- From 1961-2007, world population doubled from 3.1 billion to 6.7 billion. But modern agricultural methods using fossil fuel-based fertilizer and other energy-rich inputs achieved 2.5 more food per acre than in 1961. Higher atmospheric levels of CO_2 as a result of fossil fuel likely increased agricultural yield by more than 25 percent.

- Over the last 250 years, global income per capita has risen 11-fold from $640 to $7,300 per year. Scores of studies have shown that the major measures of the quality of human life (nutrition, income, education, lifespan, health, and that ineffable measure known as happiness) grow as income rises.[98]

Prosperity certainly does not guarantee happiness, but eliminating chronic hunger is a good start!

Less Harm from Extreme Weather

And contrary to claims of global warming alarmists from inside and outside federal agencies, the world has become less vulnerable to extreme weather events. "Despite much more complete reporting of such events and associated casualties, aggregate mortality declined by 93 percent since the 1920s," as Goklany's analyses demonstrate.[99] Global death rates from drought—formerly the leading cause of weather-related mortalities—are down 93 percent since the 1920s.[100] Goklany's extensive research on the data refutes claims that man-made climate change is now causing extreme weather with unprecedented deaths and damages.

The now more rapid and effective disaster response depends on fossil fuel-powered equipment and materials. According to Goklany: "In fact, it is inconceivable that successful and timely disaster management effort can be mounted today without diesel generators; petroleum-powered helicopters, trucks, earth-moving equipment … [and] heavy duty tents made of lightweight petroleum-derived synthetic fibers."[101]

Light

One of the greatest gifts of fossil fuels is perhaps the most assumed condition of modern life: lighting. Outdoor and indoor illumination is constantly available at our finger tips. George Gilder calls the fall in the cost of lighting "one of the most astonishing increases in wealth in the history of mankind, a million-fold increase in the abundance and affordability of light itself …"[102] In 1800, six hours of work at the average wage bought one hour of light from a tallow candle. In 2009, one-half second of work paid for an hour of illumination from a light bulb. This means the cost of light decreased to one-tenth of 1 percent the cost in England around 1800.[103]

Consider the extent to which this single factor—lighting—has contributed to education, medical procedures, safety, and ease. Yet, cheap, limitless lighting at the flip of a switch is a relatively recent and surprisingly fragile addition to living conditions.

Time

Another ineffable benefit of the abundant, affordable energy secured by fossil fuels is the gift of time. Our cars, computers, countless household appliances and machines do work that we otherwise would have to do ourselves. Not only is human muscle spared the physical exertion and drudgery. Greater freedom from compulsory work also allows individuals to choose how to spend more of their time.

Before mankind harnessed efficient fossil fuel-based energy, the bulk of all previous human populations lived in poverty. People spent nearly all their time striving to meet subsistence needs. Thanks to the energy and economic revolution starring coal, oil, and natural gas, humans have far more discretionary time. Whether that time is devoted to edifying pursuits such as education, artistic expression or charitable activities, or recreation and rest, the expansion of human freedom is a most profound benefit of the seemingly limitless supply of energy generated by fossil fuels.

The additional time has especially contributed to the wellbeing of women, whose child rearing and domestic proclivities, in the past, readily consumed all their time. "A woman's work," according to the old maxim, "is never done." Labor-saving conveniences have done more than create for women the blessing of leisure; they have allowed many women to combine professional pursuits and family responsibilities. The elderly and the disabled also have benefitted from energy-intensive technologies that give them greater independence.

No Comparable Alternatives to Fossil Fuels (For Now)

Fossil fuels remain the dominant source of energy in the U.S. and throughout the world because they remain superior to the current alternatives. Many energy policies now championed or in the early stages of implementation, however, envision a rapid transition to renewables as if all energy sources were of equal value and thus readily interchangeable. Whether based on naiveté or fact-free political rhetoric, claims made by the President and his most senior federal officials that renewable energy can supplant fossil fuels within the next decade or two are not supportable.

California intends—officially, at least—to derive 35 percent of its energy from renewable sources by 2020. The state's energy policymakers might wish to chat with a physicist or with the number crunchers at the Department of Energy. Attempts to use the power of government and billions of taxpayer-funded subsidies to force a rapid energy transition from fossil fuels to inherently inferior renewable energy risks inestimable economic damage, societal regression, and human suffering.

Vilified But Still Dominant Because Superior Energy

The animus against fossil fuels and supposed "dirty carbon pollution," however, is widespread. Policies to eliminate fossil fuels obsess the mainstream media and the cultural elite. "Decarbonizing" the world is a core issue among left-of-center policymakers. President Obama refers to oil, coal, and natural gas as the fuels of the past as he extols wind and solar as the power of the future. In his first campaign for the presidency, he promised that "the country that faced down the tyranny of fascism and communism is now called to challenge the tyranny of oil."[104] The EPA is implementing the play book of the Beyond Coal campaign in heavy-handed regulation and is keeping the Sierra Club's playbook for Beyond Natural Gas in the offing.

But, this incendiary rhetoric, now backed with government authority, has not measurably altered consumption of fossil fuels. The Energy Information Administration's (EIA) *Energy Outlook 2014* shows that the source of 82 percent of the 106 quadrillion Btu's annually consumed in the U.S. remains fossil fuel.[105] In their current *Outlook*, the EIA projects that the dominating role of fossil fuels will persist through 2040 with little change except for moderately increased use of natural gas. After aggressive deployment in the last decade, wind and solar energy accounted for less than 2 percent of energy consumption in 2012. Solar-generated electricity, so highly touted by President Obama, provided two-tenths of 1 percent (0.2%) in 2013.[106]

Reliance on Renewables: Energy Regression in Europe

After a rush to supplant fossil and later nuclear fuels with renewable energy in Germany, major media in the country report increasing energy poverty. Electricity is viewed as a luxury good for more and more German households. In 2013, the magazine *Der Spiegel* reported that 500,000-600,000 families were cut off from electricity because residents could not pay electric bills that are three times higher than average bills in the U.S.

On January 21, 2014, Germany's energy minister Sigmar Gabriel told a conference in Berlin that skyrocketing energy costs risk "dramatic deindustrialization" in Germany, one of the world's most highly industrialized countries. Germany now imports not-so-low-carbon wood pellets made in the U.S. for heating and cooking fuel. For the first time since the Industrial Revolution, energy regression and the human deprivation it causes is a policy choice in the most affluent nations of the world. The policies may not now hurt the affluent but they already hurt middle and low-income families.

Sources: "How Electricity Became a Luxury Good," *Der Spiegel* (4 Sept. 2013); Robert Bryce, "The Real Climate 'Deniers' Are the Greens," *The Wall Street Journal* (3 Feb. 2014).

After more than three decades of global warming alarmism and billions showered on renewable energy, fossils fuels remain supreme because they are preferable to consumers. Uranium may be the most energy dense and efficient fuel, but intense public resistance has long prevented widespread use of nuclear generation in the United States. Replacement of the generating capacity of the U.S. fleet of fossil-fuel fired power plants would mean building over a thousand nuclear power plants.

Energy-dense, power-dense, abundant, affordable, controllable, reliable, versatile, portable, scalable and storable: fossil fuels have far more energy advantages than *any other energy source at this point in time*. Human history is a record of endless human innovation, most of which has improved the human condition. Who knows what energy sources and technologies of the future may trump the energy benefits of fossil fuels?

Energy and Power Density

Matt Ridley notes that the secret of the Industrial Revolution was the shift from current solar power to the far more concentrated solar power stored in fossil fuels.[107] Formed by millions of years of compression and heat in the earth, fossil fuels are packed with more energy than woody plants—the product of recent photosynthesis.

Physicists define energy density simply as the quantity of energy that can be contained in a given unit of weight, volume, area or mass. The energy density of dry wood is approximately 17 megajoules per kilogram (MJ/kg). Refined petroleum has a density of 42 MJ/kg, natural gas has a density of 35 MJ/kg, and the energy density of coal is roughly 24 MJ/kg.

The higher density means that less work is involved in extraction, transport, and storage. This opens up unlimited options for conversions. The scores of technological innovations that followed Watt's steam engine powered at first by coal, then also by oil and natural gas, would not have been possible with wood-derived heat energy, no matter how large the supply of timber.

Power density is even more revealing. (See Table 4). The superior power density of fossil fuels exposes the inherent weakness of currently favored renewable energy sources from wind, solar and biomass. Energy sources with lower power density typically utilize too much material or land area to supply power at a competitive price or at the scale necessary to supply a large city or industry 24 hours a day, seven days a week.

If power is defined as the rate at which work is done, power density is defined as the rate of the energy flow that can be generated from a given unit of volume, mass or area. To understand the problem with current renewable policies, power density can be measured in Watts per square meter (Wm2).

Table 4 shows that the power density of a marginal oil or natural gas well is over 20 times higher than wind. Wind and solar require expensive inputs such as large expanse of land and long transmission lines. A good example is the Competitive Renewable Energy Zones (CREZ) in Texas. This project involves construction of the world's longest system of transmission lines dedicated to renewable energy. This recently completed project built over 3500 miles of transmission lines to connect the wind farms in the far western portion of the state to the population centers along Interstate 35, a distance at some points of more than 600 miles. The total cost is around $7 billion and will be socialized across all ratepayers under Texas law.[108]

Inputs of this magnitude, coupled with the inherent intermittency of wind and solar, may undermine the viability of huge renewable solar installations recently completed or under construction thanks to huge grants and loan guarantees from the federal government.[109]

Abundance

Less than 10 years ago, rising oil and natural gas prices, a result of soaring demand from developing giants like China and India coupled with political unrest in the Middle East, spread concern about declining global reserves. Yet within a few short years, the U.S. and global outlook reversed from increasing scarcity to rapidly increasing abundance. Developed by private-sector energy entrepreneurs in Texas, innovative technologies known as hydraulic fracturing, horizontal drilling, and seismic imaging have unlocked the massive deposits of oil and natural gas in shale rock. Al-

Table 4: Power Density in Watts per square meter (W/m2)

Corn Ethanol	0.05 W/m2
Wind	1.2 W/m2
Solar Photovoltaic	6.7 W/m2
Natural Gas Well	28 W/m2 (f marginal well producing 60,000cf/day)
Oil Well	27 W/m2 (f marginal well 10 barrels per day
Nuclear Power	56W/m2 (2,700 MW)

Source: Robert Bryce, "The Real Problem with Renewables," *Forbes* (11 May 2010).

though U.S. production now dominates increasing supply of oil and natural gas from shale formations, the same geology occurs throughout the world.

In 2007, the U.S. imported almost 60 percent of the petroleum it needed. Higher domestic production has now dramatically reduced imports and increased exports of petroleum products. The EIA reported in February of 2014, U.S. imports of foreign oil declined from 60 percent in 2005 to less than 40 percent in 2012.[110] Crude oil imports fell 9 percent in 2013, while exports of petroleum products rose by 11 percent.[111] Domestic oil production continues to increase so rapidly that the percentage of oil imports is declining faster than EIA can meaningfully estimate.*

Natural gas has experienced a similar explosion in supply. In 2007, conventional wisdom held that natural gas supply in the U.S. would continue to dwindle.[112] Import terminals were planned for construction on all the U.S. coasts. Through fracking, natural gas production has soared.[113] Those import terminals are now being retrofitted for exports of natural gas. And the U.S. has now passed Russia as the world's largest natural gas producer. (China actually has the world's biggest reserves of shale gas but is now in the early stages of production.)

The world's current supply of hydrocarbons from oil and natural gas can meet demand on the basis of current technology for several centuries.

Don't be misled by some of the metrics used to quantify the global or domestic energy supply. The Department of Energy's most recent estimate of "proved reserves" in the U.S. is only 25.2 billion barrels of oil.[114] EIA defines "proven reserves" as known oil resources producible with government consent using current technology and commercial terms.[115] This number includes neither the vast store of oil now produced from shale nor other unconventional resources, access to which is blocked by the government prohibition. When "technically recoverable resources" are added to the proven reserves, the U.S. supply increases to the equivalent of 2.2 trillion barrels. The total exceeds 2.5 trillion when all resources are considered.[116] No one really knows how much oil, natural gas or coal under the earth is producible. The recent shale revolution justifies an extremely optimistic outlook.

The world is also blessed with abundant coal: of which the U.S.—known as the Saudi Arabia of coal—has the largest reserves. The U.S. has 261 billion tons of coal in proved reserves. In the lower 48 states, the U.S. has 486 billion tons of coal in the demonstrated reserve base. This is enough coal to continue current rates of consumption for 485 years.[117]

Affordability

Perhaps the best measure of the affordability of fossil fuels is the vast volumes of energy consumed by all income groups in the U.S. and other prosperous countries. Gasoline prices, though considerably higher than 10 years ago, are tolerable for all but the lowest income households. Overall energy prices are rising in the U.S., in part as a result of the high costs of the EPA's aggressive regulation. In 2012, median income families spent 21 percent of their average after-tax income on energy, a slightly higher portion of income than spent on food.[118]

* The International Energy Agency based in Paris predicts the U.S. will surpass Russia and Saudi Arabia as the world's largest producer of oil by 2015.

Countries which have aggressively supplanted fossil fuels with renewables in the last 10 years or less have incurred steep increase in energy prices. Germany, Spain, Denmark, and Great Britain offer examples. Germany's residential electric rates are three times the average U.S. retail rate. Earlier sections of this paper have drawn attention to the startling rise of energy poverty and the risk of rapid deindustrialization in Germany.

Reliable and Controllable (Dispatchable)

In contrast to renewable energy resources from wind, solar, and biomass, man can control access to and conversion of the energy held in fossil fuels. No machine or person can control when the wind blows or at what velocity. No one can control how much of the radiant heat of the sun will hit the earth on a given day or hour. Annual weather and the growing cycle control the timing and quality of harvest of renewable biomass like corn for ethanol.

The inherent intermittency of wind and solar is a major step backward for electricity-dependent societies. Not only does weather constantly shift from cloudy to clear days. The solar maximum period—needed for photo voltaic (PV) generation—is only from 9am to 3pm.

Wind conditions not only follow seasonal shifts. Wind speeds also can change in an instant. Wind speeds too high or too low preclude generation. The over 12,000 MW of installed wind capacity in Texas generates the most electricity when Texas least needs it. West Texas, where most of the wind farms were built, has little wind during the long, hot summer—the period of peak electric demand for the state.

Wind and solar are what operators of electric grids call non-dispatchable technologies. Since electric load on the grid must be continuously balanced or the grid will go into a tail spin, generating units whose output can be varied to meet fluctuating demand in real time are what provide constant reliability to modern systems of electric generation and transmission. Being non-dispatchable, electric generation from solar and wind technologies can never provide reliability. In contrast, coal and natural gas fired (and to a certain extent, nuclear) electric generation can reliably meet peak demand and can be controlled to follow variations in demand in real time.

The intermittency of wind and solar also makes it wastefully parasitic on generation provided by fossil fuels. Because wind and solar electric output can change in an instant, a back-up generating source is needed. Natural gas-based generation is particularly suited for this role. When a wind or solar facility is actually generating electricity, a natural gas plant, in an operational mode called "spinning reserves," may be idling so that it can rapidly ramp up to give the grid stability. This is one reason for the much higher cost of renewable energy. Mandates that 20 to 50 percent of electricity must be from renewable sources are fraught with peril and pull society backward toward the preindustrial era.

Technology has yet to invent a suitable battery for wind and solar power to store and later use the power generated by wind and sunshine. Effort to do so has been underway for years. But would not recharging such a massive battery consume the lion's share of the electricity generated by solar in the first place?

Table 5: Capacity Factor
(EIA *Energy Outlook 2013*)

Wind	30-35%
Wind Offshore	37%
Solar PV	25%
Solar Thermal	20%
Advanced Coal	85%
Natural Gas	87%
Advanced Nuclear	90%

Source: Robert Bryce, "The Real Problem with Renewables."

Advocates of renewable energy stack the deck. The typical boasts that a certain wind farm will provide electricity for, as an example, 250,000 households are misleading. Those high numbers served are invariably based on the "installed capacity." Installed or nameplate capacity refers to the maximum amount of generation of which the facility is capable of operating continuously over a certain period of time —usually a year. The most important factor about renewable generation is the "capacity factor" understood as the amount of electricity *actually generated* in a year. The difference between installed capacity and capacity factor for wind and solar is glaring.

Capacity factor reveals the far higher costs of renewable electric power and the folly of the massive subsidies accorded these projects. (See Table 5). Consider this simple math applied to the Ivanpah solar thermal facility recently completed in the Mojave Desert.

Ivanpah is the largest thermal solar generating complex in the world. The $2.2 billion cost of Ivanpah was eased with a federal loan guarantee and likely a federal grant for 30 percent of the cost of construction—more than $600 million from U.S. taxpayers. The plants installed capacity of 377 MW shrinks to 75.4 MW of actual generation when the capacity factor for solar thermal (20%) is applied. The claimed 140,000 homes to be powered by Ivanpah shrink to 28,000 homes.[119]

Versatility

Much of this paper has attempted to point out the versatility of fossil fuels. In addition to providing the energy source for transportation and electric generation, fossil fuels have vastly expanded the world's food supply, material goods and services.

Fertilizer derived from energy-dense natural gas stoked the natural photosynthetic process and immensely increased agricultural productivity. The list of products derived from petroleum appears endless. What was once refuse material left after the refining process has become the feedstock for plastic, synthetic fiber and industrial chemicals vital to modern medicine, hundreds of industrial processes and consumer products.

The modern use of energy from the wind and sun is limited to generating electricity. What alternative to fossil fuels could replace 60 percent of all fibers, 48 percent of the world's food supply and all plastics?

Portable and Scalable

Fossil fuels are relatively easy to move around. Over a century, the U.S. has developed an elaborate distribution system for transporting oil, natural gas and coal. Whether through pipelines, transmission lines, rail or truck, these fuels or the power they generate can be moved to where they are in demand. Wind and solar are fixed in one place, typically occupying a large tract of property and usually at a significant distance from demand. Transmission of the electricity generated by renewables usually involves long lines connecting generation at a great distance to end user. This is not only a significant additional cost but also inefficient. Line loss over distance can eliminate 10 percent or more of the original generation.

One of fossil fuels' most beneficial attributes is the capacity to expand and increase to meet demand on a vast scale. Indeed, cost declines and efficiency rises when fossil fuels are deployed on a larger scale. Renewables lack this elasticity and efficiency because of their intermittency. Wind- and solar-generated power has never been used at scale.

The massive solar facility in the Mohave Desert plans to achieve generation on a scale that could power Los Angeles. Time will tell. Simple math and physics, and the experience of Germany, do not bode well for "Big Solar" projects like Ivanpah. Much smaller scale applications of wind and particularly solar, for residential or commercial use, is a more likely niche for renewables.

Conclusion

"Notwithstanding their flaws," Indur Goklany writes, "the fossil fuel-dependent technologies that stretched living nature's productivity and displaced some of its products not only permitted humanity to escape the Malthusian vice but saved nature itself from being overwhelmed by humanity's demands."[120]

This paper has aimed to identify rarely acknowledged but profound historical facts about the role of energy in human history and the extent to which fossil fuel derived energy has improved human well-being across the world. As a necessary condition of the Industrial Revolution, the vast store of concentrated energy in fossil fuels unleashed sustained productivity and economic growth which in turn led to monumental improvements in human living conditions as measured by life expectancy, income per capita, caloric intake, clothing, shelter and fuels. And the greatest beneficiaries of this energy revolution known as the Industrial Revolution were average workers and the most impoverished. Increasing emission of man-made CO_2 is tightly correlated with this monumental achievement.

Yet, senior leaders of the most highly developed nations and the non-governmental organizations (NGO) surrounding the United Nations Environmental Program (UNEP) decry the CO_2 emissions associated with fossil fuels as pollution so dangerous that it will overpower the physical dynamics of earth's climate system. CO_2, the gas that makes life possible on the earth and naturally fertilizes plant growth, is now characterized by U.S. Secretary of State John Kerry as "the most fearsome of weapons of mass destruction."[121] After 40 years of such vilification, fossil fuels still dominate 80-85 percent of the world's energy use because—at this point in time—these fuels are superior on many levels to the current alternatives.

Predictions of catastrophic man-made global warming have gained global political traction over the last 25 years and recently have become shriller as evidence for dangerous warming weakens. The climate science developed through the United Nation's Inter-Governmental Panel on Climate Change (IPCC) concludes that global emissions of CO_2 must be reduced by at least 85 percent "to prevent dangerous interference with the climate system."[122] This policy finding is tantamount to elimination of fossil fuel use without energy alternatives fully comparable or superior to fossil fuels.

Mandates to force an abrupt energy transition from fossil fuels to renewable sources are naïve and fraught with peril for highly industrialized economies. As this paper detailed, energy sources are not necessarily interchangeable. In energy density, abundance, reliability, versatility, and other advantages, fossil fuels are far superior to wind, solar, and biomass.

Evidence of the damage rapidly following a government-forced transition to renewable energy emerges in Germany, one of the most highly industrialized countries in the world. German officials sound the alarms of "dramatic deindustrialization" while the media reports that hundreds of thousands of German homes now are without electricity because the cost is unaffordable.[123] Likewise, Britain—the cradle of the Industrial Revolution—recently announced that one in four households live in energy poverty. The *Daily Mail* warns of the risk of 24,000 deaths of the elderly this winter who cannot afford to heat their homes.[124] That such a regression from modern living standards could occur so rapidly in these highly developed countries is a stunning turn of events that U.S. policymakers would be wise to absorb.

Relying on the vast store of dense, versatile energy in fossil fuels, the economic growth begun in the Industrial Revolution still offers the promise of an end to abject poverty. Policies which could undermine a necessary condition of mankind's greatest energy advance, surely, must rest on the most robust scientific justification. The IPCC science, however, founded on assumptions and speculative models, is increasingly contradicted by empirical evidence and thus remains unsettled. The growing doubt about catastrophic global warming was recently voiced in *The Economist*, formerly a staunch believer in man-made climate change: "If climate scientists were credit rating agencies, climate sensitivity [to increased CO_2] would now be on negative watch."[125]

IPCC science claims of 95 percent certainty that human activity is causing climate calamity are more like the dogmatic claims of ideologues and clerics than scientific conclusions. The IPCC's claim of certainty is made as if a measured statistical confidence level—a metric used throughout the IPCC science. This claim of 95 percent confidence however is pulled from thin air without any statistical analysis. Doctrinaire assertions of certainty have no place within the genuine scientific method. The IPCC science is a hypothesis whose accuracy, like all theories, must be corroborated by the evidence of measured observation.

Increasing evidence about solar activity, natural variability, sea levels, Antarctic sea ice and extreme weather weakens the credibility of the IPCC's key assumption that man-made CO_2 emissions dominate the natural dynamics of the earth's climate. The 16-year lull in warming temperatures indicates that increasing CO_2 may not be dominating the climate to the extent that the IPCC assumes. Research on the natural climatic forces such as the sun is generally marginalized throughout three decades of IPCC science. Although 99.98 percent of the energy in the earth's atmospheric system derives from the sun, solar activity plays almost no role in current climate modeling comprising the core of the IPCC science. This is not the quality of science that could justify supplanting the energy wellsprings of mankind's greatest advance!

Robust, empirical scientific research on the natural forces and natural variability of climate needs to be conducted before the industrialized nations of the world prematurely force an abrupt switch from fossil fuels to inferior energy resources. Research on the role of increased concentrations of man-made CO_2 should also continue but outside the highly politicized IPCC and the United Nations.

This paper has attempted to identify the many profound human benefits made possible by the rich energy stored in this ancient nature known as fossil fuels. Although first harnessed not much more than 200 years ago, the energy riches on which economic growth and contemporary lifestyles now depend were not fully accessible until after World War II. Without ever living in an energy scarce world, the living generations of prosperous countries assume a massive, affordable supply of energy at their fingertips.

Energy policy sits at a crossroads. Will living generations eschew high energy use made possible by fossil fuels to lower a risk of theoretically predicted global warming? Would voters choose an energy regression to less productive, efficient, comfortable, and healthy living standards? Multiple polls say no way! For the wealthy elites who make policy decisions—"the ruling class," it appears to be another story.

The vast human improvements flowing from the Industrial Revolution are still occurring in market driven economies under limited governments which uphold property rights and contractual obligation. Why would societies suppress fossil fuels—a necessary condition of the increasing efficiency inherent in productive economies and continually improved living standards? As Thomas Macaulay commented in the early days of Industrial Revolution, "On what principle is it that, when we see nothing but improvement behind us, we are to expect nothing but deterioration before us."[126]

Matt Ridley says it best. "Non-renewable resources such as coal [natural gas and oil] are sufficiently abundant to allow an expansion of both economic activity and population to the point where they can generate sustainable wealth for all the people of the planet without hitting a Malthusian ceiling, and can then hand the baton to some other form of energy. The blinding brightness of this realization still amazes me: we can build a civilization in which everybody lives like the Sun King, because everybody is served by (and serves) a thousand servants, each of whose service is amplified by extraordinary amounts of inanimate energy."[127]

Appendix

Table 1A: Energy Consumption in England and Wales(1561-70) Compared with Italy (1861-70)

Annual energy consumption per head of population (megajoules)

	Human	Draught Animals	Firewood	Wind	Water	Fossil Fuels	Total
England and Wales 1561-70	4,373	6,210	6,324	59	162	2,039	19,167
Italy 1861-70	3,832	3,053	8,894	46	127	1,206	17,158
Percentage distribution							
England and Wales 1561-70	22.8	32.4	33.0	0.3	0.8	10.6	100.0
Italy 1861-70	22.3	17.8	51.8	0.3	0.7	7.0	100.0

Note: Because of the effects of rounding, the constituent percentages do not always sum to 100 exactly.
Sources: Malanima, *Energy Consumption in Italy*, app. 1, tabs. 2 and 3, pp. 96-101; Warde, *Energy Consumption in England and Wales*, app. 1, tabs. 2 and 3, pp. 123-36.

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Prior to joining the Foundation, White served a six-year term as Chairman and Commissioner of the Texas Commission on Environmental Quality (TCEQ). With regulatory jurisdiction over air quality, water quality, water rights & utilities, storage and disposal of waste, TCEQ's staff of 3,000, annual budget of over $600 million, and 16 regional offices make it the second largest environmental regulatory agency in the world after the U.S. Environmental Protection Agency.

Prior to Governor Rick Perry's appointment of White to the TCEQ in 2001, she served as then Governor George Bush appointee to the Texas Water Development Board where she sat until appointed to TCEQ. She also served on the Texas Economic Development Commission and the Environmental Flows Study Commission. She recently completed her term as an officer and director of the Lower Colorado River Authority. White now sits on the editorial board of the *Journal of Regulatory Science*, the Texas Emission Reduction Advisory Board, and the Texas Water Foundation. Her writing has appeared in numerous publications including *National Review, Investors' Business Daily, Washington Examiner, Forbes, Daily Caller, The Hill*, and major Texas newspapers. She most recently testified before the U.S. Senate Environment and Public Works Committee.

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