Defense and Civilian Energy Systems:

Security, Sustainability and Survivability Considerations for the 21st Century

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis; however, it has been edited by an external reader. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

The United States and NATO Allies have a national security problem that is the product of America being the home of inexpensive and plentiful modern energy. A century of cheap and plentiful domestic supplies of oil has resulted in the architecture of civilian and military systems that are premised on the continued availability of cheap, high gradient conventional energy. As the pre-eminent military power of the last century, America ensured that access to secure "rear" areas, bases and supply lines can be relied on – at least until recently. With the increasing prevalence of asymmetric warfare conducted primarily with non-state actors and the loss of America's monopoly on precision munitions (PGMs), or in the event of conflict with peer competitor states, security of supply lines, staging and rear areas can no longer be taken for granted. For expeditionary forces, supply of conventional liquid fuels represents a sizable amount of tonnage required to transport combat units to battle and conduct operations. Supplies are primarily conveyed by inherently vulnerable platforms like tankers and stockpiled in difficult to harden warehouses or dumps. While there is no shortage of petroleum or conventional fossil energy worldwide, the sheer volume of fuel presently needed to conduct modern expeditionary military operations itself creates vulnerabilities. The DoD and individual services have in place long-term programs to reduce the energy intensity with valuable lessons for NATO allies as most military systems and doctrine are patterned after DoD architectures. Transfer of techniques for reducing energy intensity from defense to the civilian sector has spinoff benefits overall; for example, by making operations in remote locations such as the Arctic / Antarctic more affordable and practical, and enabling a more energy / resource efficient civilian economy. Benefits from reduction of energy use include the reduction of signatures from energy use that are expensive and difficult to mask or hide, potentially reducing vulnerabilities in both the military and civilian infrastructure.

Despite these benefits, legacy systems architectures in both defense and civilian limit energy efficiency gains. Technological advances of the past century have enabled many functions such as HVAC and lighting to be met with low gradient, low density and intermittent energy if systems are re-architectured. New designs, if standardized and rolled out quickly, offer the potential to benefit from making use of renewables like solar, wind, micro-hydro, or to use conventional high gradient energy more efficiently in combined cycle systems that often can be locally sourced even for remote forward operating bases. Low gradient energy systems, by their nature, present a smaller emissions signature issue. US-DoD has an opportunity to drive the development of the implementation of these high efficiency technologies and institutions and accelerate their spread to the civilian economy.

This thesis presents a vision of a technically, politically, economically and logistically viable pathway to a cleaner and more sustainable alternative to current dominant energy systems architecture and provides a roadmap to implementation.

Acknowledgements

"Nothing is written."

Attributed to T. E. Lawrence, played by Peter O'Toole, Lawrence of Arabia

"We are never going to move forward unless we are willing to forget. The success of the Millennium depends on how much we are allowed to forget compared to how much we are incited to remember."

- Peter Ustinov

"And if anybody today thinks that the exhilarating early days of the CORONA program were not also nerve-wracking, frustrating, and occasionally heartbreaking, imagine the persistence it took to endure 12 successive launch failures. What could go wrong did. One launch was aborted when a humidity sensor reported 100 percent. Inspection revealed that a member of the crew, four mice, had relieved itself on the sensor. That was one of the first leaks to plague the NRO."

- George J. Tenet
  NRO 40th Anniversary Gala

"May God go with you. And I don't envy God."

Attributed to William Ewart Gladstone, played by Ralph Richardson, Khartoum

"I leave nothing but your name."

Prophet Mohammad (Sahih Bukhari, vol. 7, hadith no. 155)

Table of Contents

List of Figures

Chapter 1

More Missions, Sustainability & Survivability for Less

"Necessity Hath No Law"
- Oliver Cromwell

The military as an institution is uniquely capable of sweeping reform in the face of necessity. There is, however, no pressing need for change when the United States remains the sole superpower and is unlikely to be legitimately challenged by any other regime or existential threat in the first half of the 21st Century. Existing conventional and Weapons of Mass Destruction (WMD) systems are superior to anything that can be potentially fielded by an adversary for the foreseeable future. Energy needed to operate these systems is derived from natural resources, such petroleum, natural gas or minerals, which are widely available at modest prices on the world market. Critically, America is on the path to total energy self-sufficiency, and, within a decade, will likely become a net exporter of petroleum and shale gas. Thus, at least on the domestic sphere, there is no obvious necessity to alter national energy strategies in either the civilian or military sector. The only current motivators are handling climate change and the anticipated decline in the defense budget in the aftermath of the post 2008 fiscal environment.[1]

Policies to mitigate and adapt to climate change is a priority for the US-Department of Defense (DoD). President Obama signed Executive Order (EO) 13514 on Oct. 5, 2009 that now requires all US Federal Agencies to conserve resources, improve sustainability, reduce greenhouse gas emissions (GHG), and produce annual reports documenting their progress. Typically exempted from environmental regulations, the DoD was for the first time included in the EO, which directly complements its longstanding interest at DoD in improving energy security and improving cost effectiveness. As the largest single consumer of energy in the United States, the DoD's contribution to increasing energy efficiency and reducing greenhouse gas (GHG) emissions is critical to the overall national effort. The question is whether there are sufficient mission, survivability and / or sustainment-enhancing motivators to ensure energy conservation[2] and efficiency should become a major priority at the DoD.

The issue of energy efficiency and conservation goes to the heart of DoD's ability to perform its missions at a time of shrinking budgets and rising costs. Improvements in efficiency directly translate into a simpler logistical “tail”, the vast and integrated infrastructure that supplies the “teeth” of the military, from weaponry and machinery acquisition and development, to transportation and planning support --- these services require complex supply chain management to ensure material readiness. Simplifying the supply chain reduces both energy and cost expenditures, increasing resources over the longer term, improving both flexibility and responsiveness to meeting mission requirements. These are clear benefits to the DoD, whether “on base”, such as search and rescue, or in expeditionary warfare.

The true beneficiary of energy reform may be in the area of improving survivability. Reduction in energy consumption, specifically through implementation of more efficient systems that make better use of exergy, directly contributes to survivability by reducing detectable electromagnetic and other signatures emitted by energy producing, consuming and transmission systems. Benefits are achieved indirectly by reducing the logistical tail. How is energy efficiency linked to stealthiness and, ultimately, our survivability?

During the late 20th Century, the United States enjoyed a virtual monopoly on precision-guided munitions (PGMs) that enabled missions to be accomplished with a fraction of the resources previously required. Key to precision targeting is the ability to detect and identify signatures unique to the targets using sensors, then process, interpret and act on the data. Initially, such capabilities were monopolized by the US, but over time, the capability became widespread. A key reason is the changeover to using civilian rather than military specification electronic parts for many systems. When the Pentagon switched to using Commercial Off-The-Shelf (COTS) based systems, particularly in electronics, it was able to take advantage of the latest innovations in computing and commercial systems. The “Perry Memo”[3] written by Defense Secretary William Perry in 1994 directed the DoD to purchase COTS components and systems and to adopt commercial specifications and practices whenever possible. This was formally incorporated into law in the Federal Acquisition Streamlining Act (FASA, 1994), and in the Clinger-Cohen Act (CCA, 1996) and elaborated on in Federal acquisition statues, regulations and directives.[4] As a result of the wholesale switch to COTS, the DoD cut back on its historical role of fostering technological advances in the civilian economy via the “spinoff” model.[5]

The use of COTS initially enabled a major jump in capabilities while lowering costs; however, over time, as the DoD gained experience with COTS, it became clear it would have to be more cautious and nuanced in terms of the use of civilian technologies. Notably, Gansler and Lucyshyn (2008) observed that the

DoD now has little impact on COTS development and COTS vendors who make decisions based on the need to remain competitive in fast paced and volatile markets, resulting in rapid shifts in availability and obsolescence of components, which cripples development of long-lived systems. Moreover, many commercial components are not engineered to meet security and environmental requirements; for example, methods to improve stealth through temperature reduction (removing the heat signature targeted by PGMs) is often achieved by adding a COTS cooling-unit, which expends more energy, rather than reducing the heat expenditure, and ultimately the wasted energy, of the existing technology. In addition, the commercial software expertise required to build code now resides outside the DoD. COTS often result in the DoD using proprietary architectures and standards, which results in long-term costs. Despite these problems, generally, COTS have more positives than negatives, in particular, in enabling rapid rate of technological change and reduction in costs as it is spread over a larger customer base.[6]

Over time, COTS have fundamentally changed the lay of the land in weapons systems. Using COTS parts as the building blocks of military systems has enabled "open innovation" to a wide range of basic technologies to any technically capable power. COTS have enabled PGMs to be developed and fielded by any competent middle power, and often superior systems to be fielded by peer competitors. Indeed, the use of Improvised Explosive Devices (IEDs) in Iraq and Afghanistan foreshadows how far and fast sophisticated capabilities based on consumer grade technologies have spread and how such rudimentary systems can pose a major threat to major militaries.[7] The widespread availability of PGMs mean that a modern military can no longer be assured of secure staging areas and supply lines in the "tail" from conventional, let alone nuclear threats. High tech sensors and sophisticated guidance and homing systems can now be built out of and to target COTS parts. When guerilla forces have the capability to disrupt supply lines and depots, a modern peer competitor will no doubt recognize that disruption of supply lines is the best way to defeat an expeditionary force. Stillion and Perdue's 2008 study outlined how power projection on the present model requires secure bases and seas.[8] Competition in the age of intelligent machines has shifted to this vulnerable area. Adversaries that cannot count of defeating the conventionally armed American "teeth" recognize that the "tail" is its greatest limitation. Thus, we bring the debate full circle to the weakest part of the system is in fact, the soft sided supply lines and "rear" areas.

COTS-based systems have dramatically increased homeland vulnerability since the 1990s. Whereas nuclear war was regarded as a major risk and the ability to survive some effects of nuclear war a major consideration in pre-COTS revolution weapons systems, with the advent of COTS, at least in electronic components, wholesale substitution of electronic parts with COTS semiconductor devices, particularly the widespread use of MOS / CMOS devices in integrated circuits, resulted in a tradeoff against sensitivity to known nuclear war effects such as Electromagnetic Pulse (EMP) and radiation. This tradeoff was seen as a very good bargain in the 1990s when the risk of an all out nuclear war was remote after the collapse of the Soviet Union in 1989. Substitution of COTS parts, and ultimately, the use of civilian microelectronics allowed defense systems to enjoy the steady progress documented by Moore's law.[9] However, as systems became more sophisticated and ran what became highly sophisticated software suites, the overall energy consumption, particularly in electricity to run modern battlefield electronics grew exponentially. COTS quickly became the only way that such large, sophisticated software suites could be run, and COTS components, particularly CMOS, became dominant in most systems. While it is possible to improve the survivability of metal semiconductor IC technologies, it is fundamentally difficult to harden them against EMP and radiation – in the case of a nuclear, or even smaller scale, attack many defense-critical systems would be rendered inoperable. To wit, Japan is recognized as a world leader in robotics, but yet could not field a single radiation-hardened robot following the Fukushima disaster and had to secure them from France and other nuclear powers. While this state of vulnerability was acceptable at the turn of the 20th Century, it is unacceptable in the current political climate.

The first decade of the 21st Century saw the expansion of nuclear weapons states beyond the original "club" of US, UK, France, Soviet Union (Russia), and China; the world is upon what is termed a "Second Nuclear Age" by Professor Paul Bracken.[10] New nuclear weapons states, including India, Pakistan, Israel, North Korea, and soon, Iran, are not likely to give up their nuclear weapons. In a multi-polar world of nuclear powers, it is unlikely that the dynamic that avoided war between the US and USSR will be so readily duplicated. The risk of nuclear war is real, and increasing over time. What are the ramifications for a modern industrial society? Technical limitations to shielding modern microelectronics mean that only the most critical systems can be successfully shielded against reasonably foreseeable nuclear war effects, and even then, it is by means of replacement of non-functional components with spares stored in shielded warehouses. At the same time, recent introduction of conventionally pumped electromagnetic pulse weapons means that localized disruption effects can be accomplished without crossing the nuclear threshold. Finally, apart from direct military threats, our current systems are vulnerable to geomagnetic storms, as seen in the 1989 corona mass ejection event that caused the collapse of the Hydro Quebec grid. The world has been fortunate that we have not had similar and larger events since the beginning of the modern electronic age in the 1960s. All of these are issues that drive increasing concerns about the vulnerability and fragility of existing systems and their heavy reliance on assured supplies of large quantities of modern energy to function.

The vulnerability of defense energy systems goes beyond just COTS electronics and the need for secure supply lines and bases. The assumption that the United States and Canada can provide a rear-end safe haven is no longer realistic if conflict broke out with a conventionally armed, let alone nuclear armed middle power. Geographical barriers, such as oceans, mountains, and Arctic expanses, which formerly limited conflict between North America and other powers are now bridgeable not just by a missile equipped superpower like the Soviet Union, but by any capable middle power with or without nuclear weapons. In other words, the civilian industrial base that supplies the forces is now no less vulnerable than the homelands of Germany and Japan during World War II. Despite these changes, there is little consideration to the issues of reducing, hardening or increasing the resilience of civilian infrastructure in North America.[11] Civilian systems, rather than becoming more resilient and hardened over time, have in past decades, gone in the other direction, becoming more reliant on modern electronics and in the process more fragile.

Vulnerability of North American civilian infrastructure arises from several major factors. First, with the exception of select infrastructures, most civilian installations are designed based on the premise that a major disruption (whether natural or man made) will never come, and if there is a disruption, it will be limited in duration and easily contained. Second, these installations are premised on North America being able to plug into a worldwide network of suppliers, making it unnecessary to maintain strategic stockpiles, with exception of a very select list of items (e.g. Petroleum reserves, etc.). Third, the greatest vulnerability comes from a long and well-entrenched history of low cost and abundant natural resources. North America enjoys a rich endowment of domestic natural resources, such as clean, potable water (in most areas), that are sold on an intensely competitive global market, resulting in extremely low prices for most commodities. What are the ramifications of this seemingly fortunate history?

Historically, low prices for commodities, including energy, have meant that North America, and the US in particular, have incurred enormous economic benefits from low cost resource extraction facilitated by rapid industrialization. Unlike most other jurisdictions, in which the resource belongs to the state, the US has given property owners ownership of the resources on their land, making it simple to exploit the commodity market. Plentiful resources, however, had a perverse effect. As the presumption of unlimited, modestly priced resources was implicitly or explicitly assumed by architects of new systems, these norms become engineered into the systems. Once engineered in and standardized, it is extremely difficult to make changes without explicit and compelling reasons.[12] In the case of the defense energy systems, often it is architectured with little consideration given to the true cost of sustainment at the point of final consumption.

Thus, a gallon of fuel has, until very recently, been treated by Defense logistics as a commodity that is acquired at market price in a secure base or staging area. Logisticians are only now calculating the actual "delivered" cost of fuel and supplies required for sustaining a force in a remote area. It is quickly becoming clear that the delivered cost is in fact far above the "market price" even before the cost of enemy action is taken into account. Now, while these economics apply to DoD, what about the civilian sector?

In theory, the DoD is free to adopt different practices and standards from the civilian economy, and generally will do so for weapons systems and specialized expeditionary equipment. But in practice, the DoD, like any government agency, is driven by bureaucratic rules of procurement that while allowing wide latitudes for unique government specifications, in practice, "go with the flow" and adopt many de facto civilian standards. For example, with exception of hardened facilities, there are no special standards for basic infrastructure components like lighting, plumbing, and electrical systems, for much of base operations. The DoD, with its unique capabilities to understand costs and with its critical mass, can play a leading role in change.

The DoD has historically played a leading role in many technical advances that revolutionized the American economy. The innovations fostered by DARPA (Defense Advanced Projects Agency), such as the internet, are probably the best known. But what about advances in the area of energy? Because America is the home of the modern petroleum industry, secure domestic energy supplies that are safe from distant enemies has always presumed and remains firmly embedded in the American consciousness. Twice in the 20th Century, the US went to world wars without having to be seriously concerned with the supply (as distinct from transport) of petroleum-based energy for its expeditionary forces. The only other power that shared a similar set of circumstances was the Soviet Union. The Axis powers in World War

II had to constantly plan their war around the availability of fuel and logistics. America's plentiful domestic energy supplies beget lackadaisical attitudes toward energy security.

American defense strategy only became concerned with the supply of oil as American oil production peaked and the US became a net oil importer in the 1970s.[13] This has, in turn, resulted in decades of military involvement in the Middle East that included at least two major wars and the diversion of American interests to maintaining stability in a volatile area with vital suppliers. What's more, the dependence on imported oil fueled booms in Mexico, Venezuela, and Nigeria, each creating unique security challenges for the US in these regions.

Up until the early-mid 2000s, it was presumed by many analysts that America was passé as an oil producer, and that increasing dependence on imported energy was all but certain over the longer term. This all changed, first, with the shale gas explosion, then followed by the shale oil revolution that saw American oil and gas production reverse its trends, placing the US squarely on the path to becoming a net Oil and Gas exporter by about 2020. In other words, there is no longer a compelling economic case for the US to materially alter its present mineral resource-based energy system - except to address GHG reduction and the military and national security issues discussed above.

On the other hand, there is a compelling case that can be made that natural resources, and energy commodities in particular, are grossly underpriced by the current economic and political regime. The underpricing of resources is a direct function of what economists will term "perfect competition"[14], which is appropriate for civilian needs, but problematic when national security is considered. This thesis will examine the historical reasons why current energy markets are structured as they are, how we got to where we are today, and what the issues are with respect to transitioning to a structure that can simultaneously reduce energy intensity, cut greenhouse gas emissions, and achieve improvements in security goals at the same time. It is important to reiterate that there is no economic reason for the civilian energy sector to make such a transition. In fact, relatively minor changes to the extant system (e.g. improving fuel economy of the US car and truck fleet, replacement of thermal coal power generation with natural gas, selective use of carbon capture and sequestration, etc.) would probably be sufficient to meet national GHG emission goals. However, there are compelling national security and defense rationales for taking up this challenge from a military perspective. Chapter 2 addresses the dimensions of the issues from a number of analytical perspectives, showing how institutions matter, and how broad-sweeping technological and policy transitions are intimately constrained by existing institutional arrangements. Chapter 3 addresses issues inherent to the dominant commodity-based high gradient energy infrastructure and the challenges it poses to change. Chapter 4 examines how new institutional arrangements can alter, for the better, the current high gradient commodity-based energy infrastructure. Chapter 5 applies these ideas in select areas that demonstrate the potential gains we can achieve from institutional change. Chapter 6 concludes by tying together the issues and relating them to how and why the DoD must be a driver in this process.

Chapter 2

The World As It Is

Modern militaries run primarily on liquid hydrocarbon fuels, or rely almost exclusively on traditional stationary sources of grid power, such as hydro, coal, natural gas, and nuclear generated power. In peacetime, the defense energy system complements the civilian energy system. While defense establishments may maintain their own separate generation and distribution systems and have the ability to activate dedicated capabilities to supply needs "in theater", the basic source of fuel relies on the same mineral deposits, refineries, and distribution and storage systems as the civilian sector. Thus, it can be said that vulnerabilities encompass not just the "teeth", but the entire "tail" as well once it is acknowledged that an adversary can strike at the "rear". Thus, technical and strategic challenges experienced in the civilian sector are also key challenges for defense; this is particularly true in the 21st century as more and more regimes attain the ability to strike at the supply chain.

The supply chain for modern energy systems that primarily[15] rely on "fossil" [16] fuels is one of the greatest achievements of industrialization. Around the world, present "fossil" fuel-based energy systems accounted for 81% of primary energy production in 2010[17]. On a daily basis, modern energy systems provide food, enable transportation and comfort, and fuel industry and commerce at a modest and affordable cost worldwide.[18] However, the system's reliance on "fossil" fuels is responsible for more than 90% of Carbon Dioxide (CO_2) emissions around the world.[19] Thus, limiting and reducing CO_2 emissions central to the problem of addressing Greenhouse Gas (GHG) emissions and climate change go hand in hand with reduction in the use of "fossil" fuels in net carbon emission cycles.[20] Despite concerted international action that resulted in the United Nations Framework Convention on Climate Change (UNFCCC) signed in 1992 and subsequent agreements like the Kyoto Protocol (1997), it is generally recognized that as of 2013, the world is not on track to halt the growth of CO_2 emissions, let alone reduce them.[21] While emissions have been slowed somewhat after the global slump in 2008, formulations by economists, such as the Kaya Identity[22], have closely linked GHG emissions with economic and population growth, suggesting that any progress made will soon be lost as the world economy recovers. Put together, the ongoing economic slump experienced in the European Union (EU),[23] formerly fast growing economies like China and India,[24] and every OECD economy[25] in the aftermath of the downturn that began in 2008,[26] the failure to reach agreement on legally binding international emission targets in 2011 at Durban,[27] and finally, Canada's withdrawal from Kyoto commitments[28] have raised serious questions as to the likelihood of success in reaching a binding treaty by 2015. This history of policy failures has also raised questions as to whether "(t)his catastrophic and ongoing failure of market economics and the laissez-faire rhetoric accompanying it (unfettered choice, deregulation, and so on) could provide an opportunity to think differently about climate change."[29]

This thesis presents a vision of a technically, politically, economically and logistically viable pathway to a cleaner and more sustainable alternative to current dominant energy systems architecture and provides a roadmap to implementation. This chapter will begin with an overview of the institutional properties of the extant Integrative Panel on Climate Change (IPCC) regime, noting the theoretical and practical limitations of branches of neo-classical economics[30] that dominate current political dialogue, demonstrating that the extant Framework Convention's implementation[31] is an institutional problem[32], rather than a technical, engineering, or logistical failure that has prevented the energy and climate change issues from being effectively addressed in a timely manner. This thesis will then outline from, an institutionalist perspective, how the DoD can lead critical change toward an alternative energy systems architecture. Such a new architecture must simultaneously address the issue of climate change, and produce sustainable and affordable energy in a way that is technically and logistically feasible, rapidly deployable[33] and yet meets economic, fiscal, political, technical, and other constraints of the post 2008 recession era.[34]

2.1 Climate Change Mitigation as an Engineering Challenge

Climate change and efforts to mitigate it are engineering,[35] or applied science, problems first, and an economic[36] problem second. Many of the predicted impacts from climate change, ranging from rising sea levels and flooding of low lying areas, to managing water resources in the face of too little or too much water, are historically central to the domain of Civil and Environmental Engineering and the design of new energy infrastructure.[37] However, the engineering profession often takes a back seat to environmental issues.[38] Engineers, after all, work for clients and within the broad limitations of legal and professional obligations, the customer ultimately decides on the budget and assigns resources the task; only then can engineers determine what can be built economically.[39] The scope of the engineering profession incorporates into it economics, and is defined as follows:

> "The profession in which a knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind" (ABET)[40]

The definition begs the question of *what* economics?[41] Engineers had been building structures, machines, and devices long before the advent of modern Neo-classical economics in the late 19th and early 20th centuries.[42] Ideas of what constitutes "economical" allocation of resources have changed over time and space, and with them, what constitutes the art of the possible as defined by the applied economics[43] of the time. Thus, the practice of engineering is often, but not always, limited by the dominant economic paradigm, which is itself a subset of the neoclassical economics synthesis in UNFCCC. Many practical areas of engineering, such as defense and combat engineering, are tasked to achieve outcomes using resource allocations that sharply deviate from civilian economic constraints and ideas of acceptable cost or economics.[44] This leads us to a central problem of any major civil or environmental engineering project: the dimension of policies, rules, regulations, laws, protocols, standards, and tried and true ways known in the profession as "Recognized Generally Accepted Good Engineering Practices" (RGAGEP),[45] which every practicing Engineer must be cognizant of and practice in accordance with – institutions.

2.2 Institutionalism

Institutionalism[46] is an analytical and operating perspective that makes the presumption that "rules matter". Institutions are defined as the body of rules, regulations, norms, RGAGEPs, specifications, standards[47], and architectures[48] that every practicing engineer must heed in his/her practice. Rules can matter even if they don't make any sense, rules can take on a life of their own and become their own raison d'etre.[49] The domain of engineering is replete with examples of persistent and unreasonable adherence to rules that have far-outlived their original justifications. For example, the QWERTY keyboard, which is now a world standard[50] for input of written words into electronic devices, is the product of an optimization patented in 1878 for a manual typewriter. The QWERTY keyboard was specifically engineered to sufficiently slow the touch typist's input to prevent the mechanical type bars from jamming, a technical advantage that is no longer necessary. Yet, decades after the passing of the manual typewriter, and in fact, well into the era of handheld devices and smartphones, a keyboard layout originally designed for ten finger, two handed touch typing on mechanical machines continues to be installed in electronic touchscreen devices, despite the negligible cost of and frictionless ability for the same devices to switch to a different, more optimized layout.[51] The switching cost often seems impractical to operators and users who are familiar with the old layout and have no compelling reason to learn a new one. In the same vein, civil engineers must routinely design to meet building and fire codes that were established long ago, often for reasons that are obscure, sometimes forgotten, and may have no relevance to the problem(s) at hand. The notion of "rationality" and "optimization" are, in an engineering sense, not necessarily relevant when such practices require major changes to the RGAGEP. Things are often completed as they have always been completed, and established designs or architectures are often simply copied because it is deemed unnecessary to revisit the underlying rationale for the rules. Revisiting, or questioning, the rules can be an uneconomic and risky (both professionally and practically) process when the exigencies of having to complete projects on time and under budget is a priority. Perhaps the most compelling of rules, or constraints, is what the customer is able and willing to pay for and the simplest way to fulfill the minimum requirements with a minimum of effort.[52] Deviations from RGAGEP often involve risks, as unknowns are introduced for which there is insufficient experience in the field. Such risks are often not uncovered until it becomes a major problem.[53] Finally, there is the inertia of acceptability and convenience. Any newly designed and architecture system, particularly in the manufacturing sector, must be validated, tested, and critically reviewed prior to getting new regulatory approvals, and so on. Only then will creators and engineers discover whether the new design is actually what customers want, and will therefore buy. The specter that a customer may reject a product that is too different or too much ahead of its time is a major concern.[54] It is not surprising that many designs that are not strongly and effectively protected by intellectual property laws are widely copied. Very few engineering designs are developed from a "clean sheet".

2.3 Public Policy / Government Dimension

Large-scale civil engineering projects have always required some form of coordinated allocation of resources toward the project at hand. Coordination and diversion of societal resources toward a goal or goals is not a trivial task; it is a complex political process, requiring sound planning and execution which are every bit as important as a sound technical / engineering architecture. These policy processes are often conducted in the non-market domain and are not necessarily based on a notion of rationality, let alone the narrow rationality characterized by "the economic man" presumed in neoclassical economics. A neoclassical economics version of market allocation is neither necessary nor sufficient to enable large-scale projects[55] to be done. Indeed, a case can be made that any major engineering exercise that requires an "up front" commitment of a large percentage of societal resources is inherently *ex ante*[56] in its nature and inherently non-market. It is not surprising that in ostensibly market economies, large segments of the economy, such as defense, are recognized as primarily non-market in nature.[57] Likewise, large-scale flood control,[58] energy and infrastructure projects, or the control of emissions[59] (including GHGs) in the US, are often undertaken via primarily directed /regulatory rather than market measures, using *ex ante* rather than *ex post* methods of coordination.[60] In other words, it is unlikely in many cases that major civil engineering projects will be conducted without the involvement, acquiescence and direct support from the competent authority in a jurisdiction. Large-scale civil engineering projects by their nature require the participation of the government in some shape or form and are unlikely to be done by private parties,[61] unless it involves hybrid partnerships that bring together both public and private sector stakeholders.[62] That, in turn, takes us to the role of governance structures in large organizations.

2.4 Interests / Stakeholders

Many large organizations, whether a state or a large corporation, provide (at least on paper) enormous power to their nominal leaders, potentially just one or a few people. In large modern organizations, behind the "face" of every major governance structure are found collections of interest groups.[63] The more pluralistic an organization or more diffuse its power, the greater the importance of these interests. Interests come in many forms, ranging from diffused, difficult to assemble and unorganized groups, to highly organized groups that are capable of collective action that can stymy the nominal leader of the organization. Crafting a successful policy requires that, at the very least, no interest groups with veto power are mobilized to do so and interests that benefit can be assembled to "push" the project through.[64] The present stalemate on efforts to reduce carbon emissions via policy instruments such as Feed-in-tariffs (FIT), Renewable Portfolio Standards (RPS) / Renewable Fuel Mandates (RFM) or subjecting "fossil" fuel to Carbon Taxes or Cap and Trade programs is an example of how policy formation can be tied up in gridlock despite the marshaling of well-organized and dispersed economic interests that benefitted from the schemes.[65]

2.5 Logistics

From antiquity onwards, engineers have practiced logistics management as a part of any engineering practice.[66] Yet, advocates of "clean" and "sustainable" technologies have paid scant attention to the issue of logistics. For example, proposals put forward to move 100% of the world to renewables by 2030[67] (21 years from date of publication) without detailed logistical plans that give details on necessary resources and implementation plans are not only overly optimistic, but are unlikely to be feasible once laid out as a proper project. On the other hand, the other end of the continuum that argues that energy infrastructure is long lasting and that displacing it in 50 years is impossible may be overly pessimistic.[68] History informs us that when major governments are driven by the imperatives of survival, typically in war, the impossible often rapidly becomes the actual.[69] Whatever solution proposed must be cognizant of the logistical burden implied, and identify how bottlenecks can be moved to expedite the program. An engineered, as opposed to a theoretical and speculative solution, cannot leave logistics to hope or chance, but has to subject it to validation - from simulation to overcome normal project management issues to tangible achievement of outcomes[70] that deliver at least substantially what was promised. Engineered solutions can also be perfected over time.[71]

2.6 History Matters

The preceding identification of institutional factors raises the question of “so what”? How are the constraints of institutionalism relevant to engineering problems? Can the engineering community plausibly ignore these issues in deference to a preferred focus on scientific principles and tried and true “Generally Accepted Good Engineering Practice” (GAGEP)? Perhaps. During much of the last century, basically from the 1950s onwards, there was a long period of institutional stability. Indeed, institutions, particularly in energy, remained remarkably unchanged despite major transitions into the age of electronics and information technology. [72] Small, often obscure, institutional changes can have enormous impacts not only for those who understand the change, but often, as the law of unintended consequences informs us that not all outcomes can be foreseen, even by the most perceptive observers. To recognize the importance of these factors epistemologically requires historiography. History, however, cannot be assumed to be efficient.[73] Many artifacts of history, especially in engineering, remain stubbornly unchanged despite the self-evident benefit that will finally come from changing them. For example, to this day, Japan presently operates two incompatible electric grids, one based on 50hz for Tokyo and eastern Japan, and a 60hz grid for the rest of the country.[74] Likewise, there is no method other than historiography to explain how the world failed to standardize on either left or right drive-side vehicles; instead we have ended up with two incompatible standards that are likely to persist as long as the “standard” motor car remains in service. [75] In order to craft practical and feasible engineering solutions, recognition and understanding of the relevant history is often necessary to define the art of the possible.

2.7 Feasible Policy Making

The problem of crafting feasible, implementable policy leads us to its components:

- Scientific-Technical / Engineering feasibility;
- Acceptable Economic / Financial / Resource allocations;
- Law / Regulatory / Public Policy considerations;

In a pluralistic[76] system[77], the constraint of a solution acceptable to interests or the willingness to override "hold out" interests is required. Finally, the proposed program must be logistically plausible, at least at the outset.[78] Once a consensus[79] is crafted and implemented, it is likely to persist for decades or generations, and unless it is disrupted or made obsolete[80] by later architectures, it remains working.[81] Applying this analytical framework to the UNFCCC deliberations using an institutionalist approach, it becomes self-evident why nations have had so much difficulty committing to legally binding targets in the absence of proven feasible pathway(s). First, it is not at all clear that a large-scale conversion of present energy systems to "renewables" is practical or even technically feasible. Smil demonstrated that while such transitions can happen quickly in the case of relatively small communities,[82] transitions in larger communities tend to take generations.[83] Second, the cost of conversions based on known and deployable technologies like solar and wind renewables have proven to be substantially higher than conventional "fossil" sources even after large price declines as in the case of solar since 2008.[84] With the decline in prices of natural gas and oil, and the use of hydraulic fracking[85] to exploit formerly inaccessible resources, prices of both natural gas and oil are plunging as large deposits like the Bakken shale formation comes on stream[86]. The declining public appetite for subsidies to "renewable" energy in most OECD nations and recognition of the blight caused by large renewable installations is a major issue.[87] Any attempt to transform an energy system on a large scale must reckon with the architecture of the existing system and resolve the issues and interests associated with it.[88]

2.8 Compatibility and Conflict with Existing Interests

This is one of the most neglected aspects of major institutional transformation: how the existing interests are arrayed, and how change might come about --- whether existing interests are defeated, sidelined, coopted, or accommodated. Two phenomena are observed. One is compatibility that eases the pathway to the new world, which was the case in the transition from sail to steam power for merchant and warships. Steam power initially found its way in niche-market merchant applications and gradually improved. Hybrids enabled more rapid adoption of what was then an untried and unreliable technology (steam boilers fired by coal), which ultimately, as it improved, enabled heavier and larger vessels to be built that ultimately, replaced the sail.[89] The transition from on-site steam engine to off-site electric power generation (a distance away) was eased initially by the replacement of local steam engine technologies with a similar output, single large electric motor that distributed its power via belt galleys, and over time, as the price of individual motors fell, replacement of the belt galley with individual motors at each station, and ultimately, a motor at each device until motors became commonplace. Transitions can also be rife with conflict, as was the case during the phasing out of coal in UK.[90] The transition from manufactured gas to natural gas in the UK can result in both patterns.[91]

2.9 Energy Industry Architecture

The world energy system architecture has remained largely stable and unchanged[92] since the 1950s. It consists of many elements, from law, rules and regulations, interests, as well as technical and engineering standards. Standards apply to particular attributes and can be open, proprietary, or a mix of the two. In general, standards are published (even if they are private[93]), while a system's architecture can be implicit. IEEE 1471[94] defines architecture as: "fundamental concepts or properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution". [95] Specifically, it identifies these elements:

> *"Architecture" names that which is fundamental or unifying about a system as a whole; the set of essential properties of a system which determine its form, function, value, cost, and risk.*
>
> *An architecture is a conception of a system – i.e., it is in the human mind. An architecture may exist without ever being written down. Therefore, the Standard distinguishes architectures and architecture descriptions: just as it is said, "the map is not the territory", an architecture description is not the architecture. An architecture description is what is written down as a concrete work product. An architecture description represents an attempt to express a conception of a system to share with others. The focus of the Standard is on requirements on architecture descriptions.*
>
> *An architecture is understood in context – not in isolation. To understand a system's fundamental properties (i.e., architecture) is to understand how the system relates to, and is situated in, its environment. Often, the architect cannot know what is fundamental about a system without*

> *knowing fundamental to whom? Therefore "fundamental" is to be interpreted in the context of a system's stakeholders in its environment.*
>
> *Finally, there are some things that an architecture definitely is not. An architecture is not merely the overall structure of physical components that make up a system. While physical structure can be fundamental to a system, it need not be.”*[96]

Architecture is important because in most practice areas, engineers are not free to create new architectures. However, new architectures can readily be created in new industries. For example, new architectural models are being rapidly created and obsoleted in the present internet era.[97] In the energy industry, systems have stabilized to several “dominant designs” or architectures.

What is a dominant design or architecture? It is the outcome of a three-phase process model described by Abernathy & Utterback (1978-94):

- Fluid Phase:

  Innovations begin with a fluid phase that encompasses both technological and market uncertainties.

- Transitional Phase:

  Customer needs become understood and standardization emerges, leading to a dominant design.

- Specific Phase:

  Characterized by the market coalescing into segments, specialized products are produced for every segment with performance and cost as competitive drivers.

In the field of energy, dominant design, or architecture has emerged in the major electricity, natural gas, petroleum, and nuclear energy segments. The incumbents that have thus far been displaced on the path to modern energy were fuels like wood (displaced with coal, oil, etc.) and animal fats like whale oil for illumination (displaced with kerosene), and fodder like oats (displaced by electricity powered vehicles or petroleum fueled vehicles or coal / wood fired steam).[98] The architecture of the world oil industry was defined by several key events, the present day significance[99] of which is often lost except to historians.

Each of the major energy segments: oil & gas, electricity, and nuclear, arrived at a common architecture by the 1950s, and since that time, no new set of architectures has emerged despite the proliferation of renewables like solar, wind, and biomass energy. The question is, does the current architecture fit a world trying to transition to cleaner and renewable energy sources that are fundamentally different?

Chapter 3

Energy Industry Architecture

Oil is not the oldest form of modern energy in widespread use (coal is), but it is the one source of primary energy that has had the most impact on the psyche of the world and a geopolitical impact that is second only to nuclear energy. The earliest modern adopter of oil as a fuel was the United States, which discovered that it was sitting on plentiful supplies of petroleum --- often no more than a short dig into the ground --- in the 19th Century.[100] Oil was first used to extract kerosene, which substituted for whale oil as a lamp fuel.[101] Only later did oil begin to replace coal as a boiler fuel, and much later, after the invention of the internal combustion engine, as a motor fuel. Compared to almost any other commodity, oil is extremely versatile, efficient, easy to handle[102] and cheap;[103] these factors were sufficient to alter geopolitical paths of the British Empire in the 19th Century. At that time, the British had to secure intra-empire supplies[104] from Mesopotamia for its Royal Navy to support conversion from coal to oil fired vessels, and ensure all potential choke points in transit, such as the Strait of Gibraltar, the Suez Canal and the Strait of Hormuz, were in friendly hands. This ultimately led to a century of extensive western involvement in the Middle East as a vital oil supplier. Early in the 20th Century, Japan became dependent on oil imports from the plentiful deposits in Texas, which were shipped through the Panama Canal and then California. Many Japanese regarded the American oil embargo against the Empire of Japan[105] as the proximate cause of war against the United States.[106] The US and its allies have gone to war with major oil suppliers, including both Iraq and Iran, and have a longstanding security guarantee with Saudi Arabia[107] --- the world's largest oil suppler. One can hardly imagine a commodity[108] in greater demand by the global community; nations dedicate significant resources to obtaining, securing and defending the their oil supplies. Oil has indeed, shaped empires and altered the course of world history. This will be a continuing trend, as it defines economies, societies, and becomes a major factor in whether goals for sustainable development can be met. How the world arrived at its present oil industry architecture is essential to understanding how it can be transformed in the future.

3.1 Managed Markets, Property Rights And Petroleum History

Petroleum began as a free market industry in a manner unique to America. Whereas in most areas of the world, mineral rights are the property of the sovereign, America, after it overthrew its King[109] and in the case of Texas, after secession from Mexico, enacted a different set of property regimes that granted mineral rights to the property owner.[110] This dynamic enabled rapid expansion of the oil industry and exploitation of this invaluable natural resource. Since the only "deal" that had to be made was with the surface property owner, and these land owners were then able to take their new found wealth to start new companies --- often in the same industry --- it is unsurprising that the exploitation, overproduction, and ultimately the depletion of this resource was swift. Overproduction has been a major "problem" since the earliest days of the American petroleum industry. By the early 1930s, with oil production growing explosively in East Texas, prices fell from $3.50/bbl, to $1, and bottomed out at 5 cents a barrel. Operators continued to produce because 5 cents is preferable to zero[111], which resulted in the Texas Railroad Commission expanding their regulatory role from railroads to oil and gas pipelines to becoming the regulator for, at first, oil produced in Texas beginning April 1931[112], and under President Roosevelt's New Deal, the lead US oil industry regulator under the umbrella of the Interstate Oil Compact Commission beginning in 1935 with the mandate to both conserve resources and, in the case of Texas, regulate supply via proration.[113] Thus, the oil and gas industry has from its inception had to contend with the failure of market forces to simultaneously ensure "best practices" for production while conserving and protecting the supply. When American oil firms moved abroad, they brought this modus operandi with them and again, unsurprisingly, replicated the domestic US characteristics of overproduction on the global scale.

3.2 Energy and Anti-trust

Anti-trust law predates the rise of modern industry and was not initially targeted at the energy industry; however, oil and other cartels have became the biggest targets of US anti-trust law, which formed the basis of competition policy throughout the Organization of Economic Cooperation and Development (OECD) after WWII.[114] Since oil producers could not control supply and crude pricing during this early stage in the American oil industry, refining and distribution (e.g. oil pipelines, service stations) represented the most lucrative value-added activities. This was particularly the case for the Standard Oil Company, which controlled much of the oil refinement and distribution effort.[115]. These and other "combines" monopolized the refining and distribution of oil and other commodities through rail connections that often represented state-regulated monopolies. Fear of these large combines and their market influence predate the rise of modern energy. The US Congress responded quickly to these fears by passing a series of legislative acts, including the Sherman Antitrust Act (1890),[116] which would effectively break up these monopolies and prevent market dominance by a few large terms. Electricity went through its formative years, culminating in the "current wars,"[118] which ultimately resulted in the triumph of AC current over DC for almost all applications and then the standardization on the 120VAC-60hz standard in US, followed by many provinces in Canada. Once that happened, electric utilities were successful in making the case that they are a "natural monopoly," using the precedent of railroads incorporated by acts of Congress[119] beginning in 1907 in Wisconsin[120]. Rather than being prohibited as was previously done, electric utilities became legalized monopolies, and in exchange for their legal status, came under government regulation to ensure that the consumer was protected and the public interest was served. Thus, electric utilities have service mandates that require that all customers within a jurisdiction be served in accordance with rules set by the regulator. Prices were set to give a reasonable rate of return for investors in the case of privately owned and operated utilities, and in the case of public utilities, a rate was established that was defensible for politicians. This system of regulated monopolies (either public or private[121]) is now the model used almost universally around the world.[122]

Standard Oil, was successfully sued by the US Department of Justice and broken up into 34 separate companies in 1911. This sharply constrained the margins in refining and distribution as the segment became competitive --- a pattern that persists to this day --- while at the same time increasing the margins available at the production / exploration side as refineries competitively bid up the price for oil. The "Seven Sisters"[123] that resulted from the breakup of Standard Oil recognized this, and over time, exploited their strength as large integrated oil companies with the technical and financial capacity to exploit large oil deposits anywhere around the world and to survive the cyclical nature of a commodity business. The majors became pioneers in the global hunt for oil in remote places, which undercut domestic US producers.[124]

One long lasting feature of the "robber baron" era of petroleum dominated by Standard Oil was the patchwork of state laws in the US that required prices to be posted at filling stations, which ultimately resulted in the general industry practice of posting prices inclusive of all taxes and charges[125] at almost all retail outlets. Another feature from the early era of petroleum marketing was the ubiquitous "sight glass" that was, until the 1980s, standard on every fuel pump. The sight glass allowed customers to visually see the product being sold and confirm that it is not turbid, cloudy, etc. which gives a good indication of how widespread product adulteration was in the early years of petroleum retailing.[126] Profit margins, however, at retail outlets have gradually been squeezed down since the days of integrated service, and the business of retailing gasoline is now a low-to-negative margin business that relies on the sale of convenience items or other services for its profitability.[127] Yet, customers perceive petroleum retailers and the oil business as being highly profitable across the entire value chain.[128] An industry that is modestly (or minimally) profitable is not an industry that can be pressed to finance a major change in architecture.

In the US, the largest oil companies of today, including Exxon, Mobil, Amoco, and Chevron,[129] date back to the breakup of Standard Oil. Around the same time, Britain decided to maintain competition with at least two major oil suppliers.[131] The natural gas industry, by and large, followed the same growth pattern with regulated monopolies that regulated the transportation of supplies, but with competitive suppliers that "fed" the pipeline. Coal, which is by its nature dominated by relatively large mines and expensive to transport long distances, largely conformed to this pattern. Electricity all became regulated monopolies. This industrial pattern was to remain largely stable until the advent of deregulation in the 1990s.

3.3 Nuclear Energy – New Institutions

Once it coalesced, the relatively stable industry structure of the energy industry was not upset by the USSR's introduction of nuclear energy in 1954.[132] Exploitation of civilian nuclear energy, however, did require the passing of the Atomic Energy Act in the US and equivalent legislation in other countries that enabled the civilian sector to gain access to technologies developed by the US military. Notably, the act limited a licensee's liability.[133] This is consistent with the model previously discussed whereby the introduction of major new technologies and infrastructure tends to require new laws and regulations, or institutional arrangements even though in this case, it was a relatively simple integration of a new technology with well-defined and compatible characteristics into an existing electricity generation and distribution infrastructure.

3.4 Energy Industry Deregulation

The relatively stable infrastructure of modern energy survived many crises throughout the OECD. In North America, deregulation, which originated in the 1970s with liberalization of controls in finance, transportation, energy, and communications[134], only reached electric utilities in 1992[135]. In the US, oil was subject to price controls between 1971-1980 while a windfall profits tax was levied on crude oil between 1980-1988.[136] Similarly, in Canada, the National Energy Board regulated oil prices until the end of the National Energy Program (NEP) in 1986.[137] Electricity deregulation began in 1992 in the US, and the movement ultimately spread throughout the OECD with varying degrees of implementation hurdles and outcomes. Innovations introduced since that time include time of use metering, and certainly for commercial buyers, greatly increased competition in energy supply. However, deregulation has, by and large, had minimal impact on many salient characteristics of the energy industry that have remained the same since its inception. The most basic of these characteristics is the provision of a commodity, indistinct product of high gradient, reliable energy at modest prices.

The most defining "signature" characteristic of the modern energy system architecture is low prices for a high quality[138], reliable and consistent product[139]. In any reasonably well-governed nation, and certainly in any OECD nation, it is a given that supplies of conventional (oil, gas, electricity) energy are plentiful and widely available at market prices, despite natural disasters or emergencies. An intricate system of mutual aid and support through multilateral organizations like the International Energy Agency (IEA) and International Atomic Energy Agency (IAEA) ensures that member states can count on mutual aid, support, and emergency assistance. This system has been reasonably successful in ensuring that when major suppliers like Iraq, Kuwait, Iran, Libya, and the US Gulf Coast, were disrupted by war, natural disaster, or other events, sufficient supply was never an issue.[140]

3.5 Conventional Energy Product Characteristics

The conventional energy industry has three major product lines for the end user: i) Petroleum-based fuels like gasoline and diesel, ii) natural gas or similar gaseous fuels like propane, and iii) electricity generated from a mix of fuels (nuclear, hydro, coal, natural gas, etc.) with "renewables" or "clean" fuels accounting for a very small portion of total energy consumed.[141] Regardless of the product line, the defining characteristic of these products is that it is a high quality, high energy gradient[142] product. Furthermore, it is mostly derived from primary sources[143] that typically demonstrate high energy density and stability, specifically in terms of throttleablity / dispatchability. Or, in the case of grid electricity, for all but major commercial customers, electricity utilities virtually guarantee that they can meet demand --- brownouts are not acceptable. A natural gas or oil-fired gas turbine can be throttled from idle to full power in a very short time, as can a gasoline / diesel internal combustion engine. Civilian nuclear reactors like the Canadian CANDU, however, are less throttleable unless they are engineered for the purpose as with reactors originally designed for motive power.

3.6 Customer Perceptions

The notion that high quality, high gradient energy from conventional sources is an undifferentiated commodity is reinforced by many institutional factors. At the most basic level, retail customers of the product are constantly reminded that it is an undifferentiated product. After all, the product is delivered in bulk by a pipeline to their home (Natural Gas), via a "grid" (electricity) to a common, standardized outlet that supplies electricity to devices, or is pumped into a vehicle (gasoline / diesel). This strongly reinforces its image as an undifferentiated commodity[144] product, where the only difference is price, which is conspicuously posted outside every retailer.[145] The constant reminder that price is the only differentiator makes it difficult for the customer wedded to motorized transports based on the internal combustion engine to avoid the cost of paying for fuel[146] --- which is generally purchased without cash discounts. Add to this the politicization of energy prices nearly everywhere around the world. "Fossil" fuel subsidies that price fuel below market levels at retail outlets are widespread in oil exporting countries in the Middle East, but also in populous nations with fast growing demand like China and India.[147] At the same time, monopoly electric utilities that enable politicians to have a say in electricity prices simultaneously provide for politicization of the rate setting process, while at the same time, with public utilities, offer politicians the well-known benefits of being in charge of running a large state owned enterprise. Energy subsidies, much like subsidies for food and housing, which have a large base of beneficiaries, result in populist sentiments that are easily stirred up by any obvious change, namely reductions, to the subsidy. There is no easier or better way in a pluralist system to foment unrest than to make apparently large and abrupt changes to prices of subsidized products once the populace has become accustomed to the subsidy.[148] In effect, the conventional energy system's dominant architecture has become a victim of its own delusions of plenty. By historically making their product / service available for low prices, they have encouraged long lived systems[149] to be built around the belief in continued long term availability of cheap energy, which in turn, is upset by any changes to the customers' expectations for low cost and readily available product. That leads us to the problem of price volatility.

3.7 Energy Price Volatility

Fuel prices are strongly influenced by the raw materials themselves, accounting for a large percentage of the total cost. Petroleum and natural gas prices, like many commodities, are often volatile. Volatility in prices is a boon to commodity traders and insiders, who stand to make trading profits on the volatility. At the same time, volatility to the extent experienced by the petroleum industry, which is more volatile than 95% of the commodities sold in by domestic US producers between 1945 to 2005[150] has had perverse effects of making oil (or gasoline / diesel) prices a political issue everywhere, yet volatility has continued and persisted.

There are many causes of oil price volatility, from the high fixed and low variable costs of most producing oil and gas wells and distribution infrastructure and a similar high fixed low variable cost structure at many coal mines in the US; the unique role played by the small volume of physical oil behind the most common indexes of West Texas Intermediate Crude (WTI) and Brent Crude, low option contract margins required at the exchanges where crude is traded, which makes it easy for traders to manipulate the prices.[151] The industry structure of low-to-modest margins at refining and distribution in turn contribute to the rapid transmission of price swings from wholesale to retail. Furthermore, displaying prices for retail fuel on prominent placards in front of nearly every store provides customers with a degree of awareness of current prices, sensitivity to price increases and enables politicians to exploit political populism unlike any other commodity --- the same politicians who rarely mention that taxation on energy is in fact one of the largest stable and reliable sources of revenue in most OECD nations. When managing retail energy prices becomes the task of politicians, predictable consequences follow.

Regulated utilities, on the other hand, have generally moderated electricity and natural gas price swings through a combination of building surcharges into the rate structure, long term contracts with suppliers, and using a portfolio strategy where a mix of technologies and sources are used - diversification of the supply mix. Energy retail customers, especially in applications like space heating and cooling, can find themselves technologically locked into an energy source for decades or longer and given switching costs; they have little recourse short of major retrofits or moving.[152] Deregulation was supposed to bring greater choice to customers, which appears to have worked well in many non-energy policy areas; however, in the electricity sector, many North American customers, when given the choice, elect not to choose.[153] Customers are in general very satisfied with the cheap, commodity product that is widely available for their energy needs.

3.8 Too Cheap To Meter

The energy industry can be said to be almost utility like in its organization. To understand this, it may be best to consider a similarly functioning utility that is less often in the news, but just as vital to everyday life: water. The provisioning of water has historically seen many forms, ranging from a public works based model used by ancient societies like Rome, China, and India, to the semi-private model used in

London around the 19th century that evolved into a publically operated utility early in the 20th Century until it was privatized again in 1989. The basic idea behind the Anglo-Saxon utility model is that it is a bounty from God. It is nature's wealth over which man has dominion. Natural resources are for man to exploit for common benefit. Therefore, those involved in providing services to transport it from its source (the river or well) should only be paid a nominal sum for conveying something that is essentially free for anyone who wanted to take the trouble to do so themselves. The charges for water should only be for the reasonable costs of collecting it, giving it whatever treatment is necessary to enhance its purity (in essence aiding the natural process of purification), and then distributing it.[154] Thus, a water works should provide affordable, and in essence, nearly free water. We can contrast this model of water provisioning to places where water is extremely scarce, for example, in 19th Century Arabia. Sources of water, namely natural springs or wells that are few and far between, are tightly controlled by the governing authority and jealously guarded only for the use of the sheik and their tribe.

How does the Anglo-Saxon water works model handle extreme scarcity when water demand greatly exceeds local supply? It is resolved by large-scale public works similar to the Roman model of building aqueducts. Great feats of engineering are done to bring water supplies from distant sources to satisfy demand. Dams are built to store and hold water, or deep wells sunk to obtain ground water. For much of human history, civil engineering projects have generally kept up with demand and ensured a plentiful supply of water nearly for free, at least in the western world. This is despite a sharp rise in population and an enormous increase in the standard of living that made such luxuries as water closets and daily baths a normal part of life. The purest expression of the success of this model is the universal availability of clean, potable water, and the carefree nature with which water is used (in the Western world).[155] In many parts of Canada, water is so plentiful that at one time, municipal water authorities, including in Toronto, offered "all you can eat", or unlimited use meters based on the pipe diameter. It is this model that other utilities have sought to emulate.[156]

3.9 Energy As Utility

Historically, energy is scarce. The chart below illustrates the amount of energy from just before the industrial revolution to the present. Energy before the industrial revolution came mostly from biofuels, accounting for just a little over 20 gigajoules a year until the industrial revolution was underway. Per capita energy use exploded again around 1960 when it reached the 70gj range; it is now on a path to rise sharply again.[157]

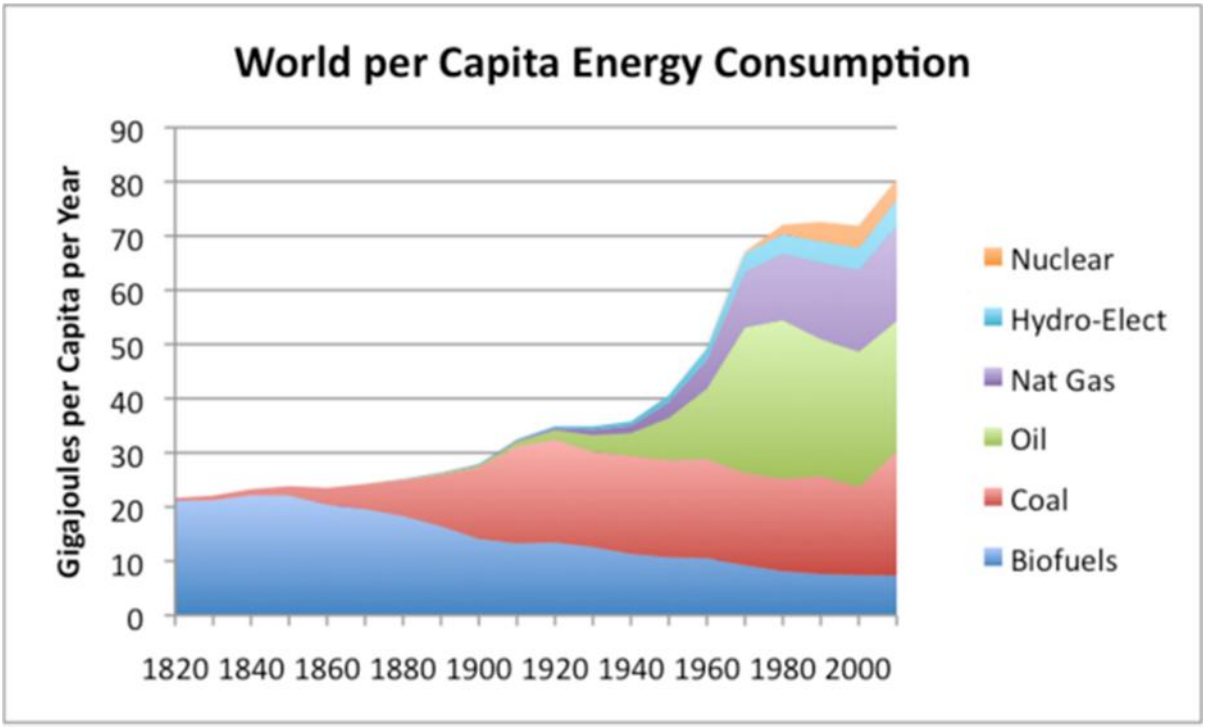

Figure 2. World Per Capita Energy Consumption[158]

The energy utilities' aspirations to mimic the water utility to cheap, nearly free product for all, was best illustrated by the hopes shared at the beginning of the nuclear energy age in the Chairman of the US Atomic Energy Commission, Lewis Strauss's speech:

> *"Our children will enjoy in their homes electrical energy too cheap to meter... It is not too much to expect that our children will know of great periodic regional famines in the world only as matters of history, will travel effortlessly over the seas and under them and through the air with a minimum of danger and at great speeds, and will experience a lifespan far longer than ours, as disease yields and man comes to understand what causes him to age."*[159]

While many cited this remark with derision, it was reasonably and plausibly based on the facts available at the time.[160] In the United States, the completion of the Hoover Dam in 1936, followed by the Colorado

River diversion and its aqueducts, which were largely completed by 1947, ensured water supplies for a parched American southwest and greatly assisted the rapid economic development of California and other states along the Colorado River's watershed. From an Ontario perspective, the Great Lake states provided essentially limitless water and the completion of the Niagara Falls Hydroelectric Generating Plant in the 1950s ensured virtually free power, excluding the cost of construction and nominal maintenance charges. It is interesting to note that many Municipal hydro utilities in the 1970s did in fact offer unlimited use, all you can eat plans for residential hot water heaters --- not exactly as Lewis Strauss promised, but certainly close, and well before the advent of nuclear energy. Thus, it was not at all a pipe dream that energy could have been too cheap to meter at the time the speech was made in 1957. While this dream was not realized in its entirety, the industry came close. Energy costs per unit, measured by wholesale prices before taxes in real dollars, are now lower than a century ago.[161] All of this is achieved within an energy industry that earns a modest profit for its efforts.[162] While the system is not without flaws, it is one of the greatest achievements of mankind that to this day and works well for the world. The question is: Why change it?

3.10 Energy and Government Revenue

From the perspective of governments, modern energy systems are a great blessing because the industry provided so many benefits to its customers at such a low price that it is possible to impose high levels of taxation without materially changing demand.[163] The industry also has many choke points where it is possible to assess and collect taxes easily and efficiently at relatively low collection costs. It is not surprising that taxation on oil and gas, electricity is a stable and reliable source of revenue for many governments. The International Monetary Fund estimated that the "fiscal breakeven" for many Middle Eastern oil exporting states requires oil at over $130/bbl while the current IMF outlook has oil prices for 2012 at about $115/bbl.[164] Royalties and revenues from oil and gas are the elixir that enables survival of many oil exporters, and they have grown accustomed to the bounty. Few countries have invested their oil revenues wisely and as resources deplete, have witnessed the petrodollar rush decline. On the consumption side, petroleum products are heavily taxed in most oil consuming countries. Electricity is taxed either directly or indirectly, as a government directed enterprise whose resources can be diverted to achieve political objectives.[165] Governments, thus, whether producers of energy or generators (via public monopolies) or collectors of taxes on the sale and use of energy, are among the biggest beneficiaries of the system of cheap energy. This leads us to the Jevon's Paradox for Governments (JPG),[166] which states that: reduction in the use of energy has the perverse effect of lowering revenues from a reliable stream that has relatively muted cycles compared to the overall economy, unless there is growth in demand. Governments have a strong vested interest in the maintenance of the system of cheap energy and growing demand. Should the price of energy rise to the point where demand becomes elastic, governments stand to lose tax revenues. Few commentators recognize this fundamental conflict of interest that drive government behavior.[167] Talking conservation is cheap, and throwing a few hundred million at programs makes for good public relations, but any sharp decline in energy consumption, for example from adopting super-efficient hybrid vehicles, is an attack on the tax base.

3.11 Old Architecture, New Challenges

There is no compelling reason to change the energy industry's architecture, with the exception of CO_2 / GHG emissions. Arguments have been made that natural resources are finite[168] and eventually there will be issues relating to peak oil and depletion; however, the foreseeable next 20 years will not be an issue.[169] In the relevant range for engineering purposes, the world energy system is nowhere close to facing the problems of depletion put forward from Malthus to the Club of Rome's early reports.[170] Nor does the argument for exponential growth prove compelling in the absence of evidence that such growth will continue unabated until it fails, rather than taper off toward an S curve as is common in many natural systems.[171] The problem of exponential population growth straining resources is not known for certain.[172] What then, can motivate our government to create a new, more sustainable energy architecture?

The reasons to create a new energy architecture, do not have to be economic (e.g. cheaper),[173] more secure,[174] or compelling. Time and time again in history, decisions to do the "right" thing turned out to be for the wrong reasons, and the proximate cause for action, like "The Great Stink" that caused the construction of sanitary sewers in London had nothing to do with the problem at hand, which was cholera caused by sewage contaminated drinking water. At that time, the science was not well established or accepted by the governing elites even as the problem was solved.[175] Thus, history tells us that there is no necessary reason to wait for science to become undisputed before acting. Acting before the science is well established, in the tradition of engineering, or doing the right thing for the wrong reasons, as long as it works, is at the heart of engineering.

3.12 Energy and GHG Emissions

Reductions in GHG emissions and the absolute amount of "fossil" energy use goes hand in hand. "Fossil" fuels reduction also directly impacts the world's largest economies, which at present, have no viable alternatives.[176] It is empirically self-evident that the world energy system is intended to serve only a small population, namely those of the OECD population and a select minority of the global elite out of a population of 7 billion. Expanding the number of users who can afford to build, operate and benefit from the present "fossil" fuel-based energy system under the existing industry architecture will cause GHG emissions to explode further --- as has already happened in China.[177] Everywhere in the developing world, it can be seen that the advent of economic development results more often than not, in *replication* of consumption patterns of the OECD nations adjusted for per capita or individual incomes rather than invention of new, more appropriate architectures and systems.[178] Indeed, increased wealth often results in a brief transitional phase where, e.g., in transportation, use of scooters was widespread, and with the next incremental increase in wealth, large scale moves to the world "standard" car. Homes and offices acquire local, then central heating and air conditioning and other creature comforts, and in due course, the entire suite of energy intensive western tastes is transferred.[179] The Chinese example illustrated how the decline in energy intensity occasioned by the use of more efficient, modern industrial processes, etc. is dwarfed by the increase in usage brought about by prosperity.[180] The power, or should we say influence of the developed world in setting architectures, standards and tastes can be seen by how follower nations struggle to do something different, and in the end, end up with the same basic architecture. This is also illustrated in the auto sector; for example, the Indian Tata Nano --- a revolution in low cost auto manufacturing and distribution --- that for all its creative genius, retained the same basic 2+2 seating layout as the world "standard" car. Likewise, despite the presence of numerous new automakers in China and literally hundreds of makers of motorcycles and scooters and the absence of innovation inhibiting issues like tightly written rules and liability concerns commonly found in OECD nations, no Chinese auto maker has successfully put forward a radically different architecture for personal transportation. This brings us back to the problem of architecture --- and the key role that architecture of systems plays in defining the field, and with it, largely defining the boundaries and borders of the possible. A coordinated, OECD-led change in the energy systems architecture is the easiest way to lower energy consumption and GHGs quickly. The next Chapter will focus on the challenges of architectural change.

Chapter 4

Changing Energy Intensive Architectures

Most of the world's modern energy system architectures originated in the presently developed world. While prices (absolute and relative) of resources are supposed to play a key part in stimulating change in the economy, in reality, as noted above, it is not self-evident that agents respond to prices as readily as economists presume once an incumbent system is architectured in. A major change in the architecture of an energy system faces the classic problem of innovators: that the incumbent or traditional energy systems using "fossil" fuels are already there, are established based on powerful interests, with a built out infrastructure that was paid for decades or longer ago, typically when public opposition to new infrastructure or major projects was much more limited, and now only requires modest upgrades and changes to keep operating. Against this backdrop comes the new entrant with products and services that have little or no infrastructure, often with unproven or untried technologies that may or may not scale, and with that, large measures of risks even at the best of times. Moreover, many new technologies that are meant to displace the incumbent are inferior based on the standard metrics used to evaluate the current system[181]. For example, there is no known way to overcome solar and wind's intermittent nature; these low energy density products will require conversion and concentration to "match" conventional energy if fed into the existing high gradient[182] energy system. Advocates of alternative energy such as solar and wind have responded to this problem by making the argument that "fossil" fuels have negative externalities[183] (or their price does not reflect scarcity), that it is finite or depleting, and have further argued that their product is cleaner[184] and can be made comparably affordable with subsidies.

4.1 "Renewable" Energy Integration Architecture

The integration of "renewable" energy into conventional energy systems is at present, handled in two principal ways. Liquid "renewable" fuels such as ethanol or biodiesel, which are deemed practical and fit for existing engines are permitted to be blended into the fuel supply in small amounts up to a mandated maximum that the population of existing engines are able to operate on. Electricity produced from solar and wind are fed into the grid and blended with conventional sources of energy and sold through the existing grid distribution system. While there are micro-scale experiments with systems that do not depend on the grid or require integration into existing conventional energy systems (e.g, a hydrogen fueled vehicle which requires an entirely new infrastructure), they are the exception rather than the norm. This is the crux of the problem. There is a fundamental misfit between the new sources of intermittent and low gradient / density energy and the existing infrastructure devised and architectured for high gradient, high quality conventional power. One workaround is to use biomass as an intermediate concentrator that produces a liquid fuel (e.g., ethanol, biofuel, wood pellets, etc.). This route has the same issue but can worked around by having microorganisms do the work of energy concentration to create a high energy density product. However, the economics of liquid biofuel production and their cost, which is generally higher than fossil fuels, preclude the use of such fuels to compete with low cost grid power.

The problems of infrastructure incompatibility manifest themselves in many ways. Solar energy that is inherently low voltage DC is captured by photovoltaics that have to convert the energy to (a minimum, above line voltage) or distribution transformer voltage (600VAC) service so as to feed into the grid and then be distributed.[185] Moreover, there is the problem of intermittency, and the nature of the intermittency. Solar energy does not match well with the normal grid peaks of early morning and late afternoon / early evening commonly seen in North American grids, though there can be a good match with air conditioning loads. Wind, on the other hand, tends to be strongest at night, when demand is the lowest. That brings it to the issue of the fit between energy supply and demand.

4.2 Energy Demand Disaggregated

A century of producing commodity products has dulled the marketing sense of an entire industry. Few question the logic or legitimacy of the ideas that electricity from the grid that arrives at high line voltages (100V+) and alternating current is the best method. Let’s go back to the fateful decision that led to the logic of this voltage and its modern version (110-240VAC). The first major practical use for electricity was lighting with carbon arc lamps.[186] Carbon arc lamps[187], and Edison’s carbon filament lamps in particular, used a DC system with a centralized generating plant and required higher voltage than later metal filament bulbs. Edison wanted to compete with gas lighting and selected 100VDC as a compromise between transmission efficiency of DC from a central station and lamp costs for his DC street lighting system.[188] This led to a bruising contest between Edison and Westinghouse, who opted for the advantages of longer distance transmission of AC, which enabled larger generating plants further away[189] to ease voltage increases (and decreases) – there was much debate about the safety of each system.[190] Elsewhere in the world, different considerations led to the standardization on 200V+ or higher AC as the "standard" voltage for the grid.[191] In heating, residences and commercial enterprises standardized on using coal, oil, or natural gas in furnaces to generate heat. Much later, electricity was introduced to operate refrigerators that replaced the ice box, and later supported air conditioning. Home electronics that were vacuum tube based initially required high gradient power. Transportation, likewise, standardized on the internal combustion engine using petroleum products and only in select instances (e.g. underground railways) were other modes of energy applied. Vehicles standardized around one of 6, 12, or 24V DC for low voltage (non-motive) applications such as headlamps.[192] The effect of this standardization on high gradient energy was profound. Early on, most of the applications required high gradient energy, but as incomes rose and energy became more and more affordable, it became increasingly used in other applications including those that have no necessity for high gradient energy. The standardization meant that alternatives that might have become competitive economically were crowded out by the relentless expansion of the electric grid and cheap energy --- abetted by mechanisms like the regulated monopoly structure that, in effect, enabled the capital costs of expansion even to remote communities to be subsidized by existing customers.[193]

The question that arises from the institutionalist perspective is, "what changed"? On the demand side, an explosion of applications beyond street lighting that would be unimaginable to Edison, his high gradient voltage standard meant that many applications that may have only required low gradient energy are instead using high gradient, high quality powered stepped down to meet their needs. For example, in North America, home heating, water heating, and clothes drying of large electricity consumers are often powered by grid electricity. They are all applications that generally only require low gradient energy --- perhaps water heating requires "step up" once cold water is warmed to near room temperature. Furthermore, many of these applications can be relatively insensitive to intermittency.[194] There is no technical reason why a majority of these needs cannot be met with low gradient, low quality energy. Furthermore, where the low gradient energy involves heating or cooling, there are opportunities to store heat in technologies such as geothermal (in ground) heat storage, which can take advantage of both daily and seasonal fluctuations in heat that occurs naturally.[195] Many applications, such as heating and cooling can be designed around intermittent power. What about lighting and home electronics? There is no longer a technical reason why lighting requires high gradient energy. Classical metal filament incandescent light can operate, albeit inefficiently, at low voltages. New technologies like semiconductor lighting require only low or modest voltage DC to generate an intense, bright, light.[196] Furthermore, semiconductor lighting can be rapidly switched on and off with effectively no impact on its lifespan, and the light output is “instant on” in nature and can be paired with sensors and control systems to automatically switch lights on and off as required. [197] In electronics, the wholesale replacement of vacuum tube based devices with semiconductor technology has transformed the world into primarily low voltage DC for a majority of electronic needs.[198] The residual set of “by necessity” high gradient energy used in an average household is for cooking and motors where the logic of transitioning from AC to DC is not clear (washing machine, HVAC, etc.). To sum up, the world has changed since the advent of electrification and the advent of AC electricity in every home. The standard AC grid system was a brilliant and great achievement. Its enormous success and low cost, and incumbent status, however, is an obstacle toward new architectures. Institutions are by their nature, hard to change --- especially when they are incumbent, work reasonably well, and by and large, satisfies most of their customers and constituents.

4.3 Technology Implementation Backlog

At the dawn of industrialization, it was not possible to track, let alone understand the nuances of demand for energy once complexity extended beyond Edison’s original streetlamp system and customers were free to “connect” any compatible device to the grid. Metering is expensive. Recall the cost of setting up meters (or filling station pump gauges), and the expense of sending out meter readers to periodically “read” the meter.[199] Today, it is no longer necessary to do so and the cost of metering, and tracking usage and demand, has fallen with the speed of Moore’s Law as computing, storage, and communication capabilities exponentially increase. The ability to track micro-level usage, and with it, the ability to uniquely price the product or service for each occasion in accordance to customer utility and other factors is in direct contrast to the industrial economic model where economies of scale and scope overrode unique preferences and quashed micro-markets. This is an enabler that empowers a century’s advances in technologies that have been developed, perfected, and widely available and are now awaiting deployment to support more efficient and effective use of energy and resources.[200] At the micro-level, it is now possible for every energy using device to be assigned a unique ID number (e.g. an IP number), and have the device communicate --- via a network over existing grid / electrical wiring[201] or via wireless networks --- its usage pattern, purpose, and other information that allows energy (and resource use) to be tightly monitored and related to the functional purpose being served. Likewise, every automobile currently made and sold in OECD nations contains the basic electronics and software to closely monitor, track, and store operational data. What does this mean for markets?

4.4 Metrics, More Metrics

Energy markets worldwide are commodity markets where an undifferentiated product is sold at the same price for each class of customers. This is based on industrial age notions of efficiency that were premised on averages and having the averages work out well, rather than any specific individual case.[202] Industrial notions that energy is an undifferentiated commodity[203] that should be sold at one price for all customers of a class is the underlying basis for the pricing of electricity, liquid fuels, an natural gas. The very idea of averaging and aggregating individual demand is key to how electric utilities can with relative ease match supply with demand. Every small individual change in demand (at each household, for example) may be large relative to the account, but when aggregated into a group, it balances out and the utility only "sees" the aggregate rise and fall and has time to adjust generating capacity to meet demand. Electricity utilities generally have relatively simple to understand tariff structures that have a few variables such as a tiered usage / charge, and in the latest iteration, time of use as a factor in pricing. But the utility is generally indifferent to how and what the customer uses the energy for once it is delivered to the house. What this means is that while there is broad concern over energy use per household, and metrics exist that assess energy use per sq. ft. (size of house), there is little issue with whether the energy use is, a) necessary, b) whether better alternatives exist, c) what can be done to manage use, and d) optimized for opportunity costs. At the residential customer's end, with the exception of large industrial and commercial customers, there is generally no provision for demand management, or "load shedding" because appliances are connected to the grid, and their architecture do not permit it to be shut down / load managed remotely. Demand management for retail customers via time of use pricing may, in and of itself, offer insufficient inducements when most customers have only limited means to move their demand around.[204]

The grid infrastructure is set to take "all comers" to meet demand at all times. Previously, the discussion centered on the lack of compelling need for high gradient, high quality energy for many applications. What about the issue of necessity? Does it make sense to use high quality, high grade energy for an application like, for example, resistance space heating when the identical job can be done more economically by natural gas heating, or by an electrically operated heat pump that "moves" more units of energy than it consumes? When the utility sells an undifferentiated product to the customer at one set of prices, the option to understand the customer's needs, and then to fill that need with the most effective and efficient method possible rest entirely on the customer responding to the price signal properly. Customers, in turn, have to choose devices and appliances based on metrics mandated by the US

Government (and adopted elsewhere) such as Energy Star Ratings, or the estimates of energy use over a period of time. Furnaces are rated by their efficiency. None of these present rating systems, which have to do with technical efficiency address the issue of whether it is the best device / appliance for the task --- which involves an evaluation of alternatives. Nor does it address the issue that the equipment has no "intelligence" that would enable it to be connected and managed for effect. This brings us to the problem of metrics, and how the existing energy system is in need of new performance metrics that reflect sustainability and effectiveness (at meeting needs) and efficiency (in the classical sense).

4.5 Metrics for Sustainability and Effectiveness First, Efficiency Next

The industrial age gave us few metrics to measure sustainability, or, effectiveness.[205] It gave us many measures of technical efficiency; for example, 97% efficient furnaces are measured in terms of energy input and percent converted to, e.g., heat at the exit duct. But what if the furnace uses a nonrenewable fuel, while other options can utilize energy sources that are sustainable (net of embodied energy and lifecycle support, maintenance, and decommissioning costs)?[206]. Similarly, vehicular fuel economy ratings are widely used and published, but give numbers in fluid quantity of fuel used / distance travelled, without consideration fore whether the vehicle is at capacity in terms of passengers or payload, or traveling with one person. It is akin to rating the fuel economy of a minivan used as mass transport loaded with its maximum of (e.g.) 7 passengers against that of a hybrid car with a single passenger on board. The metrics that are presently in use only make sense if the question of effectiveness[207] is not addressed. While technical efficiency has greatly increased in the past century, what these metrics have led us to is Jevon's Paradox.

4.6 Jevon's Paradox with Declining Prices

Jevon's Paradox was originally formulated in 1865 and suggested improvements in efficiency may not lead to lower, but higher consumption as users of energy adapt to the improvement and just use more. It is a formulation that is troubling and not generally accepted in the literature. But it is of sufficient importance, particularly in terms of its empirical support to warrant consideration and caution. Jevon's formulation was summarized as: "with fixed real energy prices, energy-efficiency gains will increase energy consumption above what it would be without these gains".[208] While it may not be completely true empirically, world energy prices, measured over a century, have fallen in real terms, and sharply fallen measured in terms of the income of the richest population of the world, which mostly reside in the OECD nations and who are the consumers of modern energy. Angus Madison, noted that "Over the past millennium, world population rose 22-fold. Per capita income increased 13-fold, world GDP near 300-fold."[209] However, per capita incomes of the world between 1950-73 rose 3% annually while GDP grew 5% per annum. Madison noted that post "Golden Age", per capita incomes still rose at a little less than half this rate.[210] How does this compare to energy prices?

Prices for whale oil peaked about the middle of the 19th Century, and then actually fell in real terms as competition came in from town gas, kerosene, and other sources of illumination.[211] Petroleum prices fell in real terms from the 1870s and only saw an uptick between 1973-78 and more recently between 2000-08.[212] Coal, a commodity that is less able to cartelize, also showed a steady fall. Zellou's recent study of long-term price trends from the 1800s onwards concluded that,

> "… real coal prices trending downward and crude oil trending upward in the post World War II period. Indeed, real crude oil prices have increased at an average rate of 2.0% over this period. This suggests that the ongoing tug-of-war between depletion, exploration and technological change is playing out quite differently for these two energy commodities. "[213]

The one energy commodity states (governments) are most able to control, monopolize, seize the resource rents and discourage consumption via excising and other forms of taxation, producers are only able to increase prices an average of 2% per annum from the post-WWII period. During the same period, global GDP and per capita GDP rose well above this rate, resulting in declining shares of income spent for the most expensive of energy sources --- oil. Coal is now known to be cheaper in real terms. Energy from natural gas, nuclear and hydro, while not part of this data set, is known to be nominally priced well below the price of oil. While there may be doubt with respect to Jevon's paradox formulated as a function of flat real prices, there is little doubt that declining prices of energy of the magnitude described (2% annual growth in real terms for oil and much less for other forms of energy vs. per capita GDP growth of 3% (1950-73, <1.5% 1974-Present, and world GDP growth of 5% annually) is a major stimulus to increased consumption. Empirically, the extent to which low prices have stimulated consumption can be seen in the history of growth in the use of modern energy.[214] Given the recent revolutions in shale oil and shale gas and the anticipated explosion of worldwide supply of oil and gas, it is likely that the price signals for these resources, in the next few decades, is unlikely to send a sufficient signal to deter demand --- especially when their customers are mostly locked into, and continue to lock onto the oil and gas architecture and infrastructure for the long term.

4.7 GHG Policies and GDP Growth

The perspective from these trends affirms the predictions of the Kaya Identity that showed GDP growth and modern energy consumption go hand in hand. It is a given that the modern political elite in almost every nation around the world is ideologically committed to the notion of continued economic growth (measured by GDP/GNP) for their economies. Proposals to limit GHGs that will likely have large negative impacts on GDP growth, which is a non-starter --- especially in the fragile economic and fiscal environment faced by nearly all major governments around the world. What are the GDP impacts of current policy instruments? There are four major policy instruments and six other ones identified by the Australian Flannery and Hueston Report[215] that comprehensively surveyed instruments on the table for mitigating GHG emissions. They are all, in the neoclassical economic tradition, market based:

- "Feed-in-tariffs" (FIT)
- Renewable Portfolio Standards (RPS) / Renewable Fuel Mandates (RFM)
- Carbon Taxes
- Cap and Trade

Additional approaches are:

- Energy efficiency standard
- Fuel content mandate
- Direct government spending
- Investment in research and development
- Subsidy or grant
- Labeling scheme"[216]

As discussed earlier, market based solutions that are premised on agents responding to market signals have not been well received. It is only with great difficulty that a few nations have implemented them. As of 2013, it is projected that carbon pricing will only cover about 33 nations plus 18 sub-national jurisdictions and cover roughly 850 million people, or 30% of the world economy, or 20% of emissions.[217] The price of carbon in these schemes is nominal. But to truly deter demand growth for energy, prices have to rise in real terms at least equal to income growth and, ideally, should rise much faster than income growth to deter consumption. Proponents of carbon taxes acknowledge that a tax in the order of $200/ton is the range required to materially change behavior. However, on a practical level, no jurisdiction in the world has implemented a carbon tax, or implemented any other mechanism that is remotely close to this level[218]. Furthermore, it is improbable that in the next few years, such a drastic change in taxation of a formerly free good is likely to transpire unless there is a legally binding treaty in place around the world. To date, while other approaches like fuel efficiency standards have delivered limited gains and labeling has raised awareness, it is unlikely that these approaches are going to sharply reduce carbon emissions unless they materially impact GDP. The question of how GDP/GNP is calculated is key to understanding underlying institutional issues.

GDP is calculated using three principal methods. The “spending method” sums up all expenditures by consumers on goods and services in the domestic economy (net of exports and imports). The “income method” sums up the incomes of everyone and organizations. Last, the “production method” adds up the value of goods at each stage of production. While national income has been intermittently estimated, it was only in the aftermath of the great crash of 1929 and the subsequent depression that measures of National Income became regular and official when the US Senate requested national income data for 1929-31 from an official agency (National Bureau of Economic Research) in June 1932.[219] However, the methodology is by nature an index of transactions in the marketplace that methodologically excludes many non-market transactions. Subsistence farmers that chose to grow their own food and not participate in the exchange economy with the exception of trading small quantities of their surplus for cash needed to pay taxes and purchases a few implements, would have the majority of their economic activity unrecorded by the system of national accounting.[220] Neoclassical economists would retort that is not material because income not expended by having “internalized” production would be spent on other things that are recorded if the assumption that consumers maximize utility were to hold --- which may or may not hold. Let’s give this proposition some further consideration: suppose a person invented a method to (at little cost) capture a local source of energy (e.g. the classic windmill or low head hydro), and provided for their entire household needs via that method. The financial cost of this occurring on a large scale is neither negligible nor insignificant to the utilities that would have otherwise have had the revenues from supplying this customer. Thus, the consequences of self-sufficiency in energy by a large number of potential customers are not just a GDP growth problem. It goes to the heart of the size of the utilities market and their growth potential.

4.8 Institutional Bias for Growth

The bias for growth is built into any large, public or private company or organization.[221] Previously, it was noted that growth is built into the system at the macro-level in terms of requirements for GDP / GNP to grow as a central tenant of political legitimacy of regimes in the 20th century from the Great Depression onwards. Many of the institutions of a modern OECD state, in fact, rely on a growing economy to support fiscally unsound policies, such as accumulating an outsized debt load from public spending, in anticipation that the relative size of the cumulative deficit would be reduced by a growing economy.[222] Countries in OECD, thus, rely on growth, if necessary secured by immigration, to bolster the economy and to avoid the stagnation or exhaustion in countries that sharply restrict immigration.[223] At the firm level, public companies are held to the discipline of stock markets, where investors seek an attractive combination of revenue and / or earnings growth, risks to choose where to invest. In the absence of these financial market pressures for growth, e.g. in the case of public monopolies, there is always a natural inclination of all organizations to want to grow. Growth provides those higher in the hierarchy with benefits of greater perks, more resources to manage, and advancement.[224] At a minimum, most organizations have strong biases toward preventing decline --- or reduction measured by the standard metrics of revenue, headcount, etc. and such reductions tend to be utilized typically when an organization faced setbacks.[225] Declines mean that growth that papered over mistakes result in the problems being magnified.[226] Managers and leaders everywhere are prized for their ability to defend their organization.[227] The defense of an organization can often take on forms and behavior that may be economically "irrational" for the firm.[228] Yet, the behavior is known to persist.

If organizations show growth, or at least, a bias against decline that is core to their behavioral pattern, and the defense of the organization's have a not necessarily economically rational component, then it makes it much more difficult to formulate an explicit policy that requires such growth to be halted, or to decline. Returning to the modern energy industry for a moment, the behavioral impetus of the industry is biased toward growth at many levels. At the production level, owners of fossil fuel resources generally show little concern with the depletion of their assets and the necessity to pay for costlier replacements unless comparable resources are found at similar or lower costs.[229] The end result is that current prices of resources are always governed by near term (e.g., spot market or contract (typically one year)) supply and demand, and longer term considerations of replacement costs rarely factor into the picture despite the well-known long transitional periods for new energy systems --- or the cost and timeline required of transitioning from one to another conventional system (e.g. natural gas to oil, etc.)[230]. With governments and firms both heavily dependent on revenues from conventional energy sales, and consumers with growing incomes that can afford it, there is realistically, no impetus for the system to limit growth, or to reduce production. The schemes described above to alter this behavior (e.g. carbon pricing, etc.) should in neoclassical economic theory, work over time in reducing overall demand.[231] But the question is, is it too little too late given the known lengthy times required for energy transitions?

4.9 Carbon Taxes: Too Little Too Late?

Resistance to change in any system of institutions is natural. If limiting GHG emissions is indeed a high priority for the international community, then it begs the question as to whether the current “standard prescription” is sufficient to achieve the amount of reduction in GHGs in a timely manner to prevent climate change beyond 2°C. Given the lack of consensus to fully implement the existing protocols pending a binding target by 2015 and implementation by 2020, it is likely to be too little too late. At best, even if carbon taxes in the $200/ton range were fully implemented today, and economic actors responded to the price signal quickly, it may still not be sufficiently fast to alter the trend line. The question then becomes, what are alternatives that can be implemented in a relatively quick timescale in the absence of carbon taxes / cap-and-trade being effective? The next chapter address: ‘What sort of program is required to successfully and simultaneously solve the technical, public policy, and economic problems inherent to the current system while meeting interests and achieving logistical feasibility?’

Chapter 5

Feasibility and Logistics

Logistical hurdles to mobilization are the first challenges to feasibility any major program that targets rapid reduction of GHGs. Mobilization of any society's resources, as in times of war, is in and of itself, an intricate and difficult task. It is extremely rare for new technologies to be successfully deployed within a short timeframe unless decades are spent establishing a feasible implementation strategy beforehand.[232] Even then, the applied engineering required to turn a feasible concept into a practical device, which includes validation and testing, ironing out production bottlenecks and the normal teething problems inherent to first-time production, can consume both time and resources.[233] Given the urgency of deploying lower GHG emitting technologies, there is simply no time to consider any technology that is not proven, off the shelf, and cannot be readily rolled out (with the considerable known and unknown problems of scaling up production and deployment). There is a historical precedent for this in energy. In the aftermath of the first oil crisis, France and England both embarked on crash programs to deploy nuclear energy to replace unreliable supplies from the Middle East. The UK opted for a risky, bold, new technology called Breeder Reactors at Dounreay.[234] France, on the other hand, under the Messmer Plan licensed an existing Westinghouse design, and mass-produced it leading to France becoming the largest nuclear reactor operator in Western Europe while Britain's program failed.[235] So it is with the current urgent need to reduce GHGs --- there is simply no time for untried technologies to be rolled out on a large scale. Whereas fiscally, OECD nations might have been able to afford the financial costs, risks and long slog and travails from prototype to scaling up untried technologies, there is simply no time and less money --- solutions must be practical and largely proven technology, capable of advancing from basic priniciples to production and deployment from Day 1.

5.1 What Are Proven Technologies?

Proven technologies are defined as technologies that meet the test of both technology and manufacturing readiness. Technology Readiness Levels (TRL) are classified by US-DoD on a 1-9 scale, and in order to be considered, a given technology must rank no lower than 6 on the scale.[236] A technology that is ready, however, does not necessarily mean it is manufacturable. A Manufacturing Readiness Level (MRL) of 8 is required on the US-DoD OSD MRL Deskbook Version 2.0.[237] By these definitions, a technology has to move from basic principles that can be reliably observed and repeated, to formulations as to how the technology can be applied, followed by experimentation and proof of concept, validation in a laboratory setting, to field trials, pilot testing in operational environment, through to qualification.[238] Manufacturing Readiness Levels, on the other hand, are defined by having a good Material solutions analysis, demonstrated manufacturability in a production environment leading to pilot line capability.[239]

The perspective of logistical and practical feasibility goes to the heart of why climate change negotiators have not been successful in reaching a legally binding agreement. At no time in the climate negotiations has the logistical and practical feasibility of targets (which were set by the scientific community – IPCC) been addressed in the context of known, proven solutions.[240] The economics community gleefully appeals to the "invisible hand" of market forces, without any hard questions asked as to precisely how an engineered solution is to be developed and deployed logistically. It is not a surprise that politicians and climate negotiators have met with skepticism as to the practical feasibility of the GHG goals and recoiled at the consequences of making a legally binding commitment. The approach here will only put forward binding targets that have at least, a plausible logistical plan with TRLs and MRLs that pass muster and have been published and independently reviewed.[241]

5.2 What can be done?

The above discussion suggests that a rapid reduction in GHGs cannot rely on new technologies. Indeed, the timeframe is so short that deployment of proven technologies (e.g. civilian nuclear reactors) with long leads times[242] is not likely to have sufficient impact to cut GHGs at the rate and volume required to meet IPCC recommended targets. This leads us back to the question of what can be done with methods and means that are rapidly deployable and can have a large effect over a very short period of time. Over and over again, the discussions about modification of behavior via economic "carrots" and "sticks" that would be sufficient to materially change GHG emissions have floundered due to public opposition to large across the board increases in costs like a carbon tax. The present instruments of RFS/RPS have, in general, been costly. Unless the costs of those programs were to decline sharply, they are unlikely to make more than a small contribution. The question is, what then?

Institutionalism teaches us about the importance of history --- in understanding it, and recognizing how we are both confined and limited by historical legacies. In many instances, the legacy of history is just that --- a legacy that can be altered at will under the right set of circumstances.[243] But these circumstances tend to not just happen, they often involve an intricate dance between interests, laws, economics, and technologies.[244] So it is with major institutional changes. What is the art of the possible? The present ways in which energy (broadly speaking) is used in the OECD originated from an age of plenty that saw increasing per capita incomes, economic growth, and slow growing or declining real energy prices. It is no surprise that OECD economies have standardized on modes of use that presumed, at best, fixed or slow rising real prices. But suppose we are to go to a clean sheet and ask, what is the art of possible if energy prices were in fact, two, three, or five times higher? What would change? The logical answer is that OECD economies would be much more energy efficient. The question is how to get there.

5.3 Implementing Energy Efficient Architectures

Incremental architectural changes that improve energy efficiency are the current modus operandi in most OECD jurisdictions and in most policy areas.[245] While these changes are generally positive and all OECD nations demonstrate a decline in energy intensity,[246] the progress is insufficient to achieve the level of GHG emissions necessary to make a major difference in climate change. The question then becomes, what changes will make a major difference in a short period of time? Architectural changes, by their nature, can potentially offer a sharp break from the past. By creating new architectures, many of the legacy problems can be addressed. It is beyond the scope of this dissertation to offer but a few examples of the realm of possibility offered by architectural changes. Below are two examples, one in personal transportation, and the other in residential building energy consumption, that are examples of what is possible should an architectural approach be taken. Changes in architecture, however, will involve coordinated change of public policy / law; technological / engineering challenges; economic / financial structures, all the while maintaining a degree of realistic logistics and satisfying key interests at the same time.

5.4 New Transportation Architecture

Transportation accounts for one fifth of energy usage within the world economy. [247] In advanced OECD economies, personal transportation accounts for a large share of that, most of which is used for commuting. By far the simplest solution would be to implement an architectural solution that cuts the amount of fuel used in the daily commute. The world has standardized on the 2 front seat abreast form factor; this has been the case from Roman times onward for both military and official traffic. In its modern form, the roads were standardized in England post 1726 when the British Crown began to centralize road building and specifications with funding from the Parish via rates that by 1843, resulted in roads were standardized in construction (gravel / stone bed 10 inches thick, and 20ft wide, with a raised center to permit water runoff).[248] While this standard may have made sense when bulk transportation of goods by animal or manpower at slow speeds was the norm, the standard is ill suited to high speed transportation of one or two persons that account for a majority of modern commuter highway traffic.[249] Converting a large share of this stream to half width (or narrow width) vehicles that are formatted to carry two persons in tandem seating can have a large impact on energy consumption as quickly as capacity can be added.[250] This kind of solution is technically feasible, if it were to be utilized and deployed quickly, the easiest means will be to power it with an off-the-shelf internal combustion drivetrain (diesel, gasoline, natural gas, etc.) and a body structure built with existing uni-body technology rather than to iron out issues with more radical technologies. With frontal cross sections of 50% or less than a standard 2 abreast commuter car, and weight reductions of at least 1/3 from even the most economical "standard" car, it goes without saying that such a vehicle if deployed in sufficient numbers quickly can slash commuter fuel consumption considerably. This is but one example of the kind of architectural changes that is within the realm of the feasible --- if other issues, from marketing / customer acceptance, etc. can be solved.[251]

5.5 Building Energy

What about energy use by buildings? Residential buildings are one of the largest consumers of energy in OECD nations. But it doesn't have to be that way. Germany and many other nations have successfully demonstrated that "Net Zero" residential buildings are practical and feasible[252]. That is, buildings that consume zero energy net of what they produce themselves for only a small increase in construction costs.[253] Furthermore, it is likely that the same technology can be devised to achieve near net zero for commercial buildings in the same timeframe.[254] Energy audits have repeatedly shown that the largest consumers of energy in OECD nations are for home comfort, or HVAC (heating and cooling), followed by hot water heating, then cooking, lighting, etc.[255] Whereas in the past, these were all serviced by high gradient energy appropriately stepped down for the need, the needs can just as easily be met by low gradient and intermittent energy such as solar or wind, with supplementation by conventional energy sources.[256] Furthermore, advances in low-grade energy storage by techniques like ground source geothermal and heat pumps are practical, and already deployable options.[257] To sum up, the technologies to slash new construction in single-family residential buildings to the Net Zero standard is already available --- technology is off the shelf. It is not a technological or manufacturability problem for the most part. It is an economics and policy issue.

5.6 Driving Policy: New Economics Needed

The abundance of viable technological solutions that meet the technological and manufacturing readiness test do not address the issue raised by the efficient market hypothesis: why has it not already been done? The answer is that efficient markets in fact only exist in the fertile imagination of the minds of economists. In the course of research for this thesis, numerous examples were found of engineering anachronisms that persisted long after their justification became irrelevant. As the example of the persistence of the QWERTY keyboard shows, it requires a large economic gradient to compel change even in the face of inertia, economic, technical, and self-evident irrationality. Humans are creatures of habit, and the kind of economic inducements being talked about, like carbon taxes --- are plainly insufficient nor can government and consumers afford the large subsidies to bring forward “clean” mandates. A new, or at least different economics is necessary to compel change.

What are the elements of the new economics? It is clear that part and parcel of the change is prices of energy from “fossil” resources must rise sharply. However, to date, price increases (e.g. $200/ton carbon taxes) from carbon taxation proposals have been largely notable for their failure to be implemented. The alternative is to phase in the increase on a model that aims sharp price increases at the place where it can be engineered in --- new vehicles or new construction. A viable policy might envision a two-tiered policy (between “old” and “new”) where prices for the identical product can be sharply different. This model has been successfully used, for example, in labor contracts where existing incumbent workers are paid much higher wages than new hires.[258] The key to being able to do so is to differentiate between the supplier or consumer (e.g. individual worker) and their status. Whereas in the past, in energy, it was not possible to distinguish between individual suppliers and customers, technologies to do so are now so advanced that not only can individual customers and suppliers be distinguished, but it is technically possible to set different prices / supply for different applications of energy within one customer. For example, vehicles made after a certain date / model year can now be charged a different price for fuel based on data that is routinely captured and stored in the vehicle’s engine computers.[259] A sharply higher price can thus, be phased in for the newest vehicles without affecting the oldest --- and least efficient ones. Such monitoring can also, for example, allow the efficiency of usage to be monitored --- and a person traveling with a mostly empty vehicle with a large number of unfilled seats can be charged a different price or penalized with taxation for inefficient usage. At the household level, it is now easily within the realm of possibility for every individual electricity or energy consumer to be assigned a unique IP address, and their usage individually monitored and billed at different rates[260] and for their demand to be controlled to regulate demand.

On the supply side, there is no longer any need to treat supplies of energy as an undifferentiated commodity. It is technically possible, for example, to uniquely identify the source of every barrel of crude oil[261] or natural gas by its unique hydrocarbon signature by oil field, or for even more ready identification, every barrel of oil or cubic meter of gas can be uniquely tagged. Being able to do so means that, for the first time, it is possible to exercise a degree of control over both production and consumption that is unimaginable to economists as recently as two decades ago. No longer do primary energy sources, and energy in general, need to be an undifferentiated commodity, nor do consumers need to be an undifferentiated "demand" whose usage is a "black box". The ramifications are that an infrastructure can be architectured to, for example, control supply or manage demand to a degree unthinkable in the 20th Century. That leads us to the art of the policy possible.

5.7 What about Interests / Stakeholders?

Changes in laws and policy are always constrained by the art of the possible. Traditionally, the conventional energy industry, as one of the most powerful interests in the world, has been able to limit the impact of new regulations and prevent any abrupt change in their business.[262] Given the size, scale, and scope of this industry, and the structural dependence on this industry by governments and consumers, without the consent of this industry, realistically no major change is possible. The question then becomes, how can the industry's consent be secured for a change that will materially affect and alter the demand for their product in the negative? The answer is to alter the economic system based on limitless resources at low cost that is part and parcel of the present conventional energy industry architecture.

The "fossil" fuel industry has historically overproduced, and suffered from severe priced declines. In fact, the world is likely within a few years of another major price crash for oil,[263] as it already happened with natural gas. With a price collapse possible, oil and natural gas interests, are ready to consider a different economic model to save them from themselves. Such a model can take the form of placing existing "fossil" fuels like oil, gas, and coal under a form of managed supply, whereby in exchange for an agreement for the industry to cap their overall level of production of CO_2 (including CO_2 generated at consumption)[264], that the industry will be relieved of their obligations under existing antitrust laws.[265] In a single stroke, the industry will be freed of the need to increase the production of conventional energy, as there will be other, better pathways to improving profits --- raise prices.[266] The industry is likely to continue its trend toward relatively moderate prices increases for existing customers even in the absence of antitrust.[267] Thus, that, in and of itself, will not address the need for sharply higher prices to force the acceptance of a new energy architecture.

To force the rapid adoption of new energy saving architectures, the conventional energy industry can be given a mandate designed so that it is compelled to sell fuel to new customers – defined as new vehicles or households or commercial customers (past a certain date) at sharply higher prices that are sufficient to lower consumption. Meanwhile price increases for existing customers can be grandfathered or price increases moderated.[268] Sharply higher prices would mean a multiple of at least two times current North American prices, sufficient, for example, to force the transformation to make the tandem seat commuter the standard vehicle of choice, or for the wholesale conversion to Net Zero homes. A policy instrument such as legal minimum prices[269] for new customers can achieve this means. Because only new customers / new construction are targeted, and existing customers are "grandfathered", there will be less strident opposition to the scheme. Such a proposal can initially exempt industrial customers, who have the power to "break" any such proposal as they did when they all received free permits under the European cap and trade system.[270]

Concurrent with a plan to sharply increase prices is the mandatory requirement for vehicle makers to introduce new vehicles on the new format, and the implementation of building standards that sharply reduce energy use. On a policy level, it may make sense to have the consumer realize a net saving in energy costs (e.g. a cut of 10%) despite the much higher prices charged for new customers. Of course, the new lower energy consuming Net Zero homes and half width vehicles will mean many other major changes. Net Zero homes will be more expensive to build and it is not clear that a compulsory change in the building code can be easily be done. Much of the objection by builders will be muted if it is understood that it affects all builders equally in an entire jurisdiction. Indeed, it is possible to deliberately drive up the price of non-Net Zero homes by refusing non-Net Zero compliant buildings government supported loans.[271]

Bringing forward a new architecture, e.g. the half width cars, or Net Zero construction, will not be a smooth transition. Many problems will need to be solved to smooth the path to consumer acceptance. Some of the problems that will need to be solved may include whether the users of this new format will be charged the same insurance rate as a regular car? Or how to handle the expense of having to keep a second "standard" car around for when additional capacity is required.[272] Seemingly simple problems like parking --- whether this new format will be granted favorable rates --- or the availability of incremental new spaces especially if the vehicle is a "second" car to supplement an existing "standard" car, are just some of the problems that must be solved on the pathway to consumer acceptance.[273] In the past, acceptance of different technologies or behavior, like hybrids or car-pooling, was supported by large per unit subsidies as well as things like access to scarce "car pool" lanes. No doubt such "push" will be necessary for this program to succeed.

5.8 Why Bother Change?

The idea that architectural change can substantially alter mankind's need for natural resources is not new. Ernst von Weizackere, in Factor 5 (Club of Rome), identified that it is possible for the world to restructure the economy to improve resource productivity by 80%.[274] The question is, why bother when for the moment, there is an abundance of resources? There is no known way, using current technologies, to have a significant fraction of the world move quickly[275] to the present modern energy system without making the predictions of alarmists about resource depletion or explosive price increases come true.[276] Whether there will or will not be a resource depletion problem for the future is difficult to say without speculation on technical progress and the art of the possible. However it is known for certain that any reduction in resource intensity and usage will create options. Thus, a compelling reason to sharply lower energy use, and with it GHG emissions, is that by lowering resource intensity, it creates options for the future. By doing so, it also enhances security of supply because in the event of a true emergency, it is always possible to fall backward to more resource intensive methods. Industries with compelling security needs have always paid a premium price for security of supply.[277] Suppose for a moment that optimistic projections of man's ability to invent and implement resource extraction techniques were to falter or fail --- that can lead to crisis in short order. By expanding the supply of presently necessary resources economically recoverable at a given time, we can provide future generations with options. Options require a premium to be paid in the present for a future requirement, which may or may not be needed. The broader and longer the option, the more costly it must to be.

Options are expensive. They are costly because it normally requires an "up front" payment of a premium in order to secure it. In terms of natural resources, stockpiles have historically been costly and in many cases, become obsolete as supplies of once scarce resources become plentiful or the need for the material is superseded.[278] Salt, for example, was scarce right up to the discovery of large underground deposits in the Great Lakes. The creation of a world market for many commodities further undermined the rationale for paying premiums for improvements for security of supply.[279] The world resource industry has done an admirable job of providing resources. Since industrialization, prices of resources in general have fallen over time in real terms. Thus, the historical trend informs us that paying a premium for an option to purchase natural resources at above market prices that presume an increase in the real price is likely to be a bad bet --- so why make one?

There is no compelling argument for rapid change based on neoclassical economics except via the value of purchasing options.[280] A more compelling argument than to create options for the future is "because we can." We have seen how under the present economic system, increasing wealth leads to increased consumption of energy because we can afford it. The OECD nations have another pivotal role in the world economy --- which is the role as world leaders in setting the standards and architectures for the rest of the world combined.[281] The power of developed industrialized economies can be seen by how every economy that followed by and large adopted Western standards in most fields, from the idea of the public sewers, highways, airports, and the "standard" car, and with rare exceptions, the West have basically created and defined the architectures of modernity for the world. To date, no major non-western nation has imagined a different future and successfully implemented it.[282] OECD nations, by taking the leadership role in this endeavor, will revolutionize not only energy consumption in OECD, but also provide a different definition of development that is both more sustainable and affordable to the rest of the world. How?

Suppose the half width vehicle and Net Zero architecture became OECD standards for new construction and new vehicles. That, in turn, will define elite tastes,[283] and make the "reach" goals of using less resources be a positive, rather than the current economic system's implicit denigration of using less as something for those who are less wealthy.[284] Such a transformation has gradually taken place in the "standard" car segment, where once upon a time, the industry expressly equated small cars with small profits.[285] That was until automakers like Lexus demonstrated how relatively small cars can earn large per unit profits. Once the truly efficient half width vehicles become a standard, it can gain acceptance in the rest of the world, which may or may not elect to implement the differential energy price system discussed above immediately. Without the higher fuel prices, the vehicles in that format can become very affordable.[286] This kind of architectural change can happen without any apparent economic need to do so. It can happen for many of the wrong reasons --- such as the obsolescence of an entire infrastructure so as to create jobs by building a new one. With the OECD economies mired in slow or stagnant growth, such a broad program of new ultra efficient energy infrastructure building will be a major drive of growth like how rearmament and war boosted the world economy out of the Great Depression. Historically, there is a precedent for change not because it is needed, but because we can, when the Royal Navy, at the turn of the 20th century, obsoleted the world's largest fleet of modern warships by building a new, modern ship called the H.M.S. Dreadnought. Likewise, America, at the onset of World War II, obsoleted its own fleet of battleships with Aircraft Carriers, and are now in the process of obsoleting their manned platforms with autonomous unmanned craft.[287]

Chapter 6

Conclusion:

Leveraging Defense Energy Strategy into the Civilian Economy

In a world of networks with relatively limited geographic and logistical barriers, the weakest node will be the highest value targets. During the cold war, the US and Soviet Union was able to come to agreements that largely prevented attacks on the "homeland" except by nuclear weapons systems in an all out war. The degree of cooperation and accommodation is such that both sides expressly agreed to not make provocative moves and took steps to prevent accidental war --- knowing that both nations were within less than 1 hour's flight time by Intercontinental Ballistic Missiles (ICBMs) and much less by Submarine Launched Ballistic Missiles (SLBM). This unwillingness to risk war extended to conscious decisions to not launch weapons like ballistic missiles armed with conventional, as opposed to nuclear warheads because it is impossible for the other side to determine whether the "en route" missile is nuclear tipped or not --- and is likely to react by pre-emptively launching nuclear tipped ICBMs before they are destroyed. The consensus extended as far as to, until recently, limit the deployment of anti ballistic missile systems (ABM) to one city each. In the aftermath of the cold war, this comfortable arrangement became obsolete, and the US unilaterally withdrew from the treaty in 2002 and started to develop and deploy ABM systems. Additional players have now joined the nuclear "club", including China and others that were outside of the US-Soviet consensus who do not share these concerns. Still others are developing conventional and nuclear tipped ballistic missiles, and hypersonic and supersonic cruise missiles; it is clear that within a few decades, North America cannot count on the restraint exercised by the Soviet Union in preventing accidental nuclear war. Countries like China are expressly developing ICBMs that are as likely to be conventional as well as nuclear armed. It is no longer possible to believe that in the event of the US and NATO allies using force against a middle power, that North America will be safe from attack unless one were to assume the widespread deployment of nearly "leak proof" ABM systems. Thus, vulnerabilities in the civilian sector are very much the weakest link in the US and allied defense complex.

How fragile are the energy systems of Canada and the US? With the exception of specially hardened and protected parts of the system, much of the civilian sector is unprotected. As was illustrated by 9/11, it is possible to cause widespread disruption by targeting a few vulnerable civilian nodes. For example, conventional precision attacks on the infrastructure of a few staging areas (ports, airports, etc.) in North America can disrupt US and allied efforts to mount an expeditionary force. In the past, countries capable of doing that were nuclear-armed powers, but within a matter of decades, many other middle powers will have the capability to mount such a strike by conventional and nuclear means. The idea that the North American continent can be subject to nuclear as well as precision conventional attack by another state (as opposed to terrorist attacks like 9/11) is something that Americans have not grappled with since WWII, when US shipping was attacked off the coasts, and a very few minor instances of attack on the North American mainland occurred. How to reduce this vulnerability?

North America has not seen war at home in over a half century. Thus, virtually every installation outside of the select hardened installations (e.g. Command and Control bunkers for nuclear war) is ill prepared. Moreover, with the extensive electronization of life, something as simple as disruption of the internet - not just via cyber attacks, but via physical attacks at key nodes – can result in major disruptions in an economy that takes reliable internet as a given. Energy systems are no different, as the past century of reliable power and fuel supplies resulted in almost every civilian installations designed with the assumption that power is rarely out, fuel rarely unavailable.

As discussed earlier, there is not an economically compelling reason to change the civilian sector. The present energy system works, it is inexpensive, supply of economically practical to recover mineral fuels are assured for over a century, and GHGs can be mitigated with any number of means while remaining on existing hydrocarbon fuels or coal. "What will it take?" to architecture a new set of resource conserving solutions that can conserve energy while greatly expanding opportunities for economic growth. This work demonstrated that once an architectural solution is created and gains acceptance, it becomes an institution, and as such, it co-develops along with its own sets of rules, regulations, economics, logistics, and interests. Once established, even as the reasons are no longer appropriate, it is very difficult to alter architectures. Yet at the same time, architectural changes, especially if it is done with existing technology and infrastructure, are the quickest, lowest risk pathways to change to a lower energy, and resource consuming system if the engineering / architectural “design lock in” gradient can be overcome. The thesis demonstrated that it is practical to change at least two areas, personal commuter transportation and single family residential housing, that slash their energy consumption to a fraction of pervious levels. Furthermore, it is possible to get a buy in from conventional energy producers for such a program if the rules of the economic game were altered in their favor. Likewise, public opposition to large-scale change can be mitigated by phasing in changes slowly with proven technologies that can be deployed to much better manage energy / resource use and tie it to economic effect. Whether such change will come, however, is a function of not economics, but whether leaders of the industrialize world can imagine a vision of a better future, and implement the plans to realize it. Since there is little political or economic reason to drive the change, the question is, can other major institutions drive the change?

Historically, the DoD has shown keen interest in energy in terms of security of supply. From the outset, petroleum was deemed to be the most critical of supplies as distinct from coal, hydro, and other sources of stationary energy. Petroleum was important because the American forces relied on it for mobility from the 20th Century onwards. During World War I (and WWI), in order to ensure adequate supply of war materials and petroleum, President Wilson created the War Industries Board in July, 1917, under which the National Petroleum War Service Committee (NPWSC) was established.[288] After WWI, this organization was reorganized as the American Petroleum Institute (API), which continued the function of ensuring adequate supply by creating the first definitions of proved oil reserves which was in turn, used in the annually published estimates of US oil reserves. During World War II (WWII), the US established the Petroleum Administration for War under EO 9276, which in turn, separated the nation into Petroleum Administration for Defense Districts (PADD)[289] which became Petroleum Administration for Defense (PAD) during the Korean War, which became a part of the US Department of Interior in 1954.[290] Thus, military leaders have historically been keenly aware that America’s military forces and that of NATO allies are dependent on the availability of liquid fuels to accomplish their mission.

The US-Department of Defense ranks as one of the largest consumers of energy in the world, using about 5 billion gallons of fuel in 2010. Consumption by service breaks down as Air Force, 57%, Navy, 34%, Army 9%.[291] Consumption at this level is during peacetime, with modest operations in the Middle East. Operational Energy Strategy is jointly managed by DoD with each of the service arms operating their own programs. DoD is perhaps the only organization large and influential enough to establish new architectures in energy, and then easing it into the civilian economy as the infrastructure is proven and manufacturing tooled up to build out the civilian sector.

What can the DoD do? The DoD, especially the US Marine Corps (USMC), is currently the world leader in reducing their needs for energy for expeditionary forces. Many of their "off-the-shelf" ideas such as solar cells to recharge batteries in the field, can readily be adopted in the civilian sector --- for example, by making every auto/truck roof top, or every hand held electronic device equipped with solar panels. A DoD requirement for such gear can ultimately percolate down to the civilian sector. Likewise, expeditionary forces consume large amounts of energy for things like making potable water and hot water heating. The ideas being currently implemented can be readily moved to the civilian sector providing that there is an impetus (either market or regulatory) to make such changes in regimes like the building code, or similar standards like the Energy Star rating system or the Corporate Average Fuel Economy (CAFE) program.

The DoD is a leader in recognizing that the commodification of energy is a major problem in mis-allocation of resources. The Fully Burdened Cost of Energy (FBCE) literature demonstrated that in fact, fuel delivered to remote areas, way stations, rack up along the way costs that in fact, make many alternatives (e.g. solar, wind) economical even before defense specific considerations like enemy action and causalities are factored in. Widespread adoption of these concepts in decommodification of energy and routinely looking at the economics alternatives is something that is not only feasible, but doable within a relatively short time --- a decade or less if it is rolled out as standard considerations for all new construction of buildings, vehicles, etc.

To conclude, the question is not whether DoD can play a leading role to transform the US economy into a far more energy efficient, and secondly, more resilient economy. It is whether or not the DoD recognizes the opportunity to do so and act on it.

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Notes

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[1] Andrew F. Krepinevich, President of the Center for Strategic and Budgetary Assessments, identified the major downward change in resources, rather than catastrophic failure, as the more likely reason for the Pentagon to change its behavior. See: Sweetman, B., 2013. Defense Cuts? Bring Them On. While budgetary pressures are reducing resources, the cost to project power is rising. See: Krepinevich, A., 20121. Strategy in a Time of Austerity. Foreign Affairs.

[2] For the purposes of this study, conservation and efficiency are limited to issues of energy, but the concepts are widely applicable to resources in general and, in particular, natural resources.

[3] See: SECDEF Memo "Specifications & Standards - A New Way of Doing Business", DTD 29 Jun 94 https://acc.dau.mil/CommunityBrowser.aspx?id=32397

[4] Gansler, J.S., Lucyshyn, W., 2008. Commercial-Off-the-Shelf (COTS): Doing It Right. DTIC Document.

[5] Alic, J.A., 1992. Beyond spinoff : military and commercial technologies in a changing world. Harvard Business School Press, Boston, Mass.

[6] Gansler, J.S., Lucyshyn, W., 2008. Commercial-Off-the-Shelf (COTS): Doing It Right. DTIC Document.

[7] Wilson, C., 2006. Improvised explosive devices (IEDs) in Iraq and Afghanistan: effects and countermeasures. DTIC Document.

[8] Stillion, J., Perdue, S., 2008. Air Combat Past, Present and Future. RAND Project Air Force, August, 6.

[9] Moore's law is explained as a forecast of the rate of progress via silicon scaling. See: http://www.intel.com/content/www/us/en/silicon-innovations/moores-law-technology.html

[10] Bracken, P., 2012. The Second Nuclear Age: Strategy, Danger, and the New Power Politics. Times Books.

[11] One of the mutual agreements reached by the US and Soviets was to eliminate "intermediate range" nuclear forces (INF: Intermediate-range Nuclear Forces defined as 500-5,500 km (300-3,400 miles)) such as ballistic missiles.

[12] Most areas of the US have plentiful water.

[13] Security of other raw material supplies is typically handled through a combination of supply diversification, stockpiling, etc. Oil is unique in that storage is expensive, and stores of petroleum are relatively modest.

[14] A necessary condition to the Coase theorem is perfect competition.

[15] "Renewable" energy sources, such as wind, renewable biomass (as distinct from non-renewable use of biomass), and hydro power account for only a small share of total energy consumption in modern industrial economies.

[16] The definition of "fossil" fuels is problematic. The International Energy Agency's statistics manual defines it as follows: "Primary energy commodities may also be divided into fuels of fossil origin and renewable energy commodities. Fossil fuels are taken from natural resources, which were formed from biomass in the geological past. By extension, the term fossil is also applied to any secondary fuel manufactured from a fossil fuel. Renewable energy commodities, apart from geothermal energy, are drawn directly or indirectly from current or recent flows of the constantly available solar and gravitational energy." IEA, 2005. Energy Statistics Manual. P. 19. The manual, last updated in 2005, also distinguishes between primary and secondary energy, but does not address other characteristics as the quality / gradient of energy, nor the issue of embodied energy. The juxtaposition of "fossil" vs. "renewable" is flawed because there are only degrees of renewability rather than absolute, exclusionary definitions. Furthermore, current machines that capture so-called "renewable" energy are themselves reliant on the availability of nonrenewable resources. At the same time, so-called "finite" fossil resources have demonstrated tremendous resilience as improved methods of extraction have enabled greater supply. See: Agency, I.E., World Energy Outlook 2012. OECD Publishing. And also, Maugeri, L., 2012. Oil: The Next Revolution. Belfert Center for Science and International Affairs, Harvard Kennedy School, Cambridge.

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[17] Agency, I.E., World Energy Outlook 2012. OECD Publishing. P. 81. The report presents three scenarios, with the most aggressive "450" scenario seeing fossil fuels decline to 63% of primary energy production in 2030 by 2035.

[18] At the household level in OECD nations the total household energy budget ranks well below that of housing.

[19] Raupach, M.R., Marland, G., Ciais, P., Le Quéré, C., Canadell, J.G., Klepper, G., Field, C.B., 2007. Global and regional drivers of accelerating CO2 emissions. Proceedings of the National Academy of Sciences 104, 10288-10293.

[20] "Fossil" fuels like hydrocarbons can, in theory, be synthesized from renewable and carbon neutral sources, like sunlight, in biomass to hydrocarbon liquids, which would be net carbon neutral sources of energy.

[21] Agency, P.N.E.A., 18-07-2012. Trends in global CO2 emissions; 2012 Report. Current data from NASA Earth Systems Research Library: US Department of Commerce, N., Earth System Research Laboratory, 2012. Trends in Carbon Dioxide. (Accessed Nov 13, 2012)

[22] Kaya, Y., 1990. Impact of carbon dioxide emission control on GNP growth: interpretation of proposed scenarios. IPCC Energy and Industry Subgroup, Response Strategies Working Group, Paris, Kaya, Y., 1995. The role of CO2 removal and disposal. Energy Conversion and Management 36, 375-380.

[23] See: OECD, OECD Economic Surveys: European Union 2012. OECD Publishing. Unemployment rates were reported to be over 25% in Greece in August 2012, and over 25% in Q3 2012. See: 2012a. Greece Unemployment Rate. (Accessed Nov 13, 2012)

[24] China and India's annual growth rate is averaging below 10% since 2009. See: TradingEconomics.com, 2012. China GDP Annual Growth Rate. (Accessed Nov 13, 2012)

[25] "The rarest resource in Europe is money," said Michael Kauch, a German parliamentarian and environmental spokesman of the business-friendly Free Democratic Party. "It's even rarer than energy or rare earth minerals." In nschutz. Quagmire in the Sahara: Desertec's Promise of Solar Power for Europe Fades - SPIEGEL ONLINE. (Accessed Dec 1, 2012)

[26] Eichengreen, B., O'Rourke, K., 2012. A tale of two depressions redux | vox, Eichengreen, B., O'Rourke, K.H., 2010. A tale of two depressions: What do the new data tell us? VoxEU. org 8.

[27] The 2011 UNCCC (COP17) held at Durban, South Africa with the aim to reach agreement on legally binding targets adjourned with an agreement to prepare a legally binding agreement in 2015 to take effect in 2020. See: COP17/CMP7, U., 2012. COP17 | CMP7. (Accessed Nov. 23, 2012)

[28] Kent, P., 2012. Environment Canada - Statement by Minister Kent. (Accessed Nov. 23, 2012)

[29] Anderson, K., Bows, A., 2012. A new paradigm for climate change. Nature Clim. Change 2, 639-640.

[30] Few outside the economics profession challenge assumptions made in the practice of comparative statistics based methodologies of neoclassical economics. For a review of the assumptions n general equilibrium theory, see: Howard, M.C., 2011. Modern theories of income distribution. Economists have long known that the assumptions, for example in consumer choice theory, are flawed but continue to use these models while ignoring the flaws. See: Cozzarin, B.P., Gilmour, B.W., 1998. A methodological evaluation of empirical demand systems research. Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie 46, 297-316.

[31] Framework conventions or agreements are agreements to agree to act that contain major parameters but not specifics. This kind of agreement is typically used in situations where it is difficult to initially secure the specifics but broad agreement on goals, objectives and means can be achieved. For a look at the history of UNFCCC, see: Hecht, A.D., Tirpak, D., 1995. Framework agreement on climate change: A scientific and policy history. Climatic Change 29, 371-402.

[32] Institutional failures are behind many of the disasters in world history. Examples: i) The 9/11 Commission outlined how a failure of imagination was the issue in preventing the attack because officials failed to foresee the method of using hijacked aircraft as a weapon. Kean, T., 2004. The 9/11 commission report: Final report of the national commission on terrorist attacks upon the United States. US Government Printing Office. ii) Ireland was a net exporter of food during the Irish potato famine. iii) The Imperial Ching court of China failed to respond with a comprehensive program of modernization during the 19th Century leading to its collapse. Têng, S., Fairbank, J.K., 1979. China's response to the West: a documentary survey, 1839-1923. Harvard University

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Press. iv) The US failed to act on early warnings of the Pearl Harbor attack. Wohlstetter, R., 1962. Pearl Harbor: warning and decision. Stanford University Press.

[33] "Rapid" is defined as reaching international consensus on the outline (Framework Agreement) within 3 years, and implementation within 5 years of that date with material results that can be empirically validated and independently audited within 10 years.

[34] Critical constraints will determine how to overcome the flawed architecture of the UNFCCC, which divided the world arbitrarily into Annex I/II (Developed) countries and Developing countries, the fiscal situation of the OECD in the aftermath of the 2008 economic crash, and the availability of solutions that can be rapidly implemented without impacting economic growth, and conflicts with other established institutional arrangements like the World Trade Organization (WTO).

[35] An engineering solution has the benefit that it does not necessarily have to rely solely on proven science, but can operate on the level of heuristics as long as it works. As an engineering problem first, it is also freed from the constraints of sole reliance on dominant neoclassical economics. Engineering, as a profession, is subject to professional liability while no comparable system exists for economists. It is unheard of for economists to be charged with malpractice and the profession has never required liability insurance.

[36] At the risk of being accused of proposing "uneconomic" solutions, it is worth noting that, historically, many problems that were regarded as "uneconomic" to solve, such as how to alleviate the Irish potato famine (solvable by confiscating wheat destined for export) ended up being even more expensive problems to solve later. While one needs to be informed by prudent economics (so as not to propose entirely uneconomic or unfeasible solutions like Al Gore Plan See: Couric, K., Feb. 11, 2009. Al Gore: Energy Crisis Can Be Fixed. (Accessed Nov. 23, 2012), there are theoretical and practical limitations to the ability of neoclassical economics to project the future (discussed below).

[37] The University of Waterloo's Civil and Environmental Engineering Department defined their domain as, "The profession ….. involved with the creation, operation, and maintenance of structures associated with water resources, transportation, power generation, and a wide range of industrial, commercial and institutional buildings and complexes including whole urban structures. The activities include investigation, planning design, construction, and evaluation." Furthermore, it states: "The Civil Engineer, regardless of whether she or he is a generalist or a specialist, draws heavily upon the work of the physical and social sciences, other professions and other branches of engineering. Moreover, as engineers have become involved in many interdisciplinary activities over the last decade, the job demarcation between boundaries of engineering has become much less restrictive." See: CIVE, U., 2012. Undergraduate Studies Calendar | University of Waterloo. (Accessed Nov. 23, 2012)

[38] For example, the Ozone layer depletion caused by Chlorofluorocarbons (CFCs) was identified as an environmental issue by Rowland and Molina, et. al. in 1973/74 and confirmed by the National Academy of Science (NAS) in 1976. See: Assembly of, M., Physical Sciences . Panel on Atmospheric, C., National Research Council . Panel on Atmospheric, C., 1976. Halocarbons, effects on stratospheric ozone. National Academy of Sciences. These findings were strongly disputed by DuPont Inc., the leading manufacturer of CFCs at the time, until DuPont obtained a patent on CFC replacements.

[39] The availability of large labor forces that are supplied by non-market mechanisms is an enabler for regimes to undertake large civil projects on a basis / scale that would be difficult to accomplish with labor that is free to bargain for "compensation". For the same reason, certain professions, such as the military, extensively make use of non-market means of inducement to recruit and retain personnel.

[40] Encyclopedia Britannica, 2012. Engineering (science) -- Britannica Online Encyclopedia. The practice of professional engineering is defined in Ontario as "any act of planning, designing, composing, evaluating, advising, reporting, directing or supervising that requires the application of engineering principles and concerns the safeguarding of life, health, property, economic interests, the public welfare or the environment, or the managing of any such act" under Section 1 of the Province of Ontario, 2012. Professional Engineers Act, R.S.O. 1990, c. P.28.

[41] A review of economic history would lead one to wonder whether theories that are convenient to the powers that be are selected and popularized to justify elite agendas rather than belief in an immutable science like physics.

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[42] The history of economic thought is blurry, but there are large differences in major strands like Mercantilism (Pre-Adam Smith) and Classical economics (Adam Smith, Ricardo, etc.) and Marxian economics, and a more blurry line toward the Neo-Classical synthesis. See: Blaug, M., 1997. Economic theory in retrospect. Cambridge University Press.

[43] Non-market methods and means in allocation are widely used in engineering. For example, the material / energy / mass balances approach is widely used in the physical sciences and does not require a "price" to be set for calculations. In economics, input-output analysis using Leontief Tableau is an accepted method of non-market forms of allocations.

[44] Civilian nuclear reactors are required to have "fail safe" devices. Military reactors on vessels are often designed to have no safety device that cannot be overridden. The rationale for this is that destruction of the vessel may be a necessary cost to achievement of the mission, which is valued above all including the loss of life and property.

[45] As an example, RGAGEP is formally included and required in many rules and regulations. See: 1910.119(d)(3)(ii) Osha, U.S.D.o.L., Process safety management of highly hazardous chemicals. - 1910.119.

[46] It is beyond the scope of this work to elaborate on the different branches of institutionalism and, in particular, the institutionalist economics perspective. For an overview, see Kaufman, B.E., 2007. The institutional economics of John R. Commons: complement and substitute for neoclassical economic theory. Socio-Economic Review 5, 3-45. And Furubotn, E.G., Richter, R., 2005. Institutions and economic theory: The contribution of the new institutional economics. University of Michigan Press.

[47] The standard engineering curriculum is not required to teach standards and the standardization process. See: Hunter, R.D., 2009. Standards, conformity assessment, and accreditation for engineers. CRC, Murphy, C.N., 2009. ISO, the International Organization for Standardization: Global Governance through Voluntary Consensus. Routledge, Zuckerman, A., 1997. International Standards Desk Reference: Your Passport to World Markets, ISO 9000, CE Mark, QS-9000, SSM, ISO 14000, Q 9000, American, European, and Global Standards Systems. Amacom New York.

[48] Architectures are distinct from technologies as they are expressions of technologies applied in a package. E.g. Windows x86 is a distinct architecture from Linux; while both do essentially the same thing, they are designed to implement similar ideas differently. For discussion on the relationship between architect and client, see: Farenhorst, 2012. Why Good Architects Act As Chameleons.

[49] As a theoretical perspective, institutionalism largely lost sway in many fields after the round of institution building from the beginning of the 20th Century to the end of World War II (WWII). The era of institutional stability characterized by the Post-War period up until the 2008 crash became the golden age of social science facilitated by technological enablers like the spread of Information Technology (IT) and exponentially increasing data processing and storage capabilities. Remarkably, in Engineering, with its close ties to practical applied knowledge, it too, became enamored by the social science quest and largely left behind, at least in terms of formal educational requirements, training for operating within and changing institutional arrangements. That instruction is left in the hands of tutelage or informal training in the field.

[50] The dominance of the standard is evident in parts of the world whose language is not based on the Arabic alphabet, such as China.

[51] QWERTY keyboards remain standard in most handheld devices, such as smartphones, tablet computers, etc.

[52] The minimum of effort in many applied engineering practices is to simply copy over a generally accepted set of specifications and design and implement it rather than doing the calculations from known principles.

[53] Many examples exist of well-known technical and scientific principles being applied improperly for simple machines, with the result of not only wiping out the "savings" but incurring large costs. For example, Ford Motor Company deployed a Cruise Control Switch with a seal that was designed (improperly) to withstand pressure from only one direction. The flaw was not recognized as a cause of failure until it was identified by the NHTSA-ODA, which demonstrated the seal leaked when subject to pressure in the opposite direction. Because the switch was standardized across many vehicles, it became one of the largest recalls in history. See: Wakabayashi, D., 2010. How lean manufacturing can backfire. Wall Street Journal.

[54] Many ostensibly well-engineered products have met their doom despite being technical successes. For examples, see: CIO Magazine, 2009. Apple Disasters: A Look at the Products that Flopped CIO.com.

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[55] The great civil engineering projects of antiquity, from the Great Wall of China, the Pyramids, and Hadrian's Wall, among many others, are examples where the basic task of resource acquisition and its diversion to achieve a technically and logistically daunting goal were accomplished without the necessity of rational economic actors. Indeed, it can be argued that the projects would not have been possible had considerations inherent to "economic man" entered into the picture. The Book of Exodus describes the history of difficult labor relations issues in the building of these projects in ancient Egypt.

[56] Myrdal, G., 1939. Monetary equilibrium. Hodge.

[57] Gansler, J.S., 2011. Democracy's arsenal : creating a twenty-first-century defense industry. MIT Press, Cambridge, Mass.

[58] In the US, the Army Corps of Engineers is the federal agency responsible for flood control civil engineering-related projects, as well as building hydroelectric facilities.

[59] US-EPA began regulating GHGs as a pollutant beginning in 2009 after finding increasing concentrations caused by human activity that "threaten[ed] the public health and welfare of the American people". See: US-EPA, Cause or Contribute Findings for Greenhouse Gases Under Section 202 (a) of the Clean Air Act, 74 Fed. Reg.

[60] Myrdal, G., 1939. Monetary equilibrium. Hodge. Outlines the classical distinction between planned and market-based economic coordination.

[61] The largest firms in the world (based on revenue) includeExxon-Mobile, Royal Dutch Shell, and Walmart, which have revenues above USD $400billion, putting them roughly on a par with economies ranked in the 20-25th in the world, but well behind countries like Switzerland, Turkey, and the Netherlands. In terms of mobilizable resources, these firms are drafted by any major industrial nation, who, in times of war, can readily mobilize half of its economy toward a specific purpose – winning a war. The US spent 42% of GDP at the peak of WWII, and 22% for WWI. Debt, U.S.G., 2012. USGovernmentSpending.com Past Debt Briefing. No private corporation diverts such percentages of its resources so readily without giving up its franchises.

[62] Public-Private partnerships have a mixed record and can be controversial.

[63] Interests, in this context, do not have to be limited to economic. They can involve many domains, ranging from political, to sociological, and emotional, and even to more culturally specific motivators, such as "face" in China. See: Hwang, K., 1987. Face and favor: The Chinese power game. American journal of Sociology, 944-974. Or organizational factors in Allison, G.T., 1999. Essence of decision : explaining the Cuban Missile Crisis. New York : Longman, New York. Or March, J.G., Olsen, J.P., 1984. The new institutionalism: organizational factors in political life. The American Political Science Review, 734-749.

[64] The issue of interests and climate change mitigation looms large in terms of policy making. Yet, there is little concern about the importance of bringing existing interests in "fossil" fuels aboard proposals for change. At the same time, interests in "renewable" resources have become adept at obtaining large subsidies for projects through a variety of mechanisms like Feed-in-tariffs (FIT) and Renewable Portfolio Standards (RFS), while "fossil" fuels are subject to Carbon Taxes or Cap and Trade programs.

[65] RPS / RFS are strongly supported by agricultural interests, which tend to disproportionately command political power in most industrialized economies. In turn, solar and wind interests have developed into powerful lobbies on the backs of subsidies for their product and output. Carbon taxes are typically enacted at levels well below the econometric projected cost necessary to actually alter consumer behavior. E.g. Australia implemented it at A$23/ton in 2012.

[66] Alexander the Great had the benefit of the best logistics team of his era, and his campaigns are closely tied to the harvest and availability of fodder and supplies. See: Engels, D.W., 1978. Alexander the Great and the Logistics of the Macedonian Army. Berkeley : University of California Press, C1978, Berkeley : University of California Press, C1978
Berkeley.

[67] Jacobson, M.Z., Delucchi, M.A., 2009. A plan to power 100 percent of the planet with renewables. originally published as" A Path to Sustainable Energy by 2030, 58-65.

[68] Smil, V., 2010a. Energy transitions : history, requirements, prospects. Praeger, Santa Barbara, Calif.

[69] Germany was not mobilized for "total" war until 1943 (and did not fully implement this capability until 1944), retaining many archaic practices such as working only a single shift at factories, or retaining many

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domestic servants. The Soviet Union, having decimated its military in the 1930s, rose to the occasion and fielded a winning army that defeated Germany.

[70] Norman Augustine lays out the extent to which major programs fail to meet cost targets. The administrative overhead for any government funded or sponsored program is another factor in this struggle: The difficulty of securing approvals from multiple layers of players and agencies and how it impacts logistics is discussed in Norman Augustine's classic. Augustine's Law XIV states, "If a sufficient number of management layers are superimposed on top of each other, it can be assured that disaster is not left to chance." Augustine, N.R., 1983. Augustine's Laws and major system development programs. New York, N.Y. : American Institute of Aeronautics and Astronautics, New York, N.Y. p.86.

[71] Economists prefer simple solutions, such as a simple carbon tax paid by consumers, to more complicated ones; however, that nothing is simple. Few economic textbooks, let alone economists, are aware of the complexities of rules that underpin seemingly simple markets like the stock market.

[72] It can be shown that very minor institutional changes can have major impacts on how an industry is arrayed. For example, the passing of a law called the Semiconductor Protection Act (SPA), originally intended to protect intellectual property by making the designs of integrated circuits embodied in lithographic masks entitled to copyright, had the effect of splitting the value chain and creating two distinct industry segments: i) design houses, which did not own manufacturing facilities, and ii) foundries, who did not need to design and market their own devices. Prior to that, an even more obscure change in tariffs by the United States to ad valorem duties for imports enabled semi-finished components to be exported to a foreign duty free zone, processed using local labor, and then re-imported to the United States while only paying duty on the value added outside of the US. The net result of these changes is the explosion of a semiconductor industry that grew at a sustained compound average growth rate of 16% from 1960 to 1994, resulting in cheap and widely available electronics devices in every corner of the world.

[73] Efficiency here refers to the weeding out of "bad" choices over time – a process that economists assume will happen from agents that find optimality. See: Kuhn, T.S., 1996. The structure of scientific revolutions. University of Chicago press.

[74] Fairley, P., May 2012. Why Japan's Fragmented Grid Can't Cope - IEEE Spectrum. IEEE Spectrum.

[75] Hong Kong retained its left side drive system after it was handed over to China in 1997.

[76] Classifications of authority systems based on the degree of centralization of power dates from Aristotle. See: Saunders, T.J., 2002. Aristotle: Politics. Clarendon Press. The very notion that power is universal and means the same thing everywhere is challenged by the late Lucian Pye, in Pye, M.W., Pye, L.W., 1985. Asian power and politics: The cultural dimensions of authority. Harvard University Press.

[77] Graham T. Allison's classic "Essence of Decision" outlines three different models: Rational actor, organizational process, and governmental politics. The book has since been updated and reissued by Allison and Zelikow. Allison, G.T., 1999. Essence of decision : explaining the Cuban Missile Crisis. New York : Longman, New York. Pluralism is a phenomenon in most organizations and groups, even in those classed as "totalitarian" or "authoritarian" systems of organizational governance.

[78] Norman Augustine notes that historically, most major program costs and scheduling tends to exceedprojections by a wide margin. Details of cost overruns from Thucydides onwards suggest that there is a systemic inability of architects, engineers, and tradespeople to meet cost and schedule targets in proposals, which speaks to either an innate capacity for optimism unjustified by history, or other systemic failures in the profession from antiquity.

[79] International multilateral treaties normally operate by consensus. Thus, in theory, even the smallest party can block a change. Boyle, A.E., Chinkin, C.M., 2007. The making of international law. Oxford University Press Oxford.

[80] The League of Nations was made obsolete by its failure to prevent World War II, and superseded by the United Nations after the League was officially liquidated in 1946 and its functions transferred to the new United Nations. Ibid, Walters, F.P., 1986. A History of the League of Nations. Greenwood Press.

[81] Disruptions to systems architecture in energy rarely happen; however, when they do, as seen in the Fukushima Diaichi incident, broken consensus are extremely difficult to repair, even as major interests (e.g.,

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large industrial power customers in Japan), threaten to shut down and leave. See: Conca, J., 2012. Fukushima Slugfest -- Japan's New Nuclear Regulation Authority - Forbes.

[82] The Dutch transitioned to natural gas very quickly after the discovery of gas near Slochteren. See: Smil, V., 2010a. Energy transitions : history, requirements, prospects. Praeger, Santa Barbara, Calif. P. 84.

[83] The slowness of transitions has variously been blamed on immitigable circumstances like power plants having an economic life of 30 years or longer.

[84] For the current status of renewable technology markets, please see Bloomberg New Energy Finance (BNEF) at bnef.com. Their quarterly "Clean Energy Policy and Market Briefing" provides a succinct summary of world trends. See: Bloomberg New Energy Finance, 2012. Clean Energy Policy & Market Briefing Q3 2012, p. Clean Energy Solutions Center. The issue raises concerns about the commitment of policy makers in the US, UK and Italy despite lower prices for photovoltaic and wind technologies. In 2012, Chinese multicrystalline PV modules fell to USD .77/W while the world price was USD .88/W. Wind turbines are now at USD 1.23m/MW.

[85] An overview of hydraulic fracturing is here: King, G.E., 2012. Hydraulic Fracturing 101: What Every Representative, Environmentalist, Regulator, Reporter, Investor, University Researcher, Neighbor and Engineer Should Know About Estimating Frac Risk and Improving Frac Performance in Unconventional Gas and Oil Wells, SPE Hydraulic Fracturing Technology Conference. Society of Petroleum Engineers, The Woodlands, Texas, USA.

[86] The technological ramifications of fracking in unlocking heretofore-unexploited sources of hydrocarbon resources (natural gas and petroleum) is not fully understood at this time. See: Kuuskraa, V., 2011. World shale gas resources: an initial assessment of 14 regions outside the United States. Energy Information Administration.

[87] The extent to which advocates for "renewable" energy failed to understand the depth of opposition to wind farms and their unwillingness to acknowledge the legitimacy of the opposition is illustrated by: Pasqualetti, M.J., 2012. The Misdirected Opposition to Wind Power. Learning from Wind Power: Governance, Societal and Policy Perspectives on Sustainable Energy, 133. Also see: Murphy, K., 2012. Hawaii's solar power flare-up: Too much of a good thing?, LA Times. And Cart, J., 2012. Solar power plants burden the counties that host them, LA Times.

[88] Abernathy, W.J., Utterback, J.M., 1978. Patterns of innovation in technology. Technology review 80, 40-47. And Utterback, J.M., 1994. Mastering the dynamics of innovation : how companies can seize opportunities in the face of technological change. Harvard Business School Press, Boston, Mass. These works describe the classical model on how architectures standardize, which has not happened for solar and wind renewables as of this time.

[89] Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Research Policy 31, 1257-1274.

[90] Turnheim, B., Geels, F.W., 2012. Regime destabilisation as the flipside of energy transitions: Lessons from the history of the British coal industry (1913–1997). Energy Policy 50, 35-49. And Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Research Policy 31, 1257-1274.

[91] Arapostathis, S., Carlsson-Hyslop, A., Pearson, P.J.G., Thornton, J., Gradillas, M., Laczay, S., Wallis, S., 2013. Governing transitions: Cases and insights from two periods in the history of the UK gas industry. Energy Policy 52, 25-44.

[92] The world energy system remains "unchanged" in the narrow sense of the term; it is recognized that in many jurisdictions, major changes, such as the phase out of coal in UK and the adoption of natural gas in the Netherlands, have occurred.

[93] The notion of public vs. private is intensely culturally and societally nuanced. Ideas of what constitutes one vs. the other, how property rights are created, altered or removed, are beyond the scope of this research. Suffice it to say that property rights are very much a creation of man-kind, an institution that is man made, and thus, can be changed by man.

[94] 2012b. ISO/IEC/IEEE 42010: Frequently Asked Questions (FAQ). (Accessed Nov. 25, 2012)

[95] Ibid. (Accessed Nov. 25, 2012)

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[96] Ibid. (Accessed Dec 1, 2012)

[97] The extent to which the internet is still evolving rapidly can be seen in the ease with which new architectures like Twitter and Facebook have been able to emerge unchallenged. It is perhaps more interesting to note how fast older architectures, such as Yahoo and MySpace, have become obsolete and faded away within two decades of their inception.

[98] See: Smil, V., 2010b. Energy Transitions: History, Requirements, Prospects. Praeger Publishers. Chapter 2 of this work provides discussion of transitions to modern energy resources.

[99] Hill, J.R., Ranft, B., 1995. The Oxford illustrated history of the Royal Navy. Oxford University Press.

[100] The 1859 discovery of oil at Oil Creek, Pennsylvania is the generally accepted beginning of the American petroleum era. There are multiple claimants to the "first" claim.

[101] At the inception of the oil age, after crude oil was refined for kerosene, it was found that the waste product left contains heavier components, like bunker oil and asphalt, and lighter components, like gasoline. They were disposed of by burning.

[102] The issue of high energy density and ease of handling cannot be overlooked. Coal had the advantage of being relatively inert and absorbed explosion and shrapnel if struck by a shell, though coal dust is explosive. However, coal is labor intensive to handle and in turn, required large crews of stokers to fuel and refuel the vessel. Coaling is a job that is difficult to undertake at sea and, given the low energy density of coal, is a frequent operation that reduced "up time" for a vessel --- the logistical nightmare of coaling operations, which required provisioning vessels to be tethered alongside the ship in calm waters, often took days and exhausted crews. On the other hand, oil fired vessels benefitted from higher energy content, smaller bulk, and ease of handling that enabled fueling while underway. Then there are tactical advantages to consider; for example, oil burned with much less visible smoke compared to the coal fired boilers of the late 19th early 20th century. See: Dahl, E.J., 2001. Naval innovation: from coal to oil. DTIC Document.

[103] Britain expended considerable effort in the late 1800s to establish a network of coaling stations worldwide, in disparate places like the Falklands, Singapore, Colombo, Mauritius, Aden, and Esquimalt. This enabled British vessels to transit the world without ever having to be concerned about being able to provision from another power. With the coming of oil, many of these stations became unnecessary as oil offered much more range and endurance.

[104] Many in the Royal Navy opposed the transition from domestic British coal to oil on the grounds that it is not plentiful, and is available only in foreign hands, etc. A Royal Commission chaired by Sir Jacky Fisher was established to study these issues, resulting in the recommendation that oil be adopted but supplies be secured via stockpiling. Interestingly, this fateful decision was made to invest in the Anglo-Persian Oil Company rather than the larger incumbent Royal Dutch Shell Company. See: Dahl, E.J., 2001. Naval innovation: from coal to oil. DTIC Document.

[105] For a Western summary of this viewpoint, see: Worth, R.H., 1995. No Choice But War: The United States Embargo against Japan and the Eruption of War in the Pacific. McFarland & Company.

[106] This perspective is common in Japanese views of the origins of World War II, which glosses over the Japanese invasion of China, itsseizure of Korea and Taiwan, and the history of Japanese conflict with China and Russia.

[107] The United States does not formally acknowledge that a security guarantee with Saudi Arabia (or any nation outside of NATO) exists,; however, but it is a known fact that when Saudi Arabia was threatened by Iraq, American forces were promptly dispatched. For the history, see: Hart, P.T., 1998. Saudi Arabia and the United States: Birth of a Security Partnership. Indiana University Press.

[108] Competing commodities would be gold, salt, saltpeter, etc.

[109] Treaty of Paris (1783) resulted in the recognition of the United States by Britain and the formal ending of the US revolutionary war.

[110] Gruy, H.J., 2000. History of the Ownerships of Mineral Rights, SPE Annual Technical Conference and Exhibition. 2000,. Society of Petroleum Engineers Inc., Dallas, Texas.

[111] Texas State Library, 2012. Hazardous Business - The Oil Wars - Page 5 - Texas State Library - Texas State Library and Archives Commission. (Accessed Nov. 25, 2012)

[112] Ibid.

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[113] Dahlgren, E.G.Dahlgren, 1942. Coordination Of Conservation Practices In The Various States. American Petroleum Institute.

[114] Antitrust exemptions vary. See: Khemani, R.S., 2002. Application of competition law: exemptions and exceptions. UN. For individual countries, the OECD provides briefs: OECD, 2012. Country reviews of competition policy frameworks.

[115] Standard Oil had a large franchise in China for lamp oil and large operations throughout Asia.

[116] The act was passed and signed into law, but lay dormant for a generation until two key cases that went to the US Supreme court clarified its scope and intent in 1911: Standard Oil and American Tobacco. See: Foer, A.A., Lande, R.H., 1999. The Evolution of United States Antitrust Law: The Past, Present, and (Possible) Future. Nihon University Comparative Law 16, 147-172. Prevention of the domination of markets by monopolies, and its converse, organization of trades, guilds and crafts into cartels are recurring themes in economic history from Roman times onward. See: Epstein, S.A., 1995. Wage labor and guilds in medieval Europe. University of North Carolina Press. Epstein, S.R., 1998. Craft guilds, apprenticeship, and technological change in preindustrial Europe. Journal of economic history 58, 684-713.

[118] For a history of the competition between AC and DC power, voltages, etc. see Shapiro, C., Varian, H.R., 1999. The art of standards wars. California management review 41. For those who think current controversies over hydraulic fracking is overblown, see: Moran, R., 2003. Executioner's current: Thomas Edison, George Westinghouse, and the invention of the electric chair. Vintage.

[119] Railroads were regulated in the US by, first, state level Railroad Commissions, and then the Interstate Commerce Commission (ICC) created under the Interstate Commerce Act (1887). Railroads, being the dominant interest of the time fought these laws and prevented the government from reducing tariffs. Ultimately, this and other abuses of monopoly power resulted in the Sherman Antitrust Act of 1890.

[120] See: Hottenroth, T., 2012. "Why a regulated monopoly?", Powerpoint Slides in: Institute, W.P.U., 2012. Energy Utility Basics–October 1-5 2012 » Wisconsin Public Utility Institute.

[121] Property rights, and the distribution of wealth are longstanding issues of controversy in economic theory. Property systems evolved gradually, and are both highly nuanced and distinct. America made a clean break from the British Crown by effectively abolishing the Crown's rights in America, and with it, abrogating treaties with Indians. For that history, see: Ely Jr, J.W., 2007. The guardian of every other right: A constitutional history of property rights. Oxford University Press, USA.

[122] It is beyond the scope of this work to examine the failures of the regulated monopoly system, however its features included creating a system that emphasized efficiency defined as low costs (at the generating and distribution level) as opposed to features of resilience. See: Jackson, S., 2009. Architecting resilient systems: Accident avoidance and survival and recovery from disruptions. Wiley.

[123] Sampson, A., 1991. The seven sisters: the great oil companies and the world they shaped. Bantam Books.

[124] The British secured oil in Mesopotamia and Burmah, the Dutch in the East Indies, and the US in Burmah then the Middle East. See: Yergin, D., 2008. The prize: The epic quest for oil, money & power. Simon and Schuster. And Longrigg, S.H., 1967. Oil in the Middle East: its discovery and development. issued under the auspices of the Royal Institute of International Affairs [by] Oxford UP. van Zanden, J.L., Jonker, J., Howarth, S., Sluyterman, K., 2011. A History of Royal Dutch Shell. OUP Catalogue.

[125] This practice of posting final prices inclusive of taxes and charges is virtually unique gasoline and diesel fuel retail outlets. No other industry does this on such a nearly universal scale.

[126] Product adulteration ceased to be a widespread problem by the 1960s in North America, but the ubiquitous sight glass remained on pumps well into the 1980s. The product adulteration problem remains an issue in many non-OECD nations.

[127] Typical North American margins for retail vendors who earn a "commission" on sale of fuel is 5 cents a liter, however, 2-2.5 cents a liter goes to the credit card processing company.

[128] Lenard, J., 2008. What Consumer Behavior? NACS Magazine, March, 16-25.

[129] A total of 34 companies were created from Standard Oil's breakup. For a detailed history, see: Tarbell, I.M., Schechter, D., 2010. The History of the Standard Oil Company. Cosimo Classics.

[131] Royal Dutch Shell and the new entrant Anglo-Persian Oil Company founded in 1908, which later became the Anglo Iranian Oil Company, then British Petroleum Company, or BP.

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[132] USSR was first to commercially produce electricity from nuclear energy in June 1954, beating the US who demonstrated the concept in December 1951 but waited for the Atomic Energy Act of 1954 to pass before commercially exploiting the technology. However, the US military nuclear program was driven by imperatives to design a nuclear reactor of compact size to enable its use on ships, particularly submarines. Canada's program, being civilian driven, was not so restricted. See: Cowan, R., 1990. Nuclear power reactors: a study in technological lock-in. Journal of Economic History 50, 541-567.

[133] 42 USC 2210 Sec. 170. Indemnification And Limitation Of Liability is the clause governing liability. It states "That the maximum amount of the standard deferred premium that may be charged a licensee following any nuclear incident under such a plan shall not be more than $95,800,000". Atomic Energy Act of 1954 (P.L. 83-703), p. 114. (Accessed Nov. 25, 2012)

[134] Winston, C., 1998. US industry adjustment to economic deregulation. The Journal of Economic Perspectives 12, 89-110.

[135] Energy Policy Act of 1992 and 2005 is the enabling legislation in the US. See Hottenroth, op. cit. Institute, W.P.U., 2012. Energy Utility Basics–October 1-5 2012 » Wisconsin Public Utility Institute.

[136] Rockoff, H., 2004. Drastic measures: A history of wage and price controls in the United States. Cambridge University Press. And, Lazzari, S., 2006. The Crude Oil Windfall Profit Tax of the 1980s: Implications for Current Energy Policy. Congressional Research Service. Circumvention of these laws was the basis of the fortune of Marc Rich.

[137] Petroleum producers who seethe at government-enforced price regulation forget that in the past they relied on government to support the price of their product and the history of overproduction.

[138] Given the volume of fuel sold and the sheer diversity in the number of vendors, it is exceedingly rare to have problems selling name brand fuel at retail.

[139] North American Electric Reliability Corporation (NERC) maintains data on electric grid reliability. See: NERC, 2012. Reliability Assessments. (Accessed Dec 1, 2012).

[140] At the time of writing, there is an international embargo against Iranian Oil.

[141] World Market Share for Renewables is 2%, while "fossil" fuels account for 87%. Coal recorded the fastest growth rate while oil lost market share since 1990. See: BP, 2012. Statistical Review of World Energy 2012 | BP. P. 1.

[142] Energy gradient from adiabatic combustion of common liquid fuels, like oil, is about 2,100 °C, which is roughly similar to coal (around 2,200 °C) and natural gas (about 2,000 °C). The actual combustion temperature is often lower in order to moderate emissions.

[143] Primary energy vs. secondary energy is defined in the IEA statistics manual. IEA, 2005. Energy Statistics Manual.

[144] This term is used in the marketing sense, not in the technical sense of the term. From the energy industry's perspective, the product is widely differentiated with oil selling for different prices according to its grade, quality, and the supply and demand in relation to infrastructure. Likewise, electricity producers will note that there are different grades / service levels (e.g. interruptible power), etc. that distinguish their product. All of this may be true, but in a marketing sense, it is an undifferentiated commodity. For a look at the meaning of these terms in a marketing sense, see: Dickson, P.R., Ginter, J.L., 1987. Market segmentation, product differentiation, and marketing strategy. The Journal of Marketing, 1-10.

[145] In one recent study of consumer behavior, the cost of fuel used to search for lower price retailers was overestimated while cost of time was underestimated. See: Castilla, C., Haab, T., 2011. Inattention to Search Costs in the Gasoline Retail Market: Evidence from a Choice Experiment on Consumer Willingness to Search. And Gillingham, K.T., 2011. The Consumer Response to Gasoline Price Changes: Empirical Evidence and Policy Implications. Stanford University.

[146] The percentage of vehicles on the road today that does not use the internal combustion engine is very small.

[147] IEA compiles data on energy subsidies. Agency, I.E., 2012. IEA - Energy Subsidies. Both China and India have made it public policy to price energy at low levels.

[148] Every jurisdiction that has historically subsidized energy has found it extremely difficult for politicians, elected or otherwise, to break the habit. See IEA, op. cit. for current developments in trying to reduce subsidies.

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[149] It is rare for life cycle fuel / energy costs to be a factor in the buying decision of energy consuming devices from vehicles to buildings.

[150] Regnier, E., 2007. Oil and energy price volatility. Energy Economics 29, 405-427.

[151] The large notional markets vs. the physical market results in an unstable market that may never "find equilibrium" according to Hyman Minsky's instability hypothesis. Minsky, H., 1992. The financial instability hypothesis. The Jerome Levy Economics Institute Working Paper.

[152] The frictional costs of moving from natural gas, electricity, and oil for most consumers who have a choice for their stationary needs are so large that few actually switch except at decision points like furnace / heating system replacement time. Builders tend to decide the initial build decision without customer input.

[153] Brennan, T.J., 2007. Consumer preference not to choose: Methodological and policy implications. Energy Policy 35, 1616-1627.

[154] Evidently, the split between electricity distribution and generation costs roughly follows this model, with distribution accounting for a large amount of the total cost.

[155] The largest usage of water for most households (not including lawn watering) on the Western model is the commode and showering.

[156] A parallel discussion can be had about the development of storm and sanitary sewers, but for the sake of brevity, the lessons of building water works is substantially the same as the ones from building sewers.

[157] Weissman, J., 2012. Chart of the Day: A Short History of 200 Years of Global Energy Use, The Atlantic.

[158]Ibid.

[159] Speech to National Association of Science Writers reported in NY Times September 17, 1954.

[160] Energy from controlled nuclear fusion at that time was thought to be achievable.

[161] Julian Simon reported that, over time, prices of natural resources have generally followed a trend that declined in real terms with normal cyclical and other spikes upward. This is also documented in long-term studies of commodity prices in coal, oil, etc. See: Zellou, A.M., Cuddington, J.T., 2012. Trends and Super Cycles in Crude Oil and Coal Prices. And Simon, J.L., 1998. The ultimate resource 2. Princeton University Press. At the same time, usage of resources has declined relative to GDP even as living standards and rising GDP increased consumption.

[162] Yahoo maintains a current list of industries and their profitability here: http://biz.yahoo.com/p/sum_qpmd.html

[163] Inelastic demand, in the economist term of art.

[164] Ahmed, M., 2012. Arab Oil Importers Under Strain.

[165] Ontario built an industrial policy around renewable energy by passing the Green Energy Act and subsequently subsidizing the production of renewables like solar panels in the province. Likewise, many Chinese municipal governments did the same, as did the US, Spain, Germany, etc.

[166] Jevon's paradox for governments is a phrase coined by the author.

[167] Hence, government programs to conserve energy often pay lip service to conservation, but programs that truly slash energy demand, and with it revenues, are likely to be strongly opposed by the Finance ministry.

[168] The late Professor Julian Simon argued that the notion of finite resources makes no sense when natural resources are properly measured. See: Simon, J.L., 1998. The ultimate resource 2. Princeton University Press.

[169] The IEA estimates that plentiful supplies of conventional energy in the form of oil, gas, etc. are available at least until 2030. Agency, I.E., World Energy Outlook 2012. OECD Publishing. Also see chart of substitutions available for conventional energy at different price points here: Fyfe, D., 2012. Oil Market Report: The Price of Oil: Fundamentals v Speculatoin & Data v Politics. IEA.

[170] Malthus, T.R., Layton, W., 1914. An essay on population. JM Dent London. Meadows, D.H., de Rome, C., 1974. The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind [By] Donella H. Meadows [And Others]. 2d Ed. Universe Books, Mesarovic, M., Pestel, E., 1974. Mankind at the turning point. The second report to the Club of Rome.

[171] The best example is stock markets where companies expand exponentially and, at a certain point, growth tapers off and then flattens. Some trends, no matter how compelling the history, are just not plausible over the long run. Norman Augustine lays out the cost of military aircraft over time since WWI and showed that if current trends continued, by 2050 the entire US defense budget will buy one fighter craft. Augustine, N.R.,

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1983. Augustine's Laws and major system development programs. New York, N.Y. : American Institute of Aeronautics and Astronautics, New York, N.Y.

[172] Historically, there are many examples of negative population growth. As of present, many countries like Russia are experiencing negative population growth in the absence of a round of virulent diseases.

[173] The transition from wood to coal as a fuel was not driven by cost in UK, as coal prices never reached "grid parity" with wood on a per btu basis. Clark, G., 2004. The price history of English agriculture, 1209–1914. Likewise, the transition to oil for the Royal Navy was not done for cost reasons, and in fact, it reduced security as Britain had to import and stockpile oil. These transitions were made to standardize the use of a more efficient resource.

[174] There is a preponderance of literature that covers energy security, but with exceptions like the US and OECD members establishing and maintaining petroleum reserves and other strategic stockpiles, generally the market is not willing to pay a premium for secured vs. traditional supplies. E.g. oil from Canada for the US is treated no differently than oil from Venezuela.

[175] London, England's parliament was goaded into action to overrule rate payers (property tax) that strongly opposed the creation of a new public good (sanitary sewers). The health and sanitary reasons were a secondary consideration insofar as the deaths from cholera mostly affected persons lower in the socio-economic scale and the science that conclusively linked cholera to water contamination from wastes was not proven conclusively. The dominant theory of the cause of cholera was "miasma" from airborne contamination at the time Joseph Bazalegette's scheme was accepted by Parliament in 1858. This allowedlocal governments to undertake sanitary sewer projects and fund it out of property taxes. The project was a sociological innovation as it undermined many well-established social institutions including the mandatory use of sanitary sewers instead of cesspools, and was collectivist because it undermined individual autonomy and privacy and eliminated the barriers between classes. See: Hollingshead, J., 2008. The London Sewer. Cleansing the City: Sanitary Geographies in Victorian London, 24. And Porter, D.H., 2001. The Great Stink of London: Sir Joseph Bazalgette and the Cleansing of the Victorian Metropolis (review). Victorian Studies 43, 530-531. And the outcome of poverty as being caused by fecklessness and ignorance is the cause of poor health. In Smith, G.D., 2001. Poverty, inequality and health in Britain, 1800-2000: a reader. The Policy Press.

[176] According to BP, China is down to 10 years domestic reserve for coal; however, alternative sources of coal from Mongolia have given coal a life extension despite the logistical difficulties and expense of moving coal long distances. Importantly, there is no alternative infrastructure, for example, to use natural gas, either from domestic shale deposits or as CNG/LNG imports from elsewhere. See: BP, 2012. Statistical Review of World Energy 2012 | BP.

[177] China's performance in reducing GHG emissions relative to its GDP has been impressive from the Deng reforms onward, when energy intensity in the economy fell. However, the overall growth in GDP is such that China became the world's largest emitter as of the time of writing. For background, see: Levine, M.D., Zhou, N., Price, L., 2009. The Greening of the Middle Kingdom: The Story of Energy Efficiency in China, p. Medium: ED.

[178] From China to India to Africa, elites, adjusted for incomes, share similar tastes for cars, air conditioning, etc. Jaffrelot, C., Van der Veer, P., 2008. Patterns of middle class consumption in India and China. Sage Publications Pvt. Ltd.

[179] There are exceptions; for example, China has a relatively low uptake of clothes dryers --- a major energy user in OECD economies.

[180] Perhaps the best illustration of prejudice is how the 1997 Kyoto Protocol placed China and India in the category of "developing countries with no binding targets".

[181] Suppose the first steam engines installed on vessels were judged by the metrics of sailing ships, they would score poorly on logistics (need regular coaling), reliability (frequent breakdowns), and ascetics (coal is dirty). In addition, coaling reduced the need for crew and introduced a new lower class - the dirty crew (engineers and stokers).

[182] There is no hard and fast delimitation of high and low gradient energy. Combustion of hydrocarbons normally result in a thermal gradient of over 1,000C, that is generally reckoned to be high gradient. Likewise,

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voltages in excess of 80V (either high or low) is generally regarded as high gradient electricity while low voltages are generally taken as below 42V.

[183] James Hansen made the case that it is cheaper to leave oil sands oil in the ground given the $200/ton cost of carbon sequestration. Strojek, B.W.a.S., 2010. Oil sands should be left in the ground: NASA scientist, Globe and Mail. The actual cost of carbon sequestration is running at a fraction of that claim. Bloomberg New Energy Finance, 2012. Clean Energy Policy & Market Briefing Q3 2012, p. Clean Energy Solutions Center. Estimates now show shale gas with carbon capture is cheaper than solar and wind.

[184] Recent estimates indicate that photovoltaic emissions of GHGs are material: "lifetime … estimates for carbon footprints are 20, 14, and 26 grams carbon dioxide equivalent per kilowatt-hour (g CO-eq/kWh), respectively, for a-Si, CdTe, and CIGS, for ground-mount application under southwestern United States (US-SW)" in Kim, H.C., Fthenakis, V., Choi, J.K., Turney, D.E., 2012. Life Cycle Greenhouse Gas Emissions of Thin-film Photovoltaic Electricity Generation: Systematic Review and Harmonization. Journal of Industrial Ecology 16, S110-S121. Natural gas produces 10 times more, diesel or fuel oil produces 20 times more, and coal produces 30 times more. See: Weisser, D., 2007. A guide to life-cycle greenhouse gas (GHG) emissions from electric supply technologies. Energy 32, 1543-1559.

[185] Wind turbines can generate either AC or DC current, but in order to feed into the grid, it must be converted to AC at the proper voltage.

[186] Edison Center, 2012. Arc Lamps - How They Work - History, Harris, J., 1993. Electric lamps, past and present. Engineering Science and Education Journal 2, 161-170.

[187] Carbon arc lamps require a minimum of about 35V and typically 50-60V or higher to function.

[188] Edison Center, 2012. Arc Lamps - How They Work - History. (Accessed Dec 1, 2012)

[189] It was considered an advantage to generate electricity far away from population centers via hydro installations until high voltage / power DC transmission became economically practical decades later.

[190] Moran, R., 2003. Executioner's current: Thomas Edison, George Westinghouse, and the invention of the electric chair. Vintage.

[191] And bruising fights over frequency standards that ultimately resulted in two dominant standards 50 and 60hz. The history of AC had frequencies from 16⅔ to 133⅓hz.

[192] Neither the early gasoline or diesel engine vehicles required a stable source of electricity to run the motor initially. Magnetos provided the spark for gasoline motors, and diesels used mechanical pumps. Electric starting was the first application that made large demands on the vehicle's electrical system. Headlamps and lighting was a relatively minor factor.

[193] The public service mandates of most electric utilities results in economically irrational actions, such as providing diesel generated energy for remote communities in a service area at the same prices as other customers on the grid.

[194] Applications like space heating, etc. can be interrupted with only limited impacts --- it does not necessarily require standard grid level reliability.

[195] Hepbasli, A., 2011. Low exergy (LowEx) heating and cooling systems for sustainable buildings and societies. Renewable and Sustainable Energy Reviews.

[196] For a detailed discussion of the realm of the possible, consult Chapter 5, "Lighting Technologies" in Systems, I.I.E.A.E.E.C.i.B.a.C., 2012. IEA Annex 45 -. And Halonen, L., Tetri, E., IEA ECBCS ANNEX 45– ENERGY EFFICIENT ELECTRIC LIGHTING FOR BUILDINGS. RAZSVETLJAVA 2006 LIGHTING ENGINEERING 2006, 5.

[197] Because semiconductor lighting devices do not "wear" appreciably from on/off cycles and have little latency, they do not have to achieve the best lumens per watt as the best technologies in that class (e.g. gas discharge) to realize large savings if they are only turned on as needed. Gas discharge lamps in common use for lighting like sodium vapor and CCFL cannot be cycled without a lifespan penalty.

[198] Higher voltages are still required in power electronics; however, with exception of the ubiquitous microwave oven, there are relatively few high-powered microwave transmitters in most homes.

[199] As an illustration, it is useful to conceive of the data reception capacity of an old fashioned utility meter (e.g. number of bits of data) compared to the cost of data collection, and then compare it to how cost of collection of data via the latest "off-the-shelf" wireless smart meters have fallen per bit of data collected.

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[200] Examples of “off –he-shelf” innovations that reduce energy usage and conserve resources have been identified by the IEA Energy Conservation in Buildings and Community Systems (ECBCS) Programme. Details: IEA ECBCS, 2012. ECBCS Program Information.

[201] Networks that communicate over ordinary household wiring have been in general use since the late 1990s.

[202] This notion can be seen in marketing with industrial age firms like Sears Roebuck in the 1960s, which had a policy of “satisfaction guaranteed, or your money refunded” that no doubt, resulted in many customers returning goods and losses taken in individual cases. But the absolute increase in business as a result of that policy, which encouraged customers to spend more because they think they can take it back, was well worth it. Similarly, many firms operate couponing programs that apparently offer sizable discounts via a “mail in” coupon, betting on the statistical likelihood that many customers will either not bother, or failed to complete the documentation correctly. Other examples are “lifetime warranties” on many products including household plumbing fixtures, which is premised on customers not living in a house long enough to make a claim, or forgetting about the guarantee, remodeling and throwing out the component rather than keeping an old piece of used equipment.

[203] A major maker of electrical equipment based in Germany once tried to market a high tech power conditioning system based on cryogenics that would have improved productivity of highly sensitive gear at microelectronics facilities. Customers, however, rejected the idea despite the demonstrated improvements in productivity.

[204] Applications like resistance space heating or water heating are examples where the load is hard wired to be insensitive to pricing. While it is possible to alter it to become “intelligent”, that has not happened in a widespread manner.

[205] Effectiveness in terms of goals achieved per unit of resource used.

[206] For an overview of current methodologies for calculating carbon footprint, see: Pandey, D., Agrawal, M., Pandey, J.S., 2011. Carbon footprint: Current methods of estimation. Environmental Monitoring and Assessment 178, 135-160.

[207] Typical dictionary definition of effectiveness: “adequate to accomplish a purpose; producing the intended or expected result” from dictionary.com

[208] Saunders, H.D., 1992. The Khazzoom-Brookes postulate and neoclassical growth. The Energy Journal, 131-148. A review of the postulate by Sorell is here: Sorrell, S., Jevons’ Paradox revisited: The evidence for backfire from improved energy efficiency. Energy Policy 37, 1456-1469.

[209] Maddison, A., 2007. The world economy volume 1: A millennial perspective volume 2: Historical statistics. Academic Foundation. P. 19.

[210] Ibid. p. 24.

[211] Details on the price and profitability of whale oil can be found in Davis, L.E., Gallman, R.E., Gleiter, K., 1997. In pursuit of Leviathan: technology, institutions, productivity, and profits in American whaling, 1816-1906. University of Chicago Press. And data in Tower, W.S., 1907. A history of the American whale fishery. Pub. for the University. Which is summarized in charts found here: Kimel, M., 2012. Prices and Quantity for Whale Oil and Whale Bone | Angry Bear - Financial and Economic Commentary. (Accessed Dec 5, 2012)

[212] Zellou, A.M., Cuddington, J.T., 2012. Trends and Super Cycles in Crude Oil and Coal Prices.

[213] Ibid.

[214] The median size of new homes in the US has steadily risen until 2007. See US Census Data. Many of the efficiency gains accrued by modern automobile since the 1930s have been consumed by the increased weight of the modern automobile and the widespread use of energy consuming accessories like air conditioning, entertainment, etc. Also see: Smil, V., 1994. Energy in world history. Westview Press, Boulder.

[215] Flannery, T., Beale, R., Hueston, G., 2012. The critical decade: international action on climate change.

[216] Ibid. P. 33.

[217] Ibid. p. 35.

[218] A tax implemented at this level will have to be constantly raised to match or exceed rises in GDP and per capita GDP that brings more consumers in the market.

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[219] Vanoli, A., 2005. A history of national accounting. Ios PressInc. P. 17 also see: Kuznets, S.S., King, W.I., National Bureau of Economic Research., 1937. National income and capital formation. 1919-1935, a preliminary report. National bureau of economic research, New York,.

[220] What Braudel would term material life. Braudel, F., 1977. Afterthoughts on material civilization and capitalism. Baltimore : Johns Hopkins University Press, Baltimore
Baltimore ; London
Baltimore : Johns Hopkins University Press, 1977.

[221] And nations. What would Canada and Australia's economic growth rate be without immigration? Few things are as hard coded in global institutions than growth or development.

[222] When issues of "sustainable development" are broached, few observers will recognize that fiscal unsustainability of OECD governments is the largest of the sustainability problems, which in turn, drives demand for economic and population growth. In engineering, fiscal unsustainability of major OECD governments would be a first order problem.

[223] For example, Japan has relatively low rates of immigration compared to the US, Canada, UK, and Australia. For current data, see: World Bank, 2012. Net migration | Data | Table.

[224] The behavioral aspects of growth and its benefits in hierarchical organizations are described in an original, but mostly neglected study of absolute vs. relative scarcity in: Hirsch, F., 1995. Social limits to growth. London : Routledge, London.

[225] The most common of this is the timing of staff cuts to deal with anticipated shortfalls in financial results. For example, for decades, AT&T undertook staff cuts as an "extraordinary measure" in lieu of a steady reduction in staff. The reasons are numerous; including the ability to take a one-time charge each time against earnings rather than to report lower earnings if the cuts are "routine".

[226] The extent to which the necessity for growth can be seen in economies that have suffered sharp declines in the past year, such as Greece and Spain. Greece does not have the capability to devalue while remaining in the Euro zone, with its economy shrinking at the rate of 7% annually, with a debt to GDP ratio of 150% with the GDP falling in nominal euros at 4% causing the debt-to-GDP ratio to rise. See: Feldstein, M., 2012. The failure of the euro. Foreign Affairs 91, 105-116.

[227] The idea that leaders have a duty to followers who in turn owe their loyalty to leaders is difficult to reconcile with neoclassical theories of economics that are premised on economic agents, or "economic man". However, there is a large literature in management on leadership and followership that expressly acknowledges that unequal relationships are core and central to societies and these unequal relationships continue to be key to how organizations function in the modern world. See: Riggio, R.E., Chaleff, I., Lipman-Blumen, J., 2008. The art of followership: How great followers create great leaders and organizations. Jossey-Bass.

[228] Unit level rationality (e.g. the Firm as "rational actor") is a weak lens to understand behavior in and of itself. In the classic "Essence of Decision", it demonstrates how multiple models are required to gain a perspective. See: Allison, G.T., 1999. Essence of decision : explaining the Cuban Missile Crisis. New York : Longman, New York.

[229] For example, Japan depleted its natural endowment of coal early in its industrialization and became dependent on energy imports. The boost from industrialization in stimulating exports, however, enabled Japan to pay for its energy exports. Norway is one of the most effective sovereign funds in investing its petrodollars and preparing for the day when they will no longer have energy to export. Alberta, however, has not been able to balance its budget despite its bounty of wealth from energy exports.

[230] In Canada, the town of Inuvik committed itself to the use of natural gas after the discovery of a small deposit in the 1990s. It is expected that, ultimately, the plentiful deposits in the Mackenzie Valley will be tapped and they can be supplied indefinitely as the town is "en route" to the deposits and proposed gas pipeline to southern markets. With the Mackenzie project is suspended indefinitely, the town is within a few years of running "out of gas" and has to rely on much higher priced diesel and fuel oil imports. Prudence would have suggested that the energy should have been priced at replacement costs, and the eventuality that is reasonably probable (no alternative except imported oil) be planned for. See: National Post, 2012. Nothing left in the tank: Inuvik is running out of gas, literally | Canada | News | National Post.

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[231] The time horizon issue , where free market advocates say that, in the long term, the market ought to reach equilibrium, was derided by Sir John Maynard Keynes, who quipped, “In the long run, we are all dead.”

[232] The Manhattan Project is one of the rare examples of a technology that was able to go from laboratory theoretical possibility to useable weapon within a relatively short timeframe, between 1941 and 1945. Much basic theoretical work and practical work occurred over the previous decades, and the US was able to concentrate talent from all over Europe for the project. See: Rhodes, R., 1995. The making of the atomic bomb. Simon & Schuster.

[233] During World War I, France fielded a revolutionary artillery technology called the Canon de 75 modèle 1897, which was manufactured by skilled craftsman. Despite the pressure of war, it required an American re-engineering of production to enable it to be mass-produced. France did not independently come up with the manufacturability solution. Hacker, B.C., Vining, M., 2006. American military technology: the life story of a technology. Greenwood Publishing Group.

[234] World Nuclear Association, 2012. Nuclear Development in the United Kingdom |UK Nuclear Energy Development.

[235] Ergas, H., 2000. Does Technology Policy Matter? The Economics of Science and Innovation 2. And Foreman-Peck, J., 2006. Industrial policy in Europe in the 20th century. EIB papers 11, 36-62.

[236] For history of TRA assessments, Mankins, J.C., 2009. Technology readiness assessments: A retrospective. Acta Astronautica 65, 1216-1223. For background, Dion-Schwarz, C., 2008. How the Department of Defense Uses Technology Readiness Levels. T. a. L. Office of the Under Secretary of Defense for Acquisition, Ed., ed. Current TRA Guidance manual is April 2011 (Version 2.0). US-DoD OSD, April 2011. Technology Readiness Assessment (TRA).

[237] A history of MRL and classifications: Morgan, J., 2008. Manufacturing Readiness Levels (MRLs) and Manufacturing Readiness Assessments (MRAs). DTIC Document. OSD, U.-D., May, 2011. Manufacturing Readiness Level (MRL) Deskbook.

[238] US-DoD OSD, April 2011. Technology Readiness Assessment (TRA). P. 2-13.

[239] OSD, U.-D., May, 2011. Manufacturing Readiness Level (MRL) Deskbook.

[240] The Montreal Protocol served as a poor precedent and model because it involved a very narrow set of products for which substitutes were possible (e.g. use of propane in vehicle refrigerator systems). GHGs and fossil fuels are so broad-sweeping that what worked for ozone depleting substances reduction cannot efficiently address GHG reduction.

[241] Such a plan would require suppliers to be identified, facilities planned, contracts signed and near “turn-key” status for the jurisdictions participating in the binding agreement.

[242] Civilian nuclear reactors in the OECD are looking at lead times above 10 years. Mez, L., 2012. Nuclear energy–Any solution for sustainability and climate protection? Energy Policy 48, 56-63. P. 59.

[243] Who would have thought in the 18th Century that as deeply embedded an institution as slavery would be largely outlawed by the end of the 19th century and eliminated as an acceptable institution worldwide?

[244] Russia, for example, chose to end the institution of slavery by making the serfs purchase their freedom through a system of redemption payments under the Stolypin reforms. The United States ended slavery with no compensation for the owners of slaves. France demanded, and received compensation from its former colony Haiti for its slaves after the French were militarily defeated. In the modern era, the argument was turned upside down with descendants of slaves demanding compensation for slavery.

[245] Geller, H., Harrington, P., Rosenfeld, A.H., Tanishima, S., Unander, F., 2006. Polices for increasing energy efficiency: Thirty years of experience in OECD countries. Energy Policy 34, 556-573.

[246] Liddle, B., 2012. OECD energy intensity. Energy Efficiency, 1-15.

[247] IEA, 2012. IEA - September:- IEA plots path to halving fuel used for road transport in under 40 years.

[248] Guldi, J., 2012. Roads to Power: Britain Invents the Infrastructure State. Harvard University Press. P. 12.

[249] Commuting is typically done by one person in the US and a similar pattern is found in most OECD nations when mass transit trips are excluded. For US data, see: US-DoT, 2012. BTS | National Household Travel Survey.

[250] The idea of narrow width vehicles is not new, but many prototypes have concentrated on making them excessively complex with active lean / tilt control, or hybrid drives, etc. See: Hibbard, R., Karnopp, D., 1996.

Twenty first century transportation system solutions-A new type of small, relatively tall and narrow active tilting commuter vehicle. Vehicle system dynamics 25, 321-347. The Nissan Leaf is an example of this kind of implementation, which focuses on new technology rather than rapid deployability.

[251] Pairing deployment of half width vehicles with implementation of a new road system for half width cars that provides priority access to scarce road space, parking spaces, and other inducements, may be sufficiently compelling for buyers to consider a switch.

[252] For definitions of Net Zero and a literature review, see: Marszal, A.J., Heiselberg, P., Bourrelle, J., Musall, E., Voss, K., Sartori, I., Napolitano, A., 2011. Zero Energy Building–A review of definitions and calculation methodologies. Energy and Buildings 43, 971-979. An overview of projects here: Musall, E., Weiss, T., Lenoir, A., Voss, K., Garde, F., Donn, M., 2010. Net Zero energy solar buildings: an overview and analysis on worldwide building projects, Proceedings of EuroSun.

[253] It is beyond the scope of this thesis to lay out the specifics of the costs associated with net zero implementations. The National Renewable Energy Laboratory built a commercial building using Net Zero implementations and was able to bring the cost to within US Federal Guidelines for Government Buildings. See: Simon, S., 2012. In Search of Net Zero.

[254] Commercial buildings are quite different depending on the type of activity inside. Net zero can be achieved by retailers that do not require large energy inputs (e.g dry goods), but can be very difficult to implement for a restraint / food court that requires high gradient energy for food preparation. Discussions of these and other issues here: Griffith, B.T., Long, N., Torcellini, P., Judkoff, R., Crawley, D., Ryan, J., 2007. Assessment of the technical potential for achieving net zero-energy buildings in the commercial sector. National Renewable Energy Laboratory. BC Hydro estimated net zero targets would raise building costs 20-25%. See: BC Hydro, 2012. BC Hydro - What can we learn from net zero homes like Harmony House?

[255] Energy audit data taken from David Mather, personal communication.

[256] The standard electric hot water heater in many North American homes can be readily converted into an energy storage / demand shifting device by rigging it to superheat water in the middle of the night. Ontario presently requires a blend valve to drop the hot water temperature so water hotter than can be used is not a problem. Surplus electricity at night can also be used to move heat or cool air in / out of geothermal storage. Natural batteries are all around us.

[257] Hepbasli, A., Akdemir, O., 2004. Energy and exergy analysis of a ground source (geothermal) heat pump system. Energy Conversion and Management 45, 737-753. And Hepbasli, A., 2011. Low exergy (LowEx) heating and cooling systems for sustainable buildings and societies. Renewable and Sustainable Energy Reviews. And Rybach, L., Sanner, B., 2000. Ground source heat pump systems, the European experience. GHC Bull 21, 16-26.

[258] Two-tiered wage structures were widely used in the US, and now Europe. Bentolila, S., Cahuc, P., Dolado, J.J., Le Barbanchon, T., 2012. Two-Tier Labour Markets in the Great Recession: France Versus Spain*. The Economic Journal 122, F155-F187, Chaison, G., 2012. The Present and Future of Unions Settling for Less. The New Collective Bargaining, 63-71.

[259] The customer can pay the same fuel price as everyone at the pump, and only periodically, e.g. every quarter, have the OBDII data read and the surcharges calculated and paid. More advanced solutions would involve wireless transmission of the data, or pumps that recognize the vehicle and charge a different price as needed.

[260] Lloret, J., Macías, E., Suárez, A., Lacuesta, R., 2012. Ubiquitous Monitoring of Electrical Household Appliances. Sensors 12, 15159-15191. And Butgereit, L., Smith, A., 2012. Using the internet of things to enable electrical load optimisation.

[261] Techniques to uniquely identify oil and gas can be extremely simple assays (viscosity, sourness, etc.) to highly complex assays that virtually “fingerprint” each oil. See: Qian, K., Rodgers, R.P., Hendrickson, C.L., Emmett, M.R., Marshall, A.G., 2001. Reading chemical fine print: Resolution and identification of 3000 nitrogen-containing aromatic compounds from a single electrospray ionization Fourier transform ion cyclotron resonance mass spectrum of heavy petroleum crude oil. Energy & fuels 15, 492-498.

[262] Exxon came out in support of carbon taxes recently, and it was taken by environmental interests as affirmation of the legitimacy of the proposal. However, the support on carbon taxes notably did not include a limitation on what quantities of hydrocarbons can be used and whether the oil and gas industry would be subject

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to quantitative restrictions as long as the taxes are paid. Gold, R., Talley, I., 2009. Exxon CEO Advocates Emissions Tax. Wall St J B 3.

[263] Maugeri, L., 2012. Oil: The Next Revolution. Belfert Center for Science and International Affairs, Harvard Kennedy School, Cambridge.

[264] This stands in contrast to the oil industry's defense whereby they claim they only emit a small portion of CO2 at the production and distribution stages, which, coincidentally, is a perspective that relieves them of downstream addiction by consumers and governments.

[265] Khemani, R.S., 2002. Application of competition law: exemptions and exceptions. UN. This shows how currently many sectors of the economy are exempt from antitrust. The profession of engineering, for example is exempt by having an exclusive monopoly to practice engineering in Canada in exchange for self-regulation.

[266] The goal of a carbon tax is to raise prices to deter demand, but the benefits accrue to government unless it is revenue neutral --- a goal that only the most idealist can imagine that is unlikely to be achieved in the context of governments under financial stress. In this proposal, the same idea is achieved but the industry gets to keep the benefits of higher prices --- a proposal that they are unlikely to turn down especially in the face of a price collapse.

[267] Other reforms will include sweeping away the laws that compel posting of prices at filling stations.

[268] Moderated, in the case of Ontario electricity prices, can mean 50% increases in the next decade.

[269] Legal minimum prices are now being proposed for alcohol in Scotland. Baumberg, B., Anderson, P., 2008. Health, alcohol and EU law: understanding the impact of European single market law on alcohol policies. The European Journal of Public Health 18, 392-398.

[270] Grubb, M., 2012. Emissions trading: Cap and trade finds new energy. Nature 491, 666-667.

[271] In the US, this would be termed "conforming" mortgages, while in Canada, the Canada Mortgage and Housing Corporation insures loans. This is a policy instrument that can substantially alter market behavior because the majority of homes purchased are financed. The typical financing formula for home loans estimates that occupancy costs, including energy, should be about 30% of income. The lending formula will need to be adjusted to reflect lower energy costs in net zero homes, for example.

[272] A solution may be for the larger cars to be available on a shared basis via rental agencies.

[273] What to do about the many residential units that have only one parking space? That is an example of the kind of institutional arrangements that need to be adjusted to ease the introduction of a new format.

[274] Smith, M.H.H., Hargroves, C., von von Weizsacker, E.U.U., 2012. Factor Five: Transforming the global economy through 80% improvements in resource productivity. Routledge.

[275] E.g. within 20 years.

[276] The international community gives lip service to world development and lavishly funds many institutions to support it. But realistically, there is not a viable model for world development unless a much less resource intensive architecture is developed and actually implemented.

[277] Most industrial nations from the late 19th Century onwards have some form of defense stockpiles of secured supplies or raw materials. IEA members participate in these arrangements by stockpiling petroleum.

[278] The US stockpiled Helium, which was regarded as a strategic material because of its use in airships dating from the WWI era Helium Act of 1925. The stockpile existed long past the point when it served the purpose. The stockpile was finally ordered to be sold off under the Helium Privatization Act of 1996, and as it dwindled, as predicted, eminent scientists warned of the consequence of its demise. See: Reserve, C.o.U.t.I.o.S.t.H., 2010. Selling the Nation's Helium Reserve. National Academy Press.

[279] United States. Congress. House. Committee on Armed Services. Readiness Subcommittee., 2010. Proposed reconfiguration of the National Defense Stockpile : hearing before the Readiness Subcommittee of the Committee on Armed Services, House of Representatives, One Hundred Eleventh Congress, first session, hearing held July 23, 2009. U.S. G.P.O. : For sale by the Supt. of Docs., U.S. G.P.O., Washington.

[280] There are in fact, no known markets operating that allow the purchase of options over 100 years out. The majority of "long" bonds are at the 30year maturity. UK floated the idea of offering 100 year gifts, which was offered during WWI. Based on this experience, it can be argued that actual market behavior showed no appetite to participate in such long term markets that deal with a realistic volume of resources.

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[281] Plus setting tastes. It cannot be over-stated how elite classes set tastes and how cycles of fads are driven by the narrow elite strata. White bread was once regarded as a premium product while only the poorer classes ate whole grain bread. See: Bobrow-Strain, A., 2012. White Bread: A Social History of the Store-Bought Loaf. Beacon Press.

[282] A potential exception is Taiwan, which has the world's highest population of motorized scooters. But even there, the private car is a badge of arrival in the global middle class.

[283] Formula 1 racing, NASCAR, and other well-publicized motor sports play a pivotal role in setting norms. The lack of attention by regulators to setting standards for these vehicles was a blunder that legitimized resource waste. Had race teams been required to post GHG emissions and pollutants emitted and were awarded "time" points, it would have had a major impact on customer tastes.

[284] The pedicab or the motorized 3-wheel taxi used widely in the developing world is a symbol of poverty. Using less is more have a parallel in microelectronics, where Moore's law created successive generations of devices that are more powerful, yet smaller, faster, and consume less power.

[285] For decades, Detroit-based auto assemblers built small cars as "entry level" vehicles that have small profits, and sold at low prices so as to bring down the Corporate Average Fuel Economy (CAFE) ratings to enable higher priced, but poorer fuel economy vehicles that earned much higher profits to be sold.

[286] When Tata devised the Nano, they kept the 2 abreast seating layout when they were in a position to build something truly revolutionary in architecture.

[287] There is no known threat to America that can compel the US to modernize its military after the collapse of the Soviet Union, but the modernization went ahead in unmanned platforms because they can, not because they must.

[288] Nash, G.D., 1968. United States oil policy, 1890-1964: Business and government in twentieth century America. University of Pittsburgh Press. P. 24.

[289] Frey, J.W., Ide, H.C., 1946. A history of the Petroleum Administration for War, 1941-1945. USGPO.

[290] Nash, G.D., 1968. United States oil policy, 1890-1964: Business and government in twentieth century America. University of Pittsburgh Press. P. 197.

[291] Roughead, Carl, Hernandez, 2012. Powering the Armed Forces: Meeting the Military's Energy Challenges by Gary Roughead, Jeremy Carl, and Manuel Hernandez. s. p. 3.