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LAW, THE LAWS OF NATURE AND ECOSYSTEM ENERGY SERVICES: A CASE OF WILFUL BLINDNESS

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The law of conservation of energy tells us we can't get something for nothing, but we refuse to believe it.[1]

In this house, we obey the laws of thermodynamics! [2]

1 Introduction

Our burning of fossil fuel has released and continues to release enormous quantities of ancient carbon into the atmosphere with relative suddenness, causing local, regional and global ecosystem harm and threatening abrupt and irreversible shifts in the state of the ecosystem as critical thresholds are approached.[3] This ancient carbon (the remains of ancient plants and animals) was sequestered by nature's services over millions of years and stored underground under enormous pressure over such long periods that the carbon comprising their structures was made into coal, oil, or natural gas.[4] Thus fossil fuels are the product of nature's ecosystem

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1 Shulman and Asimov Book of Science and Nature Quotations 75.

2 Simpson H "PTA Disbands".

3 Barnosky et al 2012 Nature 52-58.

4 Humans also consume other carbon-based sources of energy, especially wood. Large portions of developing countries rely on wood for fuel, either directly or after it has been converted into charcoal. In those regions, so much wood is used so inefficiently as fuel that the demand for wood far exceeds the rate that forests can be regenerated. However, compared to fossil fuels, forest can be regrown in a relatively short time (decades to a century, compared to tens of millions of years for fossil fuels). Goldemberg *et al* (eds) *World Energy Assessment* 65-68, 370 (hereinafter World Energy Assessment).

provisioning[5] services. Yet, the field of ecosystem services[6] ignores[7] the ecosystem services that produced fossil fuels.

Current ecosystem literature fails to address the ecosystem provisioning of fossil fuels. Even though fossil fuels are the products of millions of years of ecosystem services,[8] the literature recognises only current biomass-based energy (wood, ethanol, biodiesel) as ecosystem service products.[9] It is unlikely that these scholars have forgotten about fossil fuel energy, but it appears that they avoid it because it is outside the conceptual framework contained in the *Millennial Ecosystem Assessment.* This avoidance, whether intentional or inadvertent, results in an incomplete framework for understanding ecosystem services, missing the big picture and leading to incomplete understanding of complex systems.

This paper will examine law's failure to appreciate the enormous ecosystem energy subsidies[10] that support our economic and social systems. Only by appreciating the

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5 For operational purposes, the Millennium Ecosystem Assessment classifies ecosystem services into four functional categories: provisioning, regulating, cultural, and supporting services. Ecosystem provisioning services products include food and fibre, and fuel: wood, dung, and other biological materials that serve as sources of energy (Millennium Ecosystem Assessment *Ecosystems and Human Well-being* 55).

6 "Ecosystem services are the benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as the regulation of floods, drought, land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious and other nonmaterial benefits." Millennium Ecosystem Assessment *Ecosystems and Human Well-being* 54.

7 UNEP TEEB *Mainstreaming the Economics of Nature* 7 (Sustaining flows of ecosystem goods and services "requires a good understanding of how ecosystems function and provide services, and how they are likely to be affected by various pressures"). Ironically, the definition and list of ecosystem services used by TEEB does not even mention biomass energy as a provisioning service. See UNEP TEEB *Mainstreaming the Economics of Nature* 34. TEEB is hosted by the United Nations Environment Programme and supported by the European Commission, the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, the UK government's Department for the Environment, Food and Rural Affairs, and Department for International Development, Norway's Ministry for Foreign Affairs, Sweden's Ministry for the Environment, The Netherlands' Ministry of Housing, Spatial Planning and the Environment and Japan's Ministry of the Environment.

8 See, eg, Layke *Measuring Nature's Benefits* 4; Mäler, Aniyar and Jansson 2008 *PNAS* 9501-9506.

9 See, eg, Williamson and McCormick *Energy, Ecosystems and Livelihoods* 5-7.

10 A subsidy is a cost reduction supplied to producers or consumers either directly, through price reductions, or in less visible forms. In the context of this paper, an ecosystem services subsidy is the cost of making the product. So, for oil, nature's subsidy is equal to what it would actually cost human beings to make petroleum in large amounts, if, starting from scratch, someone actually collected

scale of this hidden, implicit subsidy can we begin to understand why sustainable energy reform is both so important and so fundamentally difficult. When we understand the scale and scope of this subsidy, we can begin to appreciate society's deep resistance to acknowledging the fossil fuel paradigm that dominates modern society, let alone the resistance to changing it.[11] The fear of losing this subsidy is profound because most people cannot imagine a world without cheap fossil fuels - they cannot imagine using energy efficiently.[12] We seem not to trust the market to respond innovatively to true price signals that reflect ecosystem fossil fuel services. Acknowledgment of the ecosystem subsidy of fossil fuels is one of the most difficult, yet necessary, challenges society faces, because blindness to that subsidy affects energy policy and influences how we address climate change. As a result we have created legal and economic systems that are similarly blind to the value of the ecosystem services that are embedded in fossil fuels.

The organisation of human societies depends on exploiting the ecosystem subsidy of fossil fuels. In a world of fewer people and less intense energy use,[13] the exploitation of natural capital advanced human development without causing significant, widespread environmental problems. As population and energy use grew, significant environmental problems developed, and nations reacted by tinkering with existing law or by adopting new, *ad hoc* laws,[14] creating jerry-rigged legal regimes comprised of independent laws addressing separate spheres of environmental concerns. Moreover, although currently law ignores the real value of the ecosystems that support life, we are continually astounded at how intractable many of our

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sunlight and converted that solar energy into petroleum. (This would include the cost of making all the necessary equipment from scratch, including the materials used.)

11 The tendency of human beings to hold onto existing paradigms, concepts and even vocabulary in the face of new paradigms, relationships, and understandings is deeply rooted. See Kuhn *Structure of Scientific Revolutions*.

12 Hodas 2007b papers.ssrn.com (demonstrating the enormous readily available potential to dramatically improve energy efficiency if well-designed energy laws are adopted).

13 In 1969 World GDP was about $14.9 trillion (2005 $); by 2010 it had grown to $52.1 trillion (2005 $) (US Dept of Agriculture [Date Unknown] www.ers.usda.gov).

14 Percival et al Environmental Regulation 61-63.

environmental problems are. We need to reformulate our legal system to reflect both the laws of ecology and of human behaviour.[15] Law, both international and domestic, should form an integrated decision-making framework for sustainable development. The central question of sustainability and climate change is if the ecosystem subsidy of fossil fuels is too big to resist, yet we will not solve the fundamental sustainability challenges until law coheres with the complex natural systems in which we live.[16]

This paper will first review the basic concepts of ecosystems and economics, and document the blind spot. It will illuminate the ecosystem subsidy of fossil fuels that we are blind to.[17] It will survey past efforts to address ecosystems in law and policy, and will survey the renewed interest policymakers are showing in ecosystems and the law. However, ecosystem services study is a subset of the larger ecological economics project of "getting the prices right," because "[a] decision not to consider external costs in itself quantifies them by setting their value at zero."[18] Recent developments in these related fields supply methodologies that could illuminate the blind spot and narrow, to the greatest extent possible, the gap between law and reality.[19]

2 Fossil fuels: thermodynamic marvels made by nature

15 Hodas 1998 Widener Law Symposium Journal 1, 16.

16 Hammond 2004 *Energy Policy* 1789, 1790. ("[T]he role of thermodynamic analysis, which so enthralled Albert Einstein, is not always sufficiently recognised, particularly amongst the 'policy analysts' …")

17 Hodas 2007a papers.ssrn.com. This paper builds on that article. Footnotes will indicate when material from that article is used here, either as previously written, or as revised and updated. To enhance readability, quotation marks will be minimally used.

18. Bland 1986 *Harv Envtl L Rev* 345, 386.

19 The laws of thermodynamics prevent us from eliminating that gap entirely. The first and second laws of thermodynamics are that
1) energy can neither be created nor destroyed; it can only change from one form into another.
2) energy flows only in one direction—from a hotter to a colder body—and in this process entropy increases. That is, the availability of energy decreases as it is transferred.
The first law states that the energy in the universe is always constant, but, according to the second law, whenever work is done or heat is exchanged, energy becomes more random and therefore less useful for doing work. Gibbons and Chandler *Energy* 142.

When we examine the role of law in achieving sustainable development we often do not recognise fundamental facts that underlie the complex systems that drive human society. These fundamental facts are so basic that they have become invisible to us — so taken for granted that we do not recognise that they operate on human society with powerful force. For instance, we take readily available, useful energy, so fundamental to our well-being, for granted. Most of the world's population wants light at night, air conditioning during hot days, warm buildings on cold days, refrigeration to preserve food, energy to cook food, vehicles that can carry us hundreds or thousands of miles in hours, and instant electronic communications. We take for granted that

> [m]odern forms of energy empower human beings in countless ways: by reducing drudgery, increasing production, transforming food, providing illumination, transporting water, fueling transportation, powering industrial and agricultural processes, cooling or heating rooms, and facilitating electronic communications and computer operations, to name just a few.[20]

Yet, as recently as the late 19th century, few if any of these routine amenities were available even to the rich.[21]

According to Professor David Goodstein, professor of physics and applied physics at California Institute of Technology, "our present standard of living has resulted from a series of inventions and discoveries that altered our expectations. … One consequence of those inventions and changed expectations is that we no longer live on light as it arrives from the sun. Instead we are using the fuels made from sunlight that the Earth stored up for us over … hundreds of millions of years."[22] The ecosystem service of collecting, concentrating, and storing solar energy as fossil

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20 Johansson and Goldemberg "Overview" 1.

21 Goldemberg "Development and Energy" 1-2. For most of human history energy consumption remained at a low, nearly constant level—only slightly more than that of the food supply. Release from this constraint was not possible until an energy supply capable of exploitation faster than human population could grow should become available. Such an energy supply is … fossil fuels. Hubbert "Energy Resources" 158.

22 Goodstein *Out of Gas* 26.

fuels (e.g., coal, petroleum, and natural gas) plays a central role in the human story. These fuels are concentrated forms of sunlight made and collected and stored by ancient ecosystem services.

To fill the gap between what we can accomplish using sunlight only as it arrives rather than sunlight stored in fuels, we borrow from our natural capital, over-consume resources, and in the process impose harmful environmental externalities on others.[23] Our legal, economic and social systems are constructed on this cheap-energy fossil fuel energy paradigm.[24] One consequence of and reason for the near total acceptance of this paradigm is our deep belief that "fossil fuel production and consumption are integral to economic growth."[25] Social, economic and legal systems sustain and support this belief and "present substantial barriers to a better energy future,"[26] such as the failure to add the value of nature's ecosystems which make oil, coal or natural gas from sunlight.

"[T]he physical, chemical and biological activities that influence the flows, storage, and transformation of materials and energy within and through ecosystems"[27] provide a wide range of goods and services essential to human well-being.[28] In one way or another, nearly all of our sources of energy depend on the supporting, provisioning, and regulation goods and services ecosystems provide daily.[29] For example, generating electricity requires large volumes of clean water. Water is needed for the steam that spins electricity generating turbines, to flow through hydroelectric turbines, and to grow biomass burned to make electricity, cook food, or power vehicles. Roughly 2 billion people depend on ecosystems such as forests to produce traditional biomass fuels, such as wood and dung, for cooking and heating,

23 IEA 2008 www.iea.org 3.
24 Tomain Ending Dirty Energy Policy 47-52.
25 Tomain Ending Dirty Energy Policy 42.
26 Tomain Ending Dirty Energy Policy 2-3.
27 US EPA Science Advisory Board *Valuing the Protection* 2.
28 Hassan, Scoles and Ash (eds) *Millennium Ecosystem Assessment* 27.
29 Williamson and McCormick Energy, Ecosystems and Livelihoods 5.

and very few of those people have access to electricity or fossil fuels.[30] We need well-managed and enhanced ecosystems to sustainably meet growing world energy demand.[31] How we harness and employ energy can severely damage the environment and ecosystems; the production, transportation and consumption of fossil fuels can be particularly harmful to ecosystems, and even some forms of renewable energy generation can have adverse impacts.[32] Ecosystem changes can significantly affect energy security— the reliability and resilience of affordable energy systems.[33]

3 Fossil fuels: ecosystem services products

The fundamental ecosystem service, of course, is photosynthesis. Photosynthesis is necessary for life on Earth. It is the source of oxygen in the atmosphere and either directly, through primary food production, or indirectly, as energy moves up the food chain, is the source of the energy in food.[34] Photosynthesis is the process by which photoautrophs (plants, algae and certain species of bacteria) create their own food. Green plants use chlorophyll and solar energy (light) to convert water, carbon dioxide, and minerals into oxygen and a wide variety of carbohydrates, amino acids, proteins, lipids (or fats), pigments, and other organic compounds.[35]

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30 Goldemberg *et al* (eds) *World Energy Assessment* 45-46 ("energy consumption patterns of poor people tend to add to their misery and aggravate their poverty…").

31 Williamson and McCormick *Energy, Ecosystems and Livelihoods* 4-5 ("In the case of biofuels and biomass-based energy, ecosystems provide both goods (biomass, feedstocks and enzyme digesters) as well as services (soil formation, climate and water regulation and pollination").

32 Williamson and McCormick Energy, Ecosystems and Livelihoods 4-5.

33 Athanas and McCormick 2011 www.worldenergy.org.

34 Bassham 2012 www.britannica.com - "If photosynthesis ceased, there would soon be little food or other organic matter on Earth. Most organisms would disappear, and in time the Earth's atmosphere would become nearly devoid of gaseous oxygen. The only organisms able to exist under such conditions would be the chemosynthetic bacteria, which can utilize the chemical energy of certain inorganic compounds and thus are not dependent on the conversion of light energy."

35 Bassham 2012 www.britannica.com - "Minerals supply the elements (e.g., nitrogen, phosphorus, sulfur) required to form these compounds."

This first order ecosystem service is also the source of fossil fuels (*i.e.,* coal, oil, and natural gas). In long past geologic ages, "green plants and small organisms that fed on plants increased faster than they were consumed, and their remains were deposited in the Earth's crust by sedimentation and other geological processes. There, protected from oxidation, these organic remains were slowly converted to fossil fuels."[36] These fuels are called fossil fuels because they are made by the same geologic process as fossils-sedimentary pressure over millions of years.[37] Over tens or hundreds of millions of years, ecosystems collect solar energy and convert that energy into plant and animal life. The dead plants and animals accumulated by the ecosystems become part of the sedimentary process. This plant and animal material is slowly "cooked" by the heat from the sedimentary pressure into coal, oil, or natural gas, depending on the biologic input, the cooking temperature, and the kind of pot (the geological formation) in which it was cooked.[38]

3.1 Ecosystem services theory's blindspot: fossil fuels

Ecosystems provide a broad range of goods and services to human society. Broadly speaking, ecosystem services are the "direct and indirect contributions that ecosystems make to the well-being of human populations" and are the product of "the physical, chemical and biological activities that influence the flows, storage, and transformation of materials and energy within and through ecosystems."[39] The *Millennium Ecosystem Assessment*[40] (MEA) broadly defines the kinds of services ecosystems provide that directly or indirectly contribute to human well-being:

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36 Bassham 2012 www.britannica.com. The first photoautrophs, blue-green algae, are thought to have appeared on earth 2 to 3 billion years ago.

37 Hodas 2007a papers.ssrn.com.

38 See Goodstein *Out of Gas* 23-24, 32-33. Methane, although located in large underground deposits generally associated with oil and coal, can also be naturally created over short time frames by bacteria acting on organic material such as garbage in dumps, bacteria in the stomachs of ruminants such as cows, and other anaerobic decomposition of organic matter such as in rice paddies, swamps, and even mulch piles. However, the gigantic underground pools of natural gas we exploit were created over millions of years in geologic formations that trapped the methane.

39 US EPA. Science Advisory Board *Valuing the Protection* 2.

40 Millennium Ecosystem Assessment *Ecosystems and Human Well-being.*

provisioning, regulating, cultural and supporting services.[41] The MEA defines *ecosystem services* as "the benefits people obtain from ecosystems … includ[ing] provisioning services such as food and water, regulating services such as the regulation of floods, drought, and land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services…"[42] Provisioning services include the products obtained from an ecosystem such as food, fuels, fibre, biochemicals, fresh water, and genetic resources. Regulating services include flood protection, human disease regulation, water purification, air quality maintenance, pollination, pest control, and climate control. Cultural services help create a sense of human place by supporting the social, spiritual, and aesthetic dimensions of people's well-being. Supporting services sustain basic ecosystem processes and functions such as soil formation, primary productivity, biogeochemistry, and provisioning of habitat.

Although the MEA definition does not mention fuels, the MEA does include a chapter titled "Timber, Fuel, and Fiber." However, that discussion is limited to biomass fuels (firewood, charcoal, etc.) as the relevant ecosystem service products. The MEA refers to fossil fuels only as the world's primary source of fuel, which renewable fuels must compete with and replace when "the availability of fossil fuels declines,"[43] and notes that "burning fossilized biomass (fossil fuels)" releases carbon into the atmosphere.[44]

Building on the MEA's recognition of the importance of ecosystem services for human well-being and business development, the World Resources Institute, World Business Council for Sustainable Development, and the Meridian Institute have developed ecosystem services guidelines and methodologies to support business

41 A narrower definition proposed by Boyd and Banzhaf includes only services that are end products of nature "directly enjoyed, consumed or used to yield human well-being." Under their definition, ecosystem functions and processes, such as nutrient recycling, are not considered services because they only indirectly contribute to human well-being (Boyd and Banzhaf *What are Ecosystem Services*? 8).

42 Hassan, Scoles and Ash (eds) *Millennium Ecosystem Assessment* 27.

43 Hassan, Scoles and Ash (eds) *Millennium Ecosystem Assessment* 260-261.

44 Hassan, Scoles and Ash (eds) *Millennium Ecosystem Assessment* 360.

development.[45] They worry that "[l]eft unchecked, [ecosystem] degradation jeopardizes not just the world's biodiversity, but also its businesses ... because companies depend on the services healthy ecosystems provide such as fresh water, wood, genetic resources, pollination, climate regulation, and natural hazard protection."[46] The *Guidelines*, a methodological tool for corporate strategy development, connects ecosystem services and business goals. However, the *Guidelines* considers only biomass fuel ("'biological material derived from living or recently living organisms-both plant and animal-that serves as a source of energy'") as an ecosystem product.[47] The *Guidelines* specifically excludes fossil fuels from the definition of ecosystem products:

> fossil fuels – coal, oil, and natural gas – are … natural resources that are not ecosystem services. The quantity and quality of … fossil fuels are not dependent upon the living component of existing ecosystems and therefore are not benefits derived from ecosystems. Although fossil fuels … come from organic material that was alive millions of years ago, this timeframe is *not relevant for business or policy decisions* (emphasis added).[48]

This reasoning is an example of problematic system borders. By drawing its boundaries so tightly, the *Guidelines* have removed the role of ecosystem fossil fuel services from routine business consideration, and from general policy consideration by businesses and other decision-makers in civil society. Certainly, business decisions are dictated by existing market and legal conditions. The ecosystem subsidy of fossil fuels, however, is one of the existing market conditions. The ecosystem subsidy is a central and material factor in business decisions because without this subsidy,[49] the price signals contained in a business' decision-making matrix would be so substantially different that it might alter the actual decision. By

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45 Hanson *et al Corporate Ecosystem Services Review*.

46 Hanson et al Corporate Ecosystem Services Review iv.

47 Hanson *et al Corporate Ecosystem Services Review* 4. Examples of biomass fuel are wood, charcoal, dung, and grain for ethanol production.

48 Hanson et al Corporate *Ecosystem Services Review* 6.

49 One measure of this subsidy is the difficulty and cost of making biofuel from algae. Although work in this area began in the 1950s "[d]espite their potential, the state of technology for producing algal biofuels … in its infancy and a considerable amount of RD&D is needed to achieve affordable, scalable, and sustainable algal-based biofuels" (US Dept of Energy *National Algal Biofuels Technology Roadmap* 1).

drawing a system boundary that excludes the dominant economic and energy input of ecosystems, business decisions will be inherently flawed and unsustainable.[50] Boundaries that worked in contexts unrelated to ecosystem services or sustainable development are not necessarily appropriate for "a structured methodology to help businesses develop strategies for managing risks and opportunities arising from their dependence and impact on ecosystems."[51] Narrow boundaries can produce a fundamentally flawed analysis. Without understanding the scope of a system, appropriate analytical boundaries cannot be established.

The right boundary for thinking about a problem rarely coincides with the boundary of an academic discipline, or with a political boundary. Rivers make handy borders between countries, but the worst possible borders for managing the quantity and quality of the water. … National boundaries mean nothing when it comes to … greenhouse gases in the atmosphere.

Ideally, we would have the mental flexibility to find the appropriate boundary for thinking about each new problem. We rarely are that flexible. We get attached to the boundaries our minds happen to be accustomed to. [52]

> It's a great art to remember that *boundaries are of our own making, and that they can and should be reconsidered for each new discussion, problem, or purpose* (emphasis original).

Yet, the *Guidelines* exemplifies our unflagging commitment to the present paradigm.

3.2 Ecosystems services literature ignores fossil fuels

Ecosystems services science, policy and legal literature do not address the ecosystem subsidies of fossil fuels. Although "[e]cosystem services are the

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50 Meadows *Thinking in Systems* 97 - "[B]oundaries can produce problems when we forget that we have artificially created them. When you draw boundaries too narrowly, the system surprises you."

51 Hanson et al Corporate Ecosystem Services Review ii.

52 Meadows Thinking in Systems 98-99.

conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life,"[53] the leading scholarship in the field does not include energy in its list of critical ecosystem services. For instance, Gretchen Daily, one of the leading scholars in the field of ecosystem services, identifies 13 life-supporting ecosystem services that we ordinarily take for granted. Her lengthy list, however, does not mention energy,[54] other than with a brief acknowledgement that ecosystem services are "driven by solar energy."[55] Daily takes fossil fuel energy for granted.

A survey by leading scientists of the history of the idea of ecosystem services contains but one, oblique mention of energy: "[a]n energy-based approach to ecosystems studies" (coining the term "emergy" to describe embedded energy concepts of ecology) in "Odum's classic [1953] textbook."[56] According to Mooney and Ehrlich, the field of study known as "ecosystem services" is comprised of 11 of nature's services; however, nature's collection, concentration and storage of solar energy are not on the list.[57] Similarly, the important, provocative 1997 article by Robert Costanza *et al* that presented an estimated monetary value of the earth's ecosystem services contributions to human welfare does not include energy

53 See, eg, Daily "Introduction" 3.

54 Daily "Introduction" 3-4. The list is comprised of 1) purification of air and water, 2) mitigation of floods and droughts, 3) detoxification and decomposition of wastes, 4) generation and renewal of soil and soil fertility, 5) pollination of crops and natural vegetation, 6) control of the vast majority of potential agricultural pests, 7) dispersal of seeds and translocation of nutrients, 8) maintenance of biodiversity, from which humanity has derived key elements of its agricultural, medicinal, and industrial enterprise, 9) protection from the sun's harmful ultraviolet rays, 10) partial stabilisation of the climate, 11) moderation of temperature extremes and the force of winds and waves, 12) support of diverse human cultures, and 13) provision of aesthetic beauty and intellectual stimulation that lifts the spirit.

55 Daily "Introduction" 3-4.

56 Mooney and Ehrlich "Ecosystem Services" 13.

57 Mooney and Ehrlich "Ecosystem Services" 14-15. Their list of nature's services was comprised of pest control, insect pollination, fisheries, climate regulation, soil retention, flood control, soil formation, cycling of matter, composition of the atmosphere, maintenance of soil fertility, and maintenance of a genetic library.

collection, concentration, and storage services among the 17 categories of ecosystem services and goods analysed.[58]

Nor does the considerable attention given to ecosystem services law and policy[59] address the ecosystem services that made fossil fuels. A review of law journal articles[60] reveals that only two articles even acknowledge an analytical link between ecosystem services and fossil fuels. One was part of the 2007 Florida State University College of Law *Symposium on the Law and Policy of Ecosystem Services.*[61] The other article discussed the relationship between energy security and sustainable development.[62]

The seminal 2001 *Stanford Environmental Law Journal* devoted to ecosystem services mentions fossil fuels only once, and then only in a footnote that places fossil fuels on the non-renewable side of the natural capital ledger.[63] More than a decade later the World Resources Institute and the World Business Council for Sustainable Development also refused to consider fossil fuels as ecosystem products.[64]

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58 Costanza *et al* 1997 *Nature* 253-260. Services on the list were: gas regulation, climate regulation, disturbance regulation (capacitance, damping and integrity of ecosystem response to environmental fluctuations), water regulation, water supply, erosion control and sediment retention, soil formation, nutrient cycling, waste treatment, pollination, biological control, refugia, food production, raw materials, genetic resources, recreation, and cultural benefits.

59 For instance, the American Bar Association House of Delegates adopted a resolution and report "urg[ing] federal, state, territorial and tribal governments, when considering and approving legislation, regulations and policies, to preserve and enhance the benefits that people derive from ecosystems…" (ABA 2008 www.americanbar.org).

60 As of 11 March 2102, 1,046 law-related articles refer to "ecosystem services." However, only 3 articles use "fossil fuels" and "ecosystem services" in the same sentence (Westlaw TP-ALL database searches by author 11 March 2012).

61 Hodas 2007a papers.ssrn.com upon which this article is built. Ruhl and Salzman's introduction to the Symposium Proceedings (Ruhl and Salzman 2007 *J Land Use & Envtl L* 157) mentions this theme also ("Hodas shows that, ironically, almost none of the literature on ecosystem services, including some of the groundbreaking work of the late 1990s as well as more recent treatments, recognises fossil fuels…").

62 Gaines 2006 *Wm & Mary Envtl L & Pol'y Rev* 321, 357 ("In other words, the United States fully uses not only the ecosystem services of the United States itself but takes an equal amount of the world's ecosystem services from the peoples of other countries."); and Hodas 2007a papers.ssrn.com 599.

63 Heal *et al* 2001 *Stan Envtl L J* 333 n1.

64 Hanson et al Corporate Ecosystem Services Review 6. ("…[C]oal, oil, and natural gas - are

The IUCN treats only a small subset of biomass-based energy as products of ecosystem provisioning services.[65] Biomass energy is important, supplying about 40% of the world's population with energy, especially in poorer nations where much of the energy is derived from traditional energy use,[66] burning wood, charcoal, leaves, agricultural residue, human and animal wastes for cooking, making charcoal and other household uses.[67] More than 94% of society's usable energy is derived from ecosystem services (fossil fuels, biomass, and hydroelectricity).[68] Fossil fuels provided 87.5% of all human energy use, releasing approximately 29 billion mt of CO_2.[69] In countries that do not generate electricity from nuclear power,[70] ecosystem services products (fossil fuels and biomass) account for virtually 100% of all energy used.

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examples of natural resources that are not ecosystem services. The quantity and quality of minerals and fossil fuels are not dependent upon the living component of existing ecosystems and therefore are not benefits derived from ecosystems…").

65 Williamson and McCormick Energy, Ecosystems and Livelihoods 5-7.

66 Karekezi, Lata and Coelho 2004 www.ren21.net 7.

67 Karekezi, Lata and Coelho 2004 www.ren21.net 2 ("[A]pproximately 50% of the population in developing countries relies on biomass energy, with some regions recording higher proportions (73% in Africa). Biomass is the energy source for the poor. This is especially true for traditional biomass energy, which is often collected as a 'free' fuel. There appears to be a correlation between poverty levels and traditional biomass use in many developing countries. As a rule, the poorer the country, the greater the reliance on traditional biomass resources." Citations omitted.)

68 In 2010 the world consumed the energy equivalent of 12.0 billion tons of oil. The energy mix was: oil, 4.0 billion tons; coal 3.6 billion tonnes of oil equivalent (btoe) (7.2 billion metric tons of coal); natural gas 2.9 btoe (3169 trillion cubic feet of natural gas); nuclear energy 0.63 btoe; hydroelectricity 0.78 btoe; and renewable energy 0.16 btoe. BP 2011 www.bp.com.

69 IEA 2011 www.iea.org.

70 Nuclear power is not an ecosystem services product because uranium, a radioactive element, is not an ecosystem service product; uranium is created by stellar nucleosynthesis in supernovas. See Vogt 2012 www.sciencedaily.com. Fossil fuels are ecosystem services products, Both fossil fuels and uranium are processed after they are removed from the ground, but only fossil fuels were made by earth's ecosystems. Fuel grade uranium is a product of remarkable human ingenuity – few nations have the technical expertise to concentrate the trace amounts (0.7%) of U^{235} in U^{238} into fuel pellets containing fuel grade uranium (about 5% U^{235}) (US Nuclear Regulatory Commission [Date Unknown] www.nrc.gov). Whether or not one considers geothermal power to be an ecosystem service depends on whether geologic phenomena such as volcanoes are within the definition of ecosystems. Except for a few special locales, geothermal energy is so small a portion of the world's energy use (0.4%) that how it is categorized is irrelevant (WRI [Date Unknown] earthtrends.wri.org).

In our fervour to maximize our use of fossil fuels, we blithely harm a wide range of ecosystems, despite the valuable services they provide. The burning of fossil fuels has a significant adverse impact on ecosystem services. These externalities have been well studied and documented[71] and they drive environmental regulation[72] and significant national, regional and international concern. However, except for the brief discussion of biomass in the MEA and elsewhere, the fundamental ecosystem service of providing usable energy to society is missing from ecosystem services literature and discussion. Without recognising energy ecosystem services we cannot hope to fully understand current energy-based ecosystem challenges, to knowledgeably analyse and critique current law and policy, or to develop effective, durable solutions. At present we cannot even adequately articulate, or even envisage what the law and policy of energy ecosystem services should be.

4 Energy and human society

The problem law faces is how to include a monetary value for ecosystem services in legal decision-making when the free market does not value the services that ecosystems provide. These priceless services[73] are valued at exactly zero,[74] which is a fundamental error that underlies some of the most challenging threats ecosystems and human society face. The laws of physics and thermodynamics govern ecosystem services, but the existing legal paradigm is based on policies and assumptions that

71 See, eg, National Research Council 2010 www.nap.edu; Ottinger *et al Environmental Costs*.

72 See, eg, United States' regulation of sulfur dioxide emissions from coal-burning electric power plants to mitigate acid precipitation, 42 USC §§ 7651 to 7651o, motor vehicle emissions and fuel standards, 42 USC §§ 7521 to 7554 and oil spills, Oil Pollution Act 33 USC §§ 2701 to 2761.

73 For an extended discussion of this problem see Ackerman and Heizerling *Priceless* in general.

74 Bland 1986 *Harv Envtl L Rev* 345, 386 ("A decision not to consider external costs in itself quantifies them by setting their value at zero").

are independent of nature's laws.[75] In our world, which is dominated by the intensive use of fossil fuels, we ignore the laws of physics at our grave peril.

Why have we so studiously avoided the energy ecosystem services question?[76] Because the role of fossil fuels is so deeply and finely woven into our lives that we do not see it. The developed nations simply take their reliable, high-quality energy for granted; developing countries would like their electricity to be reliable, and the 1.5 billion people without any electricity want to get it.[77] Yet, the vast majority of people know little more about electricity than that it comes out of an outlet in the wall and is controlled by an on/off switch. Our ignorance about energy makes it that much more difficult to peer into law's energy blind spot. Only very few of us know how electricity is generated or understand electricity's fundamental properties. Few of us know or care about how the electricity in our house or office was made, let alone what energy source was used to generate it, so long as electricity is reliably available and relatively inexpensive. We are periodically reminded that working in a coal mine[78] or on an offshore oil rig[79] is hard, dangerous work. But beyond the occasional news story about a disaster or an oil price increase, most people know little more about gasoline, diesel fuel, aviation fuel and heating oil other than that a hose is used to move it from a supply tank to the user's tank, that refineries have something to do with making the fuels, that we do not want one in our back yard,

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75 Hodas 2007a papers.ssrn.com 599, 603 ("[b]y failing to recognize the enormous public ecosystem services values embedded in fossil fuels, we have not questioned the prevailing national sovereignty–private property legal paradigm that controls the law and policy of fossil energy").

76 Hodas 2007a papers.ssrn.com 599, 603. The discussion in this section is based on this article.

77 In 2010, *UN General Assembly Resolution A/RES/65/151 Declaring 2012 the International Year of Sustainable Energy for All* recognised that "… access to modern affordable energy services in developing countries is essential for the achievement of … the Millennium Development Goals and sustainable development" and declared 2012 as the *International Year of Sustainable Energy for All*. Resolution 65/151 called on the Secretary-General, in consultation with the inter-agency group UN-Energy, to "increase awareness of the importance of addressing energy issues, including modern energy services for all, access to affordable energy, energy efficiency and the sustainability of energy sources and use."

78 US Dept of Labor [Date Unknown] www.eia.org.

79 National Commission 2011 www.oilspillcommission.gov.

and that spills of oil from tanker ships or offshore oil drilling are bad and hard to cleanup.[80] Few of us know where our gasoline comes from[81] or how electricity is made; yet, we all demand energy policy and law that guarantees low-cost, limitlessly available, and minimally polluting, high quality, useful energy.

Even preeminent scholars take energy for granted,[82] or perhaps feel so daunted by the prospect of addressing fossil fuel energy ecosystem services that they give up.[83] It takes intellectual fortitude to question a paradigm that allows us to easily use a few gallons of petroleum,[84] which nature spent a hundred million years manufacturing, when those few gallons contain "the energy equivalent of the work a [person] could do in a year."[85]

Beginning with the discovery of fire, the history of the improvement of human welfare is the story of the human ability to harness energy, almost all of which is the product of ecosystem services. At first, all human activity was driven by human muscle, which got its energy from plant and animal food. Over time human activity was fueled by exploiting the energy of the' storehouse of the earth with dramatic results.

Simply harnessing oxen, for example, multiplied the power available to a human being by a factor of 10. The invention of the vertical water wheel increased productivity by a factor of 6; the steam engine increased it by another order of

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80 National Commission 2011 www.oilspillcommission.gov.

81 For an excellent account of gasoline's journey from crude oil underground to our vehicles fuel tank see Margonelli *Oil on the Brain.*

82 National Research Council *Valuing Ecosystem Services* 17 (omitting energy from the list of life support functions ecosystems provide).

83 See, eg, Weiss *et al International Environmental Law* 758 (noting that technically hydrocarbons are renewable but only over such long time scales that they are "nonrenewable in the context of legal regimes for renewable resources." The authors also note that hydrocarbons raise the question of what legal obligations we have towards future generations in our present use of fossil fuels. Readers are referred to the philosophical materials that introduce the book).

84 We still rate our car and truck engines by horsepower, a subtle reminder of how we would transport ourselves without petroleum.

85 Goldemberg et al Energy for a Sustainable World 5.

magnitude. The use of motor vehicles greatly reduced journey times and expanded human ability to transport goods to markets.

Today the ready availability of plentiful, affordable energy allows many people to enjoy unprecedented comfort, mobility, and productivity. In industrialised countries, people use more than 100 times as much energy, on a per capita basis, [than] humans did before they learned to exploit the energy potential of fire.[86]

At every step along the path from locating the energy to using it, the law is blind both to the ecosystem services that made the energy available in a useful, concentrated form and to the external costs we impose in obtaining and using the energy. Our laws and our market-based system of economics are not consistent with the unbendable laws of thermodynamics – entropy *always* increases when energy is used,[87] or, "there is no such thing as a free lunch." Yet when it comes to fossil fuel energy we pretend it is almost free (other than the cost of getting it from out of the ground to the consumer) and inexhaustible, and that disposing of the low value waste heat and pollutants produced by burning fossil fuels is either free or is an external cost to be imposed on others.) This is a fundamental market failure.

Given that the price of fossil fuels does not include the ecosystem service of concentrating solar energy into fuel (or the human health and environmental costs inflicted by our vast efforts to obtain, transport and use the energy, which this article will not address) it would be economically irrational not to exploit such a highly subsidised good. This subsidy helps explain the world's reluctance to seriously address climate change in the face of increasingly compelling evidence that the current rate of consumption of fossil-fuels - sources of energy derived from the natural processes of the decay and compression of once-living plants and animals -

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86 World Energy Assessment 3.

87 [P]erhaps the most elegant statement of the second law of thermodynamics … [was written by] [t]he Persian poet and mathematician, Omar Khayyam…:
The moving hand writes
And having writ moves on.
Not all your piety and wit
Shall lure it back to cancel half a line,
Not all your tears wash out a word of it. Goodstein *Out of Gas* 97.

while improving the quality of human life, is beginning to significantly change the world's environment. Ironically, CO_2 is a waste by-product of humanity's global attempt to exploit part of the carbon cycle - metabolism - that created our fossil fuels. However, our experiment accelerates the process about a million-fold.

The rate at which society consumes fossil fuels far outstrips the time it took for fossil fuels to be created. Over the last century or two, by burning fossil fuels we have released carbon into the atmosphere that had been slowly removed by nature over tens to hundreds of millions of years.[88] In a little more than a century we have consumed about 1.5 trillion barrels of oil, about half of the total supply of oil.[89] Fossil fuels are renewable solar fuels; it just takes tens or hundreds of millions of years for the used fuels to be replaced. These facts are hidden in our blind spot.

Although consumption of our energy capital (fossil fuels) has allowed the developed world[90] to prosper,[91] securing and burning fossil fuels is not a harmless, cost-free activity.[92] Ecosystems are harmed by oil exploration and drilling, by oil spills associated with the transportation of oil from wellhead to end use, by oil refineries located along ocean and river coastal zones, by coal mining (both surface strip mining and underground), by electricity transmission lines, by emissions from coal-fired power plants and coal trains, etc. Some of the pollutants created by burning

88 From 1950 to 2005 the nations of the world have emitted 903 billion tons of carbon dioxide. Of this amount the U.S. contributed 240 billion tons and Europe 322 (WRI 2008 cait.wri.org).

89 Goodstein *Out of Gas* 24-30.

90 "Traditional electricity, based on central-station generation and monopoly franchise, has been successful enough to make electricity services such as electric light, electric motor power, and electronics essential to modern industrial society. However traditional electricity has failed to reach 1/3 of humanity. Its key technologies – large dams, coal-fired and nuclear power generation, and long, high-voltage transmission lines – all face increasingly severe financial and environmental problems" (Johansson and Goldemberg "Overview" 9).

91 This consumption of natural capital (fuel) is problematic if we do not reinvest the wealth generated by this consumption in the development of replacement energy sources for the future. The energy in the fuel is never lost (*vide* the law of the conservation of energy) but the fuel is lost. Unfortunately, the replacement of high-value energy capital (fuel) is very expensive because it takes additional energy to organise low-value (high entropy) energy into a useful (low entropy) form (Goodstein *Out of Gas* 48, 93-97).

92 Nor is burning wood or charcoal harmless. The indoor pollution from using wood for heating and cooking and the increasing shortage of locally available wood increases poverty and diminishes public health (*World Energy Assessment* 69-79).

fossil fuels are inherently harmful and impose external costs on society.[93] Other emissions from fossil fuel combustion, such as carbon dioxide (CO_2), are themselves benign.[94] However, in the atmosphere, CO_2, methane,[95] nitrous oxide[96] and other trace greenhouse gases[97] trap heat in the atmosphere.[98] The greater the concentration of greenhouse gases in the atmosphere, the more heat is trapped and the warmer the earth becomes.[99]

5 Ecosystem services subsidies and ecological economics

5.1 Human subsidies of fossil fuels

The effort to understand, value and use ecosystem services is part of a larger ecological economics challenge of "getting the prices right" [100] - using law and policy to have market prices of all goods and services include all the external costs associated with making and using the goods and services, as well as to remove subsidies that lower the price of goods and services produced by ecosystems.

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93 National Research Council 2010 www.nap.edu; Ottinger *et al Environmental Costs* 213-276.

94 The carbon cycle and CO_2 are central components in the web of life. In very simplistic terms, CO_2 is released when we metabolise our food to obtain the energy to live. Green plants use CO_2 in photosynthesis to create, carbohydrates, cellulose and other woody or fibrous structures and release oxygen, which animals and plants use to convert food into energy. The oceans absorb some of the carbon, and some is stored in soil. The remainder, about half of the original emissions, remains in the atmosphere for up to 200 years. The carbon cycle, in its rich complexity, is described in Denman *et al* "Couplings Between Changes in the Climate System" 511-539.

95 Forster *et al* "Changes in Atmospheric Constituents" 140-143. Methane (CH_4), the major component of natural gas, is anthropogenically released into the atmosphere from coal mining, leaking natural gas pipelines, ruminant livestock such as cows, rice paddies, and solid waste facilities.

96 Forster *et al* "Changes in Atmospheric Constituents" 143-144. Nitrous oxide, N_2O, is produced both naturally in soil and water, and by human activity in agriculture, and industrial and waste management activities.

97 Forster *et al* "Changes in Atmospheric Constituents" 143-147. Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). HFCs are non-ozone depleting chemicals that are used as a replacement for stratospheric ozone depleting chemicals known as halocarbons (CFCs, HCFCs, methyl chloroform, carbon tetrachloride, bromine halons, methyl bromine and hydrobromofluorocarbons) that are regulated under the *Montreal Protocol on Substances that Deplete the Stratospheric Ozone Layer* (1987) and its *Amendments*).

98 Solomon *et al* "Technical Summary" 23–28.

99 Solomon *et al* "Technical Summary" 31-35; Forster *et al* "Changes in Atmospheric Constituents" 131-143.

100 Muller and Mendelsohn 2009 *American Economic Review* 1714-1739.

Human subsidies of fossil fuels are substantial, and significantly influence fossil fuel consumption.[101] This helps explain why "[d]espite the growth in low carbon sources of energy, fossil fuels remain dominant in the global energy mix, supported by subsidies that amounted to $523 billion in 2011, up almost 30% on 2010 and six times more than subsidies to renewables."[102] The usual arguments favouring energy subsidies are that subsidies will promote economic growth, reduce poverty, and enhance energy security.[103] Judiciously used, energy subsidies can "be critical for ensuring access to modern energy services, including electricity, for the poorest. In addition, well-designed and targeted subsidies can overcome market failures by mitigating environmental problems in specific contexts, for example by encouraging alternatives to biomass in areas where deforestation is an issue."[104] However, fossil fuel subsidies usually cause market distortions and the economically inefficient allocation of resources,[105] resulting in unintended harmful effects. Fossil subsidies encourage wasteful consumption, threaten energy security by increasing imports, encourage fuel adulteration and smuggling, discourage investment in energy infrastructure, disproportionately benefit the middle class and rich, distort markets, create barriers to clean energy investment, dampen global demand responsiveness to higher oil prices, and increase CO_2 emissions and local pollution.[106]

These unintended harmful effects are substantial. According to the IEA,

> direct subsidies that encourage wasteful consumption by artificially lowering end-user prices for fossil fuels amounted to $312 billion in 2009. …[A] number of mechanisms can be identified, also in advanced economies, which effectively support fossil-fuel production or consumption, such as tax expenditures, under-priced access to scarce resources under government control (e.g. land) and the transfer of risks to governments (e.g. via concessional loans or guarantees)….
>
> Phasing-out fossil-fuel subsidies … would enhance energy security, reduce

101 Dernbach and Koplow 2001 *Ann Rev Energy & Env't* 361.
102 IEA et al 2012 www.worldenergyoutlook.org 1
103 IEA *et al* 2010 www.worldenergyoutlook.org 3.
104 IEA *et al* 2010 www.worldenergyoutlook.org 3.
105 IEA *et al* 2010 www.worldenergyoutlook.org 3 ("[s]ubsidies are an extremely inefficient means of assisting the poor: only 8% of the $409 billion spent on fossil-fuel subsidies in 2010 went to the poorest 20% of the population.").
106 IEA 2011 www.worldenergyoutlook.org 2.

> emissions of greenhouse gases and bring immediate economic gains. … [I]f fossil-fuel subsidies were completely phased-out by 2020, it would cut expected growth in global energy demand by 5%. This amounts to the current consumption of Japan, Korea and New Zealand combined. In terms of oil demand, the savings amount to 4.7 mb/d, or around one-quarter of current US demand. It would also represent an integral building block for tackling climate change as expected growth in carbon-dioxide emissions would be cut by 2 gigatonnes.[107]

Subsidy reform would bring about immediate economic gains. According to the IEA, without reform the spending on fossil-fuel subsidies is likely to reach almost $600 billion in 2015, or 0.6 percent of global gross domestic product. However, if these inefficient fossil fuel subsidies were to be removed, those funds could be used for "pressing priorities such as poverty alleviation, health and education."[108] This removal would be part of the larger environmental economics project of "getting the prices right."

5.2 Ecological economics

The field of ecosystem services is a subset of the larger, somewhat amorphous sphere of ecological economics, law, and policy approaches to internalising external environmental effects and advancing human welfare.[109] This area of inquiry is a response to the perceived failures of existing analytical methodologies, law and policy to adequately measure human welfare or provide tools adequate for sound sustainable development. For instance

> GDP and other current measures of national income accounting are notorious for overweighting market transactions, understanding resource depletion, omitting pollution damage, and failing to measure real changes in well-being. For example, the Index of Sustainable Economic Welfare shows much reduced improvement in real gains, despite great increases in resource depleting throughput.[110]

In an effort that ran parallel to the exploration of ecosystem services and national environmental accounting, the idea of internalising externalities was actively pursued

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107 IEA, OECD and World Bank *The Scope of Fossil-Fuel Subsidies in 2009 and a Roadmap for Phasing out Fossil-Fuel Subsidies* 3 (November 2010).

108 IEA, OECD and World Bank 2010 www.worldenergyoutlook.org 3.

109 Costanza *et al Introduction to Ecological Economics* 39-40,132-140,164, 206-207.

110 Costanza et al Introduction to Ecological Economics 1-2.

by advocates seeking to reform the United States electric utility regulatory system.[111] That line of thinking was focused on establishing a legal decision-making structure that would require the full and final costs of generating electricity to be included in the price of new electricity generation resources considered in the process known as integrated resource planning.[112] Another strand of this line of thought was the work to modify the national accounts and definitions used to calculate the gross national product (GNP) to include environmental accounts and to include natural resource degradation as part of the nation's balance sheet capital account. The World Bank,[113] World Resources Institute,[114] Resources for the Future,[115] IUCN[116] and others pursued this work actively in the 1980s and 1990s.

However, electricity deregulation in the United States, "left the power industry with an even messier structure than…before regulation" with many regulated utilities having sold their generation assets to non-regulated entities.[117] Now about half the United States is served by deregulated power retailers and about half by state-regulated retailers "who own many generators, but also buy much of their supplies, including nearly all of their renewable power"[118] from non-regulated generators. The present "byzantine legal and economic structure" and the "unhappy history of deregulation"[119] has favoured market-based approaches, such as renewable portfolio standards, and a diminished role for integrated resource planning.[120] Similarly, efforts to advance environmental accounting within the national income accounts system have slowed dramatically over the last decade.

111 National Research Council 2010 www.nap.edu 26, 71-105.
112 Ottinger *et al Environmental Costs* 36-41, 561-629. A wide range of creative approaches to regulation that internalises externalities has since emerged. See US EPA Office of Atmospheric Programs *Clean Energy-Environmental Guide.*
113 See, eg, Ahmed, El Serafy and Lutz (eds) Environmental Accounting; Lutz and El Serafy Environmental and Resource Accounting; Daly Steady State Economics.
114 See, eg, Repetto *Wasting Assets*.
115 Hecht National Environmental Accounting.
116 See, eg, Hecht 2000 users.rcn.com.
117 Fox-Penner *Smart Power* 19.
118 Fox-Penner *Smart Power* 19.
119 Fox-Penner *Smart Power* 10.
120 US EPA Office of Atmospheric Programs *Clean Energy-Environmental Guide* 6-4 - 6-7.

Thinking creatively about economics, law and policy and science is a central endeavour of ecological economics, which has been an area of interest at the World Bank, the World Resources Institute, and elsewhere for some time.[121] Ecological economics, a close relative of sustainable development, involves a multi-disciplinary effort to develop a better understanding of ecosystems and the services they provide, with the goal of incorporating the value of ecosystem services into laws and policy to promote sustainable development. Ecological economics and ecosystem valuation emerged in the early 1970s as efforts to concretely value biodiversity conservation as an important, beneficial service that ecosystems provide. It was hoped that this utilitarian approach might increase public support for conserving biodiversity within ecosystems, which faced increased challenges from human development and population growth.[122] Ecological economics adopted an integrated approach that combines science and economics to learn how environmental systems work.[123] Its aim was to question orthodox neoclassical welfare economics, which "presents itself as a single, grandly conceived, coherent theory," and is "conceptually monolithic," and to engage in integrated, interactive analysis to "comprehend and solve our most pressing and complex social problems."[124]

In part, the thinking behind ecological economics was an outgrowth of work in the early 1970s by Nicholas Georgescu-Roegen, an economist who argued that the laws of economics were flawed because they did not account for the use of energy and the 2nd law of thermodynamics (the law of entropy).[125] Georgescu-Roegen's ideas directly challenged the central, orthodox theories of economics.[126] His critics dismissed his concern about entropy — they claimed that the earth is not a closed

121 WRI 2008 www.wri.org.
122 Gómez-Baggethun *et al* 2009 *Ecological Economics* 1209-1218.
123 Costanza et al Introduction to Ecological Economics 20.
124 Costanza et al Introduction to Ecological Economics 20-22.
125 Georgescu-Roegen *Entropy Law.*
126 Interestingly, neoclassical economics was elaborated within the scientific paradigm of mid-19th century physics. However, when the early 20th century revolution in physics occurred (quantum mechanics, relativity, etc) neoclassical economics retained its belief in the abandoned paradigms. This "strange marriage between economic theory and mid-19th century physics" assumes that all resources are inexhaustible or replaceable by other resources or technology, and that there are no biophysical limits to the growth of the market system (Nadeau *Wealth of Nature* 8-11). Needless to say, the laws of thermodynamics and entropy are not matters of concern within the neoclassical economic system.

system, but rather, a system that has for billions of years received energy from the sun and will do so for billions years and into the future, so we need not worry about a diminution of useful energy. However, these traditional economists disregarded the laws of physics[127] by ignoring the fundamental fact that "modern, industrial economies are fueled by fossil hydrocarbons, accumulations of past solar energy which are clearly limited, while current solar energy is of limited flow and relatively low concentration."[128] Nevertheless, as was explained earlier, the field of ecosystem services has not the recognised this entropy problem: that we are consuming ancient fossil fuels instead of living on current energy income from the sun.

In recent years the field of ecosystem services has gained considerable attention. It has inspired creative policy innovations including the market trading of emissions allowances and using ecosystem services as a substitute for human-constructed methods of purifying water, as in the case of the New York City water system.[129] For instance, innovative policy work in the late 1980s and early 1990s on the environmental costs of electricity, which had gone into hibernation due to the deregulation of the electricity industry, has returned to the policy agenda. In 2005 the United States Congress commissioned a study from the National Academy of Sciences that would "define and evaluate the health, environmental, security, and infrastructure external costs and benefits associated with the production and consumption of energy that are not or may not be fully incorporated into the market price of such energy, or into the Federal revenue measures related to that production or consumption."[130] The National Academy of Sciences report, *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use* (2010),[131] was the first comprehensive study since Ottinger RL *Environmental Costs of Electricity* (Oceana New York 1990), "the most prominent study in the United States ... that quantified the environmental costs of electric power generation."[132]

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127 Nadeau *Wealth of Nature* 59-62; Hubbert "Energy Resources" 157, 159-161; Odum *Environment, Power and Society* 261.

128 Costanza et al Introduction to Ecological Economics 57.

129 Ruhl and Salzman 2007 *J Land Use & Envtl L* 160.

130 §1352 *Energy Policy Act* of 2005 (PL109-58). Funding for the study was not provided until 2008. *Consolidated Appropriations Act* of 2008 (PL 110-161).

131 National Research Council 2010 www.nap.edu.

132 National Research Council 2010 www.nap.edu 26 ("Ottinger *et al* followed a five-step procedure

The US Environmental Protection Agency is also focusing on ecosystem values and how to integrate those values into its decision-making processes. The US EPA is exploring the possibility of using ecosystem valuation in drafting national regulations, setting priorities, choosing among options, and in making site-specific decisions.[133] A review of the use of ecosystem service valuation at the EPA recommended that the EPA should value all ecological effects, not simply those effects that are the easiest to value.[134] The EPA's Science Advisory Board recommended that the EPA

> 1. [I]dentify from an early stage in the valuation process the ecological responses that contribute to human well-being and are likely to be of greatest importance to people, and then to focus valuation efforts on these responses. To accomplish this, the report recommends that the EPA begin each valuation by developing a conceptual model of the relevant ecosystem and the ecosystem services that it generates. This model should serve as a road map to guide the valuation.
> 2. [P]redict ecological responses in value-relevant terms … [by] focus[ing] on the effects of decisions on ecosystem services and should map responses in ecological systems to responses in services or ecosystem components that the public can directly value.
> 3. In characterizing, measuring, or quantifying the value of ecological responses to actions by the EPA or other agencies, the EPA should consider the use of a broader suite of valuation methods than it has historically employed … but also such alternative methods as measures of attitudes, preferences, and intentions; civic valuation; decision science approaches; ecosystem benefit indicators, biophysical ranking methods; and cost as a proxy for values.[135]

However, as innovative as these proposals may be, they ignore fossil fuels as ecosystem products. The EPA uses the MEA definitions of ecosystem services,[136] which exclude fossil fuels.

Internationally, in 2009 the World Bank Group[137] began drafting a new Environment

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in using these studies to value environmental damages: emissions, dispersion, exposure, impacts, and damages").

133 US Dept of Agriculture *Ecological Benefits Assessment Strategic Plan*. See also US EPA [Date Unknown] www.epa.gov.

134 US EPA Science Advisory Board *Valuing the Protection.*

135 US EPA Science Advisory Board *Valuing the Protection* 3-4.

136 US EPA Science Advisory Board *Valuing the Protection* 12.

137 The World Bank Group is the International Bank for Reconstruction and Development, International Development Association, International Finance Corporation, Multilateral Investment Guarantee Agency, and International Centre for Settlement of Investment Disputes (World Bank 2011 web.worldbank.org).

Strategy, which it then expected to complete by the end of 2010. The new environmental strategy was mandated by the World Bank Group's "enduring commitment to ensure that its support to client countries leads to sustainable outcomes, that is, development results that are economically, socially and environmentally sustainable. The new Environment Strategy will articulate a set of principles and propose an approach for achieving the environmental sustainability of the WBG's portfolio."[138] In response to "demand from public and private stakeholders from developing countries to find ways to grow and develop more sustainably," the WBG began the process of drafting a new environmental strategy. Included in the review was the proposal that ecosystem services valuation be required in World Bank Group decision-making.[139] According to its recently released 2012-2022 strategy this "will promote bringing natural capital into systems of national accounts to better assess the sustainability of growth."[140] The World Bank explains:

> [W]hen natural resources are more complex than a single commodity—such as an ecosystem that prevents erosion, acts as a storm barrier, filters water, or harbors fish—then they are seldom valued correctly in local markets or in national accounts. Although the concept of environmental or "green accounting" has been recognised and discussed for over 20 years, few, if any, countries actively include their natural assets in their systems of accounts. This systemic undervaluation of ecosystems and their services has been a key factor in poor policy formulation and global environmental decline.[141]

5.3 Extending ecological economics thinking: fossil fuels as renewable resources

In theory, fossil fuels could be renewable resources of energy—if we used the fuels at a rate no faster than the rate at which the earth manufactures replacement fuels. If the earth held about 3 trillion barrels of petroleum and it takes several million years to make a barrel of oil[142] - for estimation purposes several will be assumed to be 3 million years - then we could use 10 million barrels of oil annually forever.[143] In

138 World Bank 2009 siteresources.worldbank.org.
139 Lange, Belle and Kishore 2010 siteresources.worldbank.org.
140 World Bank Toward a Green, Clean, and Resilient World 48.
141 World Bank Toward a Green, Clean, and Resilient World 48.
142 US Energy Information Agency 2012 www.eia.gov.
143 "Natural capital is capable of reproduction on its own with no human intervention. Thanks to the

actuality, we now use about 85.7 million barrels per day[144] (about 30 billion barrels per year), and have already used about 1.5 trillion barrels since about 1900. At current rates (assuming demand does not rise in developing and developed nations, that price increases do not reduce demand, and that no new technologies such as fracking allow "tight" oil to be recovered), about 30 billion barrels per year, the last drop of the remaining 1.5 trillion barrels, will be used up in about 50 years. In other words, in about 150 years human society will have consumed the supply of petroleum that it took the earth's ecosystems untold millions of years to make. Additionally, during those 150 years we will have released to the atmosphere the carbon that the earth's ecosystems absorbed and removed millions of years ago, a release that is overwhelming and will continue to overwhelm the earth's ecosystem service of climate and temperature regulation.[145] A similar story could be told for coal. Coal is primarily used today to fire steam generation in electric power plants.[146]

What has led to this situation? Quite simply, the cost of fossil fuels does not include the cost of collecting, concentrating, and storing solar energy into a useable form. In contrast, the collection and storage of the potential solar energy in water power is paid up front in the form of a hydroelectric dam. Similarly, the costs of wind power and other forms of renewable energy are front loaded in constructing solar power capture facilities with funds obtained in a competitive capital market. As a result, the cost of these renewable energy facilities, although dropping as technology improves, remains higher than the cost of fossil fuels.[147]

Nature's storage of solar energy in transportable forms constitutes another ecosystem subsidy of fossil fuels. Solar and wind generated electricity is intermittent — it can be made only when the wind blows or the sun shines and must be used or

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steady inflow of solar energy, it is possible to invest in renewable natural capital simply by using it up slower than it replenishes itself" (Boumans *et al* 2002 *Ecological Economics* 529, 541).

144 US Energy Information Agency 2006-2010 www.eia.gov.

145 Hansen 2008 *OASJ* 217.

146 IEA 2011 www.iea.org 37. Mining and burning coal results in very serious adverse environmental and human health effects, running from black lung and other pulmonary diseases, to acid precipitation and global warming, to mining's impact on land and water resources (National Research Council 2010 www.nap.edu 71-105).

147 This difference is especially wide in the transportation sector, where liquid fuels, which store the energy, such as gasoline dominate the market.

stored the moment it is generated.[148] Except for hydroelectric dams, current forms of renewable energy, such as solar and wind generated electricity have virtually no storage capacity and must be used instantaneously.[149] Moreover, solar and wind resources must be located where the sun shines or the wind blows, which is often far from where the electricity will be used, which will require major investments in building and operating transmission grids to accommodate the transmission of the electricity from the generation site to the end user.[150] In contrast, fossil fuels such as coal are relatively inexpensive to transport by train, barge or ship to generation facilities that can be located closer to the consumers. So the cost of fossil fuels, which does not include the cost of making the resource, is broadly subsidised by the earth's ecosystem services. In contrast, wind and other solar power includes the full cost of both collecting it and using it instantly, or else of storing it, and have little if any adverse environment effects – essentially all costs of production and use are internalised in these sources of renewable energy. Hence the true cost of energy is reflected in renewable energy, and is far higher than the ecosystem subsidised cost of using fossil fuels, even without including the externalities of global warming and pollution that result from the use of fossil fuels.

6 The legal challenge

As we have seen, from an ecosystems services perspective, the use of fossil fuels represents a profound market failure. Ecosystem services subsidise fossil fuels. Governments also provide significant direct and indirect subsidies to fossil fuels,[151] but major environmental externalities are not captured in the price of consuming fossil fuels. By comparison, the cost of electricity generated by photovoltaic or wind power is fundamentally the cost of collecting the diffuse solar energy and converting it into a concentrated form: electricity.[152] To correct this market failure requires leveling the playing field. The baseline should promote sustainable energy, so fossil

148 Gerrard "Introduction and Overview" 11.

149 Electricity storage technology is rapidly advancing, but remains expensive. See US Dept of Energy [Date Unknown] energy.gov.

150 Dworkin *et al* "Energy Transmission" 531-554.

151 IEA *et al* 2010 www.worldenergyoutlook.org 3.

152 See Lewis 2007 *Engineering & Science* 11.

fuels should be treated as if they were renewable energy sources. To do this will require understanding and changing the existing property- and national sovereignty-based legal paradigms that define the right to own and exploit fossil fuel natural resources.

6.1 The private property-based energy law paradigm

If fossil fuels are an ecosystem gift, who owns (or should own) the product of these ecosystem services? The ownership and control of ecosystem goods and services is a legal problem across the spectrum of this field. Fossil fuels are owned by the sovereign nation whose land sits above the reserve.[153] Some nations control and own the resource; other nations allocate the rights to the private property owners that own the land above the resource.[154] National and state law may permit owners to further rationalise their interests by separating the property into different alienable interests – surface, mineral, etc.[155] In all cases, the owner, be it governmental or private, has received a gift from the earth and is not charged for the cost of making the fossil fuel. The owner's cost of producing oil[156] is only the

153 UN General Assembly Resolution on Permanent Sovereignty over Natural Resources (1962).

154 Bosselmann et al Energy, Economics and the Environment 353-354, 375-411.

155 Mansfield and Hickey "Oil" 7-7–7-8 explain: Unless otherwise stated, a conveyance of land includes the minerals in the land. A deed, however, may convey minerals separately or by reservation or exception remove them from the grant. When one of these activities has taken place, it is said that the minerals are severed from the surface. Generally, if the minerals are truly severed, then two estates of land are created. One is the surface estate and the other the mineral estate. The owner of the mineral estate has the right to develop the minerals, the right of access to and use of the surface for this purpose, and the right to lease the minerals and receive the proceeds of a mineral lease.
The same general doctrine applies to coal, although there is the added question of who owns the right to have the surface supported when the coal is removed. *See Pennsylvania Coal Co v Mahon* 260 US 393 (1922), and *Keystone Bituminous Coal Ass'n v DeBenedictis* 480 US 470 (1987) (describing the support estate under Pennsylvania law and the operation of the takings clause under the 14th Amendment to the Constitution with respect to state regulations affecting the support estate.) More recently, the question of who owns the coal-bed methane released during mining has been disputed. See, eg, *Carbon County v Union Reserve Coal Co* 898 P 2d 690 (Mont 1995) and *Amoco Production Co v Southern Ute Indian Tribe* 119 S.Ct 1719 (1999).

156 Ironically, the oil industry and many oil lawyers refer to the process of getting oil out of the ground as "producing" oil. They also refer to the one-way trip from discovery of oil in the ground to burning it by the consumer as a "fuel cycle." Thermodynamically, entropy teaches that even capturing the carbon and transforming it back into petroleum does not close the cycle. Calling a linear process a "cycle" stretches the geometric metaphor beyond its limits. Nevertheless, energy lawyers' persist in using the term "fuel cycle" to describe a one-way, linear process of "production … comprised of exploration (prospecting), drilling and recovery[;]" transportation of the produced oil or natural gas to a processing facility or refinery for removal of contaminants

cost of getting the resource out of the ground, processing it, and shipping it to customers. The owner does not have to reimburse the earth for producing the resource being exploited.

Unlike forests, we cannot plant coal or oil seedlings that will grow into harvestable resources in decades or a century. In contrast, in the timber industry, the original trees may have been a gift of ecosystem services, but the subsequent new growth is paid for by the timber company that plants and grows the replacement trees – in theory, a true "cycle." To be sure, the timber industry may cause serious harm to forest ecosystems, biodiversity, and water ecosystems, and in some regions of the world forests may be cut without any reforestation effort but, when regulated effectively, forestry can be sustainable.[157]

Fossil fuels, although qualitatively different, are treated as any other below-ground mineral, such as gold, copper or diamonds. From an ecosystem services perspective, however, hard rock minerals are fundamentally different from fossil fuels. First, the energy in fossil fuels is a central pillar of modern society. Without fossil fuels we would be in the horse-and-ox-driven society and economy of the Middle Ages. Energy is essential for life; gold and diamonds are not (except in jewelry ads). Second, the matter comprising gold and other minerals does not disappear when used. Rather, it is simply transformed into a different shape. Gold dust is routinely recovered and melted back into gold.[158] Gold is not concentrated energy. However, when burned, coal disappears, leaving only pure carbon and whatever other elements were in the coal, such as sulfur or mercury. The energy in the lump of coal has been released and has dissipated from a low entropy state to one of higher entropy. The energy has changed from being concentrated and useable to a diffuse, disorganised state, radiating out into the universe. To capture that radiating energy and concentrate it back into the useable form of a lump of coal would require energy

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and refining into various petroleum products; transportation and distribution of the products to the end user; and, finally the use of the product (heating, motor vehicle fuel, electricity generation, feedstock for the organic chemical industry, etc). See Mansfield and Hickey "Oil" 7-1–7-4.

157 *Millennium Ecosystem Assessment* 243-255, 585-621 (reviewing the state of forest ecosystems).

158 Amey "Gold Recycling".

— more energy than the replacement lump of coal would contain. To keep modern society going, we must either burn more fossil fuel or capture some of the energy sent to us from the sun and organise that energy into a useable form.

6.2 National sovereignty and sustainable development

Fossil fuels are critical globally to human society's well-being. Yet international law treats them as private property under the principle that national sovereignty grants the ownership of fossil fuel resources to the nation within whose territory the resources are located.[159] Each nation then chooses how it wishes to allocate and exploit its resources. For example, the United States uses a state law private property model modified by laws designed to prevent the waste and excessive drilling that ruined oil fields when oil reserves resided under more than one owner's property and every owner was pumping as hard as he or she could.[160] In most other countries, the nation retains ownership.[161] Ultimately, the national sovereignty-private property paradigm selects the winners and losers in the fossil fuel game, dominates global geopolitics, shapes the global economy, and provokes wars.[162] All of this, and more (such as the so-called "curse of oil")[163] results from failing to account for the ecosystem services embedded in fossil fuels.

The concept of national sovereignty did not exist until the 1649 Treaties of Westphalia ended the ferocious religious conflict between Catholics and Protestants known as the Thirty Years War.[164] The Treaties, based on the ideas of Hugo Grotius[165] and Hobbes, "acknowledged the sovereign authority of Europe's individual

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159 UN General Assembly Resolution on Permanent Sovereignty over Natural Resources (1962).

160 Bosselman *et al Energy, Economics and the Environment* 259-271 (discussing laws preventing physical and economic waste).

161 Bosselman *et al* Energy, Economics and the Environment 353.

162 Yergin The Prize.

163 Friedman *New York Times* 11 (discussing a study finding a significant inverse (negative) relationship between a nation's educational achievement and the nation's total earnings on natural resources as a percentage of GDP).

164 About 20% of Europe's population may have perished as a result of the war - Bederman "International Law Frameworks" 35.

165 Hugo Grotius' ideas were motivated by disgust with the slaughter in the wars:
"Throughout the Christian world I observe a lack of restraint in relation to war, such as even barbarous races should be ashamed of; I observed that men rush to arms for slight causes, or

princes and nations."[166] The idea of a nation state within an international law context was born. Among the elements of sovereignty is a nation's control over the development of the natural resources located within the state's territory.[167]

The right of national sovereignty is routinely reiterated in international environmental law treaties. For example, the UN Framework Convention on Climate Change reminds us in its preamble that

> …States have, in accordance with the Charter of the United Nations and the principles of international law the sovereign right to exploit their own resources pursuant to their own environmental and development policies.[168]

The Convention on Biological Diversity explicitly recognises "the sovereign right of States over their natural resources."[169]

Since the 1960s, many nonbinding United Nations documents have declared a nation's sovereign right to exploit its own natural resources. In 1962, in response to concerns of nations that had recently emerged from colonial status that their natural resources were being exploited by foreign corporations, the UN General Assembly adopted a resolution promoting the concept of a nation's permanent sovereignty over its natural resources: "… the inalienable right of all countries to exercise permanent sovereignty over their natural resources in the interest of their national development…"[170] A few years later Principle 21 of the 1972 *Stockholm Declaration* declared that "States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources

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no cause at all, and that when arms have been taken up there is no longer any respect for law, divine or human; it is as if, in accordance with a general decree, frenzy had openly been let loose for the commitment of all crimes" (Janis *Introduction to International Law* 162 (quoting from Grotius H *De Jure Belli ac Pacis Libri Tres* 20 (Kelsey translation, 1913).

166 Janis Introduction to International Law 167.

167 *Rio Declaration on Environment and Development* (1992) Principle 2: "States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources…."

168 UN Framework Convention on Climate Change (1992).

169 Convention on Biodiversity (1992).

170 UN General Assembly Resolution on Permanent Sovereignty over Natural Resources (1962).

pursuant to their own environmental policies…"[171] Twenty years later, Principle 2 of the Declaration signed by the nations of the world at the 1992 United Nations Conference on Environment and Development reaffirmed States' "sovereign right to exploit their own resources…"[172]

However, starting with the 1972 Stockholm Declaration, this seemingly absolute right to exploit resources has become conditioned by countervailing obligations and responsibilities. National sovereignty over natural resources is not absolute, but is subject to the general duty not to harm other nations, and the duty (which has been enforced in courts)[173] to preserve natural resources for future generations.[174] For instance, the 1972 Stockholm Declaration Principle 21, 1992 Rio Declaration Principle 2, and the U.N. Framework Convention on Climate Change preamble, after declaring the right, continue by subjecting States to "…the responsibility to ensure that activities within their own jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction." However, it is difficult to reconcile Stockholm Declaration Principle 21's affirmation of national sovereignty over resources with the general duty earlier announced in Stockholm Declaration Principle 5 that "[t]he non-renewable resources of the earth must be employed in such a way as to guard against the danger of their future exhaustion and to ensure that the benefits from such employment are shared by all mankind." Similarly, the 1992 Rio Declaration follows the sovereign right over resources with the explicit limitation in Article 3 that "[t]he right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations" and in Article 8 demands that "States should reduce and eliminate unsustainable patterns of production and consumption…."

171 Stockholm Declaration of the United Nations Conference on the Human Environment (1972).

172 Rio Declaration on Environment and Development (1992).

173 See, eg, *Minors Oposa v Secretary of the Department of the Environment and Natural Resources* 33 ILM 173 (1994) (granting standing to some children to sue on their own behalf and on behalf of future generations to bring a case, cancel a timber licence, and to ban the issue of new licences on the grounds that they would lead to the destruction of most of the remaining forests in the Philippines), and *Waweru v Republic of Kenya* (2006) as reprinted and discussed in Weiss *et al International Environmental Law and Policy* 73-74 ("The High Court of Kenya (the country's second highest court)… applied the principle of intergenerational equity to a case of water pollution").

174 See Weiss In Fairness to Future Generations.

National sovereignty may also be subject to the obligation to protect the common heritage of humanity and the need to protect matters of common concern to humanity, such as the atmosphere and biodiversity.[175] For instance, the Climate Change Convention begins by "*[a]cknowledging* that change in the earth's climate and its adverse effects are a common concern of humankind." Similarly, the Convention on Biological Diversity affirms in its preamble "that the conservation of biological diversity is a common concern of humankind," although the following sentence reaffirms that "States have sovereign rights over their biological resources."

So, as our world gets smaller and the consequences of our burning fossil fuels become universal, it is unclear what national sovereignty over fossil fuel resources means. There is no international agreement over energy and sovereignty. Neither the 1992 Rio Declaration nor Agenda 21, the detailed, extensive document outlining a global action plan to achieve sustainable development, refers to fossil fuels. Energy issues were too contentious. Disputes over fuels, especially between oil-exporting and oil-importing nations, made it difficult at UNCED to negotiate a comprehensive or meaningful energy chapter.[176] In the 20 years since the Climate Change Convention was signed, the world has yet to make much progress in agreeing on how to address the global warming externalities from burning fossil fuels. Nor has any meaningful agreement on sustainable energy emerged from meetings of the Commission on Sustainable Development devoted exclusively to the issue.[177]

7 Conclusion

Deep inside, each of us recognises that the use of fossil fuels is now an issue of such international scope that no nation can honestly say that the adverse effects of its use of fossil fuels does not extend beyond its borders. However, the use of energy is so valuable to each of us, and so deeply subsidised as a product of nature's

175 See Schrijver "Permanent Sovereignty" 486-489.
176 Robinson "Overview" xxxiv.
177 Hodas "International Law and Sustainable Energy".

ecosystem services, that we do not want to give up unlimited control over that right. Instead, we exploit the ecosystem services embedded in the fuels, keeping all the benefits to ourselves and sharing all the consequences with the rest of the world.

Perhaps we are reaching another paradigm-changing moment, as occurred in 1648, when Europe, after decades of war, abandoned the previous legal paradigm of feudalism and church-based rule for the modern idea of national sovereignty. We may be entering another "Grotian moment," a period of "uncertainty and controversy where one framework of world order is being challenged by an alternative framework."[178] In other words, the time has come for us to value the ecosystem services that created fossil fuels, and to find a legal mechanism to internalise that value into the marketplace, either as a cost on the resource or one of a wide range of renewable energy law and policy approaches that seek to harness solar energy and convert it into a usable form.

We must evaluate all aspects of our social and economic policies from an energy ecosystems services perspective. We can start with one piece: for energy planning, we should evaluate investment alternatives by including the cost to manufacture petroleum, coal or natural gas using only the current energy flow from the sun. Biofuels, solar photovoltaics, or wind energy might be useful proxies for that cost. This would be a first step in changing the operating paradigm to a least cost-energy policy based on the full social cost of the use of fossil fuel.[179] Paradigm shifts are hard to make, but first we must recognise the existing fossil fuel-based paradigm that permeates our legal, economic and social institutions. Shifting paradigms is a difficult and slow process.[180] However, after an adequate transitional phase, society will adjust to new price signals. Private firms will innovate to sell new products that maximize the efficient use of energy. Laws and policies will be modified to remove barriers to efficiency[181] and renewables and fossil fuels would compete on a level playing field in terms of up-front subsidies. Such laws and policies will bring us as

178 Weston et al International Law 1269.
179 Johansson and Goldemberg "Overview" 1-23.
180 Kuhn Structure of Scientific Revolutions.
181 See Laitner *et al* 2012 www.aceee.org; US EPA Office of Atmospheric Programs *Clean Energy-Environmental Guide.*

close to sustainable development as the limits of the laws of thermodynamics will allow. The truly amazing value of fossil fuels will then be properly appreciated.

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List of abbreviations

ABA	American Bar Association
Ann Rev Energy & Env't	Annual Review of Energy and the Environment
BP	British Petroleum
CAIT	Climate Analysis Indicators Tool
EPA	Environmental Protection Agency
Harv Envtl L Rev	Harvard Environmental Law Review
IEA	International Energy Agency
J Land Use & Envtl L	Journal of Land Use and Environmental Law
OASJ	Open Atmospheric Science Journal
OECD	Organisation for Economic Co-operation and Development
PNAS	Proceedings of the National Academy of Sciences
Stan Envtl L J	Stanford Environmental Law Journal
TEEB	The Economics of Ecosystems and Biodiversity
UN	United Nations
UN	United Nations Environment Programme
Widener L Rev	Widener Law Review
Wm & Mary Envtl L & Pol'y Rev	William and Mary Environmental Law and Policy Review
WRI	World Resources Institute