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Incorporating Emergy Synthesis into Environmental Law: An Integration of Ecology, Economics, and Law

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INCORPORATING EMERGY SYNTHESIS INTO ENVIRONMENTAL LAW: AN INTEGRATION OF ECOLOGY, ECONOMICS, AND LAW

BY

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Emergy synthesis, first developed by Dr. Howard T. Odum in the 1970s, and further expanded and refined by other scholars over the past thirty years, has the potential to transform environmental decision making by providing a methodology that can integrate ecology, economics, and law. Virtually all areas of environmental law are concerned in some way with both the ecological and the economic impacts of environmental decision making. Unfortunately, existing environmental law statutes tend to incorporate ecological and economic considerations in a simplistic, piecemeal, and awkward fashion. Emergy synthesis incorporates both ecological and economic considerations through a sophisticated scientific methodology.

Emergy synthesis relies on the "intrinsic" value of a resource or service rather than relying on consumer preferences. Accordingly, emergy synthesis is referred to as a "donor" value system as it is based on the principle that the energy embodied in a resource or service determines its value. In recent years, emergy synthesis has reached a high level of sophistication with increasing acceptance by the scientific community and scholars worldwide. However, to date, this approach has not been embraced, or even seriously considered, by the legal community.

This interdisciplinary Article explores the viability of incorporating the methods of emergy synthesis into environmental law and policy decision making. Specifically, this Article examines the viability of emergy synthesis in decision making by analyzing the advantages it offers and the mechanics of how to employ it in a variety of different contexts, using a number of existing statutory frameworks as illustrations, including the cost-benefit standard of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and the pure

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science standard of the Endangered Species Act (ESA). This Article demonstrates that emergy synthesis has the potential, not only to inform the law, but also to revolutionize environmental decision making by providing a well-developed scientific methodology that addresses both ecological and economic considerations in a comprehensive manner.

I. INTRODUCTION

Virtually all areas of environmental law are concerned in some way with both the ecological and economic impacts of environmental decision making. Unfortunately, existing environmental law statutes tend to incorporate ecological and economic considerations in a simplistic, piecemeal, and awkward fashion. Moreover, these laws have not kept pace with significant developments in ecological and economic research. Emergy synthesis,[1] which incorporates both ecological and economic considerations through a sophisticated scientific methodology, holds the potential to not only inform the law, but also perhaps to revolutionize environmental decision making.

Emergy synthesis, first developed by Dr. Howard T. Odum in the 1970s,[2] and further expanded and refined by other scholars over the past

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1 The word Emergy, spelled with an "m," is a contraction of the term "embodied energy" and "measures both the work of nature and that of humans in generating products and services." HOWARD T. ODUM, ENVIRONMENTAL ACCOUNTING: EMERGY AND ENVIRONMENTAL DECISION MAKING 1 (1996).

2 A partial list of Dr. Odum's emergy publications includes: ODUM, *supra* note 1; HOWARD T. ODUM, ELISABETH C. ODUM & MARK T. BROWN, ENVIRONMENT AND SOCIETY IN FLORIDA (1998) [hereinafter ODUM, FLORIDA]; HOWARD T. ODUM & ELISABETH C. ODUM, A PROSPEROUS WAY DOWN (2001); Howard T. Odum, *Embodied Energy, Foreign Trade and Welfare of Nations*, *in* INTEGRATION OF ECONOMY AND ECOLOGY—AN OUTLOOK FOR THE EIGHTIES: PROCEEDINGS OF THE WALLENBERG SYMPOSIA 185, 185–99 (A. M. Jansson ed., 1984); Howard T. Odum, *Folio #2,*

thirty years,[3] relies on the "intrinsic" value of a resource or service. Rather than relying on consumer preferences, emergy synthesis might be called a "donor" value system as it is based on the principle that the energy embodied in a resource or service determines its value.[4] In recent years, emergy synthesis has reached a high level of sophistication with increasing acceptance by the scientific community and scholars worldwide.[5] However, to date, this approach has not been embraced, or even seriously considered, by the legal community.[6]

This interdisciplinary Article explores the viability of incorporating the methods of emergy synthesis into environmental law and policy decision making. Specifically, it examines the viability of emergy synthesis in decision making by analyzing the advantages emergy synthesis offers and the mechanics of how to make it work in a variety of different contexts. To that end, this Article uses a number of existing statutory frameworks, including the cost-benefit standard of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)[7] and the pure science standard of the Endangered

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Emergy of Global Processes, *in* HANDBOOK OF EMERGY EVALUATION (2000) *available at* http://www.emergysystems.org/downloads/Folios/Folio_2.pdf [hereinafter Odum, *Folio #2*] (draft version for comment); U.N. Env't Programme, Reg'l Seas Reports and Studies No. 95, *Energy, Environment and Public Policy: A Guide to the Analysis of Systems* (1988) (*prepared by* Howard T. Odum); Howard T. Odum, *Self-Organization, Transformity, and Information*, 242 SCI. 1132 (1988) [hereinafter Odum, *Self-Organization*].

3 EmergySystems.org, *Publications*, http://www.emergysystems.org/publications.php (last visited Nov. 18, 2007) (listing more than 300 emergy synthesis-related publications by University of Florida faculty and graduate students).

4 Mark T. Brown & Sergio Ulgiati, *Emergy Evaluation of the Biosphere and Natural Capital*, 28 AMBIO 486, 486 (1999).

5 Jorge L. Hau & Bhavik R. Bakshi, *Promise and Problems of Emergy Analysis*, 178 ECOLOGICAL MODELING 215, 216 (2004).

6 Interestingly, during the early years of emergy research, the legal community briefly flirted with the idea of using emergy in environmental and energy decision making. *See, e.g.*, ODUM, *supra* note 1, at 277–78.

> In 1975 our initiatives through Senator M. Hatfield of Oregon caused a federal law to be introduced requiring 'net energy analysis' of new projects. Because the words 'energy' and 'embodied energy' were not clearly defined, the implementation of the law became confused and its purpose of preventing wasteful projects was circumvented. While noting the illegal substitution of economic analysis for energy analysis, the U.S. General Accounting Office (GAO, 1982) reviewed energy analysis methods describing three approaches: process analysis; input-output analysis; and our approach, which they called 'ecoenergetics.' They wrote: '[Emergy analysis] has broad appeal in its emphasis on the fullest possible measurement of the embodied energy of labor, environmental systems, and solar energy, but its analytical boundaries are more extensive than seems appropriate for the analysis of alternative energy technologies .... Moreover, a set of consistent quantitative methods has yet to be developed for it. Therefore we chose not to use [emergy analysis].

Id. See generally COMPTROLLER GENERAL, REPORT TO THE CONGRESS OF THE UNITED STATES, DOE FUNDS NEW ENERGY TECHNOLOGIES WITHOUT ESTIMATING POTENTIAL NET ENERGY YIELDS 1 (1982), *available at* http://archive.gao.gov/f0102/119139.pdf (recommending that "Congress require the Department of Energy to consider the potential new energy yields of purposed technologies").

7 Federal Insecticide, Fungicide, and Rodentcide Act, 7 U.S.C. §§ 136–136y (2000).

Species Act (ESA),[8] as illustrations. This Article demonstrates that emergy synthesis has the potential to revolutionize environmental law by providing a well-developed scientific methodology that addresses both ecological and economic considerations in a comprehensive manner. Although emergy synthesis has not been used by environmental regulators in the United States, the Environmental Protection Agency (EPA) offers a two-week emergy short course[9] and in 2005 published the report *Environmental Accounting Using Emergy: Evaluation of the State of West Virginia*.[10] Moreover, University of Florida researchers currently use emergy synthesis as part of a United Nations Environment Programme project to restore West African drylands and improve rural livelihoods.[11] Perhaps these actions indicate emergy's time has come.

II. THE NEED FOR A NEW APPROACH

A. General Considerations

The majority of existing environmental law statutes were adopted during the 1970s and early 1980s in a piecemeal fashion in response to public demand that the government address specific environmental crises resulting from water pollution, air pollution, and hazardous waste disposal.[12] Consequently, the existing suite of environmental statutes is primarily media-based and rife with inconsistencies, gaps, and overlaps.[13] These laws incorporate a variety of different approaches to considering the economic impacts of environmental regulation[14] or decision making, but do not

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8 Endangered Species Act of 1973, 16 U.S.C. §§ 1531–1544 (2000).

9 EPA, Atlantic Ecology Div., Emergy Short Course, http://www.epa.gov/aed/html/collaboration/emergycourse/presentations/ (last visited Nov. 18, 2007); EPA, Atlantic Ecology Div., *Emergy Short Course Syllabus*, http://www.epa.gov/aed/html/collaboration/emergycourse/presentations/syllabus.html (last visited Nov. 18, 2007).

10 EPA, ENVIRONMENTAL ACCOUNTING USING EMERGY: EVALUATION OF THE STATE OF WEST VIRGINIA (2005), *available at* http://www.epa.gov/NHEERL/publications/files/wvevaluationposted.pdf.

11 U.N. ENV'T PROGRAMME, AN ECOSYSTEM APPROACH TO RESTORING WEST AFRICAN DRYLANDS AND IMPROVING RURAL LIVELIHOODS THROUGH AGROFORESTRY-BASED LAND MANAGEMENT INTERVENTIONS, *available at* http://www.worldagroforestry.org/wadrylands/resources/West%20African%20Drylands%20Project.pdf; *see generally* R. M. Pulselli et al., *Emergy Flows and Sustainable Indicators: The Strategic Environmental Assessment for a Master Plan*, *in* THE SUSTAINABLE CITY III: URBAN REGENERATION AND SUSTAINABILITY 3 (F. Escrig ed., 2004) (Pursuant to the European Union's Directive 2001/42/EC, which requires environmental assessments, this assessment was recently conducted for a master plan in Ravenna, Italy, utilizing an application of emergy methodology to "appraise and to direct strategic choices within the process of terrestrial planning.").

12 *See* Michael Allan Wolf, *Environmental Law Slogans for the New Millennium*, 35 U. RICH. L. REV. 91, 99 (2001) (tracing several federal environmental laws to specific environmental crises that triggered the passage of such laws).

13 *Id.* at 99–100, 106.

14 *See generally* SIDNEY A. SHAPIRO & ROBERT L. GLICKSMAN, RISK REGULATION AT RISK: RESTORING A PRAGMATIC APPROACH (2003) (surveying existing environmental statutes to determine which contain cost-benefit standards, which contain feasibility standards, which are pure-risk based, and which utilize other methods to consider economic factors).

address ecological concerns in any comprehensive science-based manner.[15] By using emergy synthesis as an alternative to current methodologies, ecological as well as economic considerations are evaluated using an objective methodology to inform environmental decision making. Environmental law's current integration of ecological science is overly simplistic, ad hoc, and outdated.[16] Moreover, environmental law's integration of neoclassical economics has numerous shortcomings.[17] Emergy synthesis methodology, on the other hand, is scientific, well-developed, remedies many of the shortcomings of neoclassical economics, and as described below, is compatible with most existing environmental laws and programs.

B. Ecological Considerations

The ecological shortcomings in current environmental statutes are rooted in the fact that most environmental statutes were enacted in the 1970s and 1980s, prior to many of the recent developments in the ecological sciences, and most of these statutes are media-based rather than "system"-based. In fact, Congress has not adopted any significant amendments to any major environmental statutes in many years. The most recent significant changes to major federal environmental laws were: the Clean Air Act amendments of 1990;[18] the Food Quality Protection Act of 1996, which amended portions of FIFRA;[19] the Food, Drug and Cosmetic Act;[20] and the 1996 amendments to the Safe Drinking Water Act,[21] which primarily address human health concerns rather than ecological concerns. The interpretations of ecological realities on which existing statutes are based are outdated and in need of serious reexamination.[22] Although many existing environmental laws pay lip service to ecological science,[23] they do not incorporate

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15 *See* J.B. Ruhl, *Working Both (Positivist) Ends Toward a New (Pragmatist) Middle in Environmental Law*, 68 GEO. WASH. L. REV. 522, 524 (2000) (reviewing Daniel A. Farber, Eco-pragmatism: Making Sensible Environmental Decisions in a Uncertain World (1999)); *see also* Mary Jane Angelo, *Embracing Uncertainty, Complexity, and Change: An Eco-Pragmatic Reinvention of a First-Generation Environmental Law*, 33 ECOLOGY L.Q. 105, 114–18 (2006) (discussing ways in which ecological principles are consistent with eco-pragmatism).

16 *See* discussion *infra* Part II.B.

17 *See* discussion *infra* Part II.C.

18 Pub. L. No. 101-549, § 711(b) (codified as amended at 42 U.S.C. §§ 7401–7671(q) (2000)) (substantially overhauling the Clean Air Act and imposing a number of new requirements).

19 Pub. L. No. 104-170 (codified as amended at 7 U.S.C. §§ 136–136y (2000)).

20 Pub. L. No. 105-324, § 1 (codified as amended at 21 U.S.C. §§ 301–399 (2004)) (clarifying standards for pesticide residues in food and establishing a program to address endocrine disrupting chemicals).

21 Pub. L. No. 104-182 (codified as 42 U.S.C. § 300(e) to § 300bb-8 (2000)) (imposing, among other things, more stringent requirements for protecting water sources).

22 *See, e.g.*, Robert L. Fischman, *Biological Diversity and Environmental Protection: Authorities to Reduce Risk*, 22 ENVTL. L. 435, 472 (1992) (discussing how the EPA did not adequately disclose the basis of determining the annual standard for sulfur dioxide).

23 *See, e.g.*, 33 U.S.C. § 1314(a)(1) (2000) (directing the EPA to develop water quality criteria that accurately reflects the latest scientific knowledge on the effect on the health and welfare of plankton, fish, shellfish, wildlife, plant life, shorelines, beaches, esthetics, and recreation, as

scientific understanding of the ecological world in any meaningful way or are not implemented in a manner that significantly incorporates ecological science.[24] Emergy synthesis is one of the best studied developments in ecology, and is one that holds significant promise for transforming environmental law and policy.[25]

C. Economic Considerations

In the past thirty-plus years of environmental regulation, perhaps no topic has dominated the scholarly debate as much as the proper role of economic considerations in environmental decision making.[26] Economic considerations arise in the form of cost-benefit balancing or feasibility analysis required by environmental statutes, and economic analyses are often used to choose between competing project sites, pollution control technology, and environmental restoration approaches.[27] More recently, economics has been used in the valuation of ecosystem services for ecosystem services payment programs.[28] Despite the widespread use of economics in environmental law, many legal scholars, practitioners, and policy-makers have been uncomfortable with such analysis due to its numerous shortcomings.[29] The economic shortcomings of current environmental laws are partially attributable to the lack of an adequate comprehensive methodology.[30] More significantly, however, is the current

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well as on the concentration and dispersal of pollutants, or their byproducts, through biological, physical, and chemical processes and on biological community diversity); 42 U.S.C. § 9605(a)(8)(A) (2000) (outlining how the EPA's national contingency plan for hazardous discharge clean-up must take into account the potential for the destruction of sensitive ecosystems); 42 U.S.C. § 7409(a)(1)(B) (2000) (requiring the EPA to promulgate secondary national ambient air quality standards to protect the public welfare, which includes the effects of pollution on soils, water, vegetation, animals, wildlife, and climate).

24 In fact, many environmental laws that grant authority to address ecological concerns have not been utilized to do so. *See, e.g.*, Fischman, *supra* note 22, at 440–41 (stating that while virtually every statute that EPA is responsible for implementing contains language that would enable EPA to address ecological concerns in its regulatory programs, EPA has failed to utilize these broad authorities to address ecological concerns).

25 *See, e.g.*, Hau & Bakshi, *supra* note 5, at 218 (listing the numerous benefits of emergy analysis).

26 *See generally* SHAPIRO & GLICKSMAN, *supra* note 14; DANIEL A. FARBER, ECO-PRAGMATISM: MAKING SENSIBLE ENVIRONMENTAL DECISIONS IN AN UNCERTAIN WORLD (1999).

27 *See generally* FARBER, *supra* note 26.

28 *See, e.g.*, J.B. Ruhl, *Ecosystem Services and the Common Law of "The Fragile Land System,"* 20 NAT. RESOURCES & ENV'T 3, 8 (2005) ("[I]t follows as a matter of economic theory that the relevant ecosystem structure is no less than the natural capital necessary for providing economically valuable services to humans."); James Salzman, *A Field of Green? The Past and Future of Ecosystem Services*, 21 J. LAND USE & ENVTL. L. 133, 135 (2006) [hereinafter Salzman, *A Field of Green?*] (describing how the economic value of ecosystems is often not realized until they become scarce); James Salzman, *Creating Markets for Ecosystem Services: Notes From the Field*, 80 N.Y.U. L. REV. 870, 870 (2005) [hereinafter Salzman, *Creating Markets*] (reviewing current payment schemes throughout the United States and favoring them over traditional regulatory and tax-based approaches).

29 *See generally* FARBER, *supra* note 26.

30 *See, e.g.*, Kenneth F. McCallion, *A Survey of Approaches to Assessing Damages to*

reliance on neoclassical economics to value ecological resources and services.[31]

The legal scholarly literature is rife with discussions of the shortcomings of neoclassical economic analysis in environmental law.[32] It is extremely difficult, if not impossible, to assign a dollar value to many environmental resources and services using neoclassical economic methods.[33] For example, although some ecological resources and services are bought and sold on the market and thus have a market value, most are not bought and sold on the market and thus do not have a market value.[34] To assign a value to non-market goods, neoclassical economists use "contingent valuation" which determines consumers' willingness to pay for that good or service.[35] A controversial issue in the cost-benefit debate is whether environmental values are significant only to the extent that consumers are willing to pay to preserve.[36]

There is widespread criticism of whether contingent valuation is an appropriate method for valuing ecological resources and services.[37] As an initial matter, most consumers do not have perfect information or the technical understanding to determine how much money they would be willing to pay for an ecological resource or service.[38] For example, how would the typical consumer determine how much she would be willing to pay for phosphorus cycling through a cypress dome? Moreover, scholars have repeatedly demonstrated that the concept of "willingness-to-pay" typically used in contingent valuation is inherently skewed toward valuing the right to use resources rather than the right to preserve resources.[39] In fact, studies have shown that typical consumers are only willing to pay about

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Contaminated Private Property, 3 FORDHAM ENVTL. L. REV. 125, 126 (1992) (discussing the lack of a comprehensive methodology to determine environmental damages to real property and natural resources).

31 *See* FARBER, *supra* note 26, at 6–7 (discussing the widespread acceptance of cost-benefit analysis of environmental protection and noting that an executive order issued by President Ronald Reagan "requiring all government agencies to base their decisions on cost-benefit analysis . . . remains in place today").

32 *See id.* at 35 (noting that "[m]uch of the scholarship of the past twenty years has been dominated by the struggle between" political and economic approaches).

33 *See* Salzman, *A Field of Green?*, *supra* note 28, at 134–36 (discussing obstacles to valuing ecological services); *see also* James Salzman, Barton H. Thompson & Gretchen C. Dailey, *Protecting Environmental Services: Science, Economics, and Law*, 20 STAN. ENVTL. L.J. 309, 311 (2001) [hereinafter Salzman, *Protecting Environmental Services*] (noting that estimates of the value of environmental services are "inherently uncertain").

34 Salzman, *Protecting Environmental Services*, *supra* note 33, at 311–12 (observing that because there are no significant markets for most environmental services, they "are only rarely considered in cost-benefit analyses, preparation of environmental impact statements, wetlands mitigation banking, Superfund remediations, and oil spill clean-ups").

35 HERMAN E. DALY & JOSHUA FARLEY, ECOLOGICAL ECONOMICS: PRINCIPLES AND APPLICATIONS 431 (2004).

36 John M. Heyde, *Is Contingent Valuation Worth the Trouble?*, 62 U. CHI. L. REV. 331, 332 (1995); *see also* FARBER, *supra* note 26, at 52–53.

37 *See, e.g.*, Heyde, *supra* note 36, at 34–44; FARBER, *supra* note 26, at 47–51, 84–87, 99–101.

38 *See* Heyde, *supra* note 36, at 343–44.

39 FARBER, *supra* note 26, at 99–101.

half as much to protect resources and services as they would be willing to accept to allow the resources and services to be destroyed.[40] Other criticisms of contingent valuation include the obvious fact that if consumers cannot afford to protect a resource, they will not be willing to pay, regardless of that resource's value to human or ecological well-being. Finally, many have pointed out that consumer preferences have nothing to do with the importance ecological resources and services have in sustaining life on earth.[41] Many ecological goods and services are not assigned any value by neoclassical economic analysis, despite the fact that they are integral in making economically valuable products and may even be essential for life on earth. Such economic analysis is criticized as "knowing the price of everything and the value of nothing."[42]

Because the value of many ecological goods and services are not readily quantified, they are rarely included in any meaningful way in traditional cost-benefit analysis.[43] Consequently, human disruptions to ecological systems are rarely a part of cost-benefit analyses. Values inherent in ecological integrity or biodiversity are particularly ill-suited for reduction to a dollar value under neoclassical economics. Although many ecological products and services have instrumental value as food, medication, fiber, etc., that can be valued in a market system, many goods and services provided by nature have no direct instrumental value and are not traded in a market system.[44] Moreover, most consumers do not have the information available to them or the technical understanding of the life-sustaining value of many ecological goods and services.[45] For example, many species serve important roles as producers, consumers, decomposers, competitors, dispersers, or pollinators. Each of these roles provides value to other members of the ecosystem, including humans. However, due to a lack of information and technical understanding, a typical consumer's willingness to pay for these services probably has no relation to the true value that the good or service provides. Accordingly, it is unlikely that economic valuation of ecological resources and services through contingent valuation can truly capture the intrinsic value of such resources and services.[46]

The academic scientific community has been researching alternative valuation methods for many years.[47] Unfortunately, to date, most of these

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40 *Id.* at 100.

41 *See* Brown & Ulgiati, *supra* note 4, at 492.

42 FRANK ACKERMAN & LISA HEINZERLING, PRICELESS: ON KNOWING THE PRICE OF EVERYTHING AND THE VALUE OF NOTHING 8 (2004); FARBER, *supra* note 26, at 35; Angelo, *supra* note 15, at 125.

43 *See* FARBER, *supra* note 26, at 48 ("[nonuse values] can't be measured by looking at actual behavior").

44 *See* DALY & FARLEY, *supra* note 35, at 5.

45 *See* FARBER, *supra* note 26, at 49–50.

46 *See id.* at 47–51, 99–101; James Salzman, Barton H. Thompson, Jr. & Gretchen Dailey, *Protecting Ecosystem Services: Science, Economics, and Law*, 20 STAN. ENVTL. L.J. 309, 310 (2001) (concluding that the most powerful argument for protecting environmental services is their high replacement costs).

47 *See, e.g.*, DALY & FARLEY, *supra* note 35, at 5.

approaches have not been vetted in the legal discourse or incorporated into environmental laws, regulations, or policy-making.

Emergy synthesis holds the potential of providing a valuation methodology that relies on science rather than consumer preferences. Emergy synthesis has a number of significant benefits over neoclassical economic systems of assigning value to resources and services. Emergy synthesis uniquely relies on the "intrinsic" value of resources and services and is based on the principle that the energy embodied in a resource or service determines its value. Moreover, in contrast to neoclassical economics, emergy synthesis rejects the "willingness to pay" approach which emergy proponents characterize as a "receiver" system of value, in favor of a "donor" system of value.[48] As Dr. Mark Brown has stated, "[a] donor system of value based on solar emergy required to produce things is . . . the only means of reversing the logic trap inherent in economic valuation, which suggests that value stems only from utilization by humans."[49]

Proponents of emergy argue that money is not a good way to measure environmental contributions to the public good because money is paid only to people for their services, not to the ecological systems generating resources or providing services.[50] In addition, they maintain that price tends to be inversely related to the contribution natural resources make to an economy because resources contribute most to society when they are easily available, require few services for delivery, and are therefore inexpensive.[51] Emergy, on the other hand, takes into consideration contributions to the public good, regardless of human preference, and is therefore a better measure of intrinsic value.[52]

In sum, as currently implemented, neoclassical economics-based regulatory standards have significant limitations.[53] New scientific understandings and methodologies, such as emergy synthesis, hold the potential to improve decision making by incorporating ecological, economic and social concerns into a comprehensive scientifically sound methodology.[54]

III. THE EMERGY ALTERNATIVE

A. Overview of Emergy Synthesis

In the words of the father of emergy synthesis, Dr. H. T. Odum, "[e]mergy, spelled with an 'm,' is a universal measure of real wealth of the

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48 Brown & Ulgiati, *supra* note 4, at 487.

49 *Id.* at 486.

50 Odum, *Self-Organization, supra* note 2, at 1136.

51 *See* Brown & Ulgiati, *supra* note 4, at 8; *see generally* Odum, *Self-Organization, supra* note 2, at 1132–39.

52 ODUM, *supra* note 1, at 2–8.

53 *See generally* ODUM, *supra* note 1.

54 *Id.* at 2–8.

work of nature and society made on a common basis."[55] The starting point for understanding the concept of emergy is an understanding of energy. Energy is the ability to cause work to be done; it exists in many forms, including sunlight, wind, geopotential energy of elevated water, fossil fuels, and information.[56] However, not all forms of energy are equivalent. While all forms of energy can be converted to heat, one cannot say that calories of one form of energy are equivalent to calories of another form of energy in their ability to cause work to be done.[57] Energy quality is influenced by a number of factors including concentration, flexibility, ease of transportation, and convertibility.[58] The notion of energy quality requires a conception of energy that recognizes that not all forms of energy have the same qualities and that provides a quantitative means of measuring such quality; emergy is the means of assigning a quantitative value to energy quality.[59] Emergy, sometimes referred to as "energy memory," is defined as the energy required directly and indirectly to make something.[60] Emergy is expressed in the same form as the energy it represents; for example, solar energy is referred to in units of solar emergy Joules or solar emJoules (seJ).[61] Emergy can easily be converted to a money equivalent, expressed as emdollars (em$), by using a standard conversion factor: total U.S. emergy use divided by U.S. Gross Domestic Product.[62]

The emergy accounting method is termed "Emergy Synthesis," rather than emergy analysis, because analysis results in breaking apart of wholes into component parts to gain understanding. In contrast, synthesis is the act of combining elements into coherent wholes.[63] Emergy synthesis is a "top-down" approach to quantitative policy decision making and evaluation.[64] Rather than dissect and break apart systems and build understanding from the pieces upward, emergy synthesis strives for understanding by grasping the wholeness of systems.[65] Emergy is the amount of energy of one form used directly and indirectly to make something.[66] Emergy is context driven. It is a systems concept, and cannot be fully understood outside a systems context, and is a quantitative concept based on energy, but different from energy. The theory of emergy is grounded in the understanding that not all forms of energy are the same and that heat, as a measure of energy, is inadequate to describe the ability to do work, especially complex work.[67] Emergy recognizes that there are quality differences to energies of different form.

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55 Hau & Bakshi, *supra* note 5, at 215 (quoting Odum, *Folio #2*, *supra* note 2, at 2).
56 ODUM, *supra* note 1, at 4–6.
57 Hau & Bakshi, *supra* note 5, at 217; ODUM, *supra* note 1, at 4–6.
58 ODUM, *supra* note 1, at 4.
59 *Id.* at 6–8; *see generally* Brown & Uligiati, *supra* note 4.
60 ODUM, *supra* note 1, at 2.
61 Hau & Bakshi, *supra* note 5, at 216.
62 ODUM, *supra* note 1, at 288.
63 *Id.* at 276–78.
64 *Id.*
65 *Id.* at 4.
66 Hau & Bakshi, *supra* note 5, at 217–18; Brown & Uligiati, *supra* note 4, at 54.
67 Brown & Ulgiati, *supra* note 4, at 487.

In determining the value of ecological processes or goods, there are two different ways to view value. The view of value used in neoclassical economics, and therefore in traditional environmental law and policy, is the "receiver" view of value, that is, a utility theory of value.[68] Emergy synthesis, on the other hand, relies on "donor" value.[69] Receiver value is value in the eye of the beholder, whereas donor value is derived from what goes into something. The fundamental flaw in neoclassical economics and traditional environmental law is that due to lack of information and problems inherent in contingent valuation, receiver value is not a good surrogate for the intrinsic value of a natural good or service.[70] As other scientific scholars have pointed out, the most attractive characteristics of emergy synthesis are:

- It provides a bridge that connects economic and ecological systems. Since emergy can be quantified for any system, their economic and ecological aspects can be compared on an objective basis that is independent of their monetary perception.
- It compensates for the inability of money to value non-market inputs in an objective manner. Therefore, emergy analysis provides an ecocentric valuation method.
- It is scientifically sound and shares the rigor of thermodynamic methods.
- Its common unit allows all resources to be compared on a fair basis. Emergy analysis recognizes the different qualities of energy or abilities to do work. For example, emergy reflects the fact that electricity is energy of higher quality than solar insolation.
- Emergy analysis provides a more holistic alternative to many existing methods for environmentally conscious decision making.[71]

Nevertheless, emergy synthesis is not without its critics. However, a recent detailed evaluation of criticisms leveled at emergy synthesis demonstrates most of the criticisms are based on a lack of understanding on the part of the critics, insufficient communication of emergy theory outside of the scientific world of emergy scholars, lack of clear links with related concepts in other disciplines, and are the types of general criticisms often directed at new, groundbreaking ideas.[72]

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68 *See* discussion *supra* Part II.C.

69 *Id.*

70 *Id.*

71 Hau & Bakshi, *supra* note 5, at 218.

72 *Id.* at 218, 223 (reviewing criticisms of emergy and concluding that many of the criticisms leveled apply not just to emergy analysis but to all methods that focus on a holistic view); ODUM, *supra* note 1 at 275–77 (Dr. Odum himself responded to emergy critics, concluding that most criticisms are from those who are used to market price evaluations, those who have an anthro-centric view, and those who are uncomfortable with complexity). Publications that provide criticism of emergy analysis include: R.U. AYRES, ECOLOGY VS. ECONOMICS: CONFUSING PRODUCTION AND CONSUMPTION (1998); Cutler J. Cleveland, Robert K. Kaufmann & David I. Stern, *Aggregation and the Role of Energy in the Economy*, 32 ECOLOGICAL ECONOMICS 301, 307–08 (2000); B.Å. Månsson & J.M. McGlade, *Ecology, Thermodynamics and H.T. Odum's Conjectures*, 93 OECOLOGIA 582, 582–96 (1993); DANIEL T. SPRENG, NET-ENERGY ANALYSIS AND

It is important to note that while emergy synthesis may share similar characteristics with "ecological economics" approaches, there are important distinctions. Most significantly, the majority of ecological economic approaches to evaluating the environment continue to rely on human centered values, whereas emergy synthesis is based on the principle that value is derived from what goes into something rather than on what a human gets out of it.[73] Thus, emergy synthesis is a completely different approach than common ecological economics approaches, which are more of a tinkering with the neoclassical economic paradigm.

Although emergy synthesis may appear to be complex at first glance, in actuality it is a relatively simple and straightforward methodology that is less expensive to carry-out than many other approaches, and can serve as a clear benchmark against which even relatively unsophisticated decision makers and members of the public can compare relative values.

B. Potential Uses of Emergy in Environmental Law and Policy

1. General Considerations

One of the fundamental questions posed by Lewis and Clark Law School's 2007 Symposium: Law, Science, and the Environment Forum is whether there is a need to bridge the gap between law, policy, and science, or whether instead what is needed is a new model for a new science that, rather than merely bridging multiple disciplines, incorporates those disciplines in itself. Emergy synthesis, by integrating social, economic, and scientific values into one metric, is an illustration of how such a model could work. Moreover, as discussed above, although emergy synthesis incorporates this range of values, it does so in an objective, scientific manner that does not rely on the expression of human preferences for assigning value to resources. By pulling together the full range of values, emergy synthesis may provide a very user-friendly metric to inform difficult decision making that must be made in the face of less-than-perfect data.

In general, there are three ways to use a metric such as emergy synthesis in environmental decision making.[74] First, the metric itself can be used as the source of the decision making. For example, under FIFRA, the cost-benefit balancing metric is determinative of whether a pesticide is registered.[75] Second, a metric can be used as a means to inform the public in general about decisions that are being made. For example, the

THE ENERGY REQUIREMENTS OF ENERGY SYSTEMS (1988).

[73] Brown & Ulgiati, *supra* note 4, at 492–93. *See also* AYRES, *supra* note 72; Cleveland, Kaufmann & Stern, *supra* note 72, at 303–04 (discussing economic approaches to energy quality in terms of price and consumers); DALY & FARLEY, *supra* note 35 (discussing different approaches to ecological economics).

[74] This characterization is based upon comments made by Professor Sidney Shapiro, at the Lewis and Clark Science and Law Forum in April, 2007. Sidney A. Shapiro, Assoc. Dean, Wake Forest Univ. Sch. of Law, Lewis and Clark Law School Symposium: Law, Science, and the Environment Forum (Apr. 19–20, 2007).

[75] *See* discussion *infra* notes 94–120 and accompanying text.

environmental assessment under the National Environmental Policy Act (NEPA)[76] serves such a function.[77] Finally, a metric can be used to inform, rather than bind, the actual decision maker.

This Article is not suggesting emergy synthesis be applied as an actual statutory or other decision making standard such that the result of the emergy synthesis would be determinative of the decision to be made and the decision maker would be left with no discretion. The same problems inherent in any type of quantitative methodology prohibit the reliable use of such metrics as "absolute" decision making tools. However, emergy synthesis could play a very important role as an informative tool. Emergy synthesis is well suited for this purpose in that it provides a relatively simple and straightforward means of placing a value on resources and providing a basis for comparing options. Caution must be used when relying on quantitative methodologies to make environmental decisions. Any methodology, metric, or model is only as good as the data it utilizes. However, this Article is not suggesting that emergy synthesis be used as a one-size-fits-all methodology where numbers are plugged into a black box and the "answer" is spit out. Instead, we think emergy synthesis can provide a useful informational tool. The exact numbers that result from an emergy synthesis should not be used as absolute measures. A resource with an emergy value of ten should not be treated as superior to a resource with an emergy value of nine, for example. However, in many instances, using emergy synthesis to compare alternatives yields outcomes that differ by orders of magnitude. Such an outcome can provide very useful information that can inform decision making in a way that neoclassical economic analysis can never accomplish. At a minimum, emergy synthesis can provide a qualitative way of viewing the intrinsic value of, and relationships between, ecological resources. The power of emergy synthesis is not necessarily in the particular numbers, but instead is in the scale of the numbers and the comparisons that can be drawn.

2. Valuing Environmental Services and Products

Using a methodology such as emergy to value environmental services and products is useful in a number of areas of environmental law, including natural resources damages calculations, determining compensatory damages in common law nuisance and trespass cases, determining the value of mitigation required to offset wetland impacts, and determining the price to assign to ecosystem services for payment programs. Emergy scholars have developed a number of indices to evaluate services and products that could inform such determinations of value. The "Emergy Yield Ratio" is a measure of how much a process will contribute to the economy.[78] The

[76] National Environmental Policy Act of 1969, 42 U.S.C. §§ 4321–4370e (2000).

[77] *See* discussion *infra* notes 90–93 and accompanying text.

[78] Brown & Ulgiati, *supra* note 4, at 490; M.T. Brown & S. Ulgiati, *Emergy-Based Indices and Ratios to Evaluate Sustainability: Monitoring Economies and Technology Toward Environmentally Sound Innovation*, 9 ECOLOGICAL ENGINEERING 51, 56 (1997) [hereinafter

"Environmental Loading Ratio" is a ratio of nonrenewable and imported emergy use to renewable emergy use.[79] This ratio serves as an indicator of the "load" (or stress) on the environment resulting from a production system. The "Emergy Sustainability Index" is the ratio of emergy yield ratio to emergy loading ratio.[80] This index measures the contribution of a resource or process to the economy per unit of environmental loading.[81] The "Emergy Investment Ratio" is the "ratio of emergy fed back from outside a system to the indigenous emergy inputs (both renewable and non-renewable). It evaluates if a process is a good user of emergy that is invested in comparison with alternatives."[82]

These indices could be employed as tools to assess the economic value of ecological goods or services as part of ecosystem services payment programs. Moreover, these indices could be used to determine the harm to ecological resources for purposes of determining natural resources damages under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA),[83] or for determining the quantity and quality of mitigation required to offset impacts to wetlands under section 404 of the Clean Water Act (CWA).[84] To date, emergy synthesis has not been used in such decision making; however, researchers have conducted numerous analyses demonstrating the utility of such an approach. For example, researchers at the University of Florida have determined the cost of the environmental damage caused by the Exxon Valdez oil spill.[85] A similar approach has been used to determine the ability of phosphate mining reclamation to offset the environmental impacts resulting from mining activity.[86]

Monitoring Economies].

79 Brown & Ulgiati, *supra* note 4, at 490.

80 *Id.*

81 *Id.*

82 Emergy Systems.org, *Lecture 3 Introduction to Emergy*, http://www.emergysystems.org/lectures.php (last visited Nov. 18, 2007).

83 Comprehensive Environmental Response, Compensation, and Liability Act of 1980, 42 U.S.C. §§ 9601–9675 (2000). *See also* 43 C.F.R. § 11.83 (2006) (setting forth methodology for determining natural resources damages). This rule was promulgated in response to Ohio v. Dep't of Interior, 880 F.2d 432 (D.C. Cir. 1989) (holding that the principal purpose of natural resource damages is to restore the resource, and thus damages should be based primarily on "restoration costs" rather than on "use values," and that "nonuse value" damages should be compensated, using the contingent valuation method).

84 Federal Water Pollution Control Act, 33 U.S.C. § 1344 (2000).

85 *See* M.T. BROWN, R.D. WOITHE, H.T. ODUM, C.L. MONTAGUE & E.C. ODUM, EMERGY ANALYSIS PERSPECTIVES OF THE *EXXON VALDEZ* OIL SPILL IN PRINCE WILLIAM SOUND, ALASKA (1993).

86 *See* M.T. BROWN & H.T. ODUM, UNIV. OF FLORIDA CTR. FOR WETLANDS, STUDIES OF A METHOD OF WETLAND RECONSTRUCTION FOLLOWING PHOSPHATE MINING (1985) (researching techniques for wetland reestablishment on drastically altered lands, including economic and ecologic evaluations). *See also* EmergySystems.org, *Lecture 9: Emergy and Environmental Impact Assessment*, http://www.emergysystems.org/downloads/PowerPoints/Lecture9-EnvImptAssmt.ppt (last visited Nov. 18, 2007) (explaining emergy impact assessments of oil spills and phosphate mining).

Environmental services generally are considered to be the benefits humans obtain from ecosystems.[87] Environmental services include provisioning, regulating, cultural, and supporting services.[88] Provisioning services include food, fiber, fuel, genetic resources, biochemicals, natural medicines, pharmaceuticals, ornamental resources, and fresh water.[89] Regulating services include the regulation of air quality, climate, water, erosion, water purification, waste treatment, disease, pests, pollination, and natural hazards.[90] Cultural services include cultural diversity, spiritual and religious values, knowledge systems, educational values, inspiration, aesthetic values, social relations, sense of place, cultural heritage values, recreation, and ecotourism.[91] Supporting services include soil formation, primary production, nutrient cycling, and water cycling.[92] Recently, a number of both private and governmental programs have been established to compensate landowners for preserving environmental services provided by the property they own.[93] Emergy synthesis could be a useful tool in valuing such services to determine the appropriate amount of compensation warranted.

3. Comparing Options in Environmental Decision Making

Emergy synthesis can be used in a number of ways to evaluate alternative proposals. For example, emergy synthesis can be used to determine the ecological and economic fitness of a development proposal. It can also be used to compare particular alternatives to determine the best option. Moreover, emergy synthesis can be employed to determine the best use of resources to maximize economic viability.

Although environmental decision makers have relied on emergy synthesis to choose between alternative proposals in only a limited number of cases, researchers have conducted emergy syntheses in a wide variety of case studies. For example, researchers at the University of Florida have evaluated water supply alternatives for Windhoek, Namibia.[94] Emergy

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87 MILLENNIUM ECOSYSTEM ASSESSMENT, ECOSYSTEMS AND HUMAN WELL-BEING: SYNTHESIS 40 (2005), *available at* http://www.maweb.org/documents/document.356.aspx.pdf [hereinafter MEA] (assessing the state of global environmental services).

88 *Id.* at v.

89 *Id.* at 40.

90 *Id.*

91 *Id.*

92 *Id.*

93 For more discussion on ecosystem services payment programs, see Ruhl, *supra* note 28 (explaining the potential for the common law doctrine of nuisance to play a role in today's environmental regulations); Salzman, *A Field of Green?*, *supra* note 28 (discussing obstacles to the protection and recognition of ecosystem services and possible remedies); Salzman, *Creating Markets*, *supra* note 28 (discussing the potential role of the government in the regulation of markets for ecosystem services).

94 Andrés A. Buenfil, *Emergy Evaluation of Water Supply Alternatives for Windhoek, Namibia*, *in* INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS, INTERIM REPORT, POPULATION-DEVELOPMENT-ENVIRONMENT IN NAMIBIA: BACKGROUND READING 185 (Ben Fuller & Isolde Prommer eds., 2000), *available at* http://www.iiasa.ac.at/Research/POP/pde/docs/IR-00-

synthesis was conducted on three alternative water supply sources: aquifer water, Kavango River water, and desalination.[95] Each source was evaluated for a variety of factors including renewable resources, purchased inputs, and environmental and socioeconomic impacts.[96] The emergy synthesis demonstrated that the use of aquifer water was the preferable alternative primarily due to the environmental and economic costs of desalination and the downstream environmental impacts to the Okavango Delta wetlands and wildlife should water from the Kavango River be diverted.[97]

In another study, University of Florida researchers evaluated effluent treatment alternatives for wastewater discharged from an existing pulp and paper mill in Florida.[98] In this case, emergy synthesis was used to evaluate three options: 1) constructing a pipeline to pipe wastewater from the mill to the Gulf of Mexico, 2) piping water to the headwaters of an existing wetland for treatment by the existing wetland system, and 3) constructing a new wetland strand between the mill and the Gulf, through which wastewater would be discharged.[99] The analysis concluded the best option, from an emergy standpoint, was treating wastewater in the constructed wetland strand.[100]

A final example of the use of emergy synthesis to evaluate environmental options is an analysis conducted by H.T. Odum that evaluated alternatives for cooling water disposal from a nuclear power plant in Crystal River, Florida.[101] In this case, two alternatives were evaluated: 1) the construction and operation of cooling towers and 2) the discharge of hot waters to the adjacent estuarine ecosystem.[102] The emergy synthesis took into consideration a number of factors, including the ecological costs of impacts to zooplankton, juvenile fish, and ecological metabolism, and compared these costs to the emergy costs of construction, maintenance, and operation of the cooling towers.[103] The analysis concluded that a direct discharge of cooling water to the bay was the better alternative.[104]

A significant benefit of using emergy synthesis over other alternative methodologies to compare alternative proposals is that an emergy evaluation of environmental alternatives has been found to be much less expensive and time-consuming than other evaluation methodologies.[105] As an example, Dr. Odum has cited the analysis of restoration alternatives for

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031.pdf.

95 *Id.* at 187.

96 *Id.* at 191.

97 *Id.* at 192, 194.

98 *See* EmergySystems.org, *Lecture 10: Emergy Evaluation of Environmental Alternatives*, http://www.emergysystems.org/downloads/PowerPoints/Lecture10_EnvEvaluation.ppt (last visited Nov. 18, 2007).

99 *Id.*

100 *Id.*

101 *Id.*

102 *Id.*

103 *Id.*

104 *Id.*

105 ODUM, *supra* note 1, at 281.

the Cross Florida Barge Canal, where $500,000 was spent on questionnaires to find the population's preferences and only $5,000 would have been necessary to prepare a more rigorous emergy evaluation.[106]

The use of emergy synthesis to evaluate project alternatives not only can provide a useful tool to inform decision making, but also could be incorporated into existing statutory schemes requiring consideration of alternatives. For example, emergy synthesis could provide a ready tool that could be consistently applied in the "analysis of alternatives"[107] component of Environmental Impact Statements (EISs) required under NEPA.[108] Currently, the Council on Environmental Quality's (CEQ) regulations implementing NEPA state that the weighing of the merits and drawbacks of alternatives does not have to be done via classical cost-benefit analysis, in particular where there are important qualitative considerations.[109] The CEQ regulations contemplate that a variety of methodologies may be used for environmental assessments under NEPA.[110] Thus, it appears that emergy synthesis could be utilized in EIS alternatives analyses even under existing regulations. In fact, emergy synthesis can provide a means to consider the "qualitative" factors that the CEQ regulations recognize as an important component of alternatives analyses. Although to date emergy synthesis has not been used in the United States to conduct an alternatives analysis under NEPA, it is interesting to note that it is currently used in some environmental assessments conducted under a NEPA-like law applicable to countries in the European Union.[111]

4. Methodology for Evaluation Under Existing Regulatory Standards

A final way in which emergy synthesis could be incorporated into existing environmental law is as a methodology for decision making under existing regulatory standards. Current environmental regulatory standards span the range from pure science or risk-based, through a variety of feasibility or technology-based approaches, to strict cost-benefit balancing. While the legal scholarly literature is rife with discussions of the advantages and disadvantages of existing approaches, there appears to be general agreement that, for the most part, environmental decision making must be based on science, with consideration of economic and social factors.[112] Emergy synthesis could serve as a clear, well-developed methodology employable under a number of regulatory standards.

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106 *Id.* at 281–82.

107 *See* 40 C.F.R. § 1502.16(d) (2006).

108 National Environmental Policy Act of 1969, 42 U.S.C. §§ 4321–4370(e) (2000).

109 40 C.F.R. § 1502.23 (2006).

110 *Id.* § 1502.24 (2006) (requiring that agencies "identify any methodologies used" in environmental impact statements).

111 Pulselli, *supra* note 11. *See also* Council Directive 2001/42/EC, art. 1, 2001 O.J. (L 197/30) (EU).

112 *See, e.g.* Ruhl, *supra* note 15, at 529–32.

At the cost-benefit end of the environmental regulatory standard spectrum lies FIFRA, which governs U.S. pesticide regulation.[113] FIFRA requires that all pesticides sold or distributed in the United States be registered by EPA.[114] Generally, a pesticide may be registered only if it will not cause an "unreasonable adverse effect on the environment."[115] As defined by FIFRA, unreasonable adverse effects on the environment are any unreasonable risks to humans or the environment, taking into account the economic, social, and environmental costs and benefits of the use of any pesticide.[116] Accordingly, when determining whether to register a pesticide, EPA must consider not only any risks the pesticide poses to humans or the environment, but also the economic and social implications of using the pesticide. Significantly, however, while Congress did direct EPA to take into account economic factors in defining unreasonable adverse effect on the environment, it did not explicitly mandate that EPA conduct a strict cost-benefit analysis.[117] In fact, the legislative history of FIFRA suggests that adverse effects were not intended to be tolerated in absence of "overriding benefits" from the use of the pesticide.[118] Nevertheless, for more than thirty years, EPA's approach under FIFRA has been what is, in essence, a cost-benefit balancing to support pesticide registration.[119]

Although emergy synthesis has not been employed to conduct the cost-benefit balancing required to evaluate toxic or hazard substances under statutes such as FIFRA, researchers have demonstrated how it can be used to analyze environmental harm from toxicity and other hazards. In analyzing the toxicity of a substance from an emergy perspective, a critical concept is the emergy intensity of a substance usually measured in solar emergy per gram of the substance.[120] Studies have shown that as emergy intensities increase, the potential effects of a substance on ecosystems increase.[121] The effect may be either positive or negative, depending on the concentration of the toxin.[122] When the emergy of a substance released to the environment is expressed in units of areal intensity, emergy density results (much like population density).[123] The ultimate effect of a pollutant or toxic substance is not only related to its emergy intensity, but more importantly, to its concentration or emergy density.[124] If the emergy density of a stressor is significantly higher than the average emergy density of the ecosystem it is released into, one can expect significant changes in the ecosystem.[125] For

113 Federal Insecticide, Fungicide, and Rodenticide Act, 7 U.S.C. §§ 136–136y (2000).

114 *Id.* § 136a(a) (2000).

115 *Id.* § 136a(c)(5)(C) (2000).

116 *Id.* § 136(bb) (2000).

117 *See* Angelo, *supra* note 15, at 162, 182–83; SHAPIRO & GLICKSMAN, *supra* note 14, at 39.

118 Angelo, *supra* note 15, at 162.

119 *Id.*

120 *See* Emergy Systems, *supra* note 86 (discussing transformity and toxicity).

121 *Id.*

122 *Id.*

123 *Id.*

124 *Id.*

125 *Id.*

example, emergy density of an average Florida lake ecosystem is approximately 1E9 sej/m^2,[126] whereas the amount of mercury necessary to create a lethal concentration in the lake has an emergy density of 3.7E12 sej/m^2, or about three orders of magnitude greater than the ecosystem itself.[127] Consequently, the release of mercury into a Florida ecosystem at these concentrations would be expected to result in significant environmental impacts. Accordingly, emergy synthesis could be used as a methodology to carry out the "unreasonable adverse effects on the environment" determination mandated by FIFRA.

Emergy synthesis is particularly well suited for decision making regarding whether to register or cancel a pesticide. One interesting aspect of emergy synthesis regarding pesticides is that, in general, chemical pesticides will have very high emergy values because it takes an enormous amount of energy to make a chemical pesticide.[128] Energy inputs for pesticide manufacture include not merely the obvious inputs of the petrochemicals that provide the chemical basis of the pesticides, but also the intellectual energy, research and development, testing, packaging, and distribution that goes into developing a chemical pesticide. It is important to keep in mind that a high emergy value is neither good nor bad. A high emergy substance is merely an emergy dense substance. Emergy dense substances have the potential to significantly alter ecosystems. Whether a significant alteration of an ecosystem is good or bad depends on the type of alteration. For example, some types of alterations, called "ordering" alterations, will have a beneficial effect, whereas "disordering" alterations will have a harmful effect on the ecosystem.[129]

In conducting a cost-benefit analysis under FIFRA, EPA is directed to "tak[e] into account the economic, social, and environmental costs and benefits of the use of any pesticides."[130] While this standard does not necessarily mandate a strict cost-benefit balancing approach, such an approach is in fact the way EPA has chosen to implement the standard.[131] Unfortunately, there are significant shortcomings with the approach as implemented. First, EPA's analysis is not a true cost-benefit analysis because it does not require applicants to demonstrate the benefits of the pesticide.[132] Moreover, in most cases EPA does not require efficacy data prior to registering a pesticide.[133] Accordingly, at the time of a registration decision,

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126 Mark T. Brown & Sergio Ulgiati, *Emergy, Transformity, and Ecosystem Health*, *in* HANDBOOK OF ECOLOGICAL INDICATORS FOR ASSESSMENT OF ECOSYSTEM HEALTH 333, 346 (Sven Jørgensen, Robert Costanza & Fu-Liu Xu eds., 2005).

127 *Id.*

128 Donald R. Griffith & Samuel D. Parsons, *Energy Requirements for Various Tillage-Planting Systems*, PURDUE U. COOPERATIVE EXTENSION SERV., http://www.ces.purdue.edu/extmedia/NCR/NCR-202-W.html (last visited Nov. 17, 2007).

129 *See* Brown & Ulgiati, *supra* note 126, at 346.

130 7 U.S.C. § 136 (2000).

131 Angelo, *supra* note 15, at 161.

132 *Id.* at 182–85.

133 EPA has, by rule, waived all requirements to submit efficacy data unless the pesticide product bears a claim to control pest microorganisms that pose a threat to human health or a

EPA does not know how well a particular pesticide functions. In addition, EPA does not conduct an analysis to determine whether more efficacious alternatives, including non-chemical alternatives, exist. Thus, at the time EPA makes a registration decision it does not know the extent of the benefits of the pesticide and simply assumes the pesticide will have benefits.[134] Once a pesticide is registered, if EPA undertakes an analysis to determine whether the pesticide registration should be cancelled, EPA does consider the benefits of the pesticide.[135] However, even at this stage, EPA's analysis is limited to considering obvious receiver value benefits such as increased crop yield, prevention of insect-borne diseases, protection of structures from boring insects, and availability of alternative registered pesticides.[136]

Another substantial shortcoming of EPA's approach to cost-benefit balancing under FIFRA is that EPA only considers a very limited range of environmental and human health costs, and uses neoclassical economic methods to establish the value of these costs. The types of costs typically considered by EPA include human deaths, human cancer, human birth defects, human chronic effects, and fish and wildlife deaths.[137] EPA typically does not consider, and does not even require data to be submitted on other types of costs such as sub-acute neurological effects, endocrine disrupting effects, domestic animal poisonings, effects on parasites and predators of pest species, effects on pollinators, non-lethal effects on fish and wildlife, effects on invertebrates and microorganisms, or effects on ecosystem services.

Even the sophisticated scientific studies that attempt to determine the true costs and benefits of pesticide use are limited in that, although they consider a much wider range of costs and benefits, they continue to rely on neoclassical economic methods. For example, Professor David Pimentel and a group of researchers conducted a study in the early 1990s in which they found that agricultural pesticides resulted in approximately sixteen billion dollars per year in increased crop yield.[138] The cost of pesticides themselves

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claim to control vertebrates (such as rodents, birds, bats, canids, and skunks) that may directly or indirectly transmit diseases to humans. 40 C.F.R. § 158.640 n.1 (2006). The only pesticides for which EPA requires efficacy data are pesticides intended to control microbial organisms that affect human health and certain vectors of public health diseases. *See id.* However, EPA has reserved the right to require, on a case-by-case basis, submission of efficacy data for other pesticides. *Id.*

134 In determining whether to register a pesticide, EPA assumes a manufacturer would not invest the resources necessary to support registration and commercialization of the pesticide unless the pesticide was efficacious and thus has benefits. Angelo, *supra* note 15, at 184.

135 *Id.*

136 *See id.* at 169–71.

137 EPA's pesticide data requirements are found in 40 C.F.R. § 158 (2006). For a complete discussion of the data requirements and their shortcomings, see Angelo, *supra* note 15, at 186–87.

138 David Pimentel et al., *Assessment of Environmental and Economic Impacts of Pesticide Use, in* THE PESTICIDE QUESTIONS: ENVIRONMENT, ECONOMICS AND ETHICS 47, 72 (David Pimentel & Hugh Lehman eds., 1993).

was approximately four billion dollars per year.[139] However, when the environmental and social costs of pesticide use were factored in, the costs increased by more than eight billion dollars per year.[140] In this study, Pimentel looked at a wide range of costs and benefits, including crop losses due to the destruction of beneficial insects, domestic animal poisonings, crop losses due to pesticide resistance, honey and wax loss due to pollinator poisoning, fishery losses, and wildlife losses.[141] However, Pimentel himself acknowledged that he was not able to factor in a number of costs because of the inability of neoclassical economic methods to determine the values of such costs.[142] Consequently, he did not even attempt to place a monetary value on many resources and services.[143] Emergy could provide a more complete picture.

Not all resources and services that should be considered in a FIFRA cost-benefit balancing analysis have a market value. Moreover, valuing the loss of resources or services based on receiver value rather than donor value does not capture the true value of such resources or services. For example, in considering the costs of the destruction of beneficial natural predators and parasites from pesticide use, the considerations should not be limited to the market value of the cost of additional pesticide applications required and the market value of crop loss. To be complete, the analysis should also consider the lost value to natural systems resulting from destruction of the natural predators and parasites. Likewise, in analyzing the costs of the destruction of pollinators from pesticide use, the analysis should not be limited to the market value of crop loss, the market value of honey and wax loss, and the market value of bee rental services. The analysis should include consideration of the lost value that pollinators provide to natural systems. Another example is the destruction of microorganisms and invertebrates resulting from pesticide use, for which market values do not exist at all, and receiver value is a particularly ill-suited tool for determining the lost value of the breakdown of organic matter, biogeochemical recycling, nitrogen fixation, and the creation of new soils. Emergy synthesis is well-suited for determining the value of such resources and services.

At the other end of the regulatory spectrum lies certain aspects of the Endangered Species Act (ESA).[144] As opposed to the cost-benefit balancing required by FIFRA, the ESA mandates certain decisions be made without the consideration of economic or social concerns. For example, section 4 of the ESA requires the Fish and Wildlife Service (or National Marine Fisheries Service in the case of marine species) to promulgate regulations determining whether a species is an endangered species or a threatened species, based

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139 *Id.* at 72.

140 *Id.*

141 *Id.* at 48–72.

142 *Id.*

143 For example, Pimentel admits he did not attempt to place a dollar value on soil production by microorganisms because of difficulty in determining such a value. *Id.* at 69.

144 Endangered Species Act of 1973, 16 U.S.C. §§ 1531–1544 (2000).

on a list of enumerated factors.[145] Subsection (b)(1)(A) directs the agency making such a determination to base its determination "solely on the basis of the best scientific and commercial data available."[146] A strict reading of this provision suggests that the agency is not authorized to consider economic or social impacts as part of the listing determination.[147] Unfortunately, the ESA's reliance on the "solely on the basis of science" standard has forced decision making behind closed doors where the actual metric used by decision makers is not disclosed and the public process purports to use no metric whatsoever.[148] In contrast, in listing critical habitat, the agency is authorized to consider other factors, including economic impact.[149] The significance of the science mandate in listing decisions is that only listed species are subject to the protections afforded by the section 7 consultation process[150] and the section 9 prohibition on taking listed species.[151] Accordingly, the listing of a species may result in significant economic impacts. Moreover, as part of the section 7 consultation process, Congress has mandated the use of the scientific data available in determining whether a federal action is likely to jeopardize the continued existence of a listed species.[152] The strong scientific mandate of the ESA has led to considerable debate over whether, or how, to make such determinations in the absence of economic or social considerations.

Many legal scholars have argued that this "pure science" approach is fundamentally flawed in that it ignores considerations such as the value a particular species has to society or what level of risk of extinction society should tolerate.[153] The seeming inability to incorporate such considerations led to what one scholar has described as a "charade" in which agencies pretend to make what are in reality non-scientific decisions on the basis of science alone.[154] Leading to more confusion and debate, the ESA does not define or otherwise provide guidance on what is meant by the term "science," not to mention the phrase "best available science."[155] Because emergy synthesis is a scientific analytical approach that can be subjected to scientific scrutiny and includes economic and social considerations, perhaps this scientific approach would provide a useful tool for ESA listing decisions. The major contribution of emergy synthesis to the process may be that while it takes into consideration economic and social factors, it does so not based on

145 *Id.* § 1533(a) (2000).

146 *Id.* § 1533(b)(1)(A) (2000).

147 For a good discussion of how the best available science mandate has been implemented, see Holly Doremus, *The Purposes, Effects, and Future of the Endangered Species Act's Best Available Science Mandate*, 34 ENVTL. L. 397, 419–26 (2004). *See also* J.B. Ruhl, *The Battle Over Endangered Species Act Methodology*, 34 ENVTL. L. 555 (2004).

148 16 U.S.C. § 1533(b)(2) (2000).

149 *Id.*

150 *Id.* § 1536 (2000).

151 *Id.* § 1538 (2000).

152 *See, e.g.*, *id.* § 1536(a)(2) (2000).

153 Doremus, *supra* note 147, at 419.

154 Holly Doremus, *Listing Decisions Under the Endangered Species Act: Why Better Science Isn't Always Better Policy*, 75 WASH. U. L.Q. 1029, 1035 (1997).

155 Doremus, *supra* note 147, at 405; Doremus, *supra* note 154, at 1033–34, 1075.

consumer preferences or social values, but instead based on a scientific evaluation of the embodied energy of the resources and services in questions.

In addition to informing species listing decisions, emergy may be useful in critical habitat designation decision making. As stated above, the ESA mandates that economic and other factors be considered in critical habitat listing decisions. Although emergy is science-based, it does integrate economic considerations, albeit from a donor value perspective. Consequently, critical habitat listing decision making could benefit from information gleaned from emergy synthesis.

Dr. H.T. Odum recognized the importance of endangered species protection years ago and described how emergy synthesis relates to endangered species when he stated that "[a]n important part of 'natural' systems is the genetic information and biodiversity. Endangered species have very high . . . emergy values, which are estimated from the environmental processes required for their replacement."[156] To date, emergy synthesis has not been used to inform decision making under the ESA; however, as discussed above, emergy synthesis can inform species and critical habitat listing and can also be used to prioritize listings decisions and recovery plan development under the ESA.[157] The usefulness of emergy synthesis in ESA decision making is rooted in the relationship between the number of individuals of a species remaining, the trophic level of the species, and the emergy of the individuals of a species. The lower the number of remaining individuals of a species, the higher the emergy of individuals of that species will be.[158] The trophic level—i.e., primary producer, primary consumer, secondary consumer—of the species determines the general value of that species to the ecosystem.[159] Accordingly, the higher the trophic level of the species, the higher the emergy of the individuals of that species.[160] Thus, there is a point at which

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156 ODUM, *supra* note 1, at 117.

157 16 U.S.C. § 1533(f) (2000 & Supp. 2004) (requiring priority be given to those endangered or threatened species that are most likely to benefit from recovery planning). *See also* Notice of Interagency Cooperative Policy for the Ecosystem Approach to the Endangered Species Act, 59 Fed. Reg. 34,274 (July 1, 1994) (addressing prioritization in interagency cooperative policy for the ecosystems approach). It appears that prioritization is an area that could benefit from improved methodology. A recent study conducted by the Society for Conservation Biology (SCB) in cooperation with the U.S. Fish and Wildlife Service (FWS) analyzed a number of aspects of FWS recovery plans and found that a primary area that needs improving is the "'prioritization of species' plans for implementation and revision." J. Alan Clark et. al., *Improving U.S. Endangered Species Act Recovery Plans: Key Findings and Recommendations of the SCB Recovery Plan Project*, 16 CONSERVATION BIOLOGY 1510, 1517 (2002).

158 *See* ODUM, *supra* note 1, at 222–25 (explaining that it takes more emergy to create a new unit than to produce a copy of an existing unit). Also, because the evolution of a species builds up a large emergy input and the emergy of an individual would be equal to the emergy of the species divided by the number of individuals, it follows that a species with fewer remaining members would have a higher emergy value per member. *See id.* at 228 (explaining the accumulation of emergy through evolution).

159 *See* F. Stuart Chopin et al., *Consequences of Changing Biodiversity*, 405 NATURE 234, 237 (2000).

160 *See* ODUM, FLORIDA *supra* note 2, at 51–57 (explaining how sun energy is expended in an ecosystem and the relation of emergy to energy in the food-chain).

the relationship between the number of individuals remaining and the emergy of the species indicates that the species is at risk and should be protected. Of course, there is not a magic formula for determining the exact point at which protection is warranted. However, emergy synthesis may be able to inform such a determination.

IV. CONCLUSION

Current application of regulatory standards under existing environmental statutes is severely limited by outdated approaches to incorporating both ecological and economic considerations into environmental decision making. Emergy synthesis is a comprehensive, sophisticated scientific methodology that holds the potential to inform environmental decision making. By employing emergy synthesis, environmental decision makers can incorporate ecological, economic, and social concerns into their decision making without relying on subjective standards of consumer willingness to pay or other nonscientific indicators of receiver value. Because emergy synthesis is a science that values human and nonhuman inputs based on a measurable quantity and quality of energy, it has the potential for use under a variety of regulatory standards including those requiring consideration of economic and social concerns, as well as those mandating reliance on science alone. Moreover, emergy synthesis holds the potential as a significant methodological tool to be used in valuation of ecological goods and services in ecosystem payment programs, or in determining natural resource damages under CERLCA, ESA, or as part of a common law remedy. Finally, emergy synthesis could be a useful methodology to employ to inform the evaluation of alternative proposals, such as that required under NEPA.

This Article is not suggesting emergy synthesis be used in all environmental decision making processes. Many environmental laws already employ standards such as technology-based standards or feasibility analyses that have worked very well to accomplish environmental goals while still recognizing the importance of economic considerations. Nevertheless, there are certain circumstances in which emergy synthesis could dramatically enhance decision making. As described above, statutes and policies that utilize cost-benefit analysis, such as registration and cancellation decisions under FIFRA or critical habitat designations under the ESA, could be greatly enhanced by the perspective that emergy synthesis offers. In addition, using emergy synthesis under statutes, such as the ESA, that rely solely on science is a way to incorporate a more comprehensive approach while still acting within the purview of science and without considering human preferences.

Although emergy synthesis may be a useful metric in environmental decision making, this Article is not suggesting that it is a panacea or that it is the one single metric that should be used. No one metric or methodology can provide a basis for every environmental policy decision that must be made. Nevertheless, because it incorporates a broad range of human and ecological values in a manner that does not depend on consumer preferences, emergy can provide extremely useful information for decision makers.