

## Qualifying Energy's Value to Future Engineers and Scientists

**Ben W. Ebenhack** (University of Rochester)\*

**Daniel M. Martinez** (University of Southern Maine)

**Abstract:** Using our academic research and teaching modules for chemical engineering and environmental science undergraduate students, we present a method for laying a foundation for students to understand energy's value in the 21st century more robustly and within the context of both the developed and the developing world. In this paper we argue that coming transitions will be supported primarily not by new technologic inventions or discoveries, but by matching systems to consumption patterns and vice versa. It will be a societal transformation, which relates to limits, timeline, and geo-social context. First, we present data on the saturation-like character of the relationship between human development and energy consumption, and couple this with a Maslovian assessment of the pyramid of human needs. Second, we engage students to explore the role of alternative energy solutions, to also understand the values the energy systems seek to meet, which is a function both of where the society is on the energy versus human development curve and of timeline issues. Third we address timelines as they relate both to issues of depletion and to technologic maturity and urgency. Just as the depletion place limits on the sustainability of fossil fuel-based energy systems, technologies that require fundamental science breakthroughs are unlikely to be solutions to imminent shortages. We need to understand the realistic range of peak oil occurrence timing in juxtaposition with an understanding of the time-to-market of alternative energies. This equips engineering students to bring their technical expertise to bear on qualitative problems of human development.

*Keywords: engineering education, energy, unsustainable, society, international*

*\*Correspondence to: Ben W. Ebenhack, Chemical Engineering Dept., University of Rochester.  
Email: bwe@che.rochester.edu*

### 1. INTRODUCTION

The world is facing sweeping energy transitions based on three challenges: (1) to mitigate environmental impact; (2) to reduce dependence on depleting resources; and (3) to increase access to energy for the still-developing half of humanity. In order to make informed decisions to advance effective energy transitions, strategies must be well-informed of the real values and costs of energy sources and systems. Energy is too important, too broad, and too complex for simplistic, compartmentalized, disciplinary stratagems. It permeates virtually everything we use and do. Whether we embrace the transitions proactively or attempt to hide our heads in the sands of unlimited growth optimism, we will find ourselves in the midst of a sweeping energy transition within the next few decades. This requires the ability to compare alternative energy systems on common basis. We must develop strong, effective communication between technical experts and social science experts, the public, and the politicians that represent them. At the same time, engineers working on technologies for sustainability must be able to understand the social contexts and the needs their technologies are meant to serve. There must be dynamic processes of technology and social sciences informing each other.

There is a growing consensus that the resilience and sustainability of critical infrastructures will be threatened this century and that the next generation of engineering professionals will be ill-equipped to deal with that. It is imperative to understand the values added to these systems by the current energy inputs. One great challenge is the sheer magnitude of energy provided by oil, gas, and coal currently. As these resources struggle to keep pace with global demand, all systems will be stressed and it will be important to optimize energy mix solutions based on a variety of resources available. To broach these issues with students, we consider the place of energy systems in relationship to a number of infrastructural systems. Educational planning and transformation will be essential to the resiliency of changing energy systems.

We suggest that it is important to create a set of interwoven curricular models to develop new paradigmatic approaches to understand energy and its relationship to other critical systems in a more comprehensive fashion to: 1) assess the baseline energy requirements of critical, interdependent infrastructures needed to meet scalability, sustainability, and resiliency criteria in response to perturbations in the energy supply chain; 2) evaluate the real energy value added by the entire portfolio of energy technologies (both proven and speculative) in the form of goods, services, and environmental impacts they produce, all affecting infrastructures. Ultimately, the goal is to train energy professionals to understand energy using a systems approach and to think critically about the potential energy gains of new technologies in comparison to the reduction of energy inputs for stable infrastructures.

## **2. A NEED FOR MULTI-DISCIPLINARITY**

How best do we educate students about relationships between energy use and the living and non-living world? The pervasive disciplinary educational infrastructure presents a challenge in addressing innately multi-disciplinary issues. We propose systematically connected training across disciplines to enable students to engage the issues effectively. A robust understanding of the linkages between critical infrastructural systems is an essential step to achieve a more sustainable society, whose systems can respond resiliently to changes in resource supply chains or other critical systems. Since major economies depend on energy imports, we cannot ignore the impact of global stress factors on resources. With modern energy vital to every sector of the global economy and social support systems, the potential disruption caused by a forced transition from abundant energy supplies may be the defining challenge of the coming decades. Meeting this challenge demands an informed understanding of the challenge and impacts on related systems. It will also require a workforce capable of grasping the complexities of inter-related systems, and solutions dependent on social and resource contexts.

Peter Reason discusses how we have come to our present modern worldview, one which obscures the crises of sustainability, justice and poverty. These demand, he writes, that we see ourselves as participants in the planet's life systems (Reason p. 6). Others have also discussed the need to change our energy education (Dias, 2004, Orr, 1994). Emerging professionals must be equipped to evaluate the energy linkages of infrastructures and understand the needs being served. How do we best provide students with the critical, creative and futures thinking skills to

develop innovative and alternative solutions to sustainability issues? There is value in connecting the technologies studied to the needs they serve.

We suggest a cross-disciplinary approach to teaching, in which engineering interacts dynamically with health, regional and social sciences. It stands to provide educators as well as students with a greater understanding of the linkages between critical infrastructures and an example of a new pedagogical paradigm to incorporate broader, more systemic thinking into students, from the early grades, through professional training.

It will be essential to characterize the linkages between critical infrastructural systems in pursuit of more resilient and sustainable criteria. But it will be difficult to develop a robust, high-level understanding of complex systems. Since its inception, the scientific method has been widely successful at dissecting problems into ever smaller components. As we have created classifications and taxonomies, we have also created increasingly narrow specializations. While specialization has been crucial in allowing tightly focused research to penetrate the minutest levels of reality, it has also served to isolate inquiry from the whole of reality, subjugating high-level interconnectedness. With looming crises in the sustainability of our use of resources, we are confronted with the need to understand the whole of reality and the interconnectedness of systems. It is exceedingly difficult to build such understanding by reassembling the tiny pieces we have dissected into sub-specializations. To this effect, a paradigm shift is called for in educational and engineering practice toward more comprehensive analyses that view linkages between systems. While there are inter-disciplinary engineering programs emerging globally, the American academy certainly remains dominated by disciplinarity.

Our experience finds students to be highly motivated by the challenge of applying their work to important problems. They bring valuable creativity to the task. Since students are less indoctrinated by years of practice in the status quo of disciplinarity, they are prepared to employ – and to engage in developing – new paradigms to address innately inter-disciplinary problems.

### **3. WHAT CONSTITUTES A VITAL HUMAN NEED?**

How do we reconcile the range of what people consider as vital needs? One way to do so is to recognize a hierarchy (or continuum) of needs, some of which do not come into play until others have been met. Abraham Maslow suggested five hierarchical levels of need that we use as a launching point to class discussions, which are:

1. Biological and Physiological: food, water, air, warmth, sleep and procreation. These are instinctive and critical to survival. Other desires are secondary until these needs are met.
2. Security: protection from the elements, predators, enemies, disease and uncertainty.
3. Belongingness and Love: family, friendship, and community are important at this level.
4. Esteem: people seek esteem, including: the desire to achieve and accomplish, to assume responsibilities, to build personal worth and status, social recognition and reputation. Quality of life becomes particularly important at this level.
5. Self-actualizing: the need to find meaning and purpose in life and realize one's potential. Here, people seek rewarding employment, spiritual exploration, and personal freedom.

We find the idea of an evolving progression of needs helpful as we take on the question of energy's role in meeting vital human needs.

### *3.1 Energy and Maslow's Hierarchy*

Energy does not directly feed, house, or clothe people. But energy services facilitate the production of food, construction materials, and textiles. The "causal chain" leading from energy resources to improvements in people's lives can be long and complex, requiring many other non-energy inputs. Moreover, energy services often bring improvements in several areas at once. For example, consider all the uses to which electric power can be directed: lighting, refrigeration, communication, use of appliances, cooking, space heating and cooling, and even transportation.

So, while the link between energy and development may not be obvious, energy can be shown to be a basic necessity for human activity and economic and social development. For example, wide scale poverty cannot be overcome without moving up the so-called Energy Ladder. The Energy Ladder concept claims that given the opportunity, people naturally gravitate to energy systems that improve their standard of living. They do not have to be persuaded. When a system is more effective, safer, cleaner, more convenient, and affordable, it is adopted rapidly. Most Energy Ladder discussion focuses on residential energy use because household fuel (particularly cooking) demand makes up more than half of total energy demand for much of the world's poor. Raw biomass fuels are on the bottom rungs while solar and wind is at the top. Moving up the ladder, energy resources generally become progressively cleaner, more efficient, more technically sophisticated, and more expensive.

There is rarely a wholesale transition from one rung to another. No single energy source or technology can supply the breadth of energy inputs required to meet all applications. Wind and solar can provide clean efficient electricity, which is essential for many purposes, but for cooking, charcoal is a more readily adapted improvement over raw firewood. People assimilate new fuels and new technologies depending on what they want to do. In turn, new energy systems open up new applications. The progression from primitive subsistence to industrial/modern societies demands increasing energy inputs as well as new technologies for agricultural, commercial, industrial, transport, and public services, as well as household cooking.

Increased demand for energy is thus a function both of increasing population and of demand for more energy to meet higher level needs. This is both a technical and a social challenge. Combining the issues of energy use and infrastructure requirements, the five different Energy levels in Maslow's hierarchy of needs then look like:

1. *Biological and Physiological Needs.* In order to meet survival needs, food must be secured, distributed, and processed. Pure water must be delivered. Housing must be built and heated. Energy is expended in all these tasks - raw biomass provides minimal use.
2. *Security Needs.* Energy can light the dark, preserve foods, and enable production of goods. Societies that are able to employ energy in more sophisticated ways can enhance their security, but still may not be able to achieve development.
3. *Social Needs.* Communication, transportation and the building of public infrastructures become important in meeting social needs. Modern energy has facilitated large numbers of people to have their social needs met in addition to their biological and security needs.

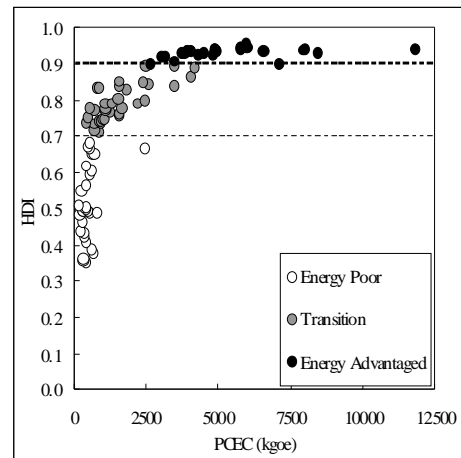
4. *Esteem Needs.* Quality of life rises to the fore once social needs are met. Education and other public services become important. The environment starts to receive attention.
5. *Self-actualizing Needs.* Although some have reached this level throughout history, self-actualization is yet to be seen by whole societies. This will be possible when most people in society enjoy a high quality of life, with very few poor. (Ebenhack & Ebenhack, 2007)

#### 4. ENERGY CONSUMPTION AND QUALITY OF LIFE

There is sufficient evidence to suggest a causative role for energy in affecting the resiliency and sustainability of the other basic infrastructural systems mentioned above (Goldemberg, 2001; Pasternak, 2000; Smil, 2005). Modern energy is requisite to schools, hospitals, and waste treatment systems. With judiciously targeted changes in policy and practice that promote broad access to locally-produced modern energy, the potential exists to achieve significant development in “Energy Poor Nations.” This can be done with modest investments in their own energy sectors, utilizing a local energy mix.

Main themes that we highlight to students:

1. The Energy Advantage Relationship. Comparing the UN Human Development Index to per capita energy consumption reveals what we call “The Energy Advantage.” This links quality of life to energy consumption remarkably well. The poorest nations do not consume enough to accommodate the most important aspects of development: mechanical power; refrigeration; lighting; transport; and communication.
2. Modern versus Antiquated Energy Sources. Most of the Energy Poor Nations lack access to modern fuels, leaving them dependent on inefficient, unhealthy, and development-crippling raw biomass, like firewood. The data show that the more a nation depends on raw biomass, the lower the quality of life its people can expect.
3. The Energy Export Curse. Some developing countries rely on energy exports. The data show that major energy exporting nations have lower qualities of life than nations purchasing their energy resources.
4. Energy Security. The problem isn’t that Energy Poor Nations lack resources, it is the lack of capital and experienced professionals to develop modern energy for their own benefit.
5. Small Investment, Huge Payoff. Theoretically, little additional energy is required in Energy Poor Nations to increase quality of life substantially.



#### 5. VALUING ALTERNATIVE ENERGY SOLUTIONS

The practical reality of energy use is that consumers do not use joules, they use services provided by energy: transportation, heating and cooling, lighting the dark, cooking meals, etc. Valuing energy provides perspective and allows us to consider energy within the context of the needs it

meets, the services it provides, and the impact it has on our way of life. So, we seek to measure not the quantity of energy contained, but the value added by the energy resource. Students focus on the effective end-use energy delivered to the consumer and the costs, or value reductions, to provide such energy. There are a number of factors to consider when determining the value of energy, including external factors that remain largely unaccounted for in energy-cost analysis. Factors to model an energy resource's real value content include: energy resource viability; energy economic viability; technical viability; social acceptance (education, cultural appropriateness); environmental concerns; health and safety.

As described by Ebenhack (2007), the proposed model conceptually looks similar to those developed for assessing value-based pricing (Feldman and Wusrt, 2001). The primary result of the model, then, is calculation of a real energy value added (REVA) index that is, essentially, a coefficient to be applied to a specific energy resource (e.g. oil, coal, solar, nuclear) to assess true energy value. The starting point is a diagram for energy source value and assumptions upon which to model future changes. REVA introduces students to traditional life-cycle assessments (LCAs) (Friedrich et al., 2007; Kara et al., 2007; Land et al., 2007; Osman et al., 2007), including 'emergy' calculations (Odum and Brown, 2007) and critical thinking about calculations and algorithms for quantifying the more social-connected variables. This engages students in assimilating information broadly across disciplines in the context of an analytical project and in critical thinking in the face of analytical uncertainty.

### *5.1 Assessing Timelines*

The urgency is both an impending shortage of petroleum and the need to expand energy options for the world's poor. In some ways, oil and gas represent 'alternative energy' to fuelwood-dependent people, but adding oil and gas to their energy mixes must include plans to address the increased competition for those resources over time. Likewise, the 'renewable alternatives' need to be assessed within a context of the role that each can play and in what time frames.

The transition toward more sustainable energy systems will not be simple. Maturation times are required for innovative technologies to move from the laboratory to demonstration scale, and on to commercial scale. Historical analogies can supplement the assessments of technologic options and how rapidly they can be adopted in various contexts. This, again, requires understanding social contexts. Many note that the developing world is 'leap-frogging' directly to cell phone technology, skipping the step of land-based telecommunications and its infrastructure. To what extent can the developing world skip over the fossil fuel step in energy development? Can a move toward more decentralized energy obviate massive infrastructure investments? Can the adoption of new energy technologies be accelerated? How do consumer preferences in the affluent world challenge the rapid adoption of new energy systems? Understanding the transition toward more sustainable energy systems involves future studies, which inevitably calls for historical analysis, layered with the other technical and social science disciplines.

### *5.2 Example: A gigajoule is not just a gigajoule*

In conventional analyses, it is all too common to compare energy units without considering their effective use, let alone externalities. Similarly, engineering students are conventionally given some exposure to basic economic analyses. We suggest that Sustainability demands systems-level thinking. To introduce this in the classroom we have also introduced several applied,

project-based energy and sustainability courses at the University of Rochester and the University of Southern Maine. One technique that we have employed is to have students identify the context and/or clientele for technologies they select to investigate. This requires them to think the application and the consumer, drawing them into social science and/or humanistic concerns.

Several of the courses we have introduced are cross-listed, to encourage a diverse enrolment. We try to encourage groups to form with multiple disciplines represented, but that has not been as broadly successful. In part, there seems to be some challenge in convincing non-technical students that a course with an engineering listing will not be prohibitively technical for them. Thus, we have commonly found imbalanced registrations, making it difficult to comprise mixed teams. We believe that this issue can be addressed through diligent publicity efforts (and in the long-term, word-of-mouth from former to future students can help this.) We consistently try to be open to supporting the direction student interests take – we offer suggestions and some direction, but not in proscriptive fashion. This has been very successful in encouraging highly motivated student efforts, but intrinsically prohibits ensuring any desired mix of disciplinary backgrounds, as students select their own groups, around projects of interest.

In one course that relates to evaluating the environmental footprint and options for enhanced sustainability on the campus and in the local community, the groups are required to identify ‘clientele’ with whom to interact and to invite to the final presentation of their project. This has been quite successful in tying their technical concepts to the realities of client needs.

## 6. CONCLUSIONS

Sustainable development requires understanding the relationship between technical aspects of energy production use and the human aspects of value energy is providing to people. This is at once an intellectual challenge and a pedagogical opportunity. Understanding the dynamics of energy's role on quality-of-life brings together technical, social, and humanistic thinking. Engineering students must engage with remote disciplines, while non-technical students can find an entrée into dialogue on technical matters. Both sets of students can benefit tremendously.

We propose that working across disciplinary boundaries to solve critical, real-world problems facilitates multidisciplinary studies. The context of the problem answers the age-old question of many technical students regarding their social science and humanities studies, "why do I need this?" At the same time, it exposes the non-technical students to technical matters in a context that reinforces the meaning of the science and the numbers. The students can see their efforts blending to address important problems. The teamwork tends to create a genuine interest in understanding each other's expertise. When Ebenhack created a cross-listed course with a colleague from anthropology in which they formed student teams of engineering and anthropology students to study options for more sustainable transportation systems, one of the delightful outcomes was expressed interest from several students to take more courses in the other discipline. Another excellent outcome was the successful development of deeper understandings of complex issues, by bringing together the perspectives of disparate disciplines.

There are gaps between technology and its use to serve human needs. Thus we believe that a new field of richly cross disciplinary research and education is emerging. Humanistic and social science studies, standing alone, will be no more robust than engineering or scientific studies standing apart from the social context. The compelling reality is that we must find new, innovative ways to work together on sweeping problems, across our disciplinary boundaries. The questions of how society is to move to more sustainable energy systems is a worthy challenge to bring students and faculty together to develop new paradigms for inter-disciplinarity.

## 6. REFERENCES

### *Journal Articles*

- Dias, R.A., Mattos, C.R., Balestieri, J.A.P.(2004) Energy education: breaking up the rational energy use barriers. *Energy Policy* 32(11), 1339-1347.
- Ebenhack, Ben W. 2007, "How Do We Get There from Here? Transitions to Sustainable Energy," *Journal of Petroleum Technology*, March 2007
- Friedrich, E., Pillay, S., Buckley, C.A. (2007). The use of LCA in the water industry and the case for an environmental performance indicator. *Water South Africa*, 33(4), 443 – 451.
- Goldemberg, J. (2001). *Energy and Human Well-Being*. UNDP.
- Kara, S., et.al. (2007). An integrated methodology to estimate the external environmental costs of products. *CIRP Annals-Manufacturing Technology*, 56(1), 9 – 12.
- Martínez, D., Ebenhack, B. (2008). Understanding the role of energy consumption in human development through the use of saturation phenomena. *Energy Policy*. 36 (3), 1430 – 1435.
- Maslow, A. *A Theory of Human Motivation*, *Psychological Review* 50(4) (1943):370-96.
- Osman, A., Ries, R. (2007). Life cycle assessment of electrical and thermal energy systems for commercial buildings. *International Journal of Life Cycle Assessment*, 12(5), 308 – 316.
- Reason, P. (2002) "Justice, Sustainability, and Participation." *Concepts and Transformations CR*, 267-82.

### *Books*

- Odum, H.T., Brown, M.T. (2007). *Environment, Power and Society for the Twenty-First Century: The Hierarchy of Energy*. New York: Columbia University Press.
- Orr, D. W. (1994). *Earth in mind on education, environment, and the human prospect*. Washington, DC: Island Press.
- Pasternak, A. (2000). *Global energy futures and human development: A framework for analysis*. Lawrence Livermore National Laboratory.
- Smil, V. (2005). *Energy at the Crossroads: Global Perspectives and Uncertainties*. Cambridge: MIT Press.

### *Conference Proceedings*

- Dixon, B., Ebenhack, B., McCabe, M., Shah, V. (2006) *Multidisciplinary Approach to Solving Energy Problems: An Engineering and Ethnographic Study of Public Transportation Society for Applied Anthropology Conference Proceedings*.
- Ebenhack, M., Ebenhack, B. (2007). *A Role for SPE in Meeting Vital Human Needs, Proceedings of the Society of Petroleum Engineers Conference on Health Safety and Environment, Nice, France*.