Supply and Demand is not Sustainable

Susan Krumdieck, Andre Dantas, Tony Burton
Department of Mechanical Engineering, Private Bag 4800
University of Canterbury, Christchurch, 8004 New Zealand
s.krumdieck@canterbury.ac.nz

Philosophy, Policy, and Practice

Abstract

What does a sustainable society look like? Prior to the industrial revolution, local societies developed and organized their resource utilisation with regard to living within the environmental constraints of their geographical area. Whether past cultures found ways to live in relative sustainability through conscious design or through limited technology may be a source of debate. The fact of resource limits has been patently obvious to people for thousands of years. However, over the past two centuries or so, engineered environments have increasingly defined the living experiences of people in the developed world where the only constraint is the consumer's ability and willingness to pay the going price. Because we *believe* in supply-and-demand as national economic policy and endless growth as economic necessity, we have collectively lost sight of the *fact* of energy and resource constraints. The challenge for our time is to apply the same powerful intellectual and technological tools that have created the illusion of perpetual growth and use them to find our limits.

At the University of Canterbury, the Advanced Energy and Material Systems Group (AEMS) is dedicated to investigating the role that new technology and modelling can play in deploying the next generation energy system. The engineering systems design approach, together with advanced modelling techniques are employed in a revolutionary methodology to determine an "energy architecture" that could meet society's needs within the limits of available resource capacity. This field of study is called Strategic Analysis of Complex Energy and Environmental Systems (SACEES).

The SACEES approach has been developed from original research describing human activity, energy consumption, and the environmental impacts in the model of a feedback control system. The system operates within a specific geographical, cultural, and economic context. In this paper, the theory is described and used to demonstrate why pricing signals through increased *cost* for fossil energy will not lead to sustainability. The feedback signals as described by the theory are discussed, showing why environmental *impacts* have also not been effective drivers for change. The role of the market is explored, and the theory explains why *supply and demand* economic policy and planning will never produce a sustainable society. Examples of historical events are given, and the conclusion is made that *availability* and *service* are the clear factors in stabilizing energy and environment systems and driving them toward sustainability.

1. Introduction

1.1 The Role of Engineering and Science

As engineers and scientists, we recognise that technology and utilisation of fossil and finite resources support the living standard in developed countries. Engineers and natural resource scientists are seldom involved in politics or in the government offices where energy and economic policy are developed. In policy development, the role of engineering and science is perceived to be secondary to economic planning. The *Free Market* between rational producers and consumers is the dominant economic ideology. The behaviour of the economy is described by the law of *supply and demand,* while the laws of motion, thermodynamics, and any other natural laws are generally irrelevant to planning for continuous, sustained economic growth.

The consensus perception holds that the driving forces for the country are primarily economic. Politicians and economists decide the best interest of the country and the economy, then look to the engineers to provide the goods and services people need and desire. The public then looks to science and technology to fix problems that arise.

The engineering profession has been successful at designing and building the infrastructure, and producing the energy and products which provide a high standard of living. Natural resources and environmental scientists have also done admirable work characterising the extent of the damage done to the environment. Government funding in many countries is used as a driver for technology research and development. However, the fact of research funding on targeted technologies then leads to research activity in areas that researchers would not otherwise pursue. This activity, in turn generates public perception that these new technologies are already extant, and will be available as a remedy for energy supply and pollution problems. Public perception then leads to a demand for something that does not exist at any price. A timely example of this break down in the law of supply and demand is "hydrogen energy". There are no customers for hydrogen at the production price, and no suppliers of hydrogen at a market price. There are no suppliers of fuel cells, and no consumers who want them to replace any existing engines. There are researchers spending their time and talents on fuel cells while no engineering breakthroughs can solve the technical issues with manufacture and operation. There is no technical basis, nor any economic basis, for a hydrogen economy, and yet there is a public perception, buoyed by significant government spending, that hydrogen will provide an answer to the problem of global warming.

This paper examines the proposition that engineering and science cannot simply fix the serious energy supply continuity and environmental problems now facing the developed nations of the world. Nor can we grow toward sustainability through further technological development as long as the context for decision making excludes engineering and scientific analysis and relies only on economic models of continuous growth which obviates physical reality. We suggest that the road to sustainability would require practice of a new economic model based on physical and environmental realities and the engineering principles of system integration and design for performance within constraints. We call this approach the *service and availability continuity model.*

1.2 The Dominant Economic Model Dictates the Engineering Approach

Sustainable growth, as understood by free market economists and the public in general, is founded on several assumptions that are not compatible with constrained, yet sustained use of resource assets.[1] According to the law of supply and demand, if there is a shortage of products, then the price will increase and new producers will become willing to enter the market and the supply will increase. If the price gets higher than what consumers are willing to pay, then a new supplier will enter the market with alternative products at a lower price. Thus, as long as customers desire or require a certain product or service, the free market will provide it.

On the supply side, the role of energy engineering in the supply and demand economy model is to provide for production of low-cost energy products.[2,3] For example, as oil wells age engineers work to enhance recovery through new technology, and refineries undergo efficiency upgrades. Higher prices from short-term shortages stimulate new exploration, which leads to more supply, which leads to lower prices. Governments and oil companies fund research into substitute fuels, such as biomass derived liquid fuels, which are expected to enter the market when the price of oil gets high enough, regardless of the technical realities.

The energy engineer can also work in demand management for business and domestic customers to improve efficiency and save money on energy costs.[4-6] The focus is to minimise energy costs through selection of high efficiency appliances and careful design and operation of energy consuming activities and processes.

1.3 Proposed Economic Model and Proposed Engineering Approach

The normal methodology for engineering of products and systems is to first define the needs, wants and desires of the user, then the requirements and constraints which the product must satisfy. Secondly, possible designs are generated through creativity and problem solving together with application of physical laws. Next, the concepts are evaluated according to the performance and requirements metrics, and further design iterations produce a final, best-case concept. The final concept is then modelled and prototyped and further evaluated and developed according to requirements. In the end, a final design is achieved which provides the desired performance, within the cost and materials constraints, and which obeys physical laws.[7] This is the process by which cars, computers and toasters are developed. In fact all products and systems follow this path into being, with the notable exception of regional energy systems.

Our research into sustainable engineering has identified the need for a new economic model of the relationship between consumers and the suppliers of energy products and primary resources (i.e. water, waste disposal, basic foods). If an economic model were to be developed along the lines of the engineering product development methodology, then the main precept of the model would be the balance of desires of the consumers and the constraints imposed either by cost, capability, or physics. We have christened this the *service and availability* economic model.

We assume that people are rational, and that they act to maximise utility. We further assume that consumers have preferences, but that the primary needs of all consumers holds primacy over individual desires. We take as given that the amount of energy or other primary products which are technically achievable are known to consumers through the mechanisms built into the system. The price of the product for service of needs is set by the cost of production and return on investments, and through the free market in the usual way. However, the quantity of the energy product produced and the distribution is determined by the balance between the consumer service requirements and the primary resource availability.

A schematic representation of the service and availability economic relationship is shown in Figure 1. The large arrows represent information and communication flows. Our concept is that the free market cost-based relationship between producers and consumers will be supplemented by communication to suppliers of consumer services desired. Additionally, activities of both producers and consumers will be done in the context of information about sustainable levels of natural resource and energy availability. From this concept, it is clear that new real-time information and communication technologies will need to be developed in order to operate a sustainable economy. In addition, new modelling to determine the sustainable level of energy and natural resource consumption which can be supported by the environment will be a major component of sustainability engineering and science.

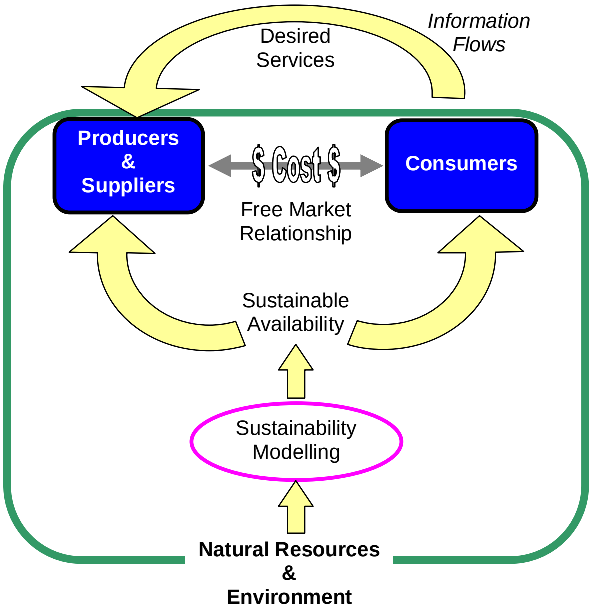

Figure 1. *Service and Availability* economic model showing the free market relationship between consumers and producers and suppliers within the context of the natural resource availability. New modelling, information, and real-time communication systems will be required.

The role of sustainability energy engineering in the service and availability economy is to provide the communications and control systems which provide real-time feedback and feed-forward information about the requests for services and the availability of energy products for continuous performance. This can only be done for a system that is designed as a whole for security and continuity of operation within the energy supply capacity constraints.

Sustainability of systems that support human endeavour cannot be achieved through operational or technology up-grades of systems that are designed for fossil fuel consumption within an economic model purporting continuous growth of consumption. Security and sustained performance can be achieved through integrated system design, which considers the service required and the availability of primary resource and impact capacity. Thus, the role of engineering and science in achieving sustainability must be to work in an integrated way within the social, economic and political context to discover the *energy and environment architecture* which would support a sustainable society.

2. The Current Economic Model and Role of Engineering

2.1 Energy Architecture

Engineering and science has contributed greatly to the infrastructure and technology which supports the lifestyle of developed countries. We have coined a term, *energy architecture*, to express the complex nature of the aggregate infrastructure, energy supply and distribution networks, and consumer appliances that support our quality of life. Architecture is the art of producing homes and community buildings. The architecture of each structure reflects the purpose and function it is meant to support, as well as other more subtle factors such as communication of purpose, values, and status to others. The building is designed to support and facilitate a given range of activities. However, the occupants are, of course, free in their use of the buildings to order and structure their activities as they choose. Buildings must be designed within constraints imposed by building codes of best practice, the size and situation of the physical site, the structural and material realities, and the budget of the building owner.[8]

Homes and buildings facilitate our daily activities, but do not dictate them. In the same way, we can think of power generation stations, the electricity grid, and our power consuming appliances as a form of architecture. In the same way that a two-bedroom home would comfortably support the daily lives of a couple or small family, a retail business or a large extended family would not function well in the same architecture. The current energy architecture of roads, parking lots, traffic control signals, and filling stations every few kilometres is structured to support unlimited mobility of a certain population. When populations become too large, average trip lengths increase due to suburban sprawl, automobile sizes increase, or fuel supplies become limited, we realize that the energy architecture no longer functions as designed.

We use *energy architecture* to refer to this aggregate built environment which is constructed to support a specific lifestyle for a given population. People are free to use the energy architecture of their community to go about their private daily activities. Activities are constrained by the capabilities of the architecture, at the same time that the community's standard of living and quality of life are *facilitated* by the architecture. However, people's desires, needs, and choice of activities are not *dictated* by the energy architecture. While this is a subtle difference, it is fundamental to understanding why we cannot persuade, force, or educate people to use the present fossil-fuel energy architecture in a sustainable manner.

2.2 Supply and Demand

The idea of supply and demand operation of a free market is widely accepted as the economic model of the industrial age, but the basic concept could apply to most trading relationships throughout history. Figure 2 shows a schematic representation of the economic model, and the classic relationship of supply and demand operating to establish the quantity and price of goods.

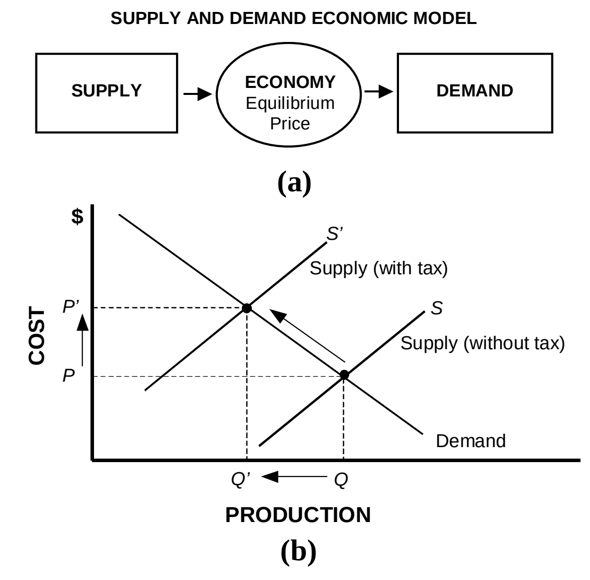

Figure 2. (a) The simple model of supply and demand represents a relationship between producers and consumers where the determining factor in quantity of resources consumed and pollution generated is cost. (b) An example of the supply and demand control over the energy and environment system shows how increasing the cost of fossil fuel by imposition of a carbon tax would result in reduced consumption and thus the desired reduction in green house gas emission. *After Goodstein (2004)*

2.3 Supply Side Energy Engineering

The economic idea of supply and demand can be demonstrated to describe the relationships between producers and consumers. However, when it is used as a model for an entire country's development, and used to justify political decisions, then the role of engineering and science is limited to trying to facilitate the continuous increase in demand by discovery and provision of ever increasing supply. The prevailing methodology for modelling future energy scenarios employs least cost technology selection to supply a projected energy demand.[9,10] These costs can include valuations of environmental impacts as well as fuel and running costs and capital costs.[11] Figure 3 gives an example analysis from one such study to develop a scenario of the electricity generation mix given technology costs (influenced by supply) and the costs of CO_2 reduction strategy through taxation.[12] Biomass and offshore wind generation are predicted to maintain overall demand growth, yet these technologies do not yet exist, and would require significant engineering development effort. There is also no discussion as to the source for the biomass (food, forest?) or the available wind sites. This type of scenario generation does not appear to provide any discernable driver for change, nor any model of the nature of the sustainability of the energy system in 2050.

The role of engineering and science on the supply side is to provide more energy supply and to fix problems:

- Oil, gas, coal exploration and extraction
- Alternative energy development: solar, wind, hydro, geothermal, wave…
- Toxic waste clean-up
- Congestion reduction on roadways, and mass transport design
- New materials, new products, automated manufacturing, mass production

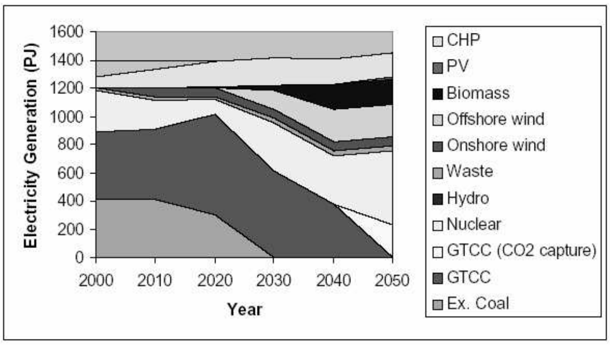

Figure 3. A representative future energy scenario showing the expected role of engineers to *provide* low cost new technologies to supply ever increasing energy demand. *After Marsh (2004).*

There is a decades-long historical experience with this economic model and the engineering development that supports it. In the supply side context, sustainability engineering would refer to technology development to keep the economy growing through development of new resources and fixing of old problems. Our analysis indicates that, regardless of substantial technology development and extraction of massive amounts of resources, the system has not become any more sustainable. Indeed, it is clear to our group that the road to sustainability in this model will be achieved by the failure of the system.

2.2 Demand Side Energy Engineering

In the nineteen sixties, pollution devastation of rivers, toxic waste dumps, dangerously polluted air, and extinction and near extinction of numerous species, including the American bald eagle, gave rise to efforts to revise the prevailing business model. When several high profile lawsuits in the United States awarded millions of dollars to people whose health had been damaged by toxic materials disposed of by industry, the cost of pollution gained recognition as a cost of business. Then, with the OPEC oil embargo and the ensuing energy and economic crisis, a new approach to energy engineering emerged.

The *performance-cost* model is a variation of the supply and demand model that implies that technology and infrastructure decisions can be made to meet the requirements of economic growth while mitigating risks of impacts by assigning costs to externalities. Engineers perform energy audits of existing facilities and design to minimise cost of both energy and impacts.[13] *Triple bottom line accounting* is one mechanism used to include environmental and social costs into operation and design decisions. Energy efficiency engineering is also focused on reducing energy costs through technology and management investments which have an economically acceptable pay-back period in savings. David Sandborn Scott has proposed a model to explain the concept that engineering is done to meet people's needs, not simply to produce supply.[14] Figure 4 shows the basic structure of the performance and cost model and the various areas pursued as sustainability engineering. In this model, the demand and supply are reversed, reflecting the idea that energy and resource consumption arise from people's needs for services, and that people purchase energy products not because they desire the energy, but because they desire the services afforded by using the energy to run various appliances.

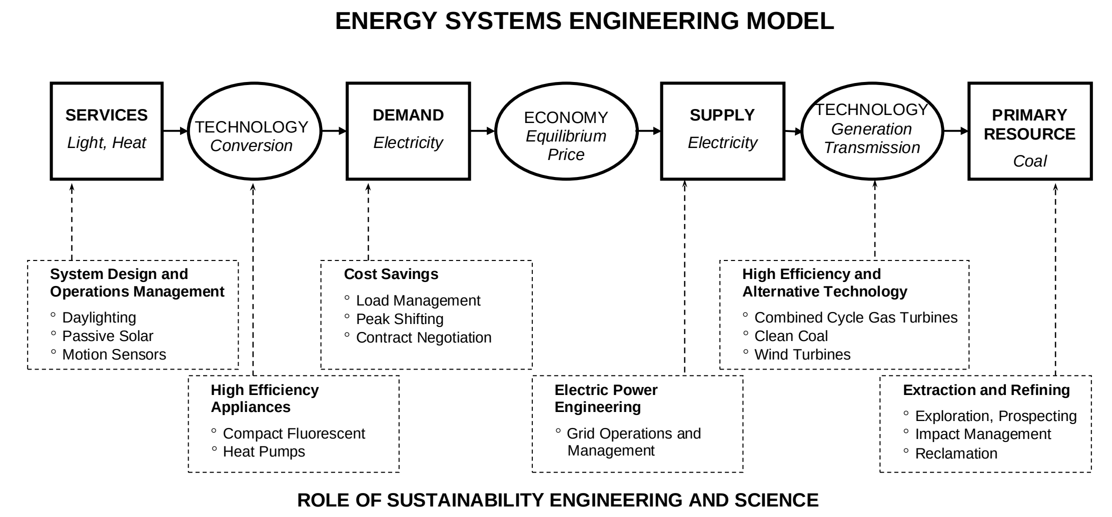

Figure 4. Energy management and energy systems engineering provide the desired services to people while minimizing social, environmental and economic costs. This process is often referred to as sustainability engineering, as are the development of the various technologies. *After Sandborn-Scott (1995)*

The problem with triple bottom line accountng is that trying to assign monetary costs to the decline of resource assets, or the health of individuals is necessarily inclusive of a range of value judgements and exclusive of moral judgements. The other problem is that, while the necessity of "reducing" costs and negative impacts is recognised, the basic assumptions of ever expanding economies, requiring ever increasing energy and resources is still fundamental.[15] The role of engineering and sciences under the cost-minimization ethos is to provide technology and system operations and management strategies:

- Energy auditing and energy management
- CO2 reduction and sequestration, including biomass energy
- Clean combustion, emissions control
- Green products and processes
- Improve energy efficiency in conversion technologies
- Bio- and eco-materials
- New and emerging energy technologies - hydrogen fuel cells
- Hybrid cars, insulation for houses

While "sustainability" is often used as a description or motivation for many of these activities, simple analysis of the long-term impacts of even the most ambitious up-take of these technologies and practices indicates that sustainability cannot achieved by attempting to improve an inherently un-sustainable energy architecture.[16]

3. System Theory Approach to Energy Modelling

3.1 Modelling Concept

Modelling, analysis, and control of dynamic engineering systems are accomplished through application of control system theory. Figure 5 shows the simplified schematic framework for a control system model. The boxes represent individual elements of the system. Desired operation is engineered through computer control by monitoring signals from various components as well as feedback signals of the performance of the system. Feedback signal values are compared to design values, and corrective actions are directed through the control signals to the various forward elements in the physical plant.[17,18]

A good example of a dynamic control system is the cruise control system on a car which adjusts the fuel supply and gearing to maintain the speed set by the driver. The operation of each component can be described and modelled independently (i.e. the accelerator in the car). The arrow lines represent the actuation of one element and the follow on effects to other elements (i.e. a depression of the accelerator will pull a cable, open a valve, and cause more fuel flow to the engine). Each element has physical or electronic parameters that describe its function (i.e. the displacement of the accelerator, engine rpm). And each of these parameters can be affected by disturbances from outside the system (i.e. fuel composition). The reference input represents the desired performance of the system (i.e. the safe highway speed). The feedback processor produces a feedback signal from measurements of the actual performance of the system (i.e. an electronic proximity sensor outputs a voltage signal from which the car speed can be calculated). The feedback signal is compared to the desired performance by the comparator element, and the resulting control signal is used by the control elements to determine what changes are necessary in the operation of the forward elements to achieve the ultimate outcome (i.e. increase fuel supply to maintain speed up a hill).

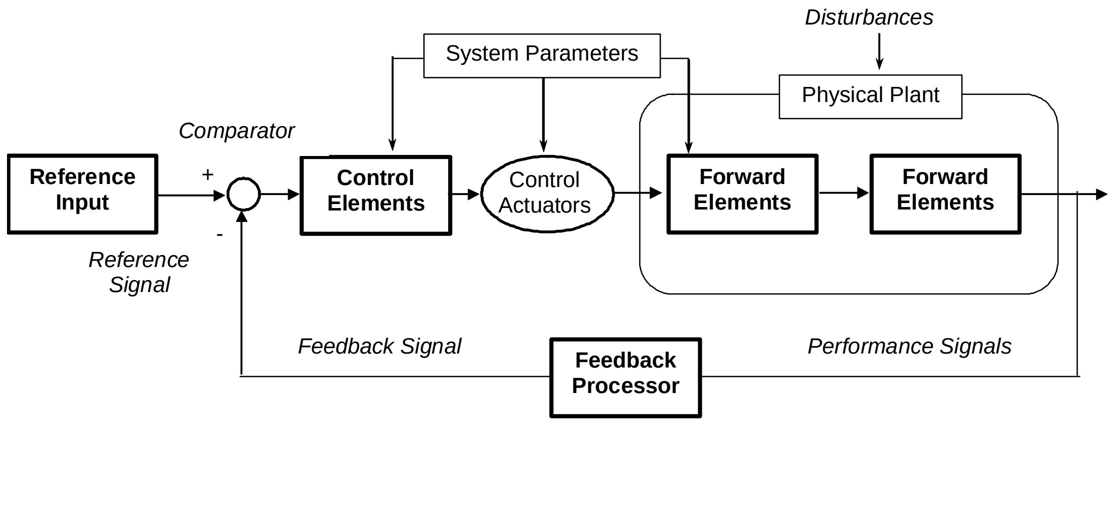

Figure 5. The general concept of a system model from control system theory. The reference input represents the steady state response of the system which is compared to the feedback and then used by the control elements to actuate parameters in the forward elements of the physical plant in order to keep the system stable, and to always move the performance toward the steady state performance.

The designers of a system analyse individual elements, and the interaction of elements so that stability can be built into the system. The controller can only keep the built system working within the range of the reference input, as long as the operational parameters of the system are not exceeded (i.e. the minimum engine speed set point which kicks off the cruise control). While maintaining desired operation is one focus of modern control theory, another equally important application is design for system stability. The control system model is used by designers to ensure that the built system is inherently stable. How well a system responds to disturbances in individual element parameters and to feedback parameters is a measure of the robustness and reliability of the system.

3.2 Energy-Environment-Economy System Model

For several years, our group at University of Canterbury, the Advanced Energy and Material Systems Laboratory (AEMS Lab), has worked with control system theory to identify technological developments that could produce sustainable operation of a civilization. We have developed a control theory-based model of the energy-environment-economy system as shown in Figure 6, but we have discovered that the role of engineering for sustainability is not limited to reducing costs, providing alternative energy resources, or fixing problems.

Our research has encompassed study of other cultures around the world and throughout history. We have been persistent in keeping the whole system perspective. We have reached the conclusion that the only means for achieving a sustainable civilization is to have an energy architecture and control parameters that are inherently stable and sustainable by design.

The operation of the regional energy system, which represents the built environment of energy production and conversion technology produced by engineers, is usually outside the control of the design engineers once it is put into service.[19, 20] The same is true for a car which is designed by engineers, but is operated at any given moment by the judgement and desires of the driver. The energy system is controlled by the individual day-to-day decisions of the region's citizens. These decisions are a result of individual needs and desires as people pursue activities, and are affected by culture, climate, history, community, and rules and regulations.

People in any number of roles must necessarily use the built environment, including infrastructure, technology and resources that are available at the present. Assuming that people are rational, and that they will act to maximize utility, people will choose to use the built environment as it has been designed, because they know that it will work. People access the built environment through the economy. The supply and demand model of the free market describes an actuating element of the system, not the driving force for the system, and certainly not a control signal toward sustainability. Thus, we have reached the conclusion that *educating* people about sustainability or adding the cost of pollution to products may cause incremental behavioural changes, but the system will remain inherently unsustainable.

The feedback in the system has three forms, availability of the built environment, the system performance as it relates to individual activities, and the impacts on the natural environment. For example, when people choose to use a car, bus or bike to get to work, they have some idea in advance of how it will work to meet their needs because they can asses what is available. They know whether the distance is comfortable for them to bike, they can call an information line to get bus timetables, and they can look at a map to find road routes and parking facilities. At present, there is no availability information about energy products or most basic natural resources like water and waste processing capacity.[21] There is immediate feedback once the trip is made as to how well that choice worked. This feedback is used in future decision analysis.

People's activities also result in environmental impacts and depletion of finite resources. While this information is known in general, (i.e. global warming, acid rain, peak oil) there is presently no mechanism to incorporate this feedback into the individual's decision analysis. The Kyoto Protocol approach is to incorporate CO_2 pollution into the economy. However, impacts can only be used to impact decisions if the built environment is actually capable of delivering the desired services within environmental constraints.

Figure 6 shows the general form of the regional energy system model. The inevitable steady state is a sustainable state. Many people perceive this inevitable state for our system as a fall or collapse.[22,23] The most desirable long-term performance of the system is a stable operation within the energy and environmental constraints. This does not imply a *static* society or economy, rather the dynamic activities of the society are conducted within the bounds of energy and resource continuity. Historically, civilizations which functioned in a continuous state for hundreds of years had strong traditions and ancestral shared knowledge which supplied the reference input for sustainability.

There is, by definition, a level of energy and resource consumption and waste generation for a given region which can be supported continually by the environment. This utilization level will, of course be a factor of the technology, infrastructure, and efficiency of the system. However, if the built environment were designed to function within these constraints, and controls were built into the system to keep it stable, then people would be free to pursue their individual desires within a free market.[24]

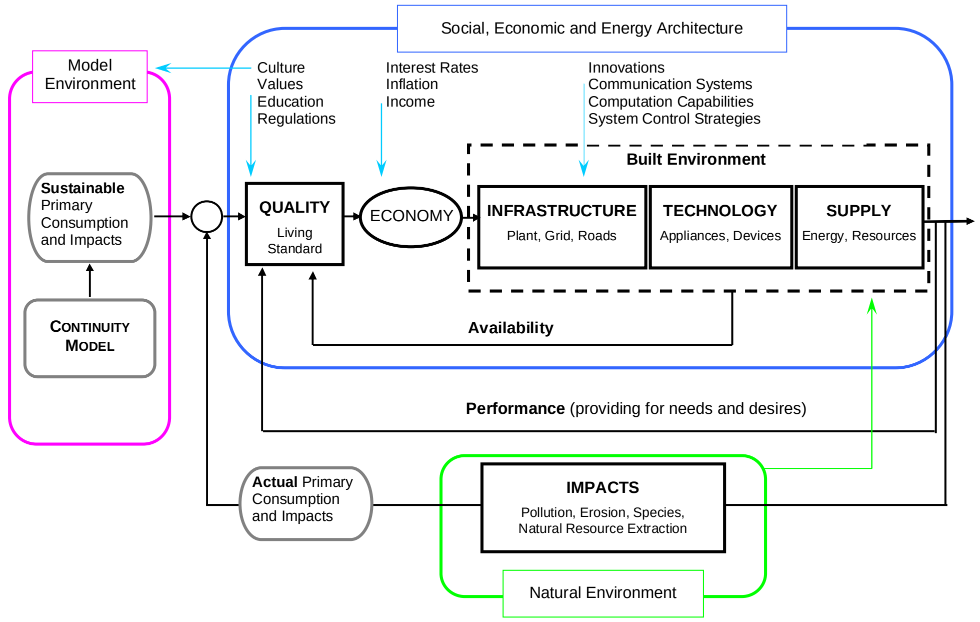

Figure 6. The continuity energy/environment/economy system model showing the role of the free market economy as an actuation element in the system, rather than as a control element. The inevitable reference input representing the steady state response is sustainability. There are three levels of feedback about the state of the built environment, the performance of the system, and environmental impacts. The control element of the system is the individual decisions of individuals which are made in the cultural, regulatory, and economic context. While technological development changes the built environment, it does not act as a driver for the system.

4. Continuity Model and Sustainability Energy Engineering

The system structure shown in Figure 6 has been related to several civilisations in different historical timeframes. One case study was the pre-Columbian American civilisation of the Southwest desert region which had an energy and resource architecture that sustained the quality of life for nearly 700 years. Near the end of the civilisation, a major political change led to increased trade and higher populations. When a very serious and prolonged drought occurred the Anasizi abandoned most of their villages and cities. The civilisation relied on sustainable farming and hunting practices enforced by tradition, culture and religion. Of course, people had direct knowledge of the oral histories and cultural beliefs which guided the methods and timing of resource extraction, planting, harvesting, etc. The availability of water, farm land, seed grain, wood, potting clay, and other resources was directly observable and understandable to all. The impacts that the Anasazi civilisation had on the environment were not nearly as immense as our own. But even minor episodes of extraction beyond availability would create obvious resource depletion. The Anasazi citizens could see directly what was available and what their impacts were. They also had a built-in sustainability model, and they had cultural management systems for distribution of limited resources.

In examining our own system it is apparent that we are missing several critical elements necessary for sustainabiltiy. Primarily, we do not have a cultural vision of sustainability. We do not have traditions or ancestral wisdom about how to do things in a way that works and has worked for generations, as indigenous people do. We are also so disconnected from the sources of energy products that we seldom give any thought to the availability of energy or the impacts that energy generation and extraction have on the environment. While development of renewable energy technologies may be useful on the evolutionary path to intergenerational stability, the emergence of a vision of our community thriving within a sustainable energy architecture will be essential.

The role of sustainability engineering and science will be in developing the critical components which are presently missing from our system:

- Model of sustainable energy and environment architecture
- Communications of sustainable built system designs to all sectors of society
- Communications systems in the built environment for access to information on availability
- Feedback processing of environmental impact data
- Comparator computational systems for real-time analysis and communication to the community in a generic and relevant way

4.1 Continuity Model

The efforts of the group at University of Canterbury working in the Advanced Energy and Material Systems Lab (AEMS Lab) are focused on developing the tools and methodology for *continuity modelling.* The idea is to select a specific community, inventory renewable energy resource flows, assess the community's fundamental desires for high quality of life, and then perform the engineering design for an energy architecture which could function continuously.

The contribution of sustainability engineering and science to social, economic, and environmental stability will primarily be in the development of modelling techniques for discovering and designing a sustainable built environment. This effort will require integration of expertise from disciplines which are currently fragmented in perspective and application. Developing continuity models must be done one region at a time, and will require coordinated effort from participants with many backgrounds.

4.2 Availability and Real-Time Information Systems

New communications and information systems will need to be developed to provide information about resource availability and impacts at the point where individual decisions are made. New computational and modelling capabilities will need to be put in place for real-time modelling and adjustment of system elements. Alternative technologies, essential to stable function of the system, will need to be explored.

As an example, work at the AEMS Lab has led to design of a system to inject availability information into the land transportation system. In the very near term, the quantity of petroleum fuel will be constrained. A system to manage the fuel distribution while decreasing the actual product delivered would consist of a magnetic strip swipe card for each customer, readers at filling stations, and an automated accounting and modelling program on a central server. Each customer would submit a periodic request for the quantity of fuel that they desire. The supplier's software processes the requests and attempts to reconcile the requested quantity with the known supply quantity of product. The distribution plan among customers is calculated, and each customer is notified of the guaranteed quantity and price available to them during the period. The customers would then use ATM-type stations and web links to their account to track their fuel availability, request additional supply at the spot market price, and offer any un-used allotment back to the market. This system would not suffer from panic price rises and runs on filling stations induced by shortage at the pumps as was seen during the OPEC oil embargo. The system would be able to handle fluctuations in supply, and so would be robustly controlled. It would also have inherent drivers toward the long-term stability point of vastly reduce fossil fuel consumption. Customers would be aware of the quantity of fuel they are secure in being able to purchase. If people want to do more travelling with the same amount of fuel, THEY will perform a rational analysis and decide about priorities in automobile fuel economy. The consumers may decide to trade in the SUV for a Civic, move closer to work, reduce unnecessary trips, share rides, ride a bike or take public transport in order to manage their activities. The constrained supply is a much greater motivation for such changes than fuel prices rises because the primary point of analysis for people is functionality.

4.3 Strategic Analysis of Complex Systems

In order to begin to make the transition to a sustainable built environment, new ideas in analysis for long range planning must be explored. The AEMS Lab is developing the Strategic Analysis of Complex Energy and Environment Systems (SACEES) methodology. This approach involves using a continuity model design as a starting point for long range planning. Once the sustainable energy architecture is conceived, then it is possible to discover planning and technology development decisions which will lead toward that structure. Figure 7 shows a scenario for transportation energy consumption in New Zealand where fossil fuel supply becomes constrained and begins to decline around the turn of the 21st Century. The energy consumption rate for a sustainable transportation system is developed using the continuity model. The scenario then has two phases, first, adaptation of the existing system to reduced and constrained supplies, and later re-building of the infrastructure as per

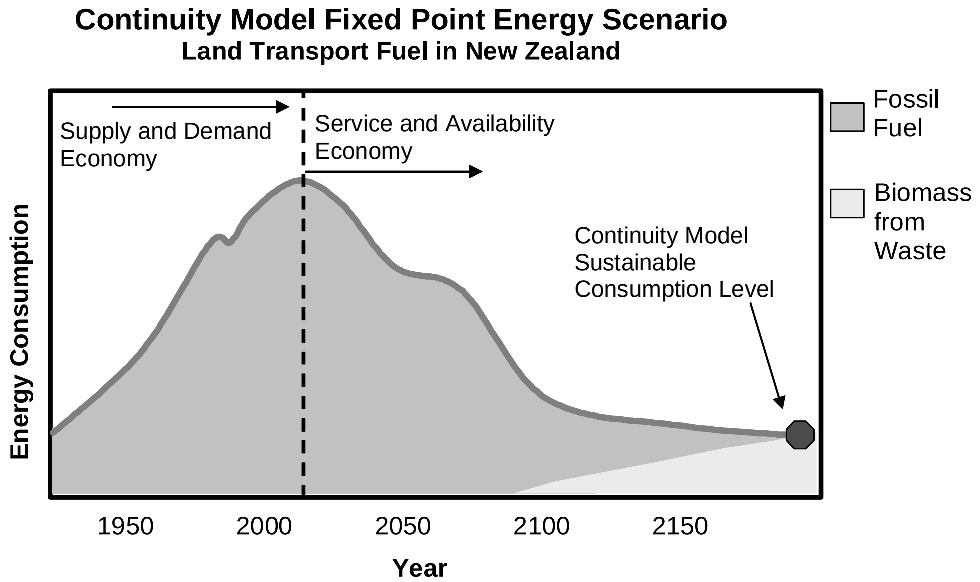

Figure 7. Example of SACEES scenario for transportation energy consumption. Large-scale changes in driving patterns and restrictions on imports of low-mileage vehicles account for 30% consumption reduction from 2004 levels. Beginning around 2060 automobiles are no longer common, and a new built environment provides access to the services people require with fuel consumption 90% less than 2004.

the continuity model sustainable architecture design. In the sustainable architecture, the communities are arranged so that 95% of the services and goods that urban people need are available within 1km, walking distance. Micro-manufacturing and integration of agriculture into the urban environment are also used to negate much of the need for transportation that the present industrialized system requires. Renewable energy provides land transport by rail, *on supply* rather than *on demand*. People and bike paths take up a small fraction of the landscape, much of which is converted to local food production and native habitat restoration for microclimate stabilization. Light electric vehicles are available for delivery and for transport of ill and infirm people. Obesity, diabetes and heart disease are rare in the sustainable system. The bulk of the fuel available is used for critical services and trade.

The AEMS Lab efforts in this area include development of virtual reality and gaming software into a powerful communication tool. Through virtual explorations, people of any background or expertise will be able to explore life in their sustainable community as designed through the continuity modelling exercise. It is not enough to describe the technical features and energy consumption of the sustainable energy architecture. The place is much different, and so must be experienced. Once people (the controllers) have an idea of how a different system

5. Conclusion

The current economic model of supply and demand is often used at the level of policy planning, and sustainability engineering is given the role of developing alternative energy technologies in order to sustain economic growth. A more modern approach to modelling the energy system places an emphasis on meeting performance goals while minimizing costs. This performance-cost approach supports sustainability engineering activities such as triple bottom line costing, operational systems management, energy efficient technology development, and advanced and alternative energy technologies. However, neither of these models has any provision for constraints on primary energy resources, and no mechanisms to control the system and produce pressures for change toward sustainability.

A model of the energy-environment-economy system has been proposed that uses the central concept of control system theory. This model explains how the whole physical, social and economic system works, and it is based on study of many societies, both modern and historical. The model shows how all of the elements of the system interact to produce a stable operating state. By comparing the system model to current developed countries it is apparent that several of the critical elements are missing.

The contribution of sustainability engineering and science in social, economic and environmental stability will primarily be in the development of modelling techniques for discovering and describing a sustainable built environment. The model development underway at Canterbury is still in early stages. Our first explorations have yielded visions of the city of Christchurch with a sustainable energy transportation system using only renewable energy. The work has also provided insights into new products and technologies which incorporate real-time information about availability of energy resources which would allow management of the system by the controllers (i.e. consumers) within resource constraints.

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