A Systems Approach for Transforming America's Agriculture and Economy from a Fossil to a Fiber-based Energy Future

By

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I. Vision of agriculture's contribution to the energy economy in 2017

With peak oil production here or not many years away, America's energy future will increasingly depend on the use of renewable energy. ***This paper outlines a systems approach for transforming America's agriculture and economy from a fossil- to a fiber-based energy future***. In our vision, agriculture's contribution to the energy economy in 2017 will be to produce vast amounts of cellulosic biomass for conversion into transportation fuels. Currently, corn grain and soybean oil are the dominant feedstocks for America's biofuel production. By 2017, fiber from perennial, non-food energy crops, agricultural and forest residues, and municipal solid wastes will be the principal feedstocks for biofuel production. Fiber was our ancestor's first energy source for heating and cooking; now it will be an energy source for transportation. In this new role of supplying feedstocks for fuel, agriculture will be transformed in unprecedented ways and the agricultural community must work together to ensure that this transformation produces outcomes desired by all.

To successfully convert to a fiber-based energy future, America's farms, ranches and forests must meet the following core parameters: 1) produce more food, feed, fiber, and fuel with greater efficiency, 2) add value to more plant and animal products, 3) expand and improve the use of marginal lands; and 4) preserve the quality and sustainability of the environment.

Producing more food, feed, and fiber per unit area more efficiently have been hallmarks of American agriculture. The new challenge will be to add fiber for transportation fuels to agriculture's list. While agriculture will continue to grow with advances in agricultural science and technology, it is likely that in the near term, the addition of producing fiber for fuel will create inefficiencies. New crops, practices, and products will be developed and eventually adopted throughout the nation to create the fiber-based energy economy. To make this transition more efficient we must replace trial-and error methods of adjusting to new crops, practices, and products with knowledge-based, decision support tools that utilize a systems approach to predict outcomes of alternative strategies that can be tailored to meet stakeholder requirements. Development of decision support tools that integrate systems methodology is central to our vision of agriculture and is discussed more fully elsewhere in this paper.

Adding value to fiber will be essential to a fiber-based energy economy. Fiber is plentiful and easy to produce, but is bulky and the cost of transporting it to processing centers diminishes its value. Thus, biorefineries must be strategically located to feedstock production areas. Transportation costs can be reduced by developing mobile processing units that can go to sites where fiber is plentiful and developing a range of economically-sized biorefineries to match the availability of feedstock produced within a short distance of the plant.

One example for a value-added fiber product is to convert it to biochar and bio-oil using mobile pyrolysis units. Charcoal with a half-life of a thousand years can be applied as a soil amendment and need not be replenished once applied to soils in sufficient quantities and will enable crop residue, such as corn stover, to be used as biofuel feedstock. Innovative use of fiber improves land quality and promotes carbon sequestration resulting in a carbon negative ecosystem. Additional value-added options will likely come from the increasing number of new chemicals and biomaterials that will be produced from biomass as we develop new ways to convert biomass into useful products.

To expand and improve the use of marginal lands, research and development of deep-rooted, high biomass yielding, perennial grasses, shrubs and trees that can utilize water and nutrients from large soil volumes should be selected and improved for fiber production on underutilized, marginal lands. Salt tolerant, drought resistant species that utilize biological nitrogen fixation, crassulacean acid metabolism to use water more efficiently and other natural processes need to be investigated to increase fiber production on marginal lands. Life cycle analysis and economic assessment of growing fiber crops on marginal lands should be undertaken to determine how such lands can be used not only in an economically sustainable manner, but in a way that adds quality and beauty to the landscape.

Regarding the last core parameter, to preserve the quality and sustainability of the land, we propose following Gordon Conway's framework for sustainable ecosystems. Gordon Conway, an agricultural economist who later became President of the Rockefeller Foundation, first proposed that all sustainable agroecosystems had four common properties. These four properties include (1) high productivity measured in yield and income, (2) high stability measured in terms of fluctuations in yield caused by weather and price variability, pest infestations and other factors, (3) high resiliency of the system to recover rapidly from large stresses such as buildup of salinity or perturbations imposed on it, and (4) high equitability or the equal sharing of benefits derived from the systems. The success of our nation's agriculture now and in the future will depend on acquiring all four properties to enable agriculture to provide our citizens with the food, feed, fiber and fuel they will need.

To achieve the core parameters as described above, the nation's federal and state institutions and agencies must join forces to make sound decisions that result in successful production outcomes. Sound decisions are inextricably linked to good predictions, and reliable predictions depend on a thorough understanding of processes operating in the system. Process level research is often considered basic research, whereas, control and management research is treated as applied research. There is a third group of researchers often referred to as knowledge engineers, who develop decision support tools by synthesizing basic process-based knowledge into rules that predict outcome(s). A national team consisting of scientists from all three categories need to be formed that integrates understanding, prediction and control/management research for biofuel production that covers the entire supply chain from producing feedstock, processing the feedstock into biofuels and bioproducts, and their use and impact on the economy and environment. The team would develop decision support tools for feedstock production and for feedstock processing. The tools would be applicable nationally and would operate with a minimum set of input data determined by team members with input from user groups throughout the nation. A national biofuel decision support system will enable all states and the nation as a whole to be well on its way to achieving a clean energy economy in 2017.

Developing a national systems methodology for the biofuel supply chain requires a decision support system that applies globally and operates on a site-specific basis due to the many aspects of agriculture such as crop production that depend on local soil, climate, crop variety and site management. Users of the system will need not only the decision support tool, but the local input data to operate the system. This means that we not only need a national decision support system, but a national data bank and data management system accessible to users throughout the nation. Such a system would enable a farmer, extension agent, or researcher to evaluate new varieties of energy crops at any location and estimate not only means and variances of yield and profit, but also enable to user to compare outcomes of alternative management scenarios. Such a system would enable policy makers to conduct policy analysis at different spatial scales at the national level. Some components for such a national system already exist, so a first step will be to inventory existing tools to avoid the cost of replicating what is already available.

Once the national systems methodology is in place it can be used to integrate research, education, and extension at the nation's land-grant institutions and research organizations. Research, education, and extension all have one purpose in common. This common purpose is to enable our stakeholders to make better decisions. Our stakeholders range from practitioners including farmers, ranchers and foresters to bankers, policy makers, and students. In the decision making process, research contributes to the understanding of processes, education to learning to understand, and extension to enabling others to apply understanding to control outcomes. The integration of research, education, and extension through the development, teaching, and application of systems methodology is described more fully in Part III of this paper. The challenge of making clean energy an integral part of how agriculture is practiced and what it produces presents a new opportunity to revitalize America's rural communities.

II. Vision of how the University of Hawaii will fit into the energy economy in 2017

Hawaii's unique combination of soils and climate ranging from balmy beaches to snow capped mountains and drenching rain forests to arid deserts, all in close proximity on a single island provides a richly diverse set of environmental conditions that have been strategically captured in sites occupied by the University of Hawaii's agricultural research stations. These unique natural and institutional resources are well-suited to contribute to a unified national systems methodology effort to develop a clean, efficient, sustainable energy future for America. To initiate this effort, researchers from the College of Tropical Agriculture and Human Resources, and the Hawaii Natural Energy Institute are currently working with the State and the U.S. Department of Energy in a long-term partnership that will result in a fundamental and sustained transformation in the way renewable energy efficiency resources are planned and used in the State. Successful development and execution of the objectives contemplated in this partnership will provide a replicable global model for achieving similar results.

The Hawaii-Department of Energy Partnership will build upon the dynamic, ongoing work of public and private organizations at the State, county and grassroots levels in order to achieve several key goals:

- To define the structural transformation that will need to occur to transition the State to a clean energy dominated economy
- To demonstrate and faster innovation in the use of clean energy technologies, financing methodologies, and enabling policies designated to accelerate social, economic and political acceptance of a clean energy dominated economy
- To create opportunity at all levels of society that ensures wide-spread distribution of the benefits resulting from the transition to a clean, sustainalble energy State
- To establish on "open source" learning model for others seeking to achieve similar goals
- To educate and build a new generation of workforce with crosscutting skills to enable and support a clean energy economy

Attainment of these goals is critical to the State's long term energy security. Ninety percent of the State's energy supply is imported, predominantly in the form of crude oil. To lessen its dependence on imported fossil fuels, the State is increasing its capacity to generate electricity from geothermal, hydroelectric, wind, and solar energy sources, but will need to join forces with an expanded network of sister institutions and agencies at the national level to benefit from and contribute to a rapidly evolving agriculture-based energy producing system. The University of Hawaii will contribute to and benefit from such a national collaborative research effort in two ways. First, the University of Hawaii has on-going relationships with a network of U.S institutions dealing with systems simulation in agriculture. This network of institutions maintains a decision support system called DSSAT (Decision Support System for Agrotechnology Transfer) for use by network members. The network also encourages others to use this system and conducts periodic workshops to train others to use this decision support tool. The network and the product it maintains can serve as a model of how the synergy of networking can be utilized to accelerate the transition from a fossil fuel to a fiber-based energy future. A more detailed description of how this system is applied in research, education, and extension is provided in the next section.

Second, the University of Hawaii's location in the tropics offers a broad genetic base from which to choose new high yielding, energy crops. Like corn and potato, both of tropical origin, future energy crops for the nation may come from the tropics and subsequently adapted for use in temperate regions. We believe that by partnering with other institutions we will be able to accelerate the development of viable energy crops.

On the local level, the state must lessen its dependence on imported oil by growing energy crops that perform well on non-prime agricultural lands. Such crops currently being evaluated by the University of Hawaii include perennial C4 grasses, and Jatropha, a drought resistant tree that can produce 1400 – 2100 liters/ha/yr of oil on land not suitable for high value cash crops. The University of Hawaii has also developed a new technology call Flash Carbonization for converting biomass into biochar. A large national firm has obtained a license to use this technology to produce charcoal briquettes for barbecuing. Locally, research is underway to use this technology to convert municipal waste, biowaste such as macadamia nut shells, corn cob from an expanding corn seed industry, biomass from invasive plant control harvesting, used rubber tires, and sewage sludge into charcoal for use as soil amendment and as a substitute for imported potting material for our orchid and plant nursery industry.

Today much of the biomass we produce is not utilized. 6 to 10Mg/ha of dry matter go up in flames when a sugarcane field is burned to rid the field of accumulated leaves before harvest, and 70Mg/ha of dry matter is mechanically pulverized and subsequently burned or allowed to decompose to clear land for the next planting. If the conversion processes now undergoing development and testing to convert fiber into biofuels and biomaterials on commercial scales become economically feasible, Hawaii will well be on its way to achieving the goals of the 25x’25 Action Plan.

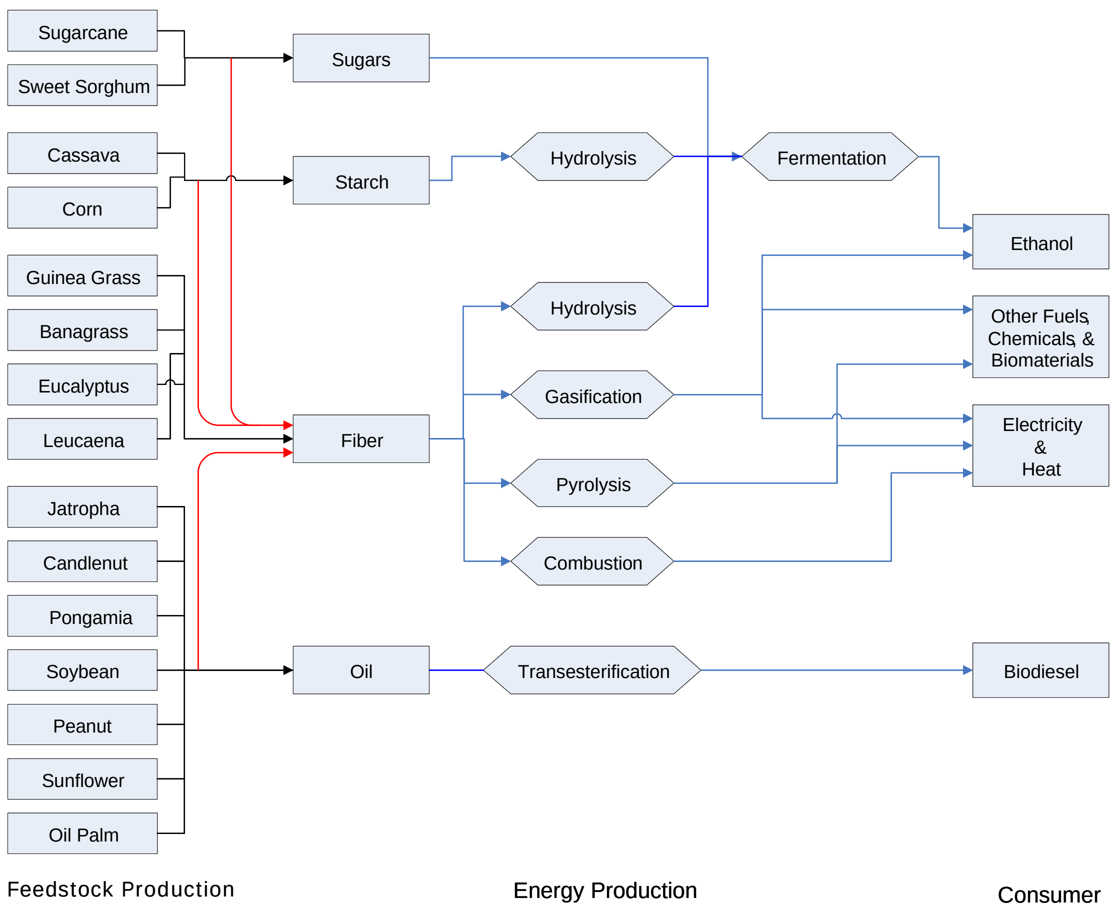
III. Vision of the institution's role in achieving the 25x'25 goal through Research, Education and Extension.

The University of Hawaii is a land-grant institution whose primary responsibility is to conduct research, education, and extension programs to meet the needs of its stakeholders. The challenge to our institution, and indeed our nation and the world, is to develop sustainable sources of energy to meet growing energy demands, while making significant reductions in green house gas emissions to attenuate or ideally, reverse global warming. To address this challenge and fulfill our land-grant mission research, education, and extension programs will be developed and implemented to provide measurable impacts toward achieving the 25x'25 goal. Although the university has many ongoing efforts related to the 25x'25 goal, only those related to agriculture will be described below, in keeping with the focus of The Grand Challenge.

Research Programs

The College of Tropical Agriculture and Human Resources (CTAHR) and the Hawaii Natural Energy Institute (HNEI) are the two units at the university that have ongoing joint research programs in bioenergy. CTAHR focuses on all agriculturally-related parts of the biofuel supply chain system including energy crops, natural resource and environmental management, economics, life cycle analysis, carbon sequestration, and crop simulation models. HNEI focuses on conversion of feedstocks into biofuels and bioproducts and biofuel testing. Figure 1 illustrates Hawaii's version of the biofuel supply chain system from feedstock production to energy production and consumer consumption. While all four feedstocks (sugar, starch, fiber, and oil) are listed in the flowchart, Hawaii's vision of a fiber-based energy future mandates concentrating on the production and conversion of fiber into energy.

Figure 1. Biofuel Supply Chain System



Development of high yield, low input fiber crops, such as C4 grasses are a research priority. Dry matter yields ranging from 75 to 100Mg/ha/yr and 50 to 75Mg/ha/yr have been obtained for Bana grass (*Pennisetum purpureum*) and Guinea grass (*Panicum maxium*), respectively. This compares with dry matter yields between 10 to 20Mg/ha/yr for switchgrass in the continental U.S. It is very likely that the yield of these understudied tropical grasses can be greatly increased with genetic modification. Additional research areas include selection and development of varieties for different environments (e.g. temperate) and tailoring plant traits to optimize both biochemical and thermochemical conversion into biofuels and bioproducts.

An integral part of research programs will be incorporating a systems approach. One component of our systems approach is the generation of crop simulation models for biofuel crops. Simulation models of biofuel crops would generate information that policy-makers and crop-producers need to make strategic and tactical decisions. As climate change proceeds, policies and practices used in the past become less applicable. New information is needed to make decisions for the future. Combining the ever-improving long-term climate forecasts with the predictive capabilities of crop models provides critical information on the production potential of crops across available lands and the natural resources needed. Policy-makers may use this information to designate land use, or make decisions about what infrastructure or resource to develop in which location. Life cycle analysis has been used to assess environmental impact over a long period, but when coupled to economic analysis the information generated would provide policy-makers with information to develop business incentives that promote environmental health. Crop-producers may use production estimates generated from seasonal climate forecast to schedule planting and harvest dates to maintain feedstock supplies and keep conversion plants operating at full capacity, or estimate water consumption for water use planning. Analyses for both strategic and tactical decisions depends on the availability of simulations models for biofuel crops.

The private sector also can take advantage of this type of tool. Seed companies that market new food and energy crops can promote their products by providing information from crop models to simulate how the plant will perform in untested locations. This type of information should be a standard part of seed certification and marketing.

With rising fertilizer costs, new products that release nutrients in synchrony with crop needs are less likely to contaminate ground water or enter streams and rivers should be developed and marketed. The chemical properties of these products should be provided, so decision support tools can use the new products optimally.

The University of Hawaii has a wealth of experience developing decision support tools and a long history of collaborative research with sister institutions in the U.S. and internationally to solve complex agricultural problems requiring the combined effort of a network of advanced research institutions. From 1974 to the present, we have worked with partners from Africa, Asia, Europe, Latin American, North America and Australia-New Zealand to transfer and share modern agricultural technology in a timely and cost-effective manner.

This technology transfer partnership was created to change technology transfer from the slow and costly trial-and-error methods to more efficient science-based approaches, and has evolved from technology transfer by analogy to the current methods of technology assessment by systems analysis and simulation. Technology transfer by analogy was first introduced to our partners in Africa, Asia and Latin America in 1974 through a federally funded international project called the Benchmark Soils Project (BSP). This ten year project demonstrated that crop production technology can be successfully transferred from its site of origin to other locations with similar (analogous) soils and climate. With rapid advances in information science and computer technology, the 1980's opened the door to enable this network of partners to explore new ways to transfer and share technology. In 1983, a project called the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) project was established with federal funds to produce software called Decision Support System for Agrotechnology Transfer (DSSAT) capable of predicting the growth, development, and yield of the major cereal, grain legume and root crops anywhere on the globe using a minimum data set of soil, crop, weather, and management data.

Unlike technology transfer by analogy that estimates average yields, DSSAT generates whole probability distributions of outcomes based on crop performance over many decades taking into account seasonal and annual weather variations. The ability to generate and display means and variances of production outcomes enables users to analyze risk and seek alternative crops or management strategies to minimize risk and increase profit. The crop simulation models contained in DSSAT not only generates information on crop yields, days to maturity, crop responses to rate and timing of supplying inputs, but enables users to compute cost of production and perform economic analyses.

DSSAT continues to be upgraded to keep up with advances in information science and computer technology, and a marketing plan is in place to pay for upgrading costs. DSSAT contains models for food crops such as sugarcane, corn, and soybean that produce sugar, starch, and oil for conversion into biofuels, and can readily accommodate models for non-food, cellulosic energy crops. Research partners involved in maintaining and upgrading DSSAT include scientists from ARS, USDA, University of Florida, University of Georgia, International Fertilizer Development Center, NOAA, and other U.S. institutions.

While DSSAT was designed to deal with food crops and food security, it can do the same for energy crops and energy security and serve as a standard decision support system for the nation. The federal government and U.S. institutions invested heavily in the development of DSSAT, and that past investment can save the same group time and resources by converting DSSAT from a food-oriented system to a new energy focus. We can no longer afford to invest in research that applies to a single state and DSSAT is a tool that applies equally well in every state. The University of Hawaii is currently working on adapting DSSAT simulation models for energy crops and will spearhead the development of collaborations with other institutions to test and validate models.

Education Programs

The fundamental goal of our educational program is to enable students to make better decisions for themselves and for society as whole, both locally and globally. Educating a workforce with crosscutting skills to support a renewable energy economy requires injecting systems thinking into their decision making. System thinking focuses on defining stakeholder needs and utilizes modeling and simulation to validate assumptions to achieve the desired end. Agricultural systems are complex and human interactions with the soil-plant-atmosphere continuum over space and time make transitioning agriculture from a primarily food-based to a food and fuel based industry is a challenging task. Fortunately, U.S. universities have mature systems programs as demonstrated by their capacity to assemble DSSAT over 20 years ago. But the existing programs remain isolated and fragmented. To incorporate systems thinking into the curriculum, DSSAT will be expanded to accommodate non-food biofuel crops and utilized as a systems device in classes from ecology and economics, to environmental and social impacts of bioenergy choices.

To facilitate development of "open-source" non-food, bioenergy systems models to determine the optimal and sustainable use of agricultural resources, students and faculty exchange programs with national and international research institutions will be created. Students and faculty exchange will accelerate transfer of the rapidly growing knowledge-base and facilitate collaboration and improvement of sustainable approaches to meet our energy needs.

Taking a systems approach to bioenergy education and training will result in a well-prepared, forward thinking workforce capable of applying multidisciplinary skills to address the complex energy-related problems our nation and indeed the world faces.

Barriers that now compartmentalize research, education and extension can be breached by adoption of a systems approach to problem solving. In the final analysis, the aim of research, education and extension is to enable individuals and groups to make decisions that produce desired anticipated outcomes. Success or failure is determined by the decision one makes, and extension is about enabling our stakeholders to make sound decisions. A systems approach is essential in decision making to avoid the unintended consequence of solving one problem at the expense of creating another. Serious problems such a global warming are unintended consequences of decisions made many years ago. Unintended consequences often have long gestation periods, which imply that a good decision support system must enable users to not only study the past, evaluate the present, but explore the future. Unintended outcomes are often weather or climate related and while agriculture is inextricably linked to weather and climate, humans have little or no control over them. For this reason, improvements in weather forecasting for the coming growing season will be critical to future extension decision support. With the onset of climate change, the ability of atmospheric scientists to forecast weather with a high degree of spatial and temporal resolution will be critical to decision support in agriculture.

Extension Programs

Bioenergy-related extension programs include k-12 and community integrated programs, DSSAT workshops, and forums and symposia. Achieving conservation and energy efficiency in our energy economy will require educating the older generation to break wasteful habits, and preventing the younger generation from acquiring them. Our k-12 programs include planting and monitoring "energy gardens," energy conservation awareness, and making biofuels. The programs will inspire a new generation to pursue careers in renewable energy and use energy wisely. Training policy makers, agricultural producers, and energy industry representatives in the use of DSSAT will ensure a broader understanding of systems-based solutions to the energy challenges and increased awareness of potential impacts. Forum and symposia that fosters scientific exchange and collaboration, as well as engagement of the general public will build the knowledge-base of all to find consensus on the selection of next steps to preserve the environment, decrease green house gas emissions, and sustainably meet our energy needs.

IV. Vision of transformational processes required to meet the 25x'25 goal

The transformational processes required to achieve the 25x'25 goal encompass our entire society and cannot be reached without strong leadership by government, academic institutions, private industry, and participation of the general public. Our vision of specific transformational processes that will facilitate attainment of the goal are discussed below.

Develop High Yield, Non-food Energy Crops and Crop Simulation Models

Increase yield of non-food, cellulosic energy crops to 50 Mg/ha/yr through genetic improvement and determine the best crop or crop variety for each location in the nation on a site-specific basis. This will require identification of crops with high yield potential and establishment of a national research group to match the genetic potential of high yielding crops to the physical characteristics of our nation's diverse agro-ecosystem. The genetic improvement effort should be linked to crop simulation model development to enable model users to predict where and how each energy crop will perform best both biologically and economically. Genetic improvement also needs to be linked to tailoring traits to optimize feedstock conversion into biofuels and bioproducts.

Invest in Energy Infrastructure

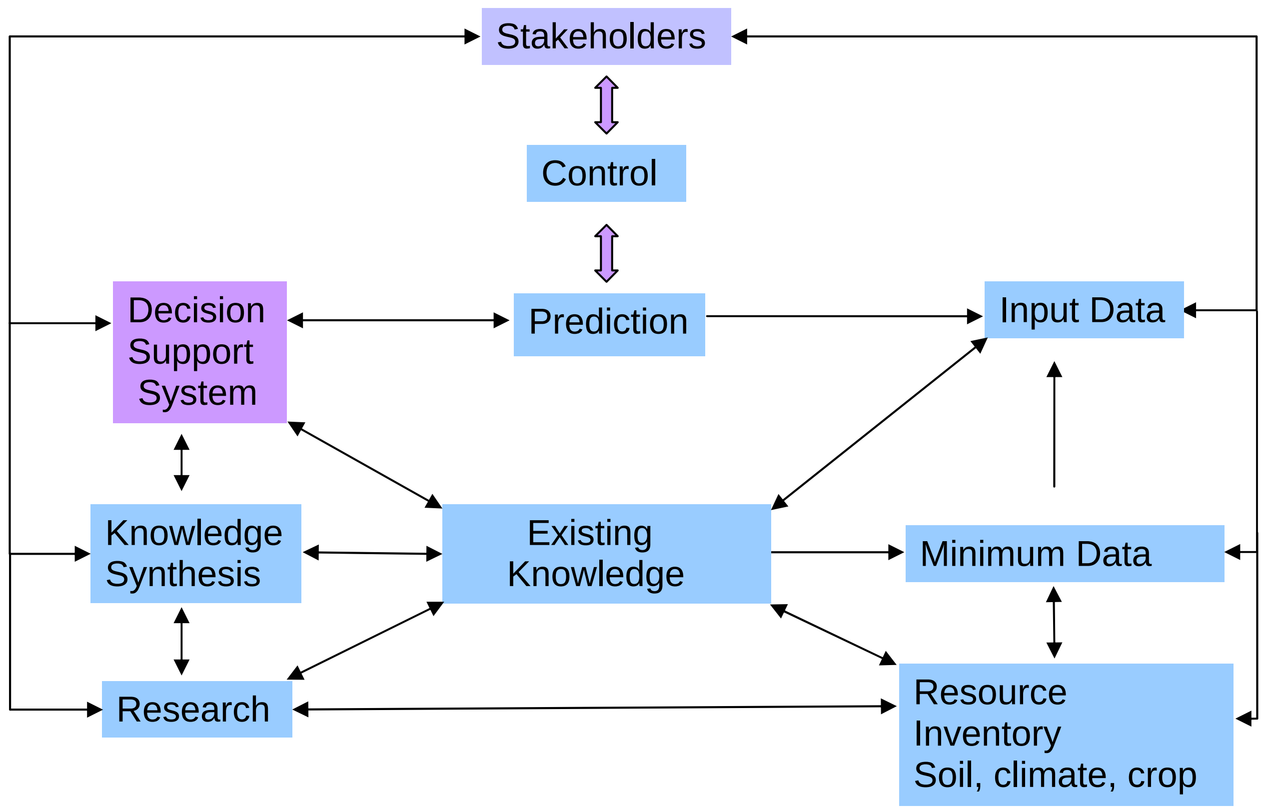
Work with elected officials to invest in a national transportation network to move biofuels and power from production sites to consumers in a timely and affordable way. There is a strong possibility that resources will be allocated in the near future to repair our neglected infrastructure. This presents opportunities for state and local governments to work together to restore infrastructure in a way that allows renewable energy to be efficiently transported to areas where customer demand is high. A related effort to streamline and expedite the permit process for energy infrastructure including pipelines, storage facilities, and transit terminals is required.

To increase the efficiency of the infrastructure, non-corrosive, non-hydroscopic biofuels that are less subject to evaporative loss need to be developed for transport through pipelines over long distances. Local and federal agencies should encourage isolated communities in rural areas to generate power through wind, solar, hydro and biomass and enable small producers to access the grid to deliver power to customers elsewhere. For example, in Hawaii biomass from invasive plants could provide ample feedstock for small gasification units that could supply energy to rural communities and the excess supply could be sent to the larger communities through a well-managed transmission and distributed power system. This would lessen the need to use expensive imported oil from foreign countries and increase our energy security. In the long term, affordable renewable energy will require strong commitment and adequate private and public investment in research for quick conversion of scientific discoveries into commercial scale energy production.

Development and Adoption of Sustainable Energy Solutions

Formation of a national team of scientists to establish a standard set of sustainability criteria, methodologies to analyze the sustainability criteria, comprehensive life cycle analysis, and knowledge-based decision support tools are essential for developing and selecting sustainable energy solutions. While it is likely that a different set of solutions will be appropriate for different locations, the key to a renewable energy future will be their adoption by stakeholders. Well-designed decision support tools will allow users to explore potential energy solutions with "what if" questions. Decision support tools for all phases of the supply chain need to be designed, developed, validated, and maintained by the national team for this purpose. Figure 2 illustrates the conversion of research-generated knowledge into predictions stakeholders can use to control outcomes.

Figure 2. Systems approach that enables stakeholders to use knowledge to predict and control outcomes.



Promote Energy Conservation and Energy Efficiency

Achieving energy conservation and energy efficiency in our energy economy will require educating the older generation to break wasteful habits and preventing the younger generation from acquiring them. Significant resources will be needed to promote energy conservation, as well as energy efficient technology development. Given the finite quantity of resources on planet earth conservation and energy efficiency will be as important to our future well being as developing renewable energy for our energy needs.