Arnold Schwarzenegger
Governor

POTENTIAL TARGETS AND BENEFITS FOR SUSTAINABLE COMMUNITIES RESEARCH, DEVELOPMENT, AND DEMONSTRATION FUNDED BY THE PIER PROGRAM

CONSULTANT REPORT

Prepared For:
California Energy Commission
Public Interest Energy Research Program

Prepared By:
Stephanie Pincetl
Paul M.E. Bunje

UCLA Institute of the Environment

Month Year
CEC-500-XXXX-XXX

Prepared By:
University of California, Los Angeles
Institute of the Environment
Stephanie Pincetl, Ph.D
Paul M.E. Bunje, Ph.D
Los Angeles, CA
Commission Contract No: 500-99-013
Commission Work Authorization No: BOA-99-207-P

Prepared For:
Public Interest Energy Research (PIER)
California Energy Commission

Erik Stokes
Project Manager

Philip Misemer
Program Area Lead
Transportation Research Area

Kenneth Koyama
Office Manager
Energy Generation Research

Martha Krebs, Ph.D.
PIER Director

Thom Kelly, Ph.D.
Deputy Director
ENERGY RESEARCH & DEVELOPMENT DIVISION

Melissa Jones
Executive Director

Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End□Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Potential Targets and Benefits for Sustainable Communities Research, Development, and Demonstration Funded by the PIER Program is the final report for the development of a sustainable communities research framework (contract number 500-99-013, work authorization number BOA-99-207-P) conducted by the UCLA Institute of the Environment. The information from this project contributes to PIER's Transportation Research Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-654-4878.

Table of Contents

Abstract

The Public Interest Energy Research (PIER) Program of the California Energy Commission has recognized the importance of sustainable communities to improving the efficiency, cost, and social and environmental impacts of energy use in California. In order for sustainable communities research, development, and demonstration (RD&D) funded by the PIER program to be effective, it is important to understand and optimize the energy-related aspects of land use planning and community design. In this white paper, a research team from the UCLA Institute of the Environment identifies a unifying framework for sustainable communities research by the PIER Program that explicitly considers sustainability with respect to energy production and use in California communities. In this context, a sustainable community is one that minimizes throughputs of energy and materials through efficient and socially sensitive production, distribution, use, and reuse of those materials and energy. The research team identifies an urban metabolism framework as the most effective framework to meet the criteria and needs of the PIER Program. Ideally, this framework for sustainable communities will guide and integrate research efforts among the PIER Program's seven subject areas so that sustainable communities RD&D funded by the PIER Program can provide optimal benefits to California.

Keywords: Sustainable communities, energy, land use, community design, urban form, urban metabolism, sustainability, California, framework.

Executive Summary

Existing patterns of urban and suburban development have resulted in increased air pollution, increased dependence on automobiles and rising fuel prices, substantial economic inequality among neighborhoods, the need for costly improvements to roads and public services, the loss of valuable farm land and native habitats, and significant increases in greenhouse gas emissions. Sustainable (or energy-smart) communities are designed and developed to address these issues within the community as well as provide other community benefits such affordable housing, increased energy and water efficiency, increased renewable energy use, and reduced waste materials. The Public Interest Energy Research (PIER) Program of the California Energy Commission has recognized the importance of sustainable communities to improving the efficiency, cost, and social and environmental impacts of energy use in California.

In order for sustainable communities research, development, and demonstration (RD&D) funded by the PIER Program to be effective, it is important to understand and optimize the energy-related aspects of land use planning and community design. However, research is first needed to identify targets for sustainable communities RD&D as well as identify research areas and themes to address those targets.

In this white paper, a research team from the UCLA Institute of the Environment identifies a unifying framework for sustainable communities research by the PIER Program. Because the research areas and themes identified will likely involve complex interrelationships, a programmatic framework is needed to guide and integrate research efforts among the PIER Program's seven subject areas so that sustainable communities RD&D funded by the PIER Program provides optimal benefits to California.

To do this, the research team first clarifies the concept of sustainability in relationship to energy production and use in California communities. In this context, a sustainable community is one that minimizes throughputs of energy and materials through efficient production, distribution, use, and reuse of those materials and energy in a socially sensitive manner.

Secondly, the research team identifies the aspects of urban and suburban environments that are necessary to support and encourage energy-smart community development, including their relationships to the hinterlands that are used for energy and resource extraction and disposal. In order to be successful, a sustainable communities framework must identify the system's boundaries, account for the inputs and outputs to the system, in a hierarchical structure that consists of decomposable elements for targeted, sectoral research, include the analysis of policy and technology outcomes with respect to sustainability goals, be an adaptive approach to solutions and their consequences, by integrating social science and biophysical science/technology.

The research team then identifies several possible frameworks for sustainable communities research, including the existing implicit framework that is not consciously integrative, an urban metabolism approach, an approach focused on the physical urban form, an ecosystem services approach, and a life-cycle energy approach. Consideration of the pros and cons of these different frameworks led the research team to conclude that an urban metabolism framework is the best way for the PIER Program to organize and integrate its important sectoral research.

An urban metabolism framework is advantageous because it meets all the criteria for an effective unifying theme: it explicitly identifies of the system's boundaries, it accounts for inputs and outputs to the system, it allows for a hierarchical approach to research, it includes decomposable elements for targeted, sectoral research, it necessitates analysis of policy and technology outcomes with respect to sustainability goals, it is an adaptive approach to solutions and their consequences by integrating social science and biophysical science/technology.

The appropriate research steps in an urban metabolism framework are:

1. Define the boundaries of a community.
2. Define the metabolic commodities and processes of the community.
3. Identify and quantify the anthropogenic metabolism of a community.
4. Identify and integrate social/political boundaries that shape social and metabolic flows and processes.
5. Assess the metabolic relationships between human activities and the natural environment in a community.
6. Measure the metabolic relationships between the community and hinterlands outside its boundaries.
7. Identify strategies for improving the metabolic efficiency and reduction of waste of the community.
8. Collaboratively develop policy solutions that address identified strategies.

Using this framework, the research team recommends pursuing several areas of research to meet the Energy Commission's sustainable communities goals. Urban metabolism research should include, at a minimum, research including:

- Indicators of the volumes of materials waste.
- Characterization of inflows and outflows of energy and materials.
- Inflow/outflow ratio and efficiency metrics for the different media.
- Degree of intensity and efficiency of resource consumption relative to urban form.
- Amount of locally available renewable resources.
- Amount of local energy and resource storage capacity.
- Inflow/outflow of social, human flows such as fiscal flows that affect the sustainability of communities.
- Local management jurisdictions that overlay and may manage or affect inputs and outputs.

Finally, given this recommended framework, the research team considers several areas of targeted sectoral research that are important for the PIER Program to pursue. Several of these areas are currently important foci of the PIER Program, which the research team highlights to underscore their importance in unifying the PIER Program's research efforts in support of producing more energy-smart and sustainable communities. The research team recommends the following research:

- Establish a common metric for assessing energy content, mass content, and land area required in various activities.
- Develop the architecture of the governmental regulatory institutions for each of these areas and their roles.
- Research the capacity for local energy production, distribution, and storage in different communities throughout the state.
- Identify the primary urban typologies (e.g. Berkeley, Irvine, San Diego, Fresno) within California and estimate the net energy and materials used in exemplars.
- Identify the institutional factors that are related to the different urban forms and energy use in each typology (e.g. zoning and building codes, transportation, general plans) and match them to the urban typologies.
- Identify the social flows that affect sustainability of communities including taxes and revenues, lending practices, educational levels, and their impacts on urban sustainability.
- Establish a standard methodology for determining the boundaries of communities in California.
- Identify the appropriate scale for land-use planning decisions given a particular policy or community goal.
- Determine and promote effective community strategies that reduce and reuse energy and materials *locally*.
- Solicit community input as to what the desired community-level outcomes are:
- Identify and publicize the financial, fiscal, regulatory, climatic, and physical barriers to implementing sustainable policies for individual community typologies, with an emphasis on needed changes to advance planning and policy goals.
- Identify and publicize transformative tools at the super-regional scale, such as statewide transportation, electricity, conservation, and water projects that promote energy-smart and sustainable policies in constituent regions around the state.
- Clarify how new legislation, specifically AB 32 and SB 375, affect existing requirements for land-use and transportation planning.
- Clarify how existing regulations, specifically CEQA and federal environmental regulations, limit or abet local and state climate and sustainability targets.
- Assess the strengths and weaknesses of currently employed mechanisms for translating scientific research into policy and decision-making contexts.
- Design an information clearinghouse to allow communities to tap into best practices and energy-smart programs/products to advance their particular sustainability goals.

1.0 Introduction

1.1. Background on Energy Smart and Sustainable Communities

The Public Interest Energy Research (PIER) Program of the California Energy Commission has been at the forefront of ensuring that Californians have access to the most technically advanced and effective research on energy production, delivery and use available. Through partnerships with public and private research, development, and demonstration (RD&D) institutions throughout the state, the PIER Program administers approximately $83 million dollars annually in targeted research funds that help to ensure that Californians have access to affordable, reliable, and environmentally safe energy sources and services.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End□Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Many of the research projects, as well as the research themes, cut widely across these research areas. The PIER Program has recognized one theme in particular that is relevant to a large portion of research goals—namely the creation of sustainable built environments and energy smart communities. Research in each of these core programs is directed at making Californian's access to clean and economical energy stable and sustainable over the long term. Energy is at the heart of modern communities. By harmonizing the above research under the existing efforts to create more sustainable human environments, PIER can foster integrative research that meets the mission of the California Energy Commission to "to improve energy systems that promote a strong economy and a healthy environment" (CEC 1997, p. 2).

The Energy Commission was created to plan for the state's energy needs; PIER research has provided significant inputs to that mandate over the past several years. It is a testimony to the Energy Commission's success that California has the lowest per capita electricity use in the nation (IEPR 2007: 3). Recently, the state has set forth a Renewables Portfolio Standard goal of producing 33 percent of the state's electricity from renewable sources by 2020, has adopted AB 32—The California Global Warming Solutions Act—to reduce the production of GHGs in the state, and in 2008 California adopted SB 375, requiring regional land use and transportation planning to reduce greenhouse gas emissions resulting from vehicle miles traveled. This legislation propels California to leadership in reducing the environmental impact of our energy use from all sources and marks the State's commitment to producing communities that are healthy and sustainable in the long term.

The PIER Program understands that in order to achieve the kinds of energy use reductions necessary to comply with these legal requirements, and the anticipated need to go beyond them, that a new, integrated research framework is required. This has been described as a Programmatic Framework for Energy Smart Communities Research, originally labeled Sustainable Communities Research.

The state, in order to make significant strides in becoming more sustainable and to reduce energy use, must now also address how Californians live on the land. This recognition was largely the impetus behind California's path breaking land-use planning legislation, SB 375. Urbanization patterns that predominate today are partly the result of the rules that guide land use planning and community design and, concomitantly, historically subsidized energy and materials (Gordon 2008). Unfortunately, the state has little empirical data on the relationship between different types and forms of land use and energy throughputs, including waste. The state also has little empirical data about the relationships between different regulations, fiscal incentives, and jurisdictional scales and their impacts on land use and energy. Consequently, California's population, including its decision-makers, do not sufficiently understand the impacts of the state's current forms of urbanization on human health, agricultural land, ecosystems, water resources, and the global climate system. A major research program must be devoted to identifying the capacities of localities for increasing their own sustainability including through judicious use and management of local renewable resources to aid California's ability to improve the sustainability of its communities through smarter energy use strategies.

Hence, the research team suggests an interdisciplinary approach to the energetics, including impacts, of urban environments. Energy underpins life on Earth. Every society is molded by the types and quantities of energy it consumes (Smil, 2008:382). Affluent, high-energy societies such as California's have, for multiple reasons, decided that they can no longer afford to continue in an energy-intensive and wasteful manner. The negative externalities are just too great and the Earth's resources too finite to support such lifestyles into the indefinite future (Turner 2008).

To begin to develop a more comprehensive understanding of the state's current patterns and their impacts, PIER has recognized an interdisciplinary research approach is required. However, it should also be understood that while this seems like the appropriate approach, and has been advocated and funded by such entities as the National Science Foundation, interdisciplinary research in general is still in its infancy (Redman et al. 2004; Lélé and Norgaard 2005). Weart (2003), in his classic book on the development of climate change science, for example, explains how it took nearly 40 years for such a thing as climate science to emerge. It took time and leadership for climatologists, paleontologists, oceanographers, modelers, and others to understand and respect each other's disciplinary epistemologies and methods. The remaining challenge was, and arguably still is, communicating findings to decision-makers and the public in such a way as to change policy (Van der Sluijs et al. 1998; Hodgson and Smith 2007). Integrated research on land use planning and community design will require the collaboration of multiple disciplines, and the PIER Program will need to evolve to manage and guide such cutting-edge research. PIER will also have to be committed to communicating results to policy makers and residents of the state. To ensure that the research approach is relevant to the community of Californians who will have to respond to the results, such outreach should start even as the questions are being developed.

At the heart of these recommendations, therefore, is the research team's belief that for the Energy Commission to be successful in this research initiative, there may need to be a new model for the relationship between the PIER Program, researchers, and the Californians who will be responsible for change. The PIER Program will have to be more proactive with the research community itself in nurturing successful interdisciplinary research initiatives. That is, there will need to be active cultivation of trust among researchers from different disciplines, mutual respect for others' disciplines, space and time for sharing of knowledge and epistemologies, opportunities to negotiate at the borders, and strong definitions of expectations of outcomes from the PIER Program. The PIER Program will also have to utilize its outreach and inclusion strategies and processes to ensure that research is informed by the end users, and also applied by those same end users. Integrated urban community sustainability research is still nascent and has intrinsic intellectual challenges that PIER will have to understand to ensure productive outcomes.

1.2. Defining "Sustainability"

The Brundtland Commission (UN 1987) defined sustainability as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Since this original framing in 1987 the concept of sustainability has evolved, especially with respect to cities and developed areas. As a concept it represents an understanding that human activities have significant—and often irreversible—impacts on the biosphere that will have catastrophic consequences for the natural world and human civilizations if the current pattern of development and resource use is continued. The intent of sustainability is therefore to mitigate this negative future by encouraging mechanisms, lifestyles, and socio-economic strategies by which humans and natural systems can survive and adapt indefinitely.

As participants in a November 22, 2008 workshop (see below) agreed, defining sustainability is difficult without explicit reference to a particular problem and place. Furthermore, applying the perspective to cities and urban areas specifically is increasingly important since, for the first time in human history, there are more urban dwellers than there are rural inhabitants in the world (Cohen 2003). In a place like California, out of over 36 million inhabitants, there are less than 1 million rural residents (USDA 2007). Most of the global and regional environmental problems originate in cities as they concentrate increasing numbers of people and human activities, exporting emissions and waste (Alberti and Susskind, 1996) Therefore, the above definition, with its focus on international economic development, that has been adapted in various contexts is not sufficient for a Programmatic Framework for research for California.

Additionally, for California—a highly urbanized state that is already one of the most efficient energy users in the U.S.—the challenge of achieving greater sustainability is both quantitatively and qualitatively different than in the rest of the country. This is true even in spite of its unique climate, indigenous resources and population characteristics. Land use in the state is considered to be denser and subject to greater land use controls than many other states in the nation, with the exception of Oregon.

A definition of sustainability that the research team suggests for the PIER programmatic research framework is as follows: A sustainable community is one that minimizes throughputs of energy and materials through socially appropriate efficient production, distribution, use, and reuse of those materials and

> A sustainable community minimizes throughputs of energy and materials through efficient production, distribution, use, and reuse.

energy. This definition recognizes that energy is a fundamental requirement for all communities, but that the current forms of energy California enjoys have an impact on all aspects of social life and urban environments. Therefore, a goal of energy smart research should be that the quality of life based on access to energy must be calibrated to energy produced in an environmentally and socially smart way. Because "higher energy use does not guarantee anything except greater environmental burdens" (Smil 2005: 386), it is imperative that an energy-smart, sustainable community preserve the economic, cultural, health, and environmental aspects for all current and future community members.

One implicit aspect of this approach is the de-coupling of the quality of life from the quantity of energy consumed. Smil (2005) cautions that though careful process energy analyses are a valuable management tool, thermodynamic efficiency should not become the overriding arbiter in social decisions. "True quality of life arises from awareness of history, from strong cultural values, and from preservation of nature's irreplaceable services" (ibid: 387). The research team recognizes as well that the dynamic sectors embodied in the seven PIER research areas all impact both energy use and quality of life issues. Access to transportation, water and other natural resources, a clean environment, and an enriching built environment are core components of a sustainable community. As the Energy Commission has already recognized, these dimensions are also critical for reducing energy use and producing more energy-smart communities (IEPR 2007).

The following components are at the heart of structuring the sustainable communities research recommended by the research team. While the following list may seem generic, these aspects of sustainability have unique specificities for California and are essential to the consideration of how to build a wholly integrated framework for sustainable communities research. This deep research already fits into the existing research programs of PIER (see Figure 1). Indeed, sustainable communities research is ongoing at PIER, though perhaps not in an appropriately integrated manner. Approaching each of these from the urban metabolism framework, using common metrics, will allow their integration. This will allow a characterization of an urban area's energy metabolism as well as comparisons among different regions and urban forms across California. These areas of deep research will also set a baseline of knowledge that can provide for sharper and more finely tuned policy direction to reduce energy use and waste in the state.

Some of the sectoral life cycle studies PIER should consider funding include:

- Food production, distribution, and consumption
- Electricity generation, distribution, and use
- Household and industrial fossil fuel use
- Water usage and delivery
- Wastewater treatment and disposal
- Solid waste disposal and recycling
- Air and water quality impacts
- Transportation systems
- Buildings and related infrastructure

When conducting detailed sustainability studies as a part of a larger energy-smart research framework, impact analysis should be undertaken for:

- Biodiversity
- Access and availability of natural resources
- Public Health
- Recreational opportunities
- Economic growth and opportunity
- Trade
- Cultural and socioeconomic opportunities

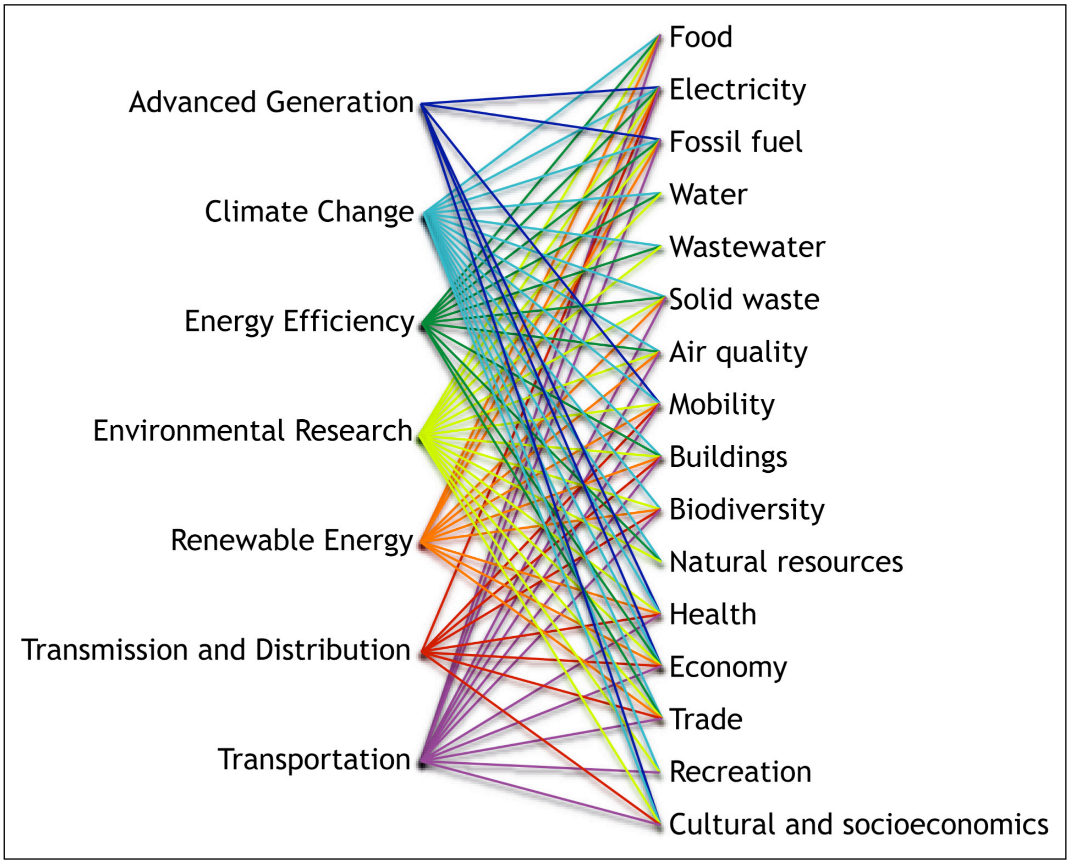

Figure 1. The seven core PIER areas have purview over many sectors of sustainable communities research. The skeleton of an integrated framework already exists.

1.3. Energy and Sustainable Communities

Energy smart communities RD&D funded by the PIER Program seeks to understand and improve the energy-related aspects of land use planning and community design. Because the research areas and themes identified involve complex, interdependent relationships, PIER has identified the need for a programmatic framework to guide and integrate research efforts among the program's seven subject areas.

Energy smart communities are communities that quantify their energetic flows, including the waste products, and implement policies and programs such that energy use and waste are reduced, energy is utilized to its maximum efficiency, environmental impacts are minimized, and the quality of life in the community is supported. Yet, reducing these activities to being energy smart only may inadvertently exclude quality of life variables that do not appear to directly relate to energy, such as housing availability, social equity, public health, ecosystem health, and green space. As such, the term "energy smart" is a subset of the broader and more commonly used concept of sustainability. The Energy Commission and energy professionals may prefer the term energy smart to sustainable, however, this approach risks excluding important interdisciplinary considerations crucial to being energy smart.

Energy is a central and perhaps primary variable in industrialized communities. But if the goal is to understand how to create more energy smart and sustainable communities, then energy cannot be successfully disembedded from the multilayered factors influencing land use. Indeed, there is a need to understand the complex interacting factors that make up communities to plan how to use energy to minimize its negative environmental and economic impacts. The PIER Program implicitly recognizes these interacting relationships between energy and the rest of an urban or suburban community as it has defined the domain of needed research to include water, environmental impacts, and transportation, among other factors.

As energy inputs and outputs impact large geographic areas through feedback loops and interacting factors, developing greater regional use and reuse of available local resources will enable local communities to become more energy smart and more sustainable. This relationship between energy use and sustainability becomes clear when communities reduce the footprint of their energy and resource use.

Energy production, delivery, and use are rightly recognized by the Energy Commission as of paramount and integral importance in designing and maintaining sustainable urban and suburban environments. As will be discussed in Section III, the research team's preferred framework for sustainable communities research focuses on a system dynamics approach (urban metabolism) that examines the sources and sinks of energy flows through and within communities as the approach to understanding the impacts of land use planning and community design.

1.4. The Importance of Sustainability to the PIER Program

Sustainability is at the core of the Energy Commission's interests and activities. Indeed, the Vision of the Energy Commission, as articulated in the 1997 Strategic Plan lays out the core tenets of creating a sustainable community: "It is the vision of the California Energy Commission for Californians to have energy choices that are affordable, reliable, diverse, safe and environmentally acceptable" (CEC 1997, p. 2). This clear emphasis on the stability and adaptable economic and environmental aspects of energy use in California implicitly commits the Energy Commission to producing sustainable energy strategies through its activities.

This vision does not proscribe how the Energy Commission will achieve these sustainability goals. Rather, it is programs such as PIER that produce the knowledge and strategies necessary to implement this broad vision. Further, through strategic planning such as the Integrated Energy Policy Report (IEPR), underappreciated aspects of energy production and use in

California can be identified. One critical area of importance that has, until recently, been underappreciated is the study and understanding of local capacity for production of energy and resource needs, and for waste absorption (sinks) treatment and reuse. This focus on the geography of energy is critical to achieving more sustainable communities. Recently, in forms such as the 2006 IEPR Update as well as the recently enacted SB 375, this relationship to land use and the geography of energy has gained attention. This development is important and should be utilized to increase PIER's focus on local energy resources and use in relation to land use patterns.

The 2006 Integrated Energy Policy Report (IEPR) Update (CEC 2006) noted that the relationship between energy use and land use planning was of critical concern if the state desired greater community and urban sustainability in California. This reflected the longstanding neglect of land-use patterns in energy planning. Recent IEPRs have made great strides in bridging the gap between land use and energy planning, and have determined this should be a priority research area for PIER.

> The 2006 IEPR Update charged the Energy Commission's Public Interest Energy Research (PIER) group with providing tools and conducting research to assist the energy and greenhouse gas reduction planning efforts of local governments. A number of currently funded projects support this charge. In the next year [2008], more than $2 million will be allocated for sustainable communities research. This funding will support initiatives designed to better understand the interaction between energy demand and environmental design principles, to identify infrastructure design impacts on energy and the environment, and to identify design improvements that would reduce energy use in California. Land use modeling tools and methodologies are critical to these initiatives.
>
> (CEC 2007)

The 2007 IEPR further clarified the central role of sustainable communities as a strategy to improving energy use in California. The 2007 IEPR recommended that the Energy Commission, in coordination with CalTrans, support research that seeks to understand how land use impacts energy needs and what research and tools are needed to allow land use stakeholders to improve their energy usage and sustainability (CEC 2007). PIER's effort to form a sustainable communities research framework is an important part of the response to this call.

1.5. Methodology for Identifying Recommendations

Energy smart urban sustainability research is necessarily interdisciplinary. The research team has mobilized the research and literature of several fields in shaping its analysis and recommendations. In addition to the core sustainability and energy technology literature, the team integrates decision support, system dynamics, urban planning, landscape ecology, and ecosystem services research to develop a comprehensive research strategy proposal. Finally, the team emphasizes the importance of a self-conscious approach to interdisciplinary research itself, as this too is a frontier for researchers.

On November 22nd, 2008, the research team hosted a day-long workshop on sustainable urban environments and the research needed to better support the regulatory and policy environment required to shift current land use toward more energy smart communities. The purpose of the workshop was to draw upon the collective expertise of individuals working in multiple facets of sustainable community development, including water use, electricity generation, urban planning, transportation, waste management, community redevelopment, environmental protection, economic development, agriculture, and green building. Because sustainable communities are the product of actors from a diversity of fields and backgrounds, the research team invited members of academia, government, business, and the non-profit sector to share their expertise and opinions. The participants in this workshop are listed in Appendix A.

The topics identified by the workshop participants form a core part of the research team's recommendations. This diverse group of experts identified, by consensus, several important areas that PIER may focus on to engender more effective research into sustainable communities.

Before laying out a framework that the research team believes best integrates sustainable communities research for the seven core PIER research areas, the team examines several alternative frameworks for integrating the relevant research themes of PIER. Out of this examination, the team identifies several critical research topics. The team discusses the existing gaps in current knowledge that prevent a thorough understanding of sustainable and energy smart communities. The team also identifies the current research priorities in PIER that are especially germane to this framework and provides recommendations on the topics and subjects that PIER should emphasize in order to more fully integrate its research priorities into a logical framework for sustainable communities research.

2.0 Identifying a Programmatic Framework for Sustainable Communities Research

2.1. Gaps in the Current Implicit Framework

The current framework for PIER research tends to enumerate possible urban form and infrastructure-related fixes that could result in energy savings, such as narrower streets, zero carbon buildings, transmission efficiencies, household and industrial energy conservation, and recycling waste materials. Though there are numerous Requests for Proposals that cut across the core PIER research areas, most research can be described as single sector deep research. These programs are essential to improving the specific mechanisms, policies, and technologies that improve Californians' access to clean and reliable energy. But through various reviews and strategic planning documents (e.g., CEC 2007), the Energy Commission and PIER have recognized the need to better integrate these different research programs and specific research questions. Framing these interrelated research efforts in a unified theme can build upon the sector-specific framework that is currently employed.

California is a tremendously diverse state, with different climatic zones, water availability and air quality, distributed natural resource, and access to energy and materials. The size and form of California's different urban areas also vary from compact to sprawled and small to large. This affects energy consumption and shapes the relationship of these urbanized areas to energy supplies, food supplies, hinterlands, and other parts of the state and nation. There is no existing baseline of energy throughputs, not only across California cities, but also geographically from north to south and east to west. Because of the interconnected nature of resource use, urban form, and energy consumption, baseline energy patterns and a thorough understanding of the capacity for different communities to meet sustainability and energy smart goals through different strategies, including greater use of locally available resources, need to be established.

Little work has been done on energy use and energy throughputs in different governmental organizations either. The research team knows, mostly anecdotally, that in various parts of the state there are agencies advancing sustainability agendas aimed to reduce both the energy footprints of their jurisdiction, and the environmental impacts of their activities. For example, the Inland Empire Water District is developing programs to become more water self-sufficient. These efforts are local and regional, and emerge from enlightened thinking at those levels. The PIER Program can learn from such efforts, and their results, and also assist such local and regional agencies in their efforts by providing greater research capacity and dissemination of results. It can also assist to better integrate, categorize, and evaluate the different efforts that are on-going, the regulatory agencies involved. Forging this kind of research can also contribute to developing sustainability policy strategies that will not be piecemeal—either sectorally or by jurisdiction. In other words, the research team knows that there are great ideas and programs being implemented, but for them to be more effective they need to be enlarged, an impossibility today, given the landscapes that have been chopped up by jurisdictional differentiations.

To date, PIER research yields intensive sectoral knowledge but interactions and scale issues remain obscure, successful experimentation remains isolated, and synergistic energy smart policy tends to be overlooked. PIER research must, therefore, also look at governance and government jurisdictions and functions and how they contribute or hinder urban and community sustainability.

Communities are, by both definition and design, complex systems. Given the numerous interacting sectors, resources, users, and agents involved in these complex systems, it is possible to decompose communities for focused analysis. This approach more closely describes the framework that PIER currently utilizes. However, because the decomposed elements of a community are all members of a hierarchical system, it is necessary to address the interactions that create the total complex system (Ostrom 2007). Expressing a framework that builds on the excellent sectoral research of PIER by acknowledging the emergent properties of sectoral interactions will result in a more utilitarian and accurate body of knowledge about the functions and products of a community.

2.2. Urban Metabolism

The energy demands of an urban community can be holistically understood with reference to the metabolic inputs and outputs of that community. The energy and materials used by a community form the metabolic behavior of a community system. The concept of urban metabolism emerges from earlier systems work conducted by Howard T. Odum who pioneered the application of thermodynamics and ecological energetics to energy flows in human society (Odum 1971). Odum argued that society faced many of the same energetic constraints that constrain other organisms and systems. Cities too are systems that require inputs and produce outputs, guided by rules.

Wolman (1965) was the first to suggest the urban metabolism concept, and used a hypothetical American city of one million people. An urban metabolism analysis is a means of quantifying the overall fluxes of energy, water, material, and wastes into and out of an urban region (Sahely et al 2003). Cities can be analyzed by their metabolic flow rates that arise from the uptake, transformation and storage of materials and energy and the discharge of waste products (Warren-Rhodes and Koenig 2001 in Sahely et al. 2003). Baccini (1997) describes an urban metabolism model as one that evaluates the metabolizing of resources as they come into, are transformed by, and then are moved out of an urban region to satisfy human needs to nourish, clean, reside, work, travel and communicate. Each of these activities leads to a specific material flux, a metabolism, which has to be monitored and regulated to make a region sustainable. Baccini further explains that this metabolizing is shaped by the nature of the society and its involvement in the world economy, which is powered mainly by fossil energy.

Urban regions are unique in that they are characterized by high metabolic rates (Hendriks et al. 2000). They induce high energy and material flows due to high population densities—and high rates of consumption. An urban metabolism for sustainability analysis implies, among other things, that the urban region (or community) is analyzed relative to its long-term resource use, both autochthonous and imported, and the renewability of those resources. Describing a city's urban metabolism is to quantify the sources and sinks of its inputs and outputs. This empirical accounting provides an understanding of what natural resources are used by the urban area, or community, to provide the quality of life of its residents. Conducting such analyses will establish baselines of inputs and out puts in different parts of the state, and by type of city form.

Urban metabolism is a way to link localized urban processes and activities together with inputs and outputs of energy and materials (including their embedded energy demands). It can link the interaction between human activities and the environment by quantifying the materials flowing into the community and the environmental impacts of the resource use, such as air pollution, water pollution, solid waste and other flows. Much the way an organism's waste identifies the efficiencies and energetic demands of an individual biological entity, the environmental impacts and waste products of a community help identify the efficiencies and energetic demands of that urban metabolism. Figure 2 offers a simple conceptual model of these inputs and outputs into a community. The interactions and processes within the community are critical to determining the efficiency of the system and thus its sustainability.

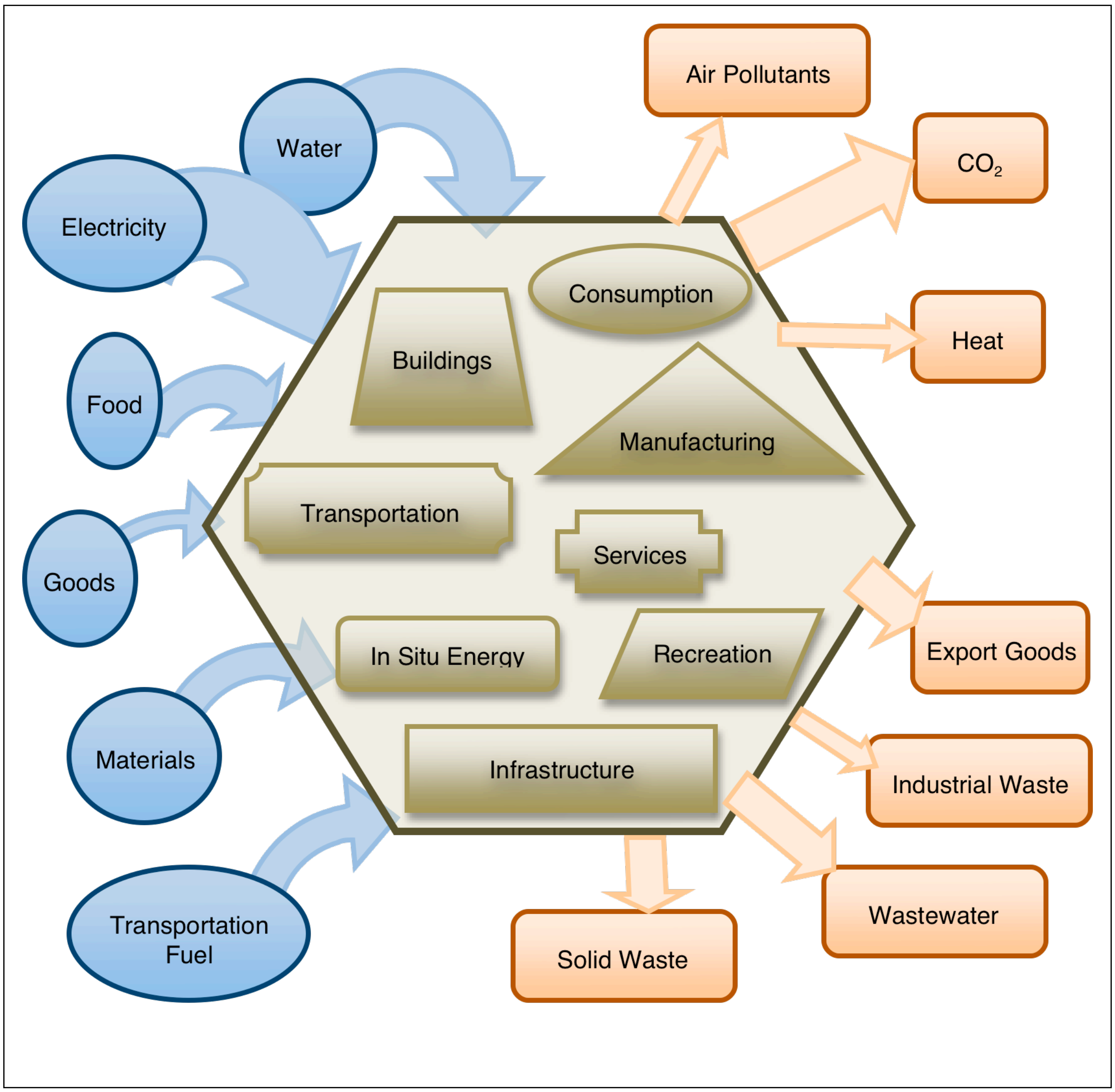

Figure 2. A simplified model of the metabolic inputs and outputs of a community. Interactions, feedbacks, and efficiencies within the boundaries of the community system influence the metabolic rate of the system. The inputs and outputs also have energetic costs that interact with each other and which should be considered in an urban metabolism study

These inputs and outputs can also link the metabolism of the city to a hinterland, showing the dependence of the city or community for the supply and disposal of materials and energy. Many cities in California, for example, import water from great distances, and all contribute carbon to the atmosphere. The efficiency of a community's metabolism—how energy smart it is—determine the total amount of inputs required and the environmental impacts of the outputs. We do not have a good understanding of these factors city-by-city, urban form by urban form, and among different regulatory regimes and fiscal constraints that exist among communities in the state.

Though urban metabolism has existed as a field of research for over 30 years, it is not widely appreciated as a methodology for understanding urban communities. This is partly because it is a complex and integrative framework, which makes it difficult as a field of academic research, and partly because it has not received widespread attention among planners and community practitioners who continue to rely on a less integrative approach to managing communities. By providing a forum for application of this framework, an agency such as the Energy Commission would allow for the appropriate application of this inherently practical approach by providing the integrative, energy-centric milieu that is necessary to see urban metabolism better utilized and understood. In fact, after a dormant period, urban metabolism analysis is now regaining interest as siloed sectoral research has not yielded the kinds of comprehensive understandings needed to address the interwoven set of factors creating existing energy intensive communities.

2.3. Urban Form

There has been a great deal written about the environmental impacts of different urban forms leading, most recently, to the call for smart growth and sustainable communities. Much of this has emerged from studies on the effects of urban sprawl, starting as early as 1974 with the landmark study called the *Costs of Sprawl* published by the Real Estate Research Corporation. Shocking the research community, that research spawned dozens of follow-up studies, either supporting or repudiating its findings, largely based on ideological predilection relative to the role of government regulation. Since the 1970s, substantial research has been conducted on the origins of land use planning ideas in the U.S., including private property protections in the U.S. Constitution, and the federal role in promoting single family housing, particularly in the early to mid 20th century (Whyte 1970, Jackson 1985, Fishman 1987, Downs 1995, Nelson 1999, Rome 2001) including the *Costs of Sprawl Revisited* (1998).

Sprawl is a term that has a variety of definitions (Johnson 2001), but among the environmental impacts of sprawl are: loss of environmentally fragile lands; reduced regional open space; greater air pollution; higher energy consumption; decreased aesthetic appeal of the landscape; loss of farmland, obesity, high vehicle miles traveled, a transfer of wealth from the inner city to suburbs, and much more. California land use and sprawl has also been examined by scholars, but not specifically with respect to energy and resource use intensity. Rather, the relationships between regulation and land patterns have been documented, a topic that underlies much of the determinates of urban form (Fulton 1997, Pincetl 1999, Schrag 1999, Hamond et al 1999, Wolch et al 2004). Several of the variables that emerge as important in shaping urban form are described in Table 1.

Table 1. A partial list of variables that determine what a particular community looks like—the urban form of rural, exurban, suburban, and urban communities (modified from Jabareen 2006).

Density	How densely people and infrastructure are spread throughout a community
Diversity	The number and relative frequency of different types of people and land uses.
Land Use	The degree to which various types of use are mixed in a community.
Compactness	The footprint of the area that the community occupies.
Transportation	The balance of types of public and private transportation and their accessibility throughout a community.
Energy	The types and impacts of energy used throughout an urban environment.
Ecology	The amount of green space and natural/biological systems in a community.

Decision support tools have been developed to model different aspects of sprawl, including individual preferences for land use type, the supply side of urban land and housing markets, and the impacts of sprawl. The California Urban Futures (REF) model is a simulation model that allows planners and decision makers to visualize and evaluate various land use scenarios at the regional, subregional, and local levels. The Smart Growth Index (www.epa.gov/livability/topics/sg_index.htm) is another model that allows the user to visualize land use plans and transportation usage outputs together with a variety of indicators such as population density, vehicle usage, and others. The Energy Commission's PLACE3S (**PLA**nning for **C**ommunity **E**nergy, **E**conomic and **E**nvironmental **S**ustainability) is a modeling tool for alternative development scenarios to help communities arrive at a Smart Growth plan. BLUEPRINTS, a non GIS decision-support tool that presents visual representations of alternative land use design outcomes, and the EPA sponsored a study titled Projecting the Impact of Land Use and Transportation on Future Air Quality (PLUTO), which integrates population and vehicle activity to estimate 2050 pollutant emissions associated with business as usual and compact growth development scenarios modeled for the upper Midwestern U.S. (Stone et al 2007), are all attempts to better understand urban growth and sprawl.

Other strategies include The National Energy Center for Sustainable Communities support of the building of models of sustainable urban design. These are communities that consume energy, water and material resources in the most sustainable manner possible while maximizing productivity, security and prosperity, and while minimizing the release of greenhouse gases, solid waste and regulated pollutants to the local and global environment. These communities are anticipated to be healthier and more productive by integrating cleaner energy systems and energy-smart planning and design into new development and redevelopment projects. One such community, supported by PIER research through the National Energy Center for Sustainable Communities, is Chula Vista, CA. LEED Neighborhood Development is another system that integrates the principles of smart growth, new urbanism and green building into a system for neighborhood design to reduce urban sprawl and create more livable communities. There is need for more tools that address the retrofitting of neighborhoods as well as the new development standards.

These methods to improve the sustainability of communities are reminiscent of a number of other design-based approaches, including an EPA-supported design charrette in the early 1980s to reconfigure land use types for greater sustainability. Three sites were chosen: a greenfield, a suburb, and a older city neighborhood. Designers spent a week re-designing them to reduce energy use and increase livability (Van der Ryn (1986). Calthorpe and Fulton revived this approach in *The Regional City* (2001), redesigning urban regions across the country for greater sustainability. Councils of Government, including the Southern California Association of Governments, the San Diego Association of Governments, and the Sacramento Area Council of Governments, have also conducted visioning processes to attempt to engage local residents in understanding the impacts of future growth on land use, and transportation and engaging participants in imagining how to densify the existing urban region to accommodate growth. These agencies have collected a great amount of data on future growth and what that growth will require in transportation infrastructure.

Another recent idea is "land readjustment." (Ewing 2008) Land readjustment addresses how land itself is organized and involves property owners pooling their land and handing control over to a third party—usually a local government, developer or trust—created for the purpose. The third party then re-plots and, in some cases, rezones the property in a way that enhances its value and makes development easier by consolidating the disparate parcels into contiguous tracts (Ewing 2008). This concept could be used in a prospective study of what specific land use changes would reduce energy use in urban environments.

All of the above studies, methodologies, and strategies for redesigning the shape and footprint of human settlements acknowledge that there is a huge energetic cost associated with urban environments and that the specific form these urban areas take vary widely with respect to their energetic requirements and environmental impacts. However, the ways in which urban typologies use energy and produce waste, as well as the relationship to social equity, are complex and the subject of ongoing study. Understanding how specific forms impact energy requirements and sustainability includes reference to the many areas of energy smart research that PIER undertakes. But because classifying individual communities into urban typologies loses the specificity associated with those communities, it is not an ideal framework for sustainable communities research. Each sustainable community will differ from all others in important ways that depend on unique environmental, economic, and sociopolitical factors—approaching these communities as types of urban form can inform sustainability goals greatly but does not effectively produce adaptive strategies for achieving greater energy savings and lower environmental impacts.

The literature on urban form and its relationship to sustainability—beginning with the analyses of the costs of sprawl and evolving to newer concepts like smart growth, green urbanism, and urban sustainability—is huge and we cannot do it justice in this discussion. Nevertheless, for the PIER Program, there is a great deal that has already been done, and can be drawn on, though there is perhaps insufficient empirical study of cities in California and energy use. For PIER, it would be useful to understand interactions among transportation mode choice, vehicle use, and energy consumption change with respect to density, location, social impacts, and land use configuration in specific places across the state. In addition, analysis about water use and electrical consumption would be important as well, correlated to specific urban forms:

residential, multiple family residential, commercial and industrial. Such an approach should be encompassed in the chosen metabolism studies.

2.4. Ecosystem Services

The threat of global warming has brought great attention to the ways in which humans' energy uses produce environmental impacts that can have substantial costs for human society. Typically, these costs are born by society at large, as a feature of the global commons. However, as the economic, health, and environmental costs become larger, external costs—externalities in the language of environmental economics—must be accounted for as a part of the real price of the activity that produces them and internalized (Fisher et al. 2008). Accounting for the economic benefits and costs of products and services provided by the environment produces a more accurate picture of the environmental footprint of human communities. To become sustainable, a community must account for the ecosystem services upon which it relies or risk producing externalities that preclude long-term sustainable communities.

In general, ecosystem services are things or characteristics of the natural world. The ecosystem processes and functions creating these services are the chemical, physical and biological interactions among ecosystem components. What may be a service in one case is a function or

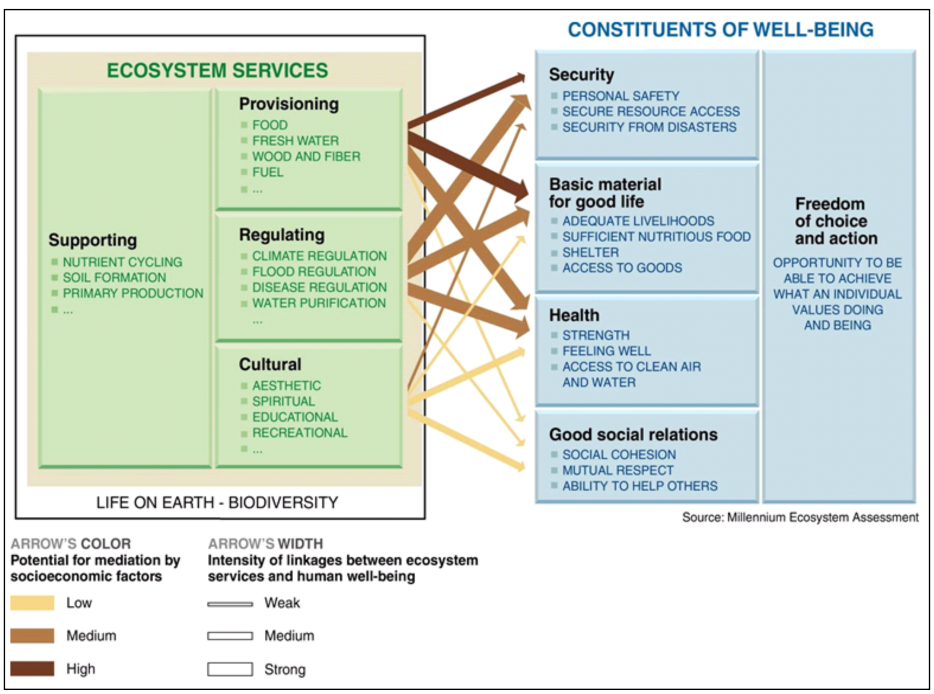

Figure 3. This conceptual model illustrates the relationship between different types of ecosystem services (left) and their contributions to human well-being (right). Modified from the Millennium Ecosystem Assessment (UN 2005).

process in another, where the process is an intermediate input to the final service. For proper accounting, services are identified in relationship to particular goals, problems, regions or decisions that are of concern.

The Millennium Ecosystem Assessment (UN 2005) included four key services upon which human health and well being depend: provisioning, regulating, cultural, and supporting. Examples of these types of services, as well as the ways in which individual services support human communities, are described in Figure 3.

Natural ecosystems and associated plants and animals provide humans with services that are often not substitutable. One of the greatest challenges in recognizing the value of ecosystem services is finding ways to identify, quantify, or consider them in ways applicable to human needs. The National Research Council (2004) defined the ecological production function as the translation of ecosystem structure and function into goods and services via the efforts of natural and human capital, labor, and other resources. While much work remains to be done to effectively value ecosystem services, there are some well-developed economic methods to characterize societal values, and decision support methods are available that do not rely on monetization.

Understanding the value of ecosystem services and anthropogenic effects on those services, including the impact of urbanization on environments, motivated the National Science Foundation to start a research program entitled Long Term Ecological Research (LTER). Two cities have been studied and monitored for over a decade: Phoenix AZ, and Baltimore MD. These programs have attempted to link studies of ecosystems in the cities and their hinterlands with social analysis, though this linkage has proven complex and slow in developing. Such an approach recognizes that fuel, nutrient and other material cycles through human communities, and their processing by people is intimately linked to the evolution of the city. Thus cities ought to be investigated as components of the Earth system. Both urban LTER sites are generating data about biodiversity impacts, water impacts, and linkages to urban type—single family residential, multiple family—and form—dense or spread out. For example, the Phoenix LTER is investigating the urban heat island and residential water use (Guhathakurta and Gober 2007), as well as biodiversity in the city (Stiles and Scheiner 2008).

The Baltimore LTER aims to articulate the different sub-systems that constitute a human ecosystem and link them though a series of direct mechanisms and feedback loops. Pickett et al (2001) also characterize the human social system in terms of social institutions, social cycles and social order. The link between the human system and the biophysical resources is mediated by the resource system, which in turn includes both cultural and socioeconomic mechanisms. The method in Baltimore is to apply a patch dynamic approach to represent the spatially explicit structure of ecological systems, but because urban areas are coupled human-biophysical systems, they propose a hybrid patch dynamic approach to integrate biological, physical, and social patches (Alberti 2008).

The Phoenix LTER proposes a more integrated approach (Grimm et al 2000). The approach is to articulate the mechanisms that link biophysical and socioeconomic drivers to ecosystem dynamics through both human activities and ecosystem processes and patterns. They build on a systems ecology perspective to study the relationships between patterns of human activities and the patterns and processes of ecosystems driven by flows of energy and information and the cycling of matter. These relationships are mediated by social institutions, culture, behavior and their interactions (Alberti 2008:11).

Alberti (2008) proposes a conceptual framework that does not distinguish between human and ecological patterns and human and ecological processes. Rather, her approach recognizes that patterns in urban landscapes are created by micro-scale interactions between human and ecological processes, and that urban ecosystem functions are affected and maintained simultaneously by human and ecological patterns.

All three approaches conceptualize urban ecosystems as interactive, complex, and dynamic—with myriad feedback loops. The goal of the studies is to characterize how ecological systems are affected by urbanization, and aim to assess how changes in ecosystem functions may in turn affect human organizations. Researchers are motivated, in part, because they hypothesize that alternative urban patterns have distinct implications for ecosystem dynamics. The dynamics of land development and resource use and their ecological impacts depend on the spatial patterns of human activities and their interactions with biophysical processes at various scales—humans generate spatial heterogeneity as they transform land, extract resources, introduce exotic species—and this spatial heterogeneity, both natural and human-induced, in turn affects resource fluxes and ecological processes in urbanized and urbanizing ecosystems (Alberti 2008).

However, urban ecosystem research is not focused on understanding what makes cities or communities sustainable *per se*. It does not, generally, examine the sources of inputs that sustain concentrated urban life, the kinds of rules—including subsidies—that drive different urban forms in different places, the ways in which urban form may or may not affect energetics of urban systems. Urban ecosystem research is yielding a great deal of information about specific ecological impacts of urbanization in specific places. It also provides a potential model for the process of interdisciplinary research for PIER, as LTER scientists have been evolving integrated concepts capable of satisfying natural and social scientists and supporting integrated research (Pickett et al 1997, Kinzig, 2001, Liu et al 2007, Musacchio and Lu, in review). Thus some of the methodological work done on integration of different disciplines in research teams and epistemological differences and how they can be transcended, would be of great utility to advancing interdisciplinary research in the PIER Program.

2.5. Life Cycle Energy Assessment

Life Cycle Assessment describes the total energy and materials requirements in addition to the environmental impacts of a particular commodity, evaluating the cost from the extraction of the commodity through every process to disposal. It is a systematic, quantitative approach to evaluating the impacts of a product or a process from 'cradle' to 'grave" (Stokes and Horvath 2006:336). For example, the production of hydrogen for use in fuel cell vehicles reduces greenhouse gas emissions at the tailpipe. A life cycle energy assessment would identify the cost in both energy and emissions in the production and distribution of hydrogen fuel. Thus the total energy balance and greenhouse gas emissions depend precisely on how that fuel is produced, distributed, used, and disposed. Since most methods for producing vehicle-use hydrogen utilize fossil fuels, the production of hydrogen fuel using solar energy can result in significant cost savings and emissions reductions (Felder and Meier 2008).

Life cycle assessments provide important detailed information on the waste generated by different activities in every stage of the process from production through end use (Rebitzer et al. 2004). For instance, retrofitting buildings with energy-efficient compact florescent lighting produces an increase in mercury entering a municipality's waste stream (Techato et a. 2009).

Accounting for these different pollutants and related environmental impacts is critical to producing sustainable communities that are energy smart with respect to total environmental impact.

While performing life cycle assessments on sectors of energy and commodities consumption is essential to achieving a comprehensive understanding of a community's energy use, this approach does not by itself provide a unifying framework for sustainable communities research. Rather, LCA should be used to develop the data in a consistent manner so as to produce current and future energy baselines for individual communities. They generally consist of four steps: goal and scope definition, inventory analysis, impact analysis, and improvement analysis (Stokes and Horvath, op cit). Summing the LCA-determined quantity of energy/materials and the environmental impacts of specific processes conducted with consistent metrics, will enable an assessment of the feedbacks and efficiencies of different sectoral energy uses. LCAs can provide a baseline profile of much of the energy demand, thus enabling the establishment of the capacity for smart energy use in a community. LCAs are important components of, and building blocks in, the construction of city and community metabolism characterizations. One example of the process by which LCA can proceed is shown in Figure 4, from Stokes and Horvath (2006).

2.6. Consideration of Possible Frameworks

Each of the possible frameworks above has components that are relevant to a cohesive research framework for sustainable communities. Given the needs of the Energy Commission and PIER, it is critical that any framework emphasize the use and impacts of energy itself—particularly electricity and gas, transportation, and water. But it is also clear that the all other relationships of energy to a particular community and to the environment that supplies and is impacted by that energy must be considered in order to engender sustainability. To form a successful framework for sustainable communities research, the role of energy in a community must be considered from its source to all of its environmental and socioeconomic impacts. This breadth of considerations demands a tremendous amount of integration among disparate scientific and technical disciplines, as well as policy, business, economics, and sociological concerns.

Several key elements to a sustainable communities research framework emerge from the above discussions (Table 2). First, it is clear that defining the boundaries of a community, and thus the boundaries of energy production, use, and waste is central to performing research at the

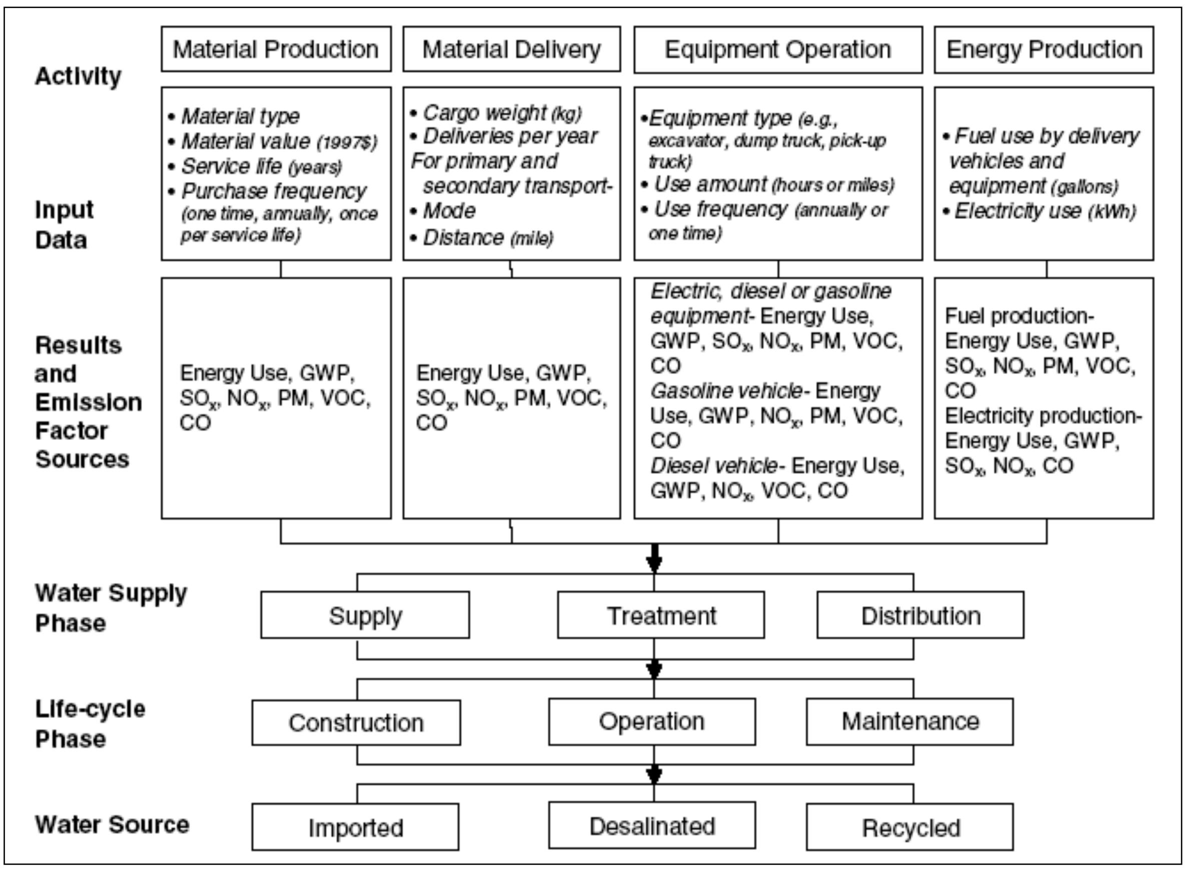

Figure 4. An example of how a life cycle assessment can progress, as applied to water resources. This figure is from Stokes and Horvath (2006).

appropriate scope and scale to capture sufficient sustainability concerns. Defining the boundaries also requires defining the pertinent service jurisdictions such as water districts, utility and sanitation districts, transportation districts, political boundaries, planning overlays, etc. The more proximate a community system is to being closed, the easier it will be to identify strategies that can achieve sustainability. Secondly, all of the energetic inputs and outputs to that system must be accounted for, including all materials and wastes that have an embedded energy cost.

Table 2. Critical Elements of a Sustainable Communities Research Framework

Identification of the system's boundaries
Accounts for inputs and outputs to the system
Hierarchical composition
Decomposable elements for targeted, sectoral research
Analyzes policy and technology outcomes with respect to sustainability goals
An adaptive approach to solutions and their consequences
Integrates social science and biophysical science/technology

Third, the hierarchical relationships between elements of a community in which energy and materials are flowing must be defined. This hierarchical composition allows relevant bounding of topical research topics—such as transit, land use, household energy, etc.—so that energy smart strategies can be effectively compared for their costs and benefits. Fourth, the framework's hierarchical elements should be decomposable such that targeted, deep research can be performed—the type of research that PIER has long experience in conducting at a high level.

In order to have research that addresses the need to produce more sustainable communities, it is imperative that the technical research be analyzed with conscious understanding and reference to the policy drivers that structure the current situation and to outcomes that will be necessary to engender the sustainability goals. Sixth, these solutions must be adaptive, so the research under a sustainable communities framework allows new solutions and strategies to supplement or replace existing ones as new knowledge and capacity is gained. Consequently, in order to see the research supported by PIER actually result in the goals set forth by the Energy Commission and identified in recent IEPRs, the framework must integrate social science research with scientific and technical research.

The PIER framework is particularly reliant on defining and understanding communities as a system. As a result, this framework should produce research that borrows heavily from a system dynamics approach. System dynamics is a methodology that takes account of the interacting processes in a complex system to analyze the mechanisms by which elements of the system work in relation to the inherent feedback loops within the system. It can be used to model the dynamic processes by which energy flows through a system and research can be structured to analyze and predict the future states of a dynamic system under various scenarios for resource availability and policy responses (Stacey 1995). One example of how this analysis can assist the study of urban environments comes from Shenzhen China, where Güneralp and Seto (2008) analyzed three scenarios for urban grown and the impacts on land use, air quality, water usage, and energy demand. The U.S. Department of Energy has recommended system dynamics as an approach to understanding energy systems behaviors in policy-planning activities (USDOE 1997).

2.7. Recommended Framework

To include all of the framework requirements outlined above, the research team recommends the PIER Program organize its research under the framework of urban metabolism. This rubric includes all of the critical elements of a sustainable communities research agenda. Crucially, urban metabolism explicitly references the role of energy in an urban environment as metabolism considers energetics as the organizing principle for understanding how a system operates. An urban metabolism framework enables the understanding of the energy flows used by urban areas, and the waste stream generated by those areas. Coupled with site-specific data that characterize that urban area's land use patterns and density, an urban metabolism analysis allows a *comprehensive accounting* for the inputs and outputs of different places within a *comparative framework*. It is likely that some cities and communities score more highly on efficiency metrics than others, this framework will allow the Energy Commission to understand what factors account for those differences in a finely grained manner as it will also include the social policy drivers.

In order to form an effective unifying framework, the research undertaken must include the jurisdictional and regulatory rules and principles that guide human decision-making. The research team suggests a coupled framework that includes the regulatory and institutional frameworks that are specific to each community in addition to the climatic, economic, cultural, geographic, and ecological details that influence the sustainability strategies of a particular community. The urban metabolisms of places are an artifact of the regulatory frameworks that determine the parameters within which these systems are developed. For example, zoning rules will affect the urban metabolism of the built environment—multiple family, single family, commercial, industrial. Each of these land uses have different metabolisms as a result of the rules about lot size, intensity of development and the specific ways in which inhabitants use their surrounding environment.

An urban metabolism method is an accounting instrument that can describe the energetics of a system. With this systems (input/output) understanding, additional assessment methodologies and approaches can be interwoven in the understanding of how cities and communities in California are currently performing, and, most importantly, why. So, for example, if a specific community or city is determine to have very high water consumption, an institutional framework analysis that shows that water is not metered will identify the determining factors in producing metabolic rates. Cities with strong construction material recycling regulations may be found to generate less waste, communities that require insulation for new homes may be found to have lower home energy use. Thus it is critical that any urban metabolism analysis be strongly coupled with institutional and policy analysis that can identify both the causes and solutions of energy use and environmental impact.

Metabolism studies themselves should include three different interconnected components (Hendricks et al 2000:315). These form the core activities of a sustainable communities research framework (Table 3).

Table 3. Research using an Urban Metabolism Framework.

1	Define the boundaries of a community.
2	Define the metabolic commodities and processes of the community.
3	Quantify the anthropogenic metabolism of a community.
4	Assess the metabolic relationships between human activities and the natural environment in a community.
5	Measure the metabolic relationships between the community and hinterlands outside its boundaries.
6	Identify strategies for improving the metabolic efficiency and wastes of the community.
7	Collaboratively develop policy solutions that address identified strategies.

Defining the anthropogenic metabolism (the energy and materials that flow through the environment in which human activities take place, or anthroposphere; Brunner and Rechberger 2002). This will identify the key anthropogenic material flows and stocks within the specific city or community. The results of this investigation will be essential to the design of efficient material management strategies within the anthroposphere.

Linking the anthropogenic and natural metabolisms. This is aimed at understanding the interaction between the anthroposphere and the environment, in particular to assess the current anthropogenic materials flowing into the environment, and to investigate the effect on the environment of decisions made with the anthroposphere. This will also include the local capacity of the natural metabolism to provide resources to the anthroposphere, and as a sink for waste (i.e. ecosystem services). The results of this analysis could also contribute to developing strategies that would reduce materials use (through efficiencies or reductions in consumption) and greater reliance on locally, renewably produced materials and local sinks. This part of the research can draw on some of the ecosystem services studies that have been conducted, and/or new studies can be informed by the methodological approaches that have been developed in the different urban LTER sites and the work that has been done for Seattle (see LTER discussion above).

Linking the metabolism of the city or community with the hinterland. This analysis will assess the dependence of the city or community on its hinterland, or far flung hinterlands to supply and dispose of materials. Examples of metabolic commodities include water, nitrogen, fossil fuels, liquefied natural gas, natural gas, food products, wastewater, solid waste, or timber.

In order to effectively define the commodities involved in a community's metabolism, as well as in order to effectively measure the metabolic inputs and outputs, sectoral metabolism studies using life cycle analysis methods should also be conducted. This will provide the informational elements necessary to understanding the larger urban metabolism. These studies are the deep research that is, in large part, already sponsored by PIER. Sectoral analyses are the critical pieces that support the urban metabolism study.

One good example of sectoral metabolism analyses comes from Taipei, Taiwan. Huan and Hsu (2003) conducted a materials flow analysis and *emergy*[1] evaluation of Taipei's urban construction. They included measures of the intensity of resource consumption, inflow/output ratios, urban livability, efficiency of urban metabolism, and *emergy* evaluation of the urban metabolism. Table 4 describes this study and the sectors that were evaluated in detail.

Table 4. Urban metabolism indicators of Taipei's urban construction (modified from Huan and Hsu 2003)

Intensity of resource consumption	
	Density of construction material use
	Per capita construction material use
	Per capita construction waste generated
Inflow/outflow ratio	
	Ratio of construction material use to urban productivity
	Ratio of construction waste to urban productivity
	Ratio of increase rate of construction material use to increase rate of construction waste
Urban livability	
	Road density
	Per capita road area
	Service ratio of sewage treatment
	Ratio of material flows to soil loss
	Ratio of material flows to net soil loss
	Ratio of increase of sediment yield to increase of material flows
	Ratio of increase of air pollutant to increase of material flows
Efficiency of urban metabolism	
	Ratio of increase of construction material use to increase of urban construction
	Ratio of increase of construction waste to increase of urban construction
Emergy evaluation of urban metabolism	
	Ratio of construction material used to total emergy use
	Ratio of construction material import to total emergy import
	Ratio of construction waste emergy to total waste emergy
	Ratio of construction waste emergy to total emergy use
	Ratio of construction waste emergy to renewable emergy

Sectoral analyses will have to be established by identifying data gaps by the collaborating PIER research programs. The important thing will be to ensure each of these sectoral analyses is undertaken using compatible metrics. This very process will identify synergetic issues and connections among the research programs. For example, building energy use analysis will elucidate water consumption, solid waste, stormwater and sewage flows, as well as materials impacts on resources and the transportation infrastructure. Added to this technical analysis should be the institutional regulatory structure: building codes, zoning and land use, waste

[1] *Emergy* is a term that was coined to allow a single metric for diverse types of energy products, it is defined as all the available energy that was used in the work of making a product and expressed in units of one type of energy (Odum 1996).

management regulations and processes, transportation infrastructure and parking regulations, levels of government, as well as socio-economic variables.

The research team recommends starting with the following metabolism research areas in representative California cities or communities, which can then be supplemented with specific sectoral life cycle or ecosystem service analyses:

- Establish indicators of the volumes of source materials source, and the waste stream for a representative sample of California cities and communities.
- Characterization of inflows and outflows.
- Determine top characteristic inflows such as fossil fuels, electricity, food, building materials, manufacturing supplies, consumer goods and metrics for these inflows.
- Determine characteristic outflows such as solid waste, air emissions, water pollution.
- Inflow/outflow ratio (and the degradation of energy in its use) and efficiency metrics for the different media.
- Degree of intensity and efficiency of resource consumption relative to urban form e.g. multiple family, single family, densities.
- Amount of locally available (autochthonous) renewable resources.
- Solar available in urbanized area relative to energy use and local capture capacity (e.g. surface area of appropriate roofs through satellite imagery).
- Water (including wastewater and stormwater), (e.g. rainfall, capacity for rainfall capture—impact of impervious surfaces—stormwater capture capacity at household, building scale, ground water capacity, capacity to reinject wastewater for reuse).
- Food (e.g. amount of productive agricultural land within a 100 km food-shed radius, type of agriculture practiced and supply chains).
- Other energy and materials (biomass, methane, recyclables (analysis of waste stream to waste disposal facilities, amount of biogas emitted from landfills, etc.).
- Correlative institutions and their rules that affect land use and resource use.
- City/County/State
    - Water Agencies at different scales (including publicly owned utilities, private water companies, joint power authorities, regional water quality control boards, Department of Water Resources)
    - Supply (including irrigation and ground water management)
    - Sanitation agencies
    - Flood control agencies
    - Regional Air Districts
    - Transportation agencies and districts
    - Planning departments
    - Metropolitan planning agencies

As an example of how an urban metabolism approach would work for a specific question, consider geographic research on energy dynamics of an urban system. The goal of such research might then be a matrix of GIS layers that brings together:

- The political boundaries of different agencies (transport agencies, water districts, utilities).
- The amount of energy used by each agency and aggregation at level of community/urban agglomeration.
- Geographic distribution of renewable resources and capacities.
- Existing energy infrastructure.
- Environmental resources and processes.
- Vectors of material and energy movement.
- Social capital indices such as transfer payments, tax revenues, investments and outflows of money, educational levels and employment.

By analyzing this data in a holistic context, PIER would then have an estimate of the geographic distribution of energy and its consequences in a given community. If the Energy Commission becomes repository for the data, along with a requirement for reporting the data, then decision-makers and regional planning efforts will possess a rich suite of information that will enable more sustainable and energy-smart communities to emerge.

3.0 Specific Topics in Sustainable Communities Research

As PIER has recognized, to achieve more sustainable communities requires interdisciplinary research—research that intentionally covers multiple program areas. But it is also important for PIER to focus on specific strategic technical research while remaining cognizant of the inherent overlap in research outcomes and the unifying framework that leads to sustainable communities.

In this section, the research team offers several recommendations for specific research topics that will provide components of urban metabolism research programs for cities across the state. Technical research questions already form the bulk of PIER's research topics. The team identifies the ways in which this technical research can be applied in a transdisciplinary manner (transdisciplinary research takes into account synergies and co-benefits associated with related disciplines or subject areas (Ramadier 2004). The team also offers recommendations for methodological research questions that structure the research framework. How research questions are set up—the methodological strategies for eliciting information—will enable PIER to structure program-wide research for integrated sustainability research

As noted in Section 2.5, the participants in the November 22nd, 2008 workshop identified several supporting research themes that were critical to producing more sustainable communities and that should be included in the PIER research program for sustainability. A number of these specific questions are subsumed in the team's proposal for an urban metabolism research program, of which LCA is a subset. However, workshop participants also stressed the importance of social-psychological-equity research and its integration into any and all research on urban areas. A description of the suggestions of workshop participants is located in the appendix. These suggestions were used to guide the recommendations made by the research team.

3.1. Recommended Sectoral Research Questions

Many of the technical research questions that need to be addressed in order to better understand the urban metabolism of a community are already being studied through PIER's program areas. It is important to keep in mind the need to integrate the following research topics into urban metabolisms and policy frameworks that will effect greater urban sustainability. The research team proposes the PIER Program consider the following specific research topics for focused proposals and methods building. Several of these are already being supported by PIER and should remain a priority, in particular research into water quality and energy intensity, transportation design, electricity generation and distribution, energy conservation, alternative fuels, etc. As noted above, these topics of deep research are critical elements to understanding a complex integrated community system. Here, the team identifies particular types of research that promote integration of types of knowledge to understand how sustainable communities can be fostered. There are several overlaps with some of the specific research projects suggested by our workshop participants

As described above, PIER must better incorporate social science research into its program areas for sustainable communities research. Without the ability to understand, communicate, and deploy new technologies and programmatic approaches in actual communities, the efforts PIER is making to reduce and improve the impacts of California's energy use will be substantially less effective. These recommended research questions are among those that should be included in the PIER Program to help California identify and effectively implement more energy-smart community efforts.

In Table 5 the research team presents some recommendations for targeted sectoral research. Included are two metrics, primacy and relevance, that can assist in setting priorities for funded research. These suggestions are meant to serve as a guide for future research and are neither comprehensive nor prescriptive. Further consideration of PIER research needs and Energy Commission goals is warranted before embarking on any of these research topics under an urban metabolism framework.

Table 5. Important areas for research that will support and advance the *Energy in Sustainable Communities* goals and outcomes. Some research questions need to be answered before others (high primacy) and some will provide more direct impact on energy sustainability metrics (high relevance). We present these to guide of different research questions under an urban metabolism framework. *Type of Research* refers to the category of research that each question falls under, for purposes of organizing the research priorities. *Primacy* refers to the questions that should be asked first as they are often precursors to other research (1-3, 1 is highest priority). *Relevance* refers to the relative influence that this research will wield over changes in state energy patterns (1-3, 1 is highest relevance).

Type of Research	Research Questions	Notes	Primacy	Relevance
		TECHNICAL RESEARCH QUESTIONS		
		Energetics Research		
Energy	Capacity for local energy production.	Analyzed for different communities around the state.	1	1
Energy	Capacity for local energy storage.	Analyzed for different communities around the state.	2	1
Resources & Materials	Regional water resource capacity.	Analyzed for different communities around the state and including the capacity for conservation and reuse.	1	1
Land-use	Existing land-use pattern for specific localities.	This should include percentages built, densities, transit, production, and green space.	1	2
Energy	Simulation forecasting of energy and resource consumption.	This should be done under varying scenarios of population growth—specifically, where in California additional populations will live and utilizing different energy and resource consumption scenarios. For example, under different RPS standards or under increasing water use restrictions.	1	1
Land-use	Identify the primary urban typologies within California.	This will provide the framework for understanding community energy use relative to built form in the state, as well as a reference point from which to identify external and internal factors that drive energy efficiencies in different urban forms.	1	1
Energy	System dynamics modeling of complex urban systems.	Specifically, identify the variables at work in an urban system and the relationships and feedbacks between them.	3	2
Land-use	Adaptive re-use of the built environment.	Research into residential adaptive re-use and commercial adaptive re-use would help define new ways in which energy intensive new infrastructure can be avoided (Gorgolewski 2008).	2	1

Type of Research	Research Questions	Notes	Primacy	Relevance
Policy & Decisions	Assessment of existing political jurisdictions.	Political jurisdictions are relevant with respect to their efficacy in implementing energy-smart policies and programs	2	3
Energy	Baseline assessment of urban metabolic values.	Fund assessments of the existing energy use, carbon emissions, water use, wastewater treatment, solid waste, transportation use, and commodities trade in a given community to establish baselines from which can be determined where cost-savings and lowered impacts can be achieved most effectively. This should be coupled with urban typologies.	2	1
Planning Research				
Land-use	Identification of the appropriate scale for land-use planning decisions.	This can be done with reference to a particular policy, community goal or regulatory targets, such as those under AB 32 or SB 375, or with reference to city/county general plans and related strategic planning documents or statewide objectives, such as water use reductions, agricultural land preservations, managing ground water, the Bay Delta restoration, or regional air quality regulations. In some cases the scale will be at the state level for regulations that impact across jurisdictions, or have inter-jurisdictional spillovers, or that can't be accomplished by existing local jurisdictions.	1	3
Social, Cultural and Equity Research				
Socio-economic	Factors affecting the adoption of energy-smart strategies or technologies.	This refers to understanding of the institutions, values,and related factors that shape the adoption of energy-smart strategies and technologies by communities and community members. This includes the identification of structural, political, and cultural obstacles or facilitative factors. The institutions will range from large-scale government to private associations and practices.	1	1

Type of Research	Research Questions	Notes	Primacy	Relevance
Socio-economic	Aesthetics of sustainable communities.	Research into the aesthetic qualities of sustainable communities and how these qualities influence individuals and institutions to maintain this balance.	2	2
Socio-economic	Socio-economic impediments to sustainability.	Understanding the socio-economic factors that impede or facilitate adoption of sustainable strategies by different communities and the strategies that can help reduce these barriers equitably. This will include tax revenues to municipalities and counties, transfer payments into and out of communities (such as tax contributions from localities to the state and federal government and back), incentive payments to businesses and governmental agencies (such as stimulus funds), levels of education, and employment possibilities.	2	2
		Regulatory and Institutional Research		
Policy & Decisions	Assessment of the institutional barriers to sustainable communities.	Understanding the financial, fiscal, and regulatory, structures that contribute to current patterns of urbanization and their roles in impeding or encouraging the implementation of sustainable policies for individual communities and regions, with an emphasis on needed changes to advance planning and policy goals.	1	1
Policy & Decisions	Assessment of regulatory policy on land-use and energy.	Specifically, this will involve the clarification of how legislation, including AB 32 and SB 375, affects existing requirements for land-use and transportation planning and how these relate to energy. Assessment of the current configuration of land use regulations from the local to the state, that structure energy intensive building and urban development.	1	2
Policy & Decisions	Impact of state and federal policy on local sustainability goals.	Clarification of how existing regulations, specifically taxation and revenue streams and policy, (including water development and management, highways and road incentives and regulations) limit or encourage local and state sustainability goals. Many of these will be indirect, and related to the underlying fiscal and infrastructure aspects of development.	1	2

Type of Research	Research Questions	Notes	Primacy	Relevance
Energy	Identifying transformative tools.	Transformative tools and strategies at the super-regional scale may produce massive improvements in energy and sustainability. This might include statewide transportation, electricity, conservation, and water projects that promote energy-smart and sustainable policies in constituent regions around the state.	3	1
		Ecosystem and Natural Resources Research		
Resources & Materials	Geographical distribution of ecosystem services.	Specifically, ecosystem services that support the urban metabolism of given communities	2	2
		Evaluation Research		
Policy & Decisions	Post-hoc analysis of energy-usage policies.	Existing energy use policies and regulations have unknown effects on intended outcomes, these should be analyzed in a sustainable communities context.	2	1
		SOCIAL SCIENCE RESEARCH QUESTIONS		
		Structural Issues		
Methods & Metrics	Identification of the appropriate jurisdictional scale(s).	The jurisdictional scale (political and other boundaries) at which the energy or metabolic balance should be analyzed is critical for informing the methodology for determining community system boundaries. This should be linked to relevant regulations and services such as water and power, and also reflect the major jurisdictional entities that either manage or use substantial amounts of energy, such as school districts and sanitation districts.	1	1
Methods & Metrics	Decision-support research.	This should aim to produce legally and scientifically defensible metrics for sustainability components such as resources, economy, quality of life, and environmental impacts/benefits.	1	1
		Processes		
Policy & Decisions	Methods for science-policy translation.	Develop methods and mechanisms for translating scientific research into policy and decision-making contexts.	3	2

Type of Research	Research Questions	Notes	Primacy	Relevance
Policy & Decisions	Mechanisms for information dissemination.	Design an information clearinghouse to allow communities to tap into best practices and energy-smart programs/products to advance their particular sustainability goals.	3	1
		Methods		
Methods & Metrics	Methodology for cumulative impacts of energy-smart strategies.	Development of a standardized method to identify and quantify the indirect effects and cumulative impacts (socio-cultural, economic, environmental) of particular strategies aimed at reducing energy use.	2	1
Policy & Decisions	Indicators for effective decision-making processes.	The process by which decisions are made is crucial to meeting societal or political goals; developing indicators of which processes are most effective will allow adoption of energy-smart strategies in diverse communities. Develop processes to elicit best practices for adoption of energy-smart strategies in diverse communities.	3	2
Methods & Metrics	Indicators of effective models of sustainable communities.	Indicators can allow exemplar sustainable communities and energy-smart policies to be easily identified by decision-makers and the public.	3	2
Methods & Metrics	Integration of uncertainty into life-cycle assessment.	Development of methods for integrating risk and uncertainty into life-cycle energy accounting, particularly in light of rapid environmental change.	2	1
Methods & Metrics	Metrics for energy content.	The energy embedded in various activities should be measured in a standard manner (specific to each process/product) that permits assessment within an urban metabolism model.	1	1
Methods & Metrics	Metrics for energy embedded in materials.	The materials required by various activities, and the energy embedded in that mass of materials, should be measured in a standard manner (specific to each process/product) that permits assessment within an urban metabolism model.	1	1

Type of Research	Research Questions	Notes	Primacy	Relevance
Methods & Metrics	Metrics for land used.	The land-area required by various activities should be measured in a standard manner (specific to each process/product) that permits assessment within an urban metabolism model.	1	1
Methods & Metrics	Metrics of energy, materials, and land required for waste.	The waste generated by communities comes in the form of energy, waste materials/resources, and land required for disposal; this should be measured in a standard manner that permits assessment within an urban metabolism model.	1	1
Methods & Metrics	Methodology for determining community boundaries.	A method to determine the boundaries of different community systems will permit identification of different urban forms, allow urban metabolism studies to progress, and inform the decision-making process within jurisdictional boundaries.	2	1

4.0 Conclusions and Recommendations

Sustainability is a response to the growing understanding that, as Vitousek et al (1997) and others have demonstrated, the functioning of the Earth's ecosystem cannot be understood without accounting for the strong, often dominant influence of humanity. Since over 50% of humanity now lives in cities, and in California the percentage is close to 99%, reducing urban environmental impacts could make a significant different in ecosystem health by reducing human impacts.

It is the state's existing patterns of urban and suburban development that have resulted in increased air pollution, increased dependence on automobiles and rising fuel prices, the need for costly improvements to roads and public services, the loss of valuable farm land and native habitats, and significant increases in greenhouse gas emissions. We know that other urban forms, like some of the dense European cities, require fewer inputs and produce less waste. Sustainable communities, in the California context, is the response that is intended to address these issues as well as provide other community benefits such affordable housing, increased energy and water efficiency, increased renewable energy use, and reduced waste materials. Changing land use planning and community design is integral to creating sustainable communities. Sustainable communities RD&D funded by the PIER Program seeks to understand and optimize the energy-related aspects of land use planning and community design based on an appropriate definition of sustainability for California's current needs.

We have suggested a definition of sustainable communities that makes sense in the context of the California environment and energy systems and that recognizes that urban areas are the result of a set of complex forces, including historical patterns. Douglass North (1990), an economist and historian, states simply: "History matters. It matters not just because we can learn from the past, but because the present and the future are connected to the past by the continuity of a society's institutions" (vii). Institutions are created by humans to guide our activities. The ways in which we use our land, including how we build our cities and communities, is a function of our institutions. Rules guide how land can be developed, and its price. Rules guide how we build what we build, and where we build it. Today we are facing some of the results of the institutional rules determining prices for natural resources—including land itself—and the ways in which other resources are moved around the world and within the state—including possible resource shortages, and high environmental impacts of profligate resource use. Understanding the energetic flows that result from these rules is just a first step. They will inform us about how much we use under what physical circumstances but such data alone will not create any change. Identifying why the condition exists can begin to outline the path for change, but the change will require changes in rules and policies, and that will not happen simply as a result of information. Hence an important component of this research program will have to be a strategy of engagement with the public and decision-makers. Not only is the research program we are proposing challenging because it is interdisciplinary—bringing together different research paradigms and epistemologies—but additionally it will require thoughtful, thorough and deliberate engagement with agents of change in our society.

4.1. Recommendations for Implementing Urban Metabolism

In order for the California Energy Commission to effectively utilize an *Urban Metabolism* framework, we recommend several Possible next steps and further research:

- Establish a common metric for assessing energy content, mass content, and land area required in various activities.
    - Possible energy-centric metrics include kWh, kJ, or MMT CO_2e
    - In addition to energy metrics, provide standard metrics for other measurable quantities in an urban metabolism, including mass (kg) of waste or input and land area (acres) used or required for production and as a waste sink.
    - Clarify how different processes and products can be calculated in terms of the energy content, mass content, and land area used
        - Food production
        - Consumer goods
        - Water resources
        - Electricity
        - Transportation
        - Air resources
        - Buildings and infrastructure
- Develop the architecture of the governmental regulatory institutions for each of these areas and their roles.
- Research the capacity for local energy production, distribution, and storage in different communities throughout the state.
- Identify the primary urban typologies (e.g. Berkeley, Irvine, San Diego, Fresno) within California and estimate the net energy and materials used in exemplars.
    - This will help to establish the role of urban form in determining energy use.
    - This will help to establish a standard methodology for obtaining estimates of energy/material inputs and outputs, without assessing the internal movements.
    - This will help to establish methods for determining the system boundaries of urban communities.
- Identify the institutional factors that are related to the different urban forms and energy use in each typology (e.g. zoning and building codes, transportation, general plans) and match them to the urban typologies.
- Establish a standard methodology for determining the boundaries of communities in California.
    - Determine how many reasonably distinct urban community systems exist in California and what their geographic extent is.
    - Research into the effectiveness of determining system boundaries is needed, including the degree of interaction between defined urban systems and rural areas as well as between the urban communities themselves.
        - How permeable and transient are these system boundaries?
        - Can we predict the changing shape of these systems in the future?
            - SB 375 is meant to impact the development of these communities.

- Identify the appropriate scale for land-use planning decisions given a particular policy or community goal.
    - This can be done with reference to particular regulatory targets, such as those under AB 32 or SB 375, or with reference to county general plans and related strategic planning documents
- Establish and promote effective community strategies that reduce and reuse energy and materials *locally*.
    - Include metrics for the energy, environmental, and cost savings associated with local strategies.
    - Identify regulatory obstacles to this strategy.
    - Identify structural factors that might need to changed to make local strategies more economically viable—for example virgin timber is still much cheaper to transform into paper than using recycled materials, or other such factors.
- Solicit community input as to what the desired community-level outcomes are:
    - Aesthetically, culturally, economically, ethical, sociological
    - Attempt to prioritize these community goals
    - Identify relationship of community goals to energy and materials production, use, and disposal (i.e. the community's urban metabolism)
- Identify and publicize the financial, fiscal, regulatory, climatic, and physical barriers to implementing sustainable policies for individual community typologies, with an emphasis on needed changes to advance planning and policy goals.
    - Maintain a clear assessment of how individual community actions have consequences for the whole. As an example, one community restricting growth can result in greater growth in another community.
    - Establish and explain the need to establish statewide policies that create a level playing field for development and energy use while at the same time, not neglecting particularities of specific communities
- Identify and publicize transformative tools at the super-regional scale, such as statewide transportation, electricity, conservation, and water projects that promote energy-smart and sustainable policies in constituent regions around the state.
- Clarify how new legislation, specifically AB 32 and SB 375, affect existing requirements for land-use and transportation planning.
- Clarify how existing regulations, specifically CEQA and federal environmental regulations, limit or abet local and state climate and sustainability targets, or whether other types of legislation are more influential.
- Assess the strengths and weaknesses of currently employed mechanisms for translating scientific research into policy and decision-making contexts.
- Design an information clearinghouse to allow communities to tap into best practices and energy-smart programs/products to advance their particular sustainability goals.

4.2. Summary

In conclusion, for PIER to successfully launch research on urban sustainability, three areas need to be addressed. These include the research itself, and we have suggested urban metabolism studies of representative cities and communities of California to establish an understanding of materials sources and sinks and their energetics, based on the creation of common baseline indicators; the process of interdisciplinary research, with energy commission staff exercising a strong integrative role to bridge the different epistemic communities; and finally, the ways in which the research is both shaped and utilized by communities and policy makers.

To successfully support sustainable communities research, PIER should also focus on an interactive research process. Very often, the challenges of implementing energy-smart strategies only become apparent in the implementation phase. By incorporating implementation into the research agenda—through post-hoc analysis, continued assessment of programs, and thorough engagement with researchers and implementing agents—PIER can more successfully understand the complex feedbacks that govern sustainable communities.

Finally, one should not overlook the importance of designing policy implications into scientific research. We recommend that PIER include an explicit emphasis on the policy implications and means by which policy can be altered or utilized into the individual research projects that are funded under this rubric of sustainability.

5.0 References

Alberti M. 2008. Advances in Urban Ecology, Integrating Humans and Ecological Processes in Urban Ecosystems. New York: Springer.

—— 1996. Measuring urban sustainability. Environmental Impact Assessment Review 16: 381-424.

Alberti M., Susskind L. 1996. Managing urban sustainability: an introduction to the special issue. Environmental Impact Assessment Review. 16: 213-221.

Baccini P. 1997. A city's metabolism: toward the sustainable development of urban systems. Journal of Urban Technology 4: 27-39.

Brunner P.H., Rechberger H. 2002. Anthropogenic metabolism and environmental legacies. *in* Causes and Consequences of Environmental Change (Vol. 3 of Encyclopedia of Global Environmental Change), ed. I. Douglas. Chichester: Wiley. Pp. 54-72.

Burchell R. 1997. The Costs of Sprawl Revisited: The Evidence of Sprawl's Negative and Positive Impacts. Transportation Research Board and National Research Council. Washington DC: National Academies Press.

CEC. 1997. Strategic Plan. California Energy Commission. 46 pages.

CEC. 2006. 2006 Integrated Energy Policy Report Update. California Energy Commission. CEC-100-2006-001-CMF.

CEC. 2007. 2007 Integrated Energy Policy Report. California Energy Commission. CEC-100-2007-008-CMF.

Cohen J.E. 2003. Human population: the next half century. Science 302: 1172-1175.

Downs A. 1995. New Visions for Metropolitan America. Washington DC: The Brookings Institution.

Ewing R. 2008. Land readjustment—learning from international research. Planning February 2008, p. 58.

Felder R., Meier A. 2008. Well-to-wheel analysis of solar hydrogen production and utilization for passenger car transportation. Journal of Solar Energy Engineering 130: 011017.

Fisher B., Turner K., Zylstra M., Brouwer R., de Groot R., Farber S., Ferraro P., Green R., Hadley D., Harlow J., Jefferiss P., Kirkby C., Morling P., Mowatt S., Naidoo R., Paavola J., Strassburg B., Yu D., Balmford A. 2008. Ecosystem services and economic theory: integration for policy-relevant research. Ecological Applications 18: 2050-2067.

Fishman R. 1987. Bourgeois Utopias, the Rise and Fall of Suburbia. New York: Basic Books.

Fulton W. 1997. The Reluctant Metropolis, the Politics of Urban Growth in Los Angeles. Point Arena CA: Solano Press Books.

Gordon I. 2008. Density and the built environment. Energy Policy 36: 4652-4656.

Gorgolewski M. 2008. Designing with reused building components: some challenges. Building Research and Information 36: 175-188.

Grimm N.B., Grove J.M., Pickett S.T.A., Redman C.L. 2000. Integrated approaches to long-term studies of urban ecological systems. BioScience 50: 571-584.

Guhathakurta S., Gober P. 2007. The impact of the Phoenix urban heat island on residential water use. Journal of the American Planning Association 73: 317-329.

Güneralp B., Seto K.C. 2008. Environmental impacts of urban growth form and integrated dynamic perspective: a case study of Shenzhen, South China. Global Environmental Change 18: 720-735.

Hamond M.J., Wolff G., Cobb C., Frame M. 1999. Greening the Golden State: a Tax Reform for California's Future. San Francisco: Redefining Progress, May.

Hendricks C., Obernosterer R., Müller D., Kytzia S., Baccini P., Burnner P.H. 2000. Material flow analysis: a tool to support environmental policy decision making. Local Environment, 5: 311-328.

Hodgson S.M., Smith J.W.N. 2007. Building a research agenda on water policy: an exploration of the Water Framework Directive as an interdisciplinary problem. Interdisciplinary Science Reviews 32: 187-202.

Huang S.L., Hsu W.L. 2003. Materials flow analysis and emergy evaluation of Taipei's urban construction. Landscape and Urban Planning 63: 61-74.

Jabareen Y.R. 2006. Sustainable urban forms: their typologies, models, and concepts. Journal of Planning Education and Research 26: 38-52.

Jackson K. 1985. Crabgrass Frontier: The Suburbanization of the United States. New York: Oxford University Press.

Johnson M.P. 2001. Environmental impacts of urban sprawl: a survey of the literature and proposed research agenda. Environment and Planning A, 33: 717-735.

Kinzig, A.P. 2001. Bridging disciplinary divides to address environmental challenges, Ecosystems 4: 709-715.

Lélé S., Norgaard R.B. 2005. Practicing interdisciplinarity. BioScience 55: 967-975.

Liu J., Dietz T., Carpenter S.R., Alberti M., Folke C., Moran E., Pell A.N., Deadman P., Kratz T., Lubchenco J., Ostrom E., Ouyang Z., Provensher W., Redman C.L., Schneider S.H., Taylor W.W. 2007. Complexity of coupled human and natural systems. Science 317: 1513-1516.

Musacchio L.R, Wu J. In Review. Developing a synchronicity in urban ecology as sustainability science: linking ecology, design and planning. Frontiers in Ecology and the Environment.

North D.C. 1990. Institutions, Institutional Change and Economic Performance. Cambridge: Cambridge University Press.

Nelson A.C. 1999. Comparing states with and without growth management: analysis based on indicators with policy implications. Land Use Policy 16: 121-127.

Newman P.W.G. 1999. Sustainability and cities: extending the metabolism model. Landscape and Urban Planning 44: 219-226.

Odum, H.T. 1971. Environment, Power and Society. New York: John Wiley.

Ostrum E. 2001. A diagnostic approach for going beyond panaceas. Proceedings of the National Academy of Sciences 104: 15181-15187.

Pickett S.T.A., Cadenasso M.L., Grove J.H.M., Nilon C.H., Pouyat R.V., Zipperer W.C., Costanza R. 2001. Urban ecological systems: linking terrestrial ecological, physical and socioeconomic components of metropolitan areas. Annual Review of Ecology and Systematics 32: 127-157.

Pickett S.T.A., Burch W.R. Jr., Dalton, S.E., Foresman, T.W., Grove J.M., Rowntree, R. 1997. A conceptual framework for the study of human ecosystems in urban areas. Urban Ecosystems 1: 185-199.

Pincetl S. 1999. Transforming California, a Political History of Land Use in the State. Baltimore: Johns Hopkins University Press.

Ramadier T. 2004. Transdisciplinarity and its challenges: the case of urban studies. Futures 36: 423-439.

Real Estate Research Corporation. 1974. The Costs of Sprawl. Washington DC: U.S. Government Printing Office.

Rebitzer G., Ekvall T., Frischknecht R., Hunkeler D., Norris G., Rydberg T., Schmidt W.P., Suh S., Weidema B.P., Pennington D.W.. 2004. Life cycle assessment part 1: framework, goal and scope definition, inventory analysis, and applications. Environment International 30: 701-720.

Redman C.L., Grove J.M., and Kuby L.H. 2004. Integrating social science into the Long-Term Ecological Research (LTER) Network: social dimensions of ecological change and ecological dimensions of social change. Ecosystems 7: 161-171.

Sahely H.R., Dudding S., Kennedy C.A. 2003. Estimating the urban metabolism of Canadian cities: Greater Toronto Area case study. Canadian Journal of Civil Engineering 30:468-483.

Schrag P. 1999. Paradise Lost: California’s Experience, America’s Future. Berkeley: University of California Press.

Smill V. 2008. Energy in Nature and Society, General Energetics of Complex Systems. Cambridge Mass: The MIT Press.

Stacey R.D. 1995. The science of complexity: an alternative perspective for strategic change and processes. Strategic Management Journal 16: 477-495.

Stiles A., Scheiner S.M. 2008. Nestedness of remnant Sonoran Desert plant communities in metropolitan Phoenix, Arizona. Ecology 89: 2473-2481.

Stokes J., Horvath A.P. 2006. Life cycle energy assessment of alternative water supply systems. International Journal of LCA 11: 335-343.

Stone B. Jr., Mednick A.C., Holloway T., Spak S.N. 2007. Is compact growth good for air quality? Journal of the American Planning Association 73: 404-418.

Techato K.A., Watts D.J., Chaiprapat S. 2009. Life cycle analysis of retrofitting with high energy efficiency air-conditioner and fluorescent lamp in existing buildings. Energy Policy 37: 318-325.

Turner G.M. 2008. A comparison of The Limits to Growth with 30 years of reality. Global Environmental Change 18: 397-411.

UN World Commission on Environment and Development. 1987. Our Common Future. Oxford: Oxford University Press.

USDA. 2007. http://www.ers.usda.gov/Statefacts/CA.htm (accessed 1.31.09).

USDOE. 1997. Introduction to System Dynamics: A Systems Approach to Understanding Complex Policy Issues. http://www.systemdynamics.org/DL-IntroSysDyn/ (accessed 1.29.09).

Van der Ryn S., Calthorpe, P. 1991. Sustainable Communities: a New Design Synthesis for Cities, Suburbs and Towns. San Francisco: Sierra Club Books.

Van der Sluijs J., van Eijndhoven J., Shackley S., and Wynne B. 1998. Anchoring devices in science for policy: the case of consensus around climate sensitivity. Social Studies of Science 28: 291-323.

Vitsousek P.M., Mooney H.A., Lubchenco J., Milillo J. 1997 Human domination of Earth's ecosystems. Science 277: 494-499.

Weart S. 2003. The Discovery of Global Warming. Cambridge: Harvard University Press.

Whyte W. 1970. The Last Landscape. New York: Doubleday Anchor.

Wolch J., Pastor M. Jr., Dreier P. 2004. Up Against the Sprawl, Public Policy and the Making of Southern California. Minneapolis: University of Minnesota Press.

Appendix

Participants in the November 22nd Workshop

Stephanie Pincetl	*Director* Urban Center for People and the Environment UCLA Institute of the Environment
Paul Bunje	*Executive Director* Center for Climate Change Solutions UCLA Institute of the Environment
Timothy Brick	*President, Board of Directors* Metropolitan Water District
Mikhail Chester	*Postdoctoral Researcher* Dept. of Civil & Environmental Engineering UC Berkeley
Bowman Cutter	*Assistant Professor* Pomona College
Michael Dieden	*Company Principle* Creative Housing Associates
Terri Hogue	*Assistant Professor* Dept. of Civil & Environmental Engineering UCLA
Mindy McIntyre	*Water Program Manager* Planning and Conservation League
Timothy Papandreou	*Transportation Planning Manager* Los Angeles County Metropolitan Transportation Agency
Diane Pataki	*Associate Professor* Ecology and Evolutionary Biology & Earth Systems Science UC Irvine
Gary Patton	*General Counsel* Planning and Conservation League
Charles Redman	*Director, Professor* School of Sustainability Arizona State University
S. Bry Sarté	*Principal, CEO* Sherwood Design Engineers
Walker Wells	*Director* Resource Efficiency and Sustainable Communities Program Global Green USA

Suggested Research Themes of the Workshop Participants

Social Research

- What are the psychological, sociological, geographical, and ethical dimensions of designing urban environments in a sustainable manner?
- This research includes understanding impacts on housing, open space, transportation access and mobility, environmental justice, equity impacts of new rules and regulations to support more sustainable land use and development.
- How can diverse economic sectors be integrated into urban planning and development?
    - Specifically, building, transportation, electricity, manufacturing, and food production/consumption.

Energetics and Flows

- How do energy and materials travel through communities?
- What is the full life-cycle cost of urban energy and materials usage?
    - Specifically, water, energy, products, waste, and pollution.
- What is the appropriate scale(s) for assessing sustainability in an urban environment? How do energy and materials interact at these different scales in sustainable or non-sustainable ways?
- What are the urban forms that are more or less sustainable in different parts of California, and why?
- What are the appropriate metrics for sustainability in communities?
    - Specifically, carbon, VMT, transit usage, waste streams, pollutants, water quality and quantity.

Policy and Program Implications

- How can we contextualize the research that suggests urban design and form?
    - How can policy be altered to reflect this research and how can the research be better applied in a political/policy context?
- How can best-practices, current research, and related information be better communicated and utilized by urban planners and policy-makers?
- How can policy and planning be reformed to reflect identified needs in sustainable communities development?
    - What are the tools, mechanisms, and barriers to implementing more sustainable communities?