Jerry Brown
Governor

CREATING SUSTAINABLE ENERGY SYSTEMS IN CALIFORNIA COMMUNITIES: A RESEARCH ROADMAP

CONSULTANT REPORT

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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.

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Issue Statement

Current levels of energy use in California communities are unsustainable and produce greenhouse gas emissions among the waste products generated. Urban metabolism (UM) offers a new framework for quantifying and measuring the use of energy in California communities (water transportation, purification and waste treatment, electricity, natural gas, building materials, gasoline and other petroleum fuels), and the waste flows that result from those activities (air emissions, water pollution, solid waste).

Accounting for and aggregating these different energy uses at a community census block level, combined with socioeconomic data, will provide important new knowledge about energy use in communities in California and an ability to better anticipate the future changes in demand due to things such as shifting demographics. Combined with policy analysis, such as land use and transportation plans, urban metabolism can provide better insights into the connections between energy use and policy decisions, creating the possibility of better calibrating policy to reduce energy and anticipating possible unintended consequences.

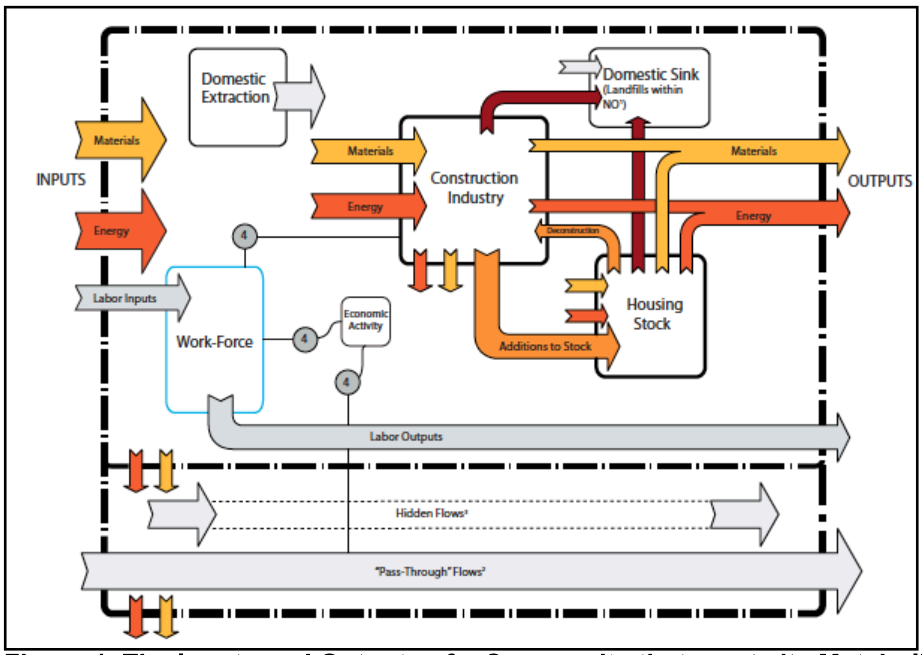

Figure 1. The Inputs and Outputs of a Community that create its Metabolism From David Quinn, School of Architecture + Planning MIT April 2007

Public Interest Vision

California is at a crossroads. A national leader in climate change regulation and environmental protection, it is also a state with some of the worst air quality, longest commutes, poorest rural counties, and highest number of mortgage foreclosures in the nation. These characteristics are both causes and consequences of California's energy system. Energy consumption, which continues to increase in absolute terms, has allowed society to achieve higher standards of living for more people than in any other time in human history. But our current major energy sources are limited in quantity, and also cause serious environmental and social harm. The materials we use to build our cities, move our goods, manufacture products and that we consume also require energy to extract, process, transport and dispose of. These too can contribute to pollution and health impacts, and may be increasingly scarce. While California communities are generally more energy efficient than communities in other parts of the United States, the state's energy profile is unsustainable. Local governments in California need to re-evaluate the way they use energy.

The purpose of this Roadmap is to provide a new framework for energy research for the state of California that is integrative and will provide the basis for greater sustainability.

Research Timeline, Matrix, and Definitions

Timeline

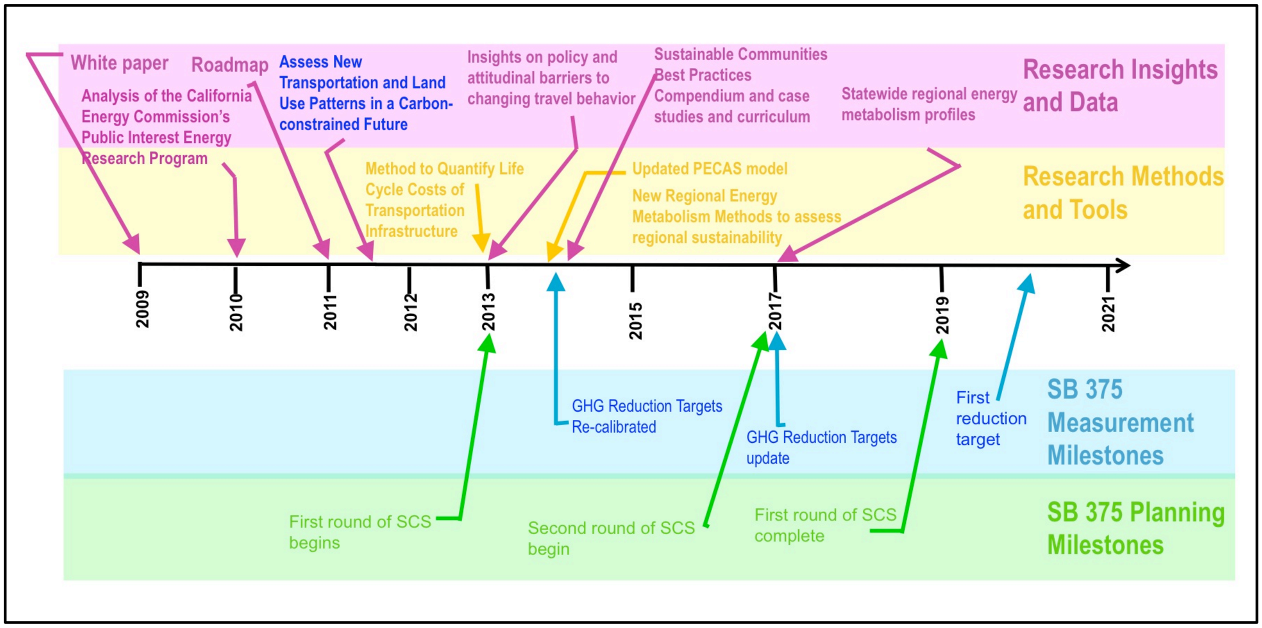

Figure 2.Timeline of the urban metabolism framework and implementation of the research recommendations from this roadmap.

Matrix of Roadmap Implementation Timeline

Roadmap Implementation Timeline

Year	Milestone	Benefits
1	Evaluate statewide research capacities	Identify expert and gaps, target funding, capitalize on synergies in existing and future efforts
	Expert Surveys	Data
	Transportation Project	Application of LCA, development of new techniques, quantification of embedded energy & GHG costs and benefits of new transportation infrastructure
	Baselines Project	Methods, tools, data for quantifying and understanding community sustainability
2	Assemble, create, synthesize new data	Provide information needed to quantify regional energy use patterns, improve decision-making and comply with regulation (SB 375). Improve CEC energy forecasting capacity

	Regulatory analysis	Identify policy frameworks and links among them that impact energy/GHG/Land use; inform new policy development
3	Sustainable communities best practices compendium	Provide examples of successful sustainable community development strategies
	Sustainable communities case studies	Provide assesesments of the costs and benefits of community development strategies
	Identification of and report on policy drivers of land use and energy use patterns	Improve implementation of GHG and energy policies (AB 32, SB 375 etc), inform new policy development
	Assesments of key energy/land use relationships	Identify environmental, economic, land use and social outcomes of sustainable communities development
4	Regional energy/ghg quantification tools and methods for sustainable community development	Tools and methods practitioners can use to quantify regional energy use, land use pattersn and socioeconomic effects
	Curriculum, Trainings and Workshops	Workforce development and training
5	Regional energy/ghg profiles	Inform ARB SB 375 target setting and sustainable communities planning by providing detailed informaiton on regional patters of energy use, land use and sociodemographics in California

Definitions of Terms Used in this Roadmap

Urban Metabolism

Urban metabolism is defined as the energy and material flows through human settlements, in which material inputs are transformed into useful energy, physical structure and waste (Decker et al 2000).

Expanded Urban Metabolism Framework

The expanded urban metabolism framework described in this roadmap is an attempt to add explanatory power to traditional urban metabolism methods by coupling additional analyses including socioeconomic, demographic, and policy decisions that govern a community system's processes. In addition, the expanded framework is a means to incorporate additional methodologies that include life cycle assessment, economic input-output modeling, transportation and land use planning modeling, and policy analysis.

Life Cycle Assessment

Life-cycle assessment (LCA) describes the cradle-to-grave (or cradle-to-cradle) material, economic, energy, and pollution assessment of products, processes, and/or services, and their larger systems. LCA includes inventorying the flows of resource inputs and emissions outputs, assessment of the impacts of the resource use and emissions, and interpretation of system processes and parameters.

International Organization for Standardization definition of LCA procedure (ISO 2006:14040): goal and scope definition, inventory analysis, impact assessment, interpretation of results, and reporting.

Life Cycle Cost Analysis

The economic assessment component of a life-cycle assessment, in which the economic costs associated with the process or commodity are analyzed.

Sustainability

In the context of urban metabolism, sustainability means the ability to provide the same quantities of inputs into the urbanizing regions as are currently the norm, over an indeterminately long period of time. Sustainability is not maintaining the status quo. Sustainability includes the sense of sufficiency, in which it is recognized that to meet the needs of the current and future generations, current urban metabolisms must change.

Brundtland Commission (UN 1987) definition: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

Sustainable Community

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 energy.

Stock/Source

The stock or source is the upstream origin (cradle) of the energy or material being inputted into the system. The stock is analyzed within the suite of methods utilized by an expanded urban metabolism framework.

Sink

The sink is the downstream destination (grave) of the energy or material being outputted from the system. This includes, in particular, the reservoir for waste and pollution from a system, such as the ocean for much water-borne waste. The sink is analyzed within the suite of methods utilized by an expanded urban metabolism framework.

Sprawl

Sprawl is used in this roadmap to describe urbanization that is highly auto dependent, characterized by single family dwellings, relatively low densities and segregated land uses.

Energy

In physics, the energy of a system is equal to the transfer of heat within the system minus the transfer of work in the system. In the context of urban metabolism, energy is similarly that which allows work and process to occur in an urban system. It includes explicit energy such as electricity and fuel that power urban systems as well as the embedded energy in the infrastructure and materials of those systems.

Embedded Energy

Embedded energy is the energy that was used to make, transport, and/or dispose of the material, building, or product. Thus all of the materials flows in a community also include embedded energy that represents the direct energy inputs used in creating, transporting, and disposing of that material, building, or produce. In some cases, embedded energy may include the potential energy in a product that can be transformed into work (e.g. in incinerating waste for electrical power).

Ecosystem Services

Ecosystem services are the societal benefits provided by natural systems and biological processes.

Sociodemographics

Sociodemographics are the demographic and sociological factors that describe a community's population. This includes descriptions of age, race, ethnicity, income, employment, immigration status, family status, and related characteristics of populations as well as the spatial, temporal and equity patterns of distribution throughout a community.

1.0 Introduction

There is a widespread understanding that the reliance on nonrenewable sources of energy is unsustainable. California already uses less energy per capita than any other state in the nation, but energy use is more complex than gasoline consumption, or electricity use and reducing consumption is more complex than using new vehicle fuels and improving the efficiencies of light bulbs. To reduce energy use in the state to a more sustainable level and reduce the state's emissions of greenhouse gases and other waste streams, requires detailed sectoral analysis of energy use at the community level.

For example, while attention has been focused on reducing vehicle miles traveled to reduce greenhouse gases and gasoline consumption, little is known about the energy required for building and maintaining roads, which form the foundation of our transportation system. Similarly, construction standards include insulation requirements that have reduced building energy use, but little is known about the energy that it took to make the construction materials and to transport them. Or take for example a simple glass of orange juice, a common and ubiquitous drink of choice. What amount of energy did it take to grow the oranges, harvest them, process them into juice, distribute the processed product to grocery stores and drive the product home?

Each of these systems, transportation, building construction and food manufacturing use energy from start to finish. There are no doubt opportunities for greater efficiencies throughout the process, yet until decision-makers tend to break these systems down into their components and instead of looking at the relationships between components. For example, is it more effective to reduce the energy used to build cars or the energy used to drive cars? To maximize gains in efficiencies decision-makers must begin this type of analysis. The next step for energy use reduction involves a more complex and in depth accounting of energy use in California communities in order to target programs and polices.

This research roadmap proposes a new framework for such an analysis. Urban metabolism, or the accounting for energy inputs into communities, and the waste outputs, provides a method to better identify and quantify the multiple forms that energy takes in sustaining California's communities, and the waste emitted. This roadmap outlines how to enrich this quantification method with additional important information, including sociodemographic information about the users of energy, and the policy drivers that structure communities and directly and indirectly energy use and waste.

Setting goals is a great deal easier than attaining them, even with better accounting and quantification. One of the big obstacles to reducing energy consumption is that we don't have a full understanding of the processes and incentives that lead us to consume energy in the ways we do. Without that information, the state won't be able to meet its goals. This is why the roadmap suggests coupling energy accounting with identifying policy that structure our current community systems.

This road map outlines a way to get to the important information about energy use and the complexity in its use. It does this in two ways. The first is that it focuses on land use and land use regulations, which have not been topics that scholars examining energy consumption have traditionally focused on. Second, the road map advocates coupling urban metabolism with life cycle analysis, to form a broader, more holistic approach to studying energy consumption. The road map proposes that using these two novel forms of analysis, urban metabolism and life-cycle analysis will provide critical information by necessary for taking a more comprehensive approach to evaluating energy use and its externalities

The roadmap specifically suggests urban metabolism as both a conceptual framework and a method for determining the quantities and types of energy that support California's communities.

1.1. Overview of Urban Metabolism

Urban Metabolism is a method first developed in the 1960s by Abel Wolman, an engineer. He wanted to know the energy footprint of a city. He developed the analysis for an abstract US city of 1 million people and went about quantifying how much water was needed, electricity and other inputs to support that one million person city, and how much waste was produced by the inhabitants. Urban metabolism is the quantification of the flows of resources that sustain the functioning of cities, and the waste products that are produced.

Approximately 50 urban metabolism studies have been conducted to date, These quantify water, fuel, food and materials that come into cities, and waste products such as air and water pollution and solid waste. Urban metabolism is defined as the energy and material flows through human settlements, in which material inputs are transformed into useful energy, physical structure and waste (Decker et al 2000).

The roadmap builds on the classic scope of urban metabolism so as to better address California's energy future. The roadmap proposes urban metabolism to study materials flows coupled to socioeconomic data about the community as well as land use and policy drivers. The roadmap proposes that urban metabolism be spatially explicit and that the forces underlying energy use (transportation incentives, zoning rules, mortgage lending) be part of the analysis.

The roadmap therefore is expanding the scope of urban metabolism analysis to provide a framework for explaining energy use in California communities.

There are two big challenges to this research program:

1. There is a lack of data at a local scale—most energy information is at a regional or state level.
2. Work of this sort is interdisciplinary. There is no precedent for bringing together these types of information in an interactive framework.

2.0 Background

2.1. Trends and Drivers

"Increasingly, we realize that overall societal and demographic trends can dwarf our efforts to encourage individual consumer investments in clean and efficient energy services. To truly reduce our energy and transportation-related greenhouse gas impacts, we need to change the way we think about our approach to community development and economic growth". **-The Energy Commission's 2008 Energy Action Plan Update**

Energy consumption has multiple consequences in today's society. In a time when there has never been more urbanization and as much need for energy to sustain urban regions, there is also the realization of limits to energy resources as well as the myriad negative environmental, social, economic and security impacts that come from this extensive energy use. These factors have led to the Energy Commission's interest in alternative strategies, including urban or community sustainability. The Energy Commission and the state's government have undertaken a number of initiatives over the past decades that serve as the backdrop and context for this roadmap.

In this section of the report we summarize current trends in California communities, explain how these trends have led to increases in energy consumption, and discuss policies that, if enacted, could result in more efficient and less environmentally harmful patterns of energy use.

2.1.1. Trends

Increasing Energy Demand

The CEC forecasts that state energy demand will increase 1.2% per year between 2010 and 2018; the annual 2009 Integrated Energy Policy Report (IEPR) projects that this demand will need to be met by increased energy efficiency and demand response, a larger renewable energy portfolio (33% by 2020), and clean burning fossil fuels (2009: IEPR, 1). Many of the energy efficiency programs will be implemented at the community level. These programs will include traditional incentives for efficiency appliances and lighting, but could also include updated building standards and compact land use and transportation planning. But as the 2008 Energy Action Plan Update states (above), the increased demand is likely to outstrip any gains in efficiency.

Changing Socio-demographics

California is moving into a new era demographically; the state is projected to be majority Latino by 2025. Already this is the case in Los Angeles County. The implications of this demographic transition are unknown, especially with regard to energy consumption and environmental awareness. The shift toward a Latino majority will likely involve changes in the average family size, housing preferences, educational attainment, private vehicle use, and energy consumption patterns. Any effort to forecasting energy needs for California, and to find opportunities for improvement in the state's energy efficiency, will need to account for the potential impacts of demographic change.

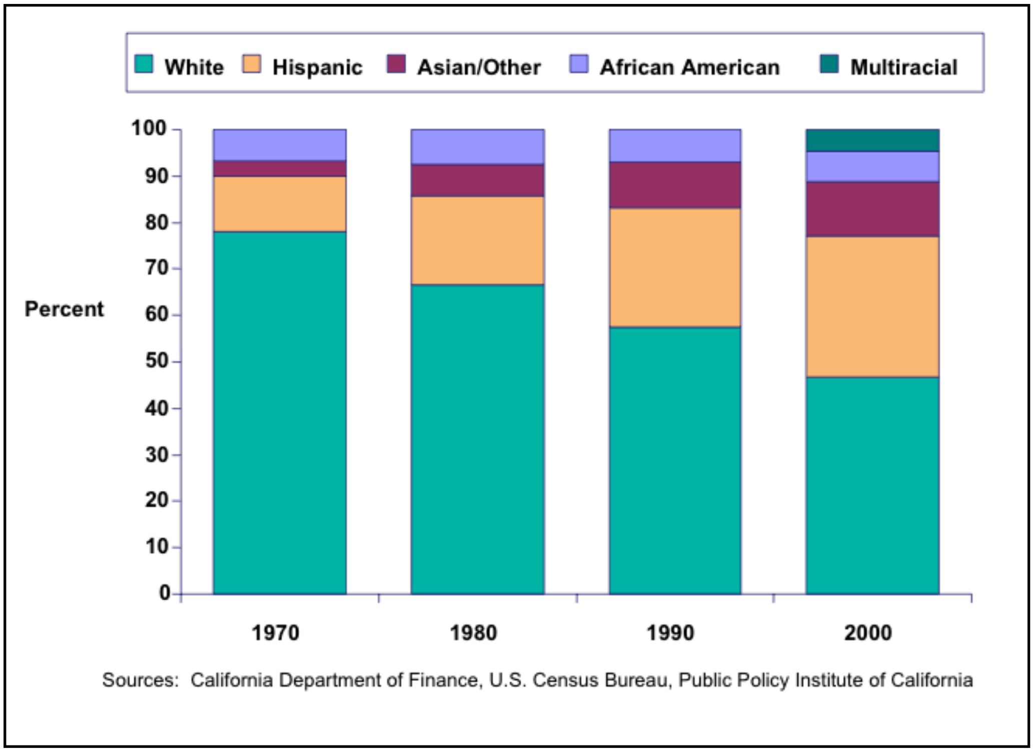

Figure 3. Breakdown of the change in racial identification in the California population.

Climate Change

The effects of climate change are likely to increase over coming decades. In California this will mean higher risks of floods, wildfires, water scarcity, air pollution, deadly heat waves and changes in agricultural patterns. Many of the causes and effects of climate change occur at the regional scale, and should therefore be addressed at the regional scale as well. For example, passenger vehicles are estimated to be the single largest source of greenhouse gas emissions in California, accounting for 30% of total annual emissions. (This is before accounting for the embedded GHGs that result from the construction of roadways and other infrastructure). California's transportation patterns are in part a result of regional policies and decisions about how land is developed, and where jobs and housing are located. The state's ability to reduce emissions is directly related to local planning and development.

Water Scarcity

Water and energy are inextricably linked. Water is used in the generation of electricity and fuel. Energy is used to clean, heat and transport water. Yet in California the availability of water has long been unstable. From 2007 to 2009 California experienced a drought and in 2010 experienced below average runoff from snowpack—less snow meant that there was less water. In February 2009, Governor Arnold Schwarzenegger declared a state of emergency water shortage for the State of California. In June 2009, the Governor issued Executive Order S-11-09, requiring specific state agencies to provide emergency food and economic relief to those affected by drought. Changes in the water supply will have direct affects on energy consumption. Further, the effects of climate change include droughts being more common and more severe.

Increasing energy demand, a growing and changing population, the risks of climate change and water insecurity are pushing California past the point of being able to ensure that its communities can sustain current patterns of land use and consumption. These trends are both causes of and threats to current development patterns. To restore and secure the vitality of California regions decision-makers need tools and information about community energy systems that will enable effective change.

2.1.2. Policy Drivers

Several state laws direct the energy commission to assist in reducing regional energy consumption and the various negative impacts associated with it.

Integrated Energy Policy Reports

The 2009 Integrated Energy Policy Report (IEPR) Update notes "Community design decisions impact transportation choices, energy consumption, and GHG emissions." The 2006 Integrated Energy Policy Report Update (IEPR) states that the "single largest opportunity to help California meet its statewide energy and climate change goals" is sustainable regional development that focuses on revitalizing central cities and older suburbs, supports and enhances public transit, promotes walking and bicycling, and preserves open spaces and agricultural lands (2009 IEPR). This approach was also emphasized in the 2009 IEPR Update which states that smart land use planning and growth are increasingly important strategies to combat declining air quality and the loss of open space and wildlife habitat and to improve the quality of life for California's residents (39). The context for these comments included concern about GHG emissions as well. The report goes on to note the need to "assemble easy to-use data and provide assistance to local and regional government officials to help them make informed decisions about energy opportunities and undertake sustainable land use practices, while recognizing the different needs of rural and urban regions" (246).

California Senate Bill 375

California's Senate Bill SB 375 was passed with the goal of reducing greenhouse gas emissions at the regional level through improved land use and transportation planning. In recognition of the fact that passenger vehicles are the largest single source of greenhouse gas emissions in the state, the bill requires ARB to establish greenhouse gas reduction targets for passenger vehicles. California's 18 Metropolitan Planning Organizations (MPOs)—the regional bodies that oversee planning—are then required to develop Sustainable Community Strategies to help their regions meet those targets. The bill is notable in aligning, for the first time, Regional Transportation Plans (RTPs) with Regional Housing Needs Assessments (RHNAs). By officially linking housing and transportation planning, the bill aims to reduce urban sprawl and promote compact development.

California Senate Bill 732

California Senate Bill 732 recognizes the need for increased land use planning coordination at the state level, and establishes the Strategic Growth Council (SGC) to oversee and promote sustainable growth efforts. The bill instructs the SGC to:

> *"identify and review activities and funding programs to improve air and water quality, improve natural resource protection, increase the availability of affordable housing, improve transportation, meet the goals of the California Global Warming Solutions Act of 2006 (Division*

25.5 (commencing with Section 38500) of the Health and Safety Code), encourage sustainable land use planning, and revitalize urban and community centers in a sustainable manner."

In addition, the council will 1) recommend policies and strategies that the State can initiate to encourage sustainable communities; 2) provide funds and distribute data to local and regional governments to increase sustainability; and 3) manage and award grants to support sustainable community development.

Amendments to the CEQA Guidelines Addressing Greenhouse Gas Emissions (Senate Bill 97)

In 2007, the State Attorney General sued San Bernardino County because its General Plan did not account for greenhouse gas impacts. The County defended itself by arguing that the California Environmental Quality Act (CEQA) did not explicitly require General Plans to consider greenhouse gas emissions. In 2010, Senate Bill 97 officially amended of the CEQA to include greenhouse gas emissions.

The California Global Warming Solutions Act 2006 (Assembly Bill 32)

AB 32 mandates that California reduce greenhouse gas emissions to 1990 levels by 2020. In response to AB 32, the California Air Resources Board developed a Scoping Plan for implementation, which outlines potential greenhouse gas reductions in the following six sectors: 1) energy and electricity, 2) transportation, 3) waste and recycling, 4) industry, 5) forestry and 6) agriculture. Regional development, including of communities impacts greenhouse gas emissions from each of these sectors. The scoping plan recognizes the essential connections between regional development and greenhouse gas emissions and urges action at the community level.

The above set of laws and statutes direct the Energy Commission, CARB and other agencies of the State of California to address the need for sustainable community energy systems that reduce the negative impacts of current development patterns, particularly greenhouse gas emissions, without compromising the economic or social vitality of the state or its communities. Community energy consumption is a complex and multifaceted issue that requires coordinated research across multiple disciplines and collaborative action between multiple agencies and institutions. To create meaningful and actual greenhouse gas reductions and increase sustainability at the community level, decision-makers need tools to accurately account for community energy consumption in its multiple forms. Once that accounting has occurred, benchmarks can be established to reduce energy use. But for this to be done optimally, criteria will need to be created and priorities developed.

Clearly there is an intention to address energy consumption and GHG emissions at multiple scales that are nested and tiered. At the heart of these policies are individual communities that can include small towns or cities, or communities within cities. Each of these are complex interactive systems in themselves, and they are enmeshed in larger political, economic, social and energy systems such as pipelines, transmission lines and grids and power plants. Transportation systems are as complex and include air travel too.

Regions are made up of cities and counties and are generally aggregated into metropolitan planning organizations, or MPOs. MPOs under SB 375 are the entities that have been tasked to lead their region through coordinated regional and local planning for housing and transportation to the reduction of GHGs. The actual language used by these policies is not always clear as to the definitions of community, cities, urban or region, but the roadmap is using the terms in a hierarchical scale order. Each of these levels interacts with the other, and jurisdictions within each tier also interact. There is a high level of complexity and interdependency among the different geographical scales.

Figure 4. A nested and tiered gradient of urbanization

The desire for interdisciplinary, systems oriented research aimed at helping the state move towards more sustainable energy systems has been a recurrent theme within the CEC and PIER program. The annual Integrated Energy Policy Report (IEPR), stresses integration and the 2007 and 2009 IEPRs and the Environment Area Roadmap include language emphasizing integrated approaches. This research Roadmap suggests a framework to integrate much of the past research to enable policy makers and multiple stakeholders to target energy use reductions by identifying the stresses and drivers of current energy consumption.

2.2. The Impacts of California's Land Use Patterns

California is the nation's most populous and economically productive state. It also has the nation's largest variety of plants and animals, and greatest range of climate regimes and sensitive landscapes. Over the past 40 years, California added 17.5 million people, growing from 20 million to 37.5 million. This growth has not come without costs. Land use, transportation and energy form a complex system in California, composed of energy flows and sinks facilitated directly and indirectly by policy and investment drivers.

Over the past 50 years, a variety of academics, advocates and policymakers have conducted research and proposed policies to address the energy- and land-intensive nature of California planning. California SB 375 is the most recent attempt; it targets greenhouse gas emissions that result from California's sprawling cities. Statewide land use planning efforts have failed to be passed by the state legislature, though energy-related policies have been more successful. Each successive energy policy has had circumscribed success such as fuel standards.

One obstacle that hinders such policies is the relative dearth of integrated spatially explicit data and research on energy use in California. While aggregated data on cities and regions exist for many energy sectors, little analysis has been done to ascertain energy use by census block, for example.

Even less knowledge exists about the articulation of policies and energy use. In the end the state's urbanized regions have both expanded outward and densified, impacting the quality of the environment and increasing demand for energy, water, materials and transportation infrastructure. The question before the state is whether it is possible to sustain these patterns of growth. By sustaining we mean the ability to provide the same quantities of inputs into the urbanizing regions as are currently the norm, over a long period of time. With climate change it is widely accepted that there will be less water available in the state. Thus, there will be water shortages at current consumption levels. Sustainability in the sense of continuing the status quo, will not be feasible. Sustainability in the sense of sufficiency to meet the needs of the current generations and the generations to come will require change.

In 1962, California Tomorrow published a plan called California Going, Going, which advocated coordinating land planning at the regional level. Regional Planning, it was argued, would forestall spatial inequality, reduce waste and rein in sprawl. Sprawl is a slippery term that has many definitions, however in this roadmap it is used to describe urbanization that is highly auto dependent, characterized by single family dwellings, relatively low densities and segregated land uses.

Since that time, there have been regular calls for coordinated planning due to the impacts of unrelenting growth and weak regional and local planning. Much of the growth in California since the mid-1960s has been outside of the central cities. White flight was an early contributor to this land use pattern, underwritten by federal support for housing construction away from the urban core, transportation subsidies for freeways, and subventions for greenfield developments, such as inexpensive water and availability of agricultural lands. Successive waves of urban emigrates followed these same incentives as the decades progressed. Perhaps this era has reached its limits; further research will reveal current urbanization patterns and perhaps help us forecast their future.

2.2.1. Sprawl and its Consequences

According to Bank of America, it is difficult to find a major sector of California's economy and society that has not been adversely affected by sprawled land development patterns. Businesses, residents, agriculture and the environment are just a few of the sectors that are most negatively affected by sprawl. This land use pattern is still dominant in the state, and its consequences must be appraised in order to create a more sustainable future.

The Bank of America study found that the business climate suffers because sprawl results in higher transport costs, a less accessible labor force and a loss of the economies of agglomeration and scale. Of course these claims are highly contested and need further research, but it is significant to note that it is of concern to one of the prime business institutions in the state and the country. Regardless, little has been quantified about the energy component of this question.

Although many people enjoy living in low-density areas, and would doubtless do so even in the absence of any regulations that encourage low-density, sprawl is, to a large degree, a product of government regulations, just as the lack of real choices for more dense living. It means it's a choice that is preordained, people cannot choose an alternative if they have no experience of it, and it is not available. Low density development patterns are a result of federal laws that over time, have favored large homes, local land use regulations that favor large lots and plentiful land devoted to streets and parking spaces and other factors. Proposition 13 (limiting property taxes), 218 requiring a 2/3rd vote to increase local taxes, along with recently passed Proposition 26 that requires 2/3rd vote for any new fees, affect land use and housing availability by making greenfield development easier. This land use has significant energy implications for the state that only now being taken into account. Greenfield development starts afresh, this avoids the legacy of old infrastructure that needs maintaining and the costs associated, and avoids the need to go to the voters to adjust fees if costs outstrip revenue for the services provided. Creating a more level cost and service cost playing field between infill and Greenfield development is a challenge. An urban metabolism analysis can help unpack this complex interactive set of policies that create unintended consequences.

The geographical mismatch now inscribed in the landscape due to the existing land use patterns between workers and jobs also leads to higher transportation costs, energy use, labor costs, and lower worker productivity. Some examples:

- Forbes magazine has ranked California as the most expensive of the contiguous 48 states to own a car.[1]
- The Texas Transportation Institute and INRIX routinely rank many of California's metropolitan areas as among the worst for congestion, and leaders in becoming more congested.[2]
- When combining transportation costs—which in California are almost exclusively automobile costs—with housing costs, California's metropolitan areas rank among the most expensive. For households earning between $20,000 and $50,000 annually, in most American metropolitan areas transportation and housing costs combine to account for about half the household budget. Among California's metropolitan areas these costs approach or exceed 60 percent.
- Suburbs are often perceived as "low-tax" locations, when, in fact, most new suburban homebuyers in California must pay additional taxes (such as Mello-Roos taxes) to cover the costs of new roads, schools, and other infrastructure required in new communities. These additional taxes and other fees can often double a new homeowner's property tax bill—even after considering their property taxes are also the highest they can be under Proposition 13, which imposes the highest effective tax rates on the most recent sales.

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[1] http://www.forbes.com/2008/02/14/cars-states-ownership-forbeslife-cx_ae_0214cars.html

[2] See http://mobility.tamu.edu/ums/ and compare multiple years of California metropolitan areas to others.

Figure 5 below shows how these policy driven land use factors have direct affects on the metabolism of the places affected though. The connections between these factors need further exploration.

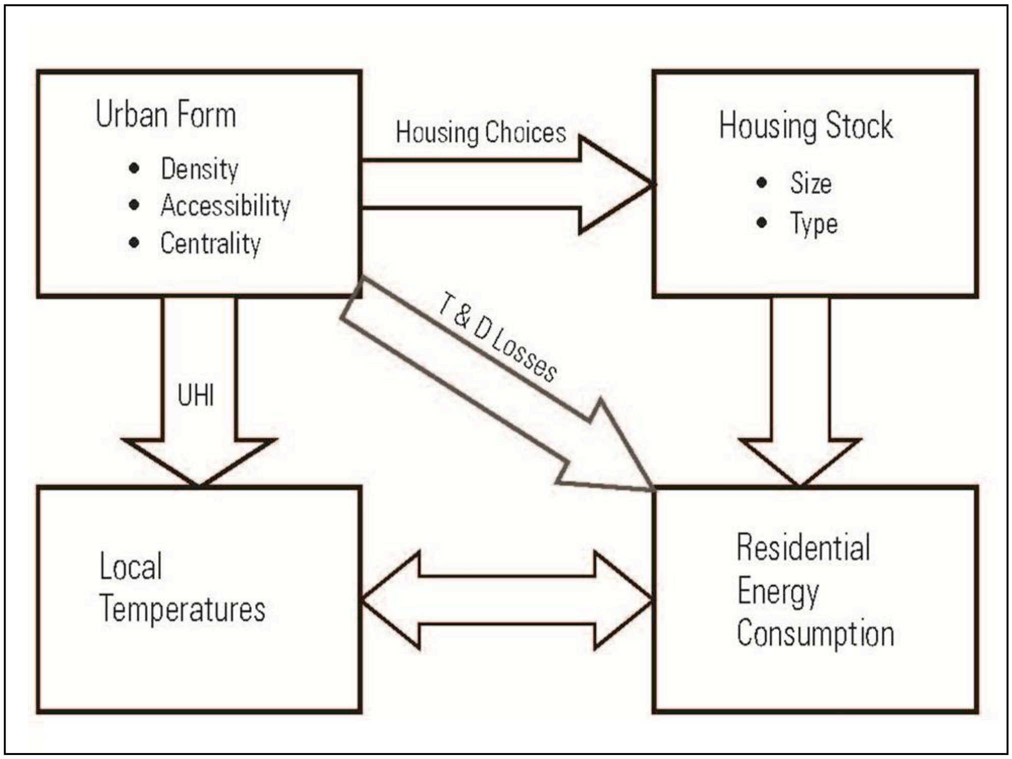

Figure 5 Causal paths between urban form and residential energy consumption (Ewing and Rong, 2008). UHI: Urban Heat Island; T & D: Transmission and Distribution.

2.2.2. Densification and the Development Industry

In recent years many California communities have adopted zoning bylaws designed to encourage infill development in at least some parts of their cities. In particular, many of these municipalities are encouraging mixed use development and/or transit oriented design. Infill programs of this sort are relatively new and often involve complex financial and public-private partnerships (for instance, a public agency might contribute funds to upgrade or build a transit stop, while a private developer will build housing nearby). There has not been much research devoted to evaluating the outcomes of these developments. There are more mixed use, transit oriented and dense developments being built, but their location and success in reducing vehicle miles travelled is poorly documented.

While HUD and other agencies have funded research about the organizational obstacles to creating these development types, other areas such as financing and their overall energy use—both by the buildings and the embedded energy in the construction—is little known. Embedded energy is the energy that was used to make the building, or the product. Construction activities require energy, and the materials they use also required energy to make them, and transport them. As these infill developments become more prevalent, research into their real energy, transportation and other impacts will become more important.

2.3. Developing Interdisciplinary Sustainable Communities Research

Since its creation, the Public Interest Energy Research Program, funded by ratepayers after energy deregulation in California, has sponsored research on specific technologies, products, decision-support tools and basic science related to energy or climate change. The program has sponsored relatively less research, however, on the influence that politics, policy and demographics have on California's energy consumption. PIER's research, in other words, has tended to be technological rather than behavioral or institutional. Yet energy consumption is fundamentally a product of individual behavior, and individual behavior is often shaped by institutional frameworks. Decisions about transportation, land use, agriculture and food systems, for instance, all represent an interplay of technology, institutions, and individual choices. An ideal research agenda on energy consumption in California, therefore, would be an interdisciplinary one, which incorporated aspects of all three. Yet as Wheeler et al (2010) point out that only 4 percent of PIER's 1,400 reports appear to contain significant interdisciplinary content.

Such a "big picture" approach is not only desirable because of its comprehensiveness, but also because it is often the interaction of various factors, not the factors in isolation, which increases energy consumption. Thus any effort reduce the negative effects of energy consumption and improve sustainability should account for the relationships between economic development, transportation, land use, and water use.

This roadmap proposes a method to create a state, region, or community-wide picture of energy use in California. This approach can provide detailed answers to basic questions such as "Where does our energy come from?" "What do California communities and regions use energy for?" "What are the unintended consequences in terms of human and environmental health of that energy use?" And "How might energy consumption and waste best be reduced to reduce negative externalities?" Given the relationship between climate change and energy use studies of systemic energy use at community, regional and state scales will assist in identifying existing energy uses in order to then determine how and where wasteful and negative impacts of energy use may best be reduced.

3.0 Research Roadmap

The following research areas highlight areas for research that address the complexity of community activities and interdependencies. Research in these areas should tease out the interactions among these topic areas and the need for interdisciplinary research to account for energy use and its imbrication, or interwoven nature into the fabric of activities and how the activities in turn, affect energy use.

We divide our research recommendations into nine topic areas:

1. Housing and building industry finance and regulation
2. Land Use Planning and General Plans
3. Transportation Finance and Policy
4. Agriculture and Food
5. Water
6. Materials Flows, Consumption, and Waste
7. Energy system management, energy institution structure; Distributed electricity generation technology and policy
8. Natural Resources and Ecosystem Services
9. Demographics and Socioeconomics

This section provides a general overview of the type of research needed to help develop sustainable communities in California. In Chapter 3 these concepts are further fleshed out into specific research recommendations.

3.1. Areas of Research

Understanding how Californians live on the land is an essential component of any research agenda dealing with sustainability. Energy consumption is in part a result of urbanization patterns, and the urbanization patterns that predominate today are in turn partly the result of the rules that guide land use planning and community design (Gordon 2008). This relationship will vary across the state as California communities are not all the same.

Land use regulation is mostly local, localities are responsible for land use planning—the creation of general plans, zoning codes, transportation plans and infrastructure. The result is a landscape of diverse array of zoning laws, fiscal incentives, and other rules, each developed separately from the adjacent locality. Little inter-jurisdictional coordination and collaboration is required, though councils of government attempt to do so through information sharing and transportation funding. Matters are complicated because state and federal standards are delegated to localities to implement and enforce. This leaves a patchwork of different approaches. Local decisions have substantial impacts on the state's current forms of urbanization, on human health, agricultural land, materials flows, ecosystems, water resources, and the global climate system. Individually they add up, but with no coherence. Each of the individual decisions made in the many jurisdictions affect the metabolism of each place—they can determine whether the place has high energy flows and high waste, or conversely parsimonious energy flows and less waste—and ultimately the region.

Research that can identify the impact decisions such as economic incentives for industries, or zoning in specific cities have on energy consumption will be most useful. Local officials should know which sectors have a high energy use (and where its located due to likely pollutant flows), whether in direct inputs like electricity, or indirectly because they need energy-intensive materials like virgin aluminum or are highly dependent on imported materials thus requiring high vehicle miles traveled to supply them. Moreover there may be policies that result in higher or lower energy use such as zoning for multiple family buildings, but in a location disconnected from schools, shopping and jobs. As the state's metropolitan areas become both more dense and more extensive in their land uses, a better accounting for energy use accounting for these disparate trends is increasingly urgent to develop at the local specific level.

Energy Accounting, Tools, Data and Methods

There is little actual data and research that exists to account for total energy use (broadly defined to include all processes and products) across geographically-defined California communities. Even less knowledge exists about the articulation of policies and energy use. For example, the energy use of new communities in the Central Valley by city, building type and socioeconomic group would be useful to know, and to contrast and compare this information with other regions in the state to assess how similar or different they are.

Data on the Effects of Existing Policies

Many of the state programs and policies designed to reduce greenhouse gas emissions are implemented as single programs in isolation, or implemented with insufficient data to most effectively target the new programs. Little monitoring of their effects is undertaken. Monitoring that includes the collection of detailed information is needed to be able to assess their success.

Methods and Data on the Interactions Between Changing Land Use Patterns and Transportation

SB 375 has made a clear commitment to reduce greenhouse gases by addressing the relationship between land use and transportation. While not in the historical purview of the Energy Commission, land use has a significant effect on energy consumption, whether by creating automobile dependency, increased water use, or inefficient home energy needs. Moreover, with the recent boom in housing in places of the state where more household cooling is required and far from employment centers, energy consumption is likely to have increased as a direct effect of land use decisions. Yet little research exists that investigates the relationships among location and type of development and energy use. This research framework will begin to fill these knowledge gaps. With the collapse of the housing market and an apparent consumer shift toward smaller dwelling units and increased demand for housing in already-urbanized centers, interactions among factors such as energy, housing trends and financing need to be better quantified. Such integrated research will assist in the implementation of SB 375, and help decision-makers enact land use regulations that can meet both consumer demand for housing and regulatory mandates to reduce the negative impacts of energy consumption.

Analysis of the Energy Embedded in Transportation Infrastructure

It is generally recognized that reducing emissions from transportation requires a three pronged approach: 1) increasing the efficiency of vehicles, 2) reducing the carbon content of fuels and 2) reducing vehicle miles travelled. In California, separate legislation targets each of these areas. We recommend a research agenda that will take a more comprehensive and integrated view of the total energy and GHGs associated with transportation. This comprehensive analysis can improve decision-making at the local level and inform policy at the state level. For example, the neglect of GHGs in road building itself shows there are many additional factors that are important to include in the accounting of GHGs that might be enormously significant to their reduction.

Collaborative Interdisciplinary Research

Energy use undergirds our contemporary society, so changes in any one sector—transportation, land use, infrastructure, goods movement—impact all the others and alters energy use. Singling out sectors for analysis is important, but it can also isolate important findings by discipline; research results from transportation scholarship stay in transportation circles, electricity generation results stay within the circle of professionals who study electric power, and so on. This isolation results in lost opportunities for collaboration and innovation. By its very nature, the study of energy is interdisciplinary. As the 2008 Energy Action Plan Update notes, "there is an increasing need for coordination and integration of our agencies' overall actions across all of the targeted research area" (5). This also suggests a need for greater collaboration with other state agencies that affect energy use, pollution mitigation and urbanization policy.

3.2. An Urban Metabolism Research Framework

UM has traditionally measured five main flows: 1) energy, 2) nutrients, 3) materials, 4) water and 5) pollution. Its weakness has been that it offers little explanatory power. For example 2 studies of Hong Kong reveal that when Hong Kong was a manufacturing center, its UM (gross accounting using the categories above) was lower than when Hong Kong was no longer a manufacturing center, and instead became a commercial sales city. The simple flows analysis could not explain the change in UM. For UM to be useful to decision makers and analysts, it needs to be coupled with additional information, such as the sociodemographic profile of the community, economic activities, and policy decisions that shape energy use. This can include a policy decision to move away from manufacturing to a goods distribution economy, for example. In addition, a life cycle analysis will provide information about hidden energy costs, costs that come with products or infrastructure itself. The roadmap proposes how these aspects can be added to urban metabolism to more comprehensively establish measures from which to create regional sustainability goals.

The 2005 Sustainable Urban Energy Systems Roadmap, written by consultant Alex Lantsberg, identified the need for an integrated energy systems framework, and proposed *Urban Metabolism* as just such a framework.

The urban metabolism approach, as in the discussion about land use, transportation and fiscal needs of communities above, identifies the multiple elements in the system and then asks how one impacts the outcomes of another. There have been urban metabolism studies across the globe (see Appendix II). In particular, the European Union has adopted urban metabolism as a decision support tool to assist planners in various sectors evaluate planning alternatives' energy use implications. The two leading projects are The BRIDGE Programme and The SUME Project, both of which are collaborations of multiple research and government institutions in Europe.

The Sustainable Urban Metabolism for Europe (SUME) is focusing on the way future urban systems can be designed to be consistently less damaging to the environment than in the present. The concept of urban metabolism is being used to understand and analyze the way urban societies use resources of the environmental system such as energy and land for maintaining and reproducing themselves. The project is examining the flows of resources, energy and waste maintain European urban systems and their impacts on resource use. The project started in November 2008 and is slated to last until October 2011 (http://sume.at).

3.2.1. Developing and Implementing Interdisciplinary Research Evaluating Sustainable Energy Systems: An Expanded Urban Metabolism Platform for Research

This roadmap proposes an expanded UM analysis that includes

- Life cycle cost Assessment
- Policy Drivers underlying energy use
- Sociodemographic data correlated with energy use

Life Cycle Assessment (LCA) is a cradle-to-grave analysis of the environmental, social and economic impacts associated with a product, process, service or system. Cradle-to-Grave means taking into account the source origin of the subject of analysis (such as the mining activity for gravel) through to its final disposal in, for example, a landfill. LCA is particularly valuable when evaluating the sustainability of complex urban systems because it accounts for and examines the direct, indirect and supply chain effects of a process or decision. While LCA has become synonymous with the study of environmental impacts (energy consumption, greenhouse gas emissions, criteria pollutants, toxic and carcinogenic releases, etc), it can also inventory other social and economic indicators like the availability of labor and resources. So, for example, it could take into account the labor involved in mining the gravel and its energy use for commuting to work, or the health hazards involved in mining and costs of injuries.

COMPONENTS of LCA

Direct Component: The immediate product or process of interest.

Indirect Component: Processes and products that must exist for the direct component to function.

Supply Chain Component: Upstream products or processes that exist throughout an economy to support direct and indirect components in some way.

Together, urban metabolism and LCA provide a powerful combination of methodologies for quantifying, examining and explaining energy flows and sinks in California communities.

The recommended research platform involves a set of nested levels of research tasks. They begin with a gross accounting of a community's energy use (the traditional flows that have been accounted for by UM). This accounting then allows an identification of sectors in that community that should receive LCA analysis. For example, in the Los Angeles region, there is a large food processing industry. Measuring water use, electrical needs, packaging requirements, distribution impacts, labor needs and neighborhoods impacted will provide a greater ability to identify key ways in which the industry might reduce energy needs, and perhaps in ways that might not be obvious without all this information. Once the UM and sectoral LCAs have been conducted, along with detailed socio-demographic analysis, the policy drivers that shape consumption and waste patterns need to be articulated with those findings. The urban metabolism analysis will then inform on the relevant energy utilization issues for that place. This drilled down can provide a better explanation of complex energy systems.

Next, as will be explained in more detail, will be to identify the policy factors that condition the energy flows, and the correlated sociodemographic factors.

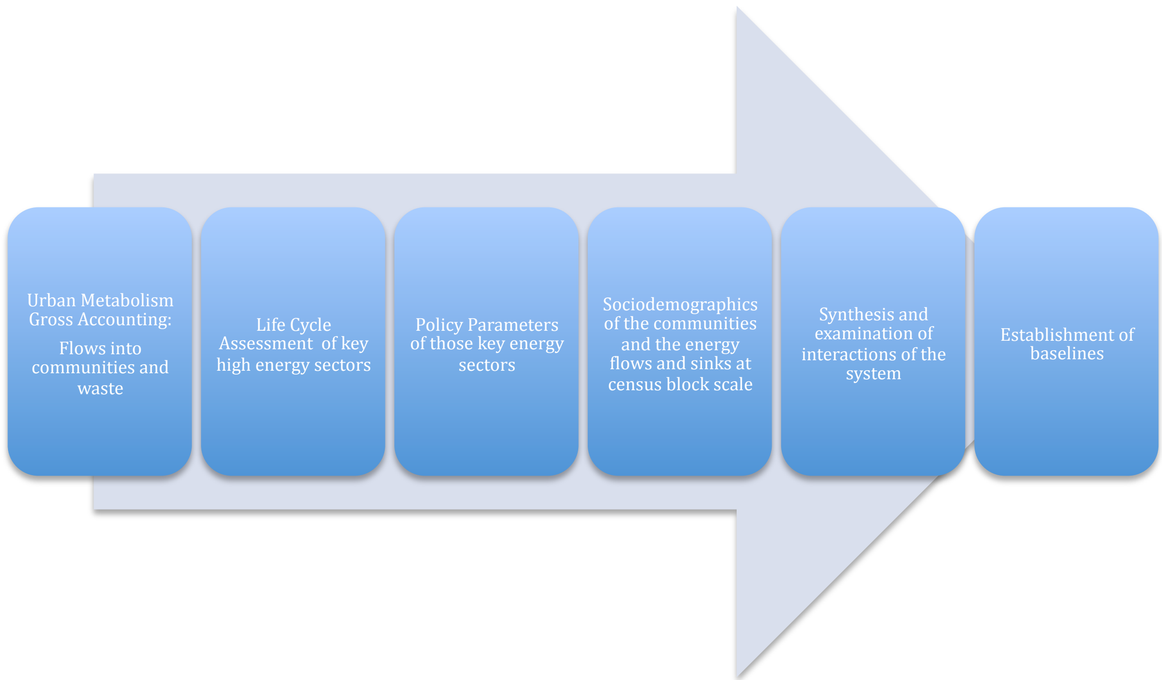

Figure 6. Generalized process for establishing energy baselines using the expanded urban metabolism framework.

3.3. Implications of the Interdisciplinarity of Sustainable Communities Research

Communities are more than a sum of their parts—they exist and thrive on complex interactions among the individual components. Figure 7 shows just some of the many processes that drive a community's functions, including the required inputs and generated waste. Examining both the individual components as well as the system in which they exist will lead to a broader understanding of the policy context that shapes California's energy system, and ultimately, to more policy relevant solutions.

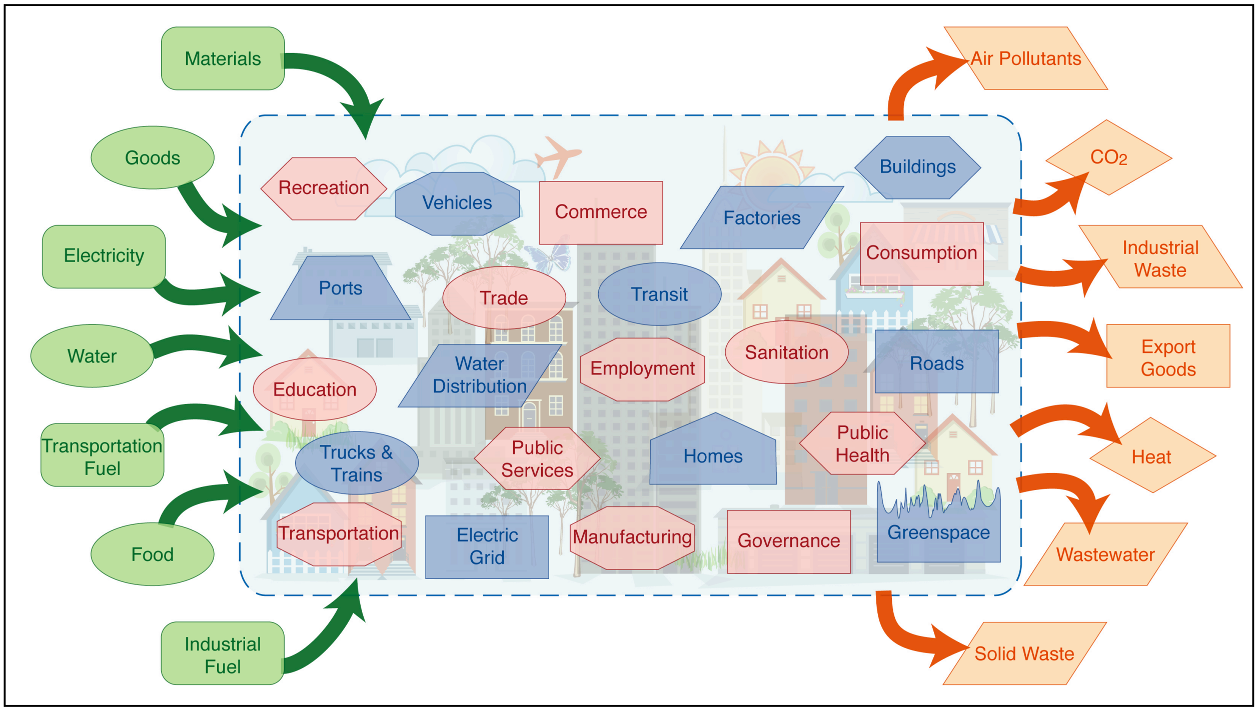

Figure 7. A simplified description of the central issues in creating sustainable energy systems, showing the critical inputs and outputs to the community system, along with the elements and processes that drive metabolism within the community system. These examples are not an exhaustive list of relevant elements in an urban metabolism or energy system.

Evaluating the sustainability of communities and energy systems involves several components. First, there must be an accurate accounting of energy consumption and waste. Second, the policy context that governs the energy system must be examined. Finally, decision support tools and alternative scenarios should be built to help identify and implement sustainable energy systems. Figure 8 shows these relationships. It also shows how the PIER subject areas fit into cross-cutting research themes discussed in the research recommendations section.

Sustainable communities research will couple biophysical and engineering specialties with social science and policy expertise to construct an explanatory picture of energy use in California communities. Building up from these data-rich examinations of energy use in diverse California communities, the Energy Commission would have a strong basis upon which to recommend progressive energy policies.

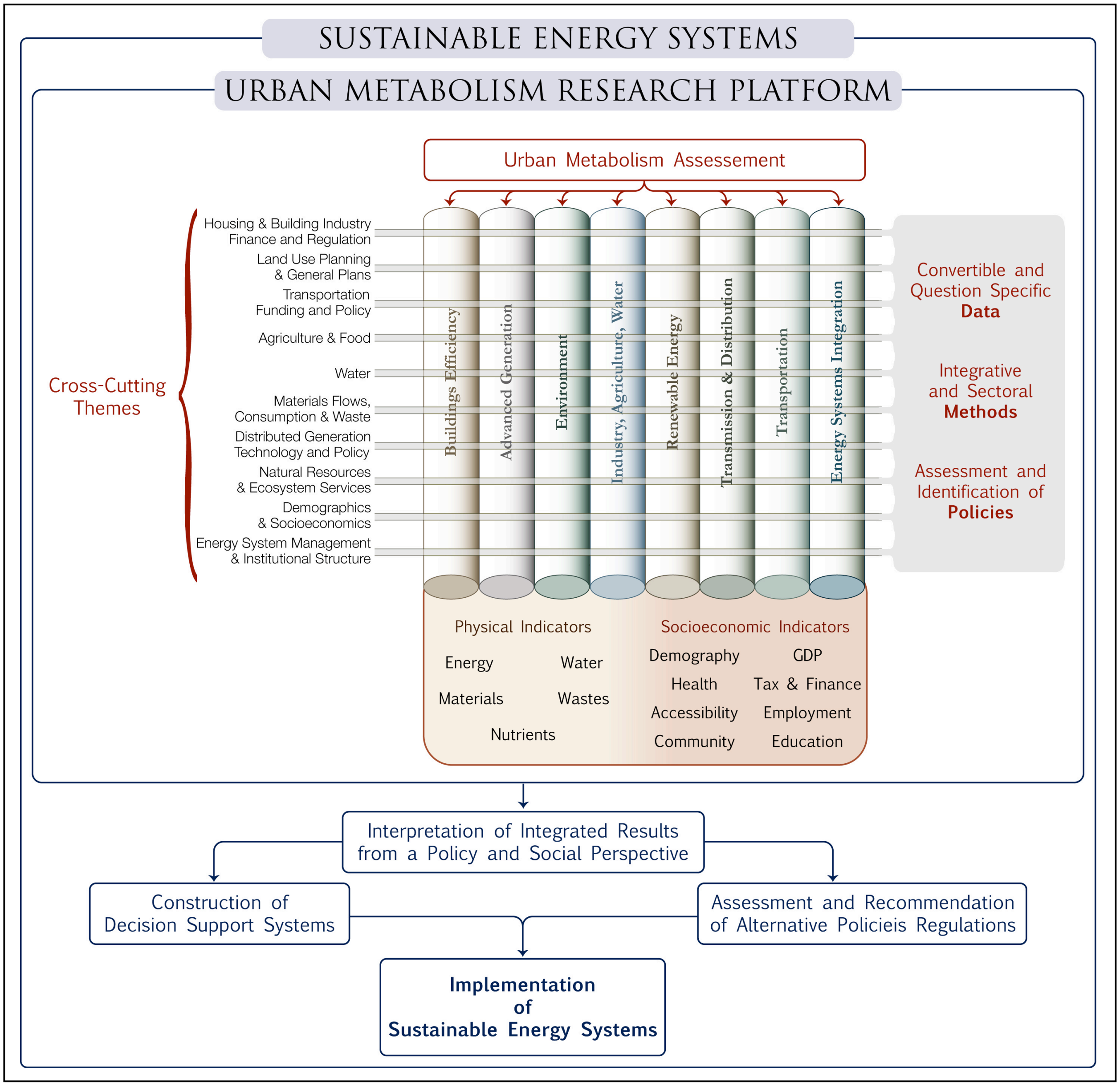

Figure 8. Generalized process for "sustainable energy systems" research. The process is capable of incorporating multiple disciplinary studies and methods into an urban metabolism framework for analysis and interpretation of a community's comprehensive energy profile.

3.3.1. Developing and Implementing Interdisciplinary Research

Developing urban metabolism research and data for greater energy sustainability for California is inherently about approaching energy use in the state as a complex, interacting and interdependent system. To develop and implement interdisciplinary research is no easy matter.

Some of the proposed research areas will require the summoning of key researchers and research centers to brainstorm the specific questions that will reveal the interdependencies discussed in this roadmap. In an interactive process between PIER staff and researchers, specific questions can be developed, and priorities for research funding over the next decades can be elaborated in a research plan for the EC to develop the information to identify and quantify energy use in different California communities and the reasons that drive the energy use profiles.

3.3.2. Factors for Successful Interdisciplinary Research

To be successful, integrated research requires:

- Metrics. Setting consistent standards of energy measurement and units across energy types, materials types, and other physical or socioeconomic indicators that should be analyzed.
- Data curation. Developing consistent methods for gathering data across energy types and accounting for embedded energy in accessible databases.
- Methods. Establishing integrated research programs that require interdisciplinary collaboration on RFPs.
- Prioritizing research. Developing short, medium and long-term research programs with criteria for funding particular research projects that will enable appropriate

3.4. Recommended Research topics

The UCLA research team identified a preliminary set of cross-cutting themes, based on PIER's existing research areas. These research themes organize the research recommendations described in the next section.

1. Housing and building industry finance and regulation
2. Land use planning and general plans
3. Transportation funding and policy
4. Agriculture and food
5. Water
6. Materials flows, consumption and waste
7. Energy system management, energy institution structure; Distributed electricity generation technology and policy
8. Natural resources and ecosystem services
9. Demographic and socio-economics

Research topics, suggested funding levels and timing for each of these nine areas are listed in the following table.

Table 1. Details of Research Recommendations with Suggested Funding Levels and Timeframes

Research Needs	Suggested Funding Level	Timeframe
HOUSING & BUILDING INDUSTRY FINANCE AND REGULATION **Larger scale developer/builders and projects have changed the housing and building industry over the past 20 years with. At the same time, financing has changed with the deregulation of banking and changes in mortgage rules. Understanding changes to finance policies and industry structure are crucial to the energy consumption of existing and future urban form, land**		

use patterns and building projects.		
Study cost-effectiveness of energy efficient technologies in new and existing buildings, and propose tools for more accurate economic analysis. (For example, current lending practices use a cost-effectiveness measure may not allow energy efficient technologies to pencil out because they do not incorporate increased rental and sale values)	$100k	1 yr
Analyze how lending practices and criteria (for builders, buyers and renters) incentivize construction of single family homes compared to multiple family homes, and how this affects energy consumption	$150k	1 yr
Determine how changes to housing / building policies and lending practices (for example, the financial regulation of mortgage lending) have impacted land use, urban form (building type, pace and location) and energy	$200k	2 yrs
Longer term: what are the urban metabolism effects of lending and regulation policy—specific LCAs	N / A	N / A
LAND USE PLANNING & GENERAL PLANS **Land use planning and general plans are the frameworks that guide urban form. We know little about their impacts on energy consumption.**		
Identify the urban typologies and land-use patterns within each MPO in California to better connect how urban form affects energy profiles of the MPOs	$75k	1 yr
Determine the effects of spatial allocation of land use patterns (retail, industrial, residential, service) on energy, materials and waste flows	$100k	1 yr
Conduct comparative research of the effects of in-fill development on urban metabolism (energy consumption, water use, materials flow, nutrient cycling and waste flows) using case studies that represent urban typologies in the MPOs	$400k	3 yrs
Identify and analyze communities with adaptive reuse ordinances to determine the net impact on energy, materials and waste flows	$300k	1 yr
Analyze the effects of tax policy (especially property and sales taxes) on building types, land use patterns and urban form from 1980 to 2010	$500k	3 yrs

TRANSPORTATION FUNDING & POLICY **Too often transportation outcomes and infrastructure are not linked back to funding, incentives and rules about circulation and infrastructure requirements (street widths, etc). We need research that connects the requirements of transportation funding and industry standards to energy use outcomes. This research should also address the energy effects of changes in population density.**		
Determine the life-cycle effects (emissions, materials and waste) of increased density on transportation in California's urban and suburban areas	$400k	2 yrs
Determine the systems impacts of transportation policy on energy; Topics to cover include how transportation policy impacts urban form, economic distribution, the jobs-housing balance, and the balance between energy used in the transportation system versus infrastructure upgrades	$500k	3 yrs
AGRICULTURE & FOOD **Cities import food and export food waste. The warming climate will cause increased water scarcity in California, a major food supplier to the world. California's ability to produce food in the face of decreased water supply and increased energy conservation is crucial to the health of our communities and our economy.**		
Determine the energy and waste impacts (locally and in farming communities) of alternative agricultural production practices (including organic operations, dense industrial operations, and locally-grown practices) using life-cycle assessment	$300K	1 yr
Analyze the potential to produce food locally (within a 150 mile radius of major metropolitan areas), determine energy, land use and price impacts	$250k	1 yr
Create a 'food map' to determine what types of food are available in each community, where the food comes from, and the life-cycle impacts, including the health impacts of that food,	$250k	2 yrs
Determine how food waste relates to community demographics, form and the food industry	$200k	2 yrs
Analyze food distribution methods (big box retailers like Walmart, small neighborhood grocery stores, fast food outlets, farmers markets, etc) using life-cycle assessment to determine cost effectiveness and sustainability of each method	$275k	2 yrs
WATER **Water transportation in California represents the single highest use of electricity in the state. Detailing water use in the state in its different regions, how water supply will change over time, and how water impacts energy will be important in the face of climate change.**		
Analyze overall water use in urban areas by category, including indoor and outdoor community water consumption; water consumption by building type (single family, multi	$1 mil	3

family, commercial, industrial); water consumption by socio-demographic group; and water consumption by microclimate		yrs
Determine the likely impacts of climate change on local water resources	$250k	2 yrs
Complete a comparative analysis of the energy used to transport water to the major MPOs in California	$150k	1 yr
Analyze the potential for local water recycling in each MPO, and determine the life-cycle energy impact of water recycling	$350k	2 yrs
Analyze the social, environmental and economic costs of water supply options, including dual meters, multi-piping (gray water or purple pipes), and water import	$200k	1 yr
Examine different land use patterns for various hydrologic or MPO regions around the State (both existing and planned or potential development), and estimate the varying water consumption (and wastewater treatment/disposal) footprint of those land use patterns, and the overall level of energy associated with water use and disposal/treatment in each one.	$200K	2 yrs
Analyze the various ways in which energy can be extracted from the water infrastructure "cycle" including such possibilities as generation of bio-gas from wastewater treatment facilities and co-generation of heat (or cooling) and electricity from wastewater or water treatment processes. Analyze projects and studies worldwide for these technologies.	$150K	2 yrs
Develop a uniform and low cost/user friendly methodology for assessing the full, life cycle energy implications of the water systems typically used in urban areas in California. Using various existing studies of water pricing, consumption and conservation in different regions of the State, assess how different pricing structures could lead to different levels of conservation, and determine what recommended policies might influence water pricing.	$400K	3 yrs
Assess the energy demands from water consumption in the rural and agriculture sectors in different hydrologic regions around the State; and assess the potential for agricultural conservation to reduce energy demand.	$200K	2 yrs
MATERIAL FLOWS, CONSUMPTION & WASTE **Materials flows into cities, consumption and waste flows out of cities contain substantial embedded energy. Careful accounting of these flows, stocks and sinks will provide significant information about energy use in California communities, including implications for waste disposal.**		
Conduct life-cycle analysis on recycling in the major MPOs to track the full costs and benefits on energy use and the environment	$175k	1 yr

Determine the life-cycle impacts and energy costs of goods movement for communities within each MPO	$450k	3 yrs
Determine the energy, materials and waste in the life-cycle of the building industry	$300k	2 yrs
Industrial vs. consumption goods movement (how much is locally manufactured compared to imported and transported within, among and out of regions)	$500k	3 yrs
Analyze the energy balance of different recycling techniques used in California; examples include exporting recyclable goods, increased recycling of different materials, reduced consumption	$200k	2 yrs
DISTRIBUTED GENERATION TECHNOLOGY AND POLICY **Little is known about the best way to produce and transmit non-fossil fuel energy. We do not know the actual local capacity for energy production in California's diverse urban communities, including how much land will be needed to store locally-produced energy, or the acreages of available and suitable roof tops (for solar production). We also don't know the life-cycle impacts of distributed generation versus centralized generation, and there are no full economic analyses of energy conservation that are geographically specific.**		
Analyze capacity for local energy production and storage in regions across the state	$400k	3 yrs
Conduct an economic and environmental impact assessment for distributed generation versus centralized generation	$300k	2 yrs
Study the full economic impact of energy conservation, including materials and energy conserved	$250k	3 yrs
Conduct a life-cycle assessment of the different types of distributed and renewable energy sources	$500k	3 yrs
Determine the impacts of energy type (source and physical distribution) on urban form, the transportation sector, and price	$500k	3 yrs
Assess the barriers and mechanisms for implementation of community solar and wind generation projects (i.e. the local, state, and federal policies and financial rules impacting small-scale, multi-owner, cooperative renewable energy generation facilities).	$300K	2 yrs

NATURAL RESOURCES & ECOLOGICAL SERVICES **While ecological services are increasingly recognized as important to the physical and economic well-being of humans, little research had been conducted into their specific functioning and their services with respect to urban metabolism and sustainability. Natural resources provide inputs for products humans use, as well as water, air, and other life-supporting functions. Nature is also an important pollution sink. Inventorying the ways that natural resources and ecological services contribute to the urban metabolism of California communities will assist in policy making.**		
Identify and develop indicators and metrics of ecosystem services and disservices, including urban tree canopy cover (urban cooling vs. water use), bioswales (water capture and purification vs. cost to reconfigure urban morphology), etc.	$400k	3 yrs
Assess how ecosystem services could be integrated into monitoring programs, including existing or new management plans, regulations and institutions may be required	$150k	1 yr
Identify the impacts of urban growth on regional ecosystem services in the "urban/wildland" interface (fire, degradation of ecosystems, water use, air quality, runoff, infrastructure provision)	$400k	3 yrs
DEMOGRAPHICS AND SOCIOECONOMICS **Very little analysis exists about energy use in communities by different groups. For future energy forecasting and potential for energy conservation, we must examine the relationship between socioeconomic and demographics factors and energy.**		
Determine how fiscal flows and financial transfers impact urban form, energy use, economic activity and energy consumption	$500k	3 yrs
Determine how land use patterns in diverse communities affect development, transportation and energy consumption	$500K	3 yrs
ENERGY SYSTEM MANAGEMENT AND INSTITUTIONAL STRUCTURE **Changes in the energy supply, distribution of generation capacity, distribution of consumption patterns, and novel technologies for both consuming and conserving energy are placing increased demands on the providers of energy. It is critical that energy providers and managers—including utilities, the transportation fuel industry, and regulators—are organized and managed in such a way as to plan for and effectively manage a more integrated and complex energy supply system than the current one.**		
Analyze the institutional actors—utilities, regulators, industries, technology producers—who are responsible for key sections of the energy market and their capacity to manage a highly integrated electricity system. How these organizations are organized and can change their management structures to better represent and manage highly integrated systems (including variable electricity from renewables, integrated storage systems, distributed generation, smart grid technologies, electric	$500K	3 yrs

vehicles) will affect the process.		
Investigate the role that regulators, including the CEC and the CPUC, play in enabling and hindering the adoption of technological advances and changes to the energy supply.	$200K	2 yrs
Analyze the capacity of existing utilities to manage distributed electricity generation capacity, with special attention to customer ownership of energy across jurisdictions.	$300K	2 yrs

4.0 Detailed Discussion of Research Recommendations

This section provides more detail about each of the research areas outlined in Section Three. Based on PIER's existing research areas, a preliminary set of cross-cutting themes emerge. The research recommendations in the next section are organized around the following themes:

1. Housing and building industry finance and regulation
2. Land use planning and general plans
3. Transportation funding and policy
4. Agriculture and food
5. Water
6. Materials flows, consumption and waste
7. Energy system management, energy institution structure; Distributed electricity generation technology and policy
8. Natural resources and ecosystem services
9. Demographic and socio-economics

4.1. Housing and Building Industry Finance and Regulation

Overview of the Issue

The structure of the housing and building industry has changed over the past several decades, as larger scale builders and larger scale developments now operate on the urban periphery while smaller infill developers work in the core of urban areas, as do larger builders. This structure is the result of several factors, including consolidation in the building industry itself, changes in regulation, the use of environmental regulations to contest development and changes in the lending industry. A large research investment needs to be made to untangle these factors as they have major implications for energy use. This would include local land use regulations and the revenue needs that sometimes shape them; state regulations about water availability; federal banking and interest rate policies; incentives and disincentives for infill development; and partnerships between nonprofit organizations and builders. Ultimately for the CEC, the question is the impact of these factors on energy consumption by the home sector.

State level policy makers and decision makers in the building industry need to unpack industry finance and regulation to better measure their impacts on energy. For example, what are the potential urban metabolism impacts of the criteria lenders use to calculate return on investment for new construction by type? Do they now take into account energy impacts of any sort from gas and electricity to water and transportation? building or development level energy or water conservation? What are the new—if any—standards that are emerging? Similarly, do mortgage lenders, who have specific criteria about what will provide sustainable returns on investment, include energy or water conservation potential in the balance sheet?

Research Recommendations

- Study existing measures for financing energy efficient technologies in new and existing buildings, and build methods for more accurate economic analysis of the cost-effectiveness of energy-saving technologies.

- Analyze how lending practices and criteria—for lenders, buyers and renters—incentivize construction of single-family homes rather than multi-family homes, and determine how this affects energy consumption.
- Determine how changes to housing and building policies and development fees as well as lending practices have impacted land use, urban form and energy. The analysis should include the impact on the type, speed and location of new development.
- Identify and analyze how lending criteria affect energy, material and water requirements for indoor heating and cooling, land use, water consumption, waste generation, and transportation. This analysis should be conducted for new large-scale developments as well as in-fill development.
- Identify what changes in local, state and federal regulation of the building industry have occurred over the past 20 years. Determine how these changes have influenced development patterns, building practices, and lending practices.
- Determine the relative importance of different finance rules on lending practices and development in California real estate. Finance rules to be studied should include mortgage lending, government subsidies, brokerage practices, capital financing, and complex financial products based on mortgages.
- Account for the infrastructure life cycle costs associated with infill developments and Greenfield development.
- Study the energy impacts of state tax policy. This research should include sales tax revenues, redevelopment agencies revenues, property tax revenues, among others.
- PIER should assemble a team of private sector actors, land use decision-makers and university experts in a workshop to determine and prioritize these specific research agendas. The research should develop an explanatory framework for the evolution of contemporary land uses, pinpoint the policy linkages and potential areas for reform and, of course, the energy implications. This research will have to be conducted by regions, perhaps starting with the major MPOs but also considering smaller jurisdictions such as the, Eight MPOs of the San Joaquin Valley, the Redding/Red Bluff area, the Imperial Valley, the San Luis Obispo area and northern Coastal metropolitan areas.

4.2. Land Use Planning and General Plans

Overview of the Issue

Land use planning and general plans are the frameworks that guide urban form, yet we know little about their impacts on energy flows and community energy use. What we do know is that different urban forms (compact, sprawled, mixed-use, etc) most likely result in different levels of resource consumption and waste generation.

As a result of Proposition 13, California's cities have a strong incentive to zone for commercial development rather than residential development, because a sales taxes can be a larger revenue stream than property taxes. Commercial development, however, often places greater demands on the energy grid as well as on the roads, and does so at peak hours. To the extent that the fiscal incentives facing California cities result in "excess" commercial zoning and development, these incentives may also result in excess energy use. Policy makers at the state and local level would benefit from a greater understanding of the precise relationships between local fiscal policy, land use decisions and energy consumption.

Researchers should examine how the change of land use affects the fluxes of energy, water, waste and pollutants. Furthermore they should overlay property, sales and other tax revenue or expected revenue with land use patterns and energy consumption.

California's cities are growing denser, and this too has energy effects. Density is correlated with traffic congestion, and increased congestion in urban areas has increased GHG emissions as it takes longer to commute in cities themselves on surface streets. Congestion and density can increase air pollutants that are harmful to human health, and increased densities require more electricity.

To date, land extensive urbanization has received more attention than infill relative to its infrastructure requirements. Preliminary studies show that infill development is more energy and infrastructure efficient than the outward expansion of suburban development, but the sheer volume of infill must have an impact on energy and the infrastructure that carries and creates it (for example, infrastructure in central areas tends to be older, so the new round of infill development may be placing it under strain). Other factors are important as well. Emerging transit oriented design and multiple use developments have been built in part to reduce energy and transportation use. Some research has been conducted but substantially more research needs to be done to evaluate whether the claims about these new developments have been borne out. Does transit-oriented design translate into real energy reductions and more use of public transportation in the different regions of the state? Research of this sort will yield better information about why some advertised "sustainable communities" development types are more successful than others.

Shifts in development approval processes enacted by localities will also affect the size, scale and level of infrastructure provided by new development. For example, Development Agreements (California code section 65864-6989.5: Article 2.5), a law passed in 1979 by the state legislature, encourages the upfront approvals of large-scale phased developments. The law guarantees that the development cannot be challenged in the future, even if the will of the public changes. As a result of the law, localities are able to exact more concessions from developers (schools, roads, sewage plants, parks) than they might have through the traditional incremental regulatory review process. Yet no one has examined how DAs have changes land use patterns, nor how those changes have influenced energy consumption, transportation and GHG impacts, or impacts on ecosystem services and the water supply.

Research Recommendations

- Expand on existing research emerging in the land use and transportation fields to identify the urban typologies and land-use patterns within each MPO in California to better connect how urban form affects energy profiles of the MPOs. Typologies developed to date emphasize transportation energy use. Typologies may need to be modified to examine and correlate building energy, water and waste associated with each land use and urban form type.
- Research the rate, pace, and scale of energy hookups (water, power and gas) for infill and suburban growth from 2000 -2010, and the level of energy use in each urban form.

- Examine the relationship between total energy use in communities designed to minimize automobile use, and in communities designed with other typologies.
- Determine the effects of different of land use patterns—locations of retail, industrial, residential, and service uses—on energy, materials and waste flows.
- Conduct comparative research of the effects of in-fill development on urban metabolism (energy consumption, water use, materials flow, nutrient cycling and waste flows) using case studies that represent urban typologies in the MPOs.
- Identify and analyze communities with adaptive reuse ordinances to determine the net impact these laws have on energy, materials and waste flows.
- Analyze the effects of tax policy (especially property and sales taxes) on building type, land use patterns and urban form from 1980 to 2010.
- Identify changes to land-use patterns within each MPO in California over time since 1990 and correlate energy, water and waste associated with these changing patterns.
- Correlate land use changes to tax revenues in major cities in each MPO in California.

Each form of land use and development will have a concomitant energy metabolism which needs to be ascertained. However, as this research section shows, there needs to be links between energy profiles of land uses and the structural conditions shaping those land use and development patterns.

4.3. Transportation Funding and Policy

Overview of the Issue

Transportation policy has received a great deal of legislative and state attention in recent years, largely due to the passage of SB 375 and AB 32. Transportation is a significant source of energy consumption, and a significant source of emissions, including emissions of greenhouse gases. However, transportation outcomes and infrastructure are rarely linked back to funding, incentives, standards and rules about circulation and infrastructure requirements such as street widths. Thus research that connects the requirements of transportation funding to energy use is needed.

Part of the impetus for the passage of SB 375 was the recognition that transportation planning—and transportation behavior—is a result of urban and suburban development. When development takes place on the urban fringe, roads often seem to be the only way to provide new residents with access to destinations. Yet the causality runs both ways: building roads can sometimes induce development, even while development sometimes induces road building. SB 375 sought to integrate transportation and land use planning in the hope of curbing the cycle of road-building and outward residential expansion. But SB 375 has also cast into sharp relief the need for more proactive transportation science. Policymakers need more evidence about the efficiency tradeoffs associated with different modes of transportation, if they are to direct planning and investments in a manner that enhances mobility, sustainability and equity.

Research Recommendations

- Determine the life-cycle effects (emissions, materials and waste) of different development typologies on transportation in California's urban and suburban areas.

- Determine the systems impacts of transportation policy on energy; topics to cover include how transportation policy (taxes, tolls, parking policy, etc.) impacts urban form, and economic distribution and energy.
- Determine the impacts of transportation infrastructure investment; topics to cover include how the provision of increased accessibility by mode effects real estate values, how real estate values affect land use preferences.
- Analyze the embedded energy costs of different transportation infrastructures over time and relative to transportation modes.
- Correlate local, state and national transportation infrastructure (road sizes and hierarchies), safety rules to constraints in changing transportation modes.

This research could be further refined by assembling engineers, transportation planners and transportation builders as well as elected officials.

4.4. Agriculture and Food

Overview of the Issue

The agricultural sector uses a relatively small amount of energy, compared to other industries, but is increasingly mechanized and therefore heavily reliant on the timely availability of energy (Randy Schnepf, Congressional Research Service). At the same time there is increased interest in food self-sufficiency at the local and regional levels. This interest is a response to the realization that some urban areas have food deserts (no grocery stores), particularly in poorer areas. Increased food production in urban areas will have effects on those places' energy metabolism, including water use, transportation, although the effects may be small.

Small changes to the supply and price of energy can have significant effects on the profitability of large-scale California farms, the mix of farm management practices, and the cost and availability of goods on grocery store shelves. Urban water prices, if they increase, may also influence local food production. Food processing and distribution also are reliant on energy and impact both the need for energy in communities and transportation GHGs and the transportation system. For example, the Los Angeles metropolitan region employs over 40,000 workers in food processing; more needs to be known about the energy intensity of that employment, as well as the impacts from food processing in the Central Valley and other places in the state where such employment is prevalent.

Research Recommendations

- Determine the energy and waste impacts of agricultural processing (including organic operations, dense industrial operations, and locally-grown practices) using life-cycle assessment.
- Analyze the potential to produce food locally (within, for example, a 150 mile radius of major metropolitan areas), determining energy, land use and price impacts and how much food consumed in those MPOs comes from the local food sheds. Analyze how moving toward more local food growing systems would affect energy consumption.
- Create a 'food map' to determine what types of food are available in each community, where the food comes from, and what the life-cycle impacts are of that food, including health impacts.

- Analyze food distribution methods (big box retailers like Walmart, small neighborhood grocery stores, fast food outlets, farmers markets, etc) using life-cycle assessment, to determine the amount of energy used by each method.
- Compare the energy impacts of processed and non-processed foods.
- Identify how many of California's processed and non-processed agricultural products are consumed in the state.
- Determine what the energy costs are of food processing by sector, and identify the source of energy for that processing in the different parts of the state.
- Study the treatment of food waste in the state, and make explicit the energy implications of that treatment.

This research will assist in establishing the energy profile of food consumption in the urban areas of the state.

To further refine these non-comprehensive research areas, and to determine what data sources are required to conduct the research, working with the California Department of Food and Agriculture, the California Farm Bureau and the network of organic growers and farmer's markets in the state as well as the major food store chains to further detail and define the questions that impact energy use in California communities related to the food system will be necessary.

There are other aspects of the food supply that will also need to be considered. For example it would be useful to identify food processors in the major growing regions and metropolitan regions and to create a matrix of energy flows and product profiles.

Distribution chains will be important to identify as well.

Initially this food and agriculture research area will require a mapping effort to ensure the sectors are fully represented.

Ultimately an analysis of energy and food policy will have to include the impacts of national farm and food policy. A series of high level discussions about the state's agricultural metabolism will have to be developed in order to identify the relevant drivers , including crop subsidies, biofuels policy, water policy and land use that will need to be integrated into a metabolic description of food and the state's urban regions.

4.5. Water

Overview of the Issue

Little in California state politics is as controversial or important as water. With a changing climate and likely reductions in the state's primary water supplies (the snow pack in the Sierra and the Colorado River basin), the consumption and waste of become important components of the urban metabolism framework. Water and energy are inextricably linked in the southwest and in California. Water generates electricity, and utilities use large amounts of energy to pump, treat and deliver water. Additional energy is used to heat, cool and use water in homes, businesses and industrial facilities, and substantial energy is used to treat wastewater before disposal. The single largest user of electricity in California is the California State Water Project, which uses 2 to 3 percent of all electricity consumed in the state to deliver water from the San Francisco Bay Delta to agriculture, oil pumping and to Southern California.

Currently, the PIER program, the state Department of Water Resources, the Water Quality Resources Control Board and water purveyors all have robust water research programs. This roadmap proposes integrating that existing research into a larger metabolism framework. There is, in fact, a substantial amount of data collected by DWR and other agencies that describe California's water resources, use patterns, and geographic distribution. For example, the CUWCC keeps extensive and timely records on over 400 water purveyors in terms of per capita water use by region and by land use and by year, and DWR has recorded all of those in the State Water Plan. Better integration of these data into energy planning concerns, and with access for research in an urban metabolism framework, can capitalize on this knowledge to improve our estimate of water resource impacts on California energy systems.

PIER Use of LCA for Water

PIER's Life-Cycle Energy Assessment of Alternative Water Supply Systems in California approached alternative water supply systems in an integrated, systematic and quantitative manner, using life-cycle analysis (LCA) to consider the energy and environmental implications of the alternatives, including importing, recycling and desalinating water. The entire life cycle, including design, planning, material extraction and production, manufacturing or construction, use, maintenance, and end-of-life (reuse, recycling, or landfilling) was taken into account. The PIER research found that the alternative water supply systems examined would require more energy than conservation, as they would require additional energy. Increased energy requirements would cause different environmental effects, including higher levels of air pollution emissions. Recycled water was found to be energy intensive in the alternatives studied, but less than desalination. While the energy demand of water recycling was found to be larger than importation for the Northern Californian region, importation and recycling had similar energy requirements for Southern California. Treatment of imported and recycled water were not important contributors to energy demand and emissions for either case study, but treatment was the largest contributor to the desalination emissions in both Marin Municipal Water District and the Oceanside Water District. On the other hand, while imported water resulted in most environmental impacts occurring in the supply phase, for both of the recycled water systems studied, the distribution phase had the highest energy use and GHG emissions (Hovarth PIER contract# 500-02-004).

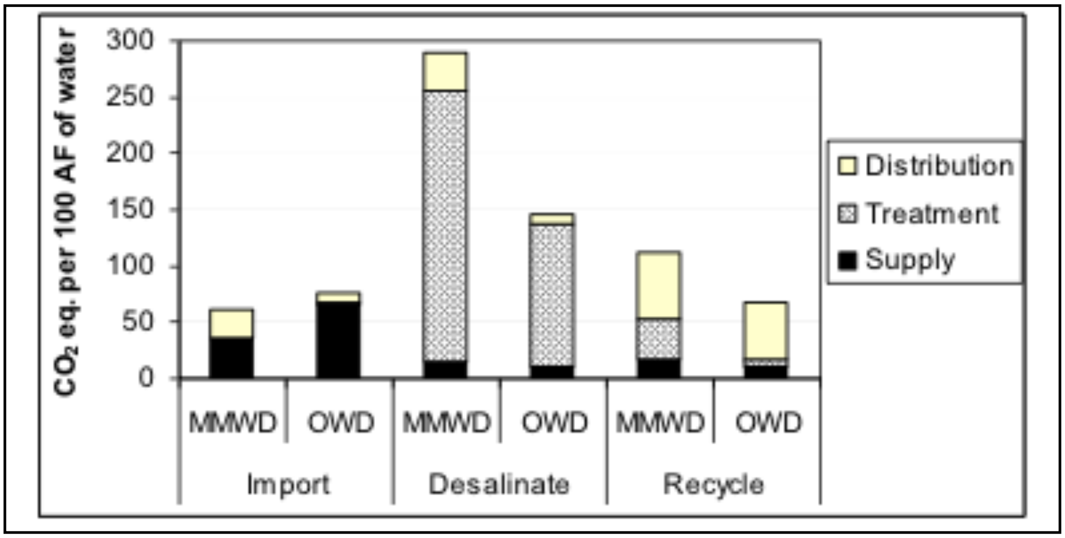

Figure 9. Energy use and global warming potential of water supply alternatives by water supply.

This type of research points to the importance of LCA analysis as a component of urban metabolism. Research that PIER has already funded, integrated with research on other sectors in an urban metabolism framework, will help policymakers understand the trade-offs between, for example, using more energy to transport or recycle water, and better managing autochthonous (native) ground water resources and local ecosystems.

Potential Water Management Resources for Urban Metabolism

Integrated Regional Water Management Plans (IRWMPs) are a collaborative effort to manage all aspects of water resources in a region, a planning process required by the state Department of Water Resources. IRWMPs cross jurisdictional, watershed, and political boundaries; involve multiple agencies, stakeholders, individuals, and groups; and attempt to address the issues and differing perspectives of all the entities involved through developing mutually beneficial solutions. There is little or no information about the success of this program, which is being implemented in most regions of the state, nor have IRWMP's generally considered energy use in their plans.

Water management is recognized as a priority by the state Understanding Regarding Urban Water Conservation in California (Memo Of Understanding; MOU)[3]. This MOU is an agreement signed by most of the large urban water suppliers in California, and it outlines a series of water conservation best management practices, as well as national and state efficiency standards for certain water appliances. The MOU does not require agencies to implement all cost-effective conservation strategies, but assigns levels of implementation such as the percent of customers to be audited or toilets to be replaced. Additionally the MOU signatories are not required to include energy savings when determining if a best management practice is cost effective. Energy savings could be included in this MOU.

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[3] See California Urban Water Conservation Council, The Memorandum of Understanding Regarding Urban Water Conservation in California, (http://www.cuwcc.org/mou-main-page.aspx), (April 10, 2010).

Water Use in Urban Communities

Urban communities in 2000 consumed approximately 8.9 million acre feet per year (af/yr).[4] Almost 4 million af/yr of this use (approximately 53%) went to the state's residential sector. This sector accounted for 48% of both the electricity (approximately 13.5 GWh) and natural gas (approximately 2 million therms) consumption associated with urban water use.[5] Any community energy analysis must include a more finely grained understanding of water use than this, because macro accounting cannot account for differences in and among communities, including differences in climate and vegetation. Manufacturing water use —the water required by supply-chains would also need to be included. Water use in communities and its embedded energy for conveyance, treatment, distribution and management as a waste flow must first be outlined and described, then measured. This is not as easy as it might appear. Accurately determining the amount of water used for urban vegetation, as opposed to indoor water use, will be hard, because there are no dual meters in place that separately measure indoor and outdoor water use. This is significant because of concern that with the reduction in water supply likely due to climate change, determining whether there is sufficient water for human needs (in contrast to outdoor water use for irrigation of yards), will be important. Urban runoff, especially when it is shunted to water bodies directly, is also very difficult to measure.

Some regions of the state have significant ground water resources, while others—such as the Central Valley—had significant ground water resources that have been mined through ground water pumping. In the Los Angeles region, vast ground water resources have been contaminated by toxic chemicals. The potential of each area to recover the ability to draw on those autochthonous resources and manage them into the future has significant energy implications, but has not been analyzed.

Agricultural areas are pumping deeper and deeper for water, which is increasingly energy intensive, and has negative externalities such as subsidence, exhaustion of the aquifer, and increased reliance on conveyed water. Many of the remaining aquifers in the Central Valley are contaminated and create health problems for the people who depend on them. Contaminated aquifers are difficult to clean and require pumping, capturing and disposing of the contaminants.

A full life cycle cost analysis of water and energy will take all the factors above into account to improve water use and management of the state.

Research Recommendations

- Develop an assessment of the progress of the state's IRWMP processes and their policy implications for water use. Determine whether IRWMPs have been implemented and assess their success. What considerations have been included regarding energy in the IRWMPs?
- Develop data on water use in urban areas by category, including indoor and outdoor community water consumption; water consumption by building type (single family,

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[4] California Department of Water Resources, Statewide Water Data 1972-2003, (http://www.waterplan.water.ca.gov/waterpie/faf_data.cfm), (April 10, 2010).

[5] Klein et all., ibid., p. 15.

multi family, commercial, industrial); socio-demographic characteristics; by microclimate and either census blocks or some other fine unit of spatial analysis.

- Using established analyses of urban water use (indoor and outdoor) by land use category, by specific water supplier, and by region throughout the State, calculate the relative water/energy footprint for each region. Address water consumption by socio-economic status, and by land use types.
- Beginning with the data generated by the Landscape Water Conservation Task Force and related DWR and CUWCC studies, assess the potential for landscape water conservation savings in different hydrologic regions around the State, and determine total energy savings that could result (including inputs of high energy products needed to maintain landscapes).
- Determine the impacts climate change will have on local water resources.
- Complete a comparative analysis of the energy used to transport water to agriculture and to the major MPOs in California.
- Quantify local water resources (ground water resources, surface flow resources and potential reclaimed water resources such as waste water).
- Identify and quantify pollution impacts on local water resources.
- Quantify capacity of local water resources to supply local residents at "life-line" water consumption rates for indoor water use.
- Quantify storm water, dry weather and waste -water flows.
- Examine the relative life cycle energy costs of water extraction and conveyance, water treatment and wastewater treatment facilities and processes in different regions around the State, paying particular attention to the carbon footprint of the energy used for these processes.
- Develop life-cycle energy impact analyses of the potential for local water recycling in each MPO. Recycling of this sort would include installing purple pipe infrastructure (purple is the standard color of pipe adopted internationally to distribute treated reclaimed water), storage including groundwater basins (including remediating polluted ones), and water purification. This research could be undertaken by region, starting with regions that import the most water. Beginning with data generated by DWR and various recycled water organizations, determine the potential for additional recycled water use in the different hydrologic regions of the State, and the life cycle energy implications of these changes (noting the differences in alternative water available in each region).
- Determine the life cycle costs of treating sewage in different regions of the state, and identify if and why they differ.
- Identify and determine the water requirements of regional power plants. Identify and determine the water supply and water quality implications for various types and categories of energy power plants throughout the State; analyze the future water implications of proposed energy facility types.
- Identify the likely changes in potential for local water capture and recapture over the next 50-100 years, considering the differential local effects of climate change.

- Determine and compare the life cycle energy impacts of new potential sources of water for different parts of the State. These sources would include desalination, recycled water, water conservation, off-stream reservoir storage, conjunctive use of surface and ground water, remediation of ground water, and additional imported water through the State, federal and "local" projects. This would include the analysis of the potential for grey water treatment at the residential level to reduce loads on sewage sanitation plants and for reinfiltration; assessment of the potential for grey water use in low density development throughout the different hydrologic regions of the State, and energy implications this may have.
- Survey the condition of ground water basins (if any) in the major metropolitan regions, and their potential for conjunctive water management.
- Assess the potential for storm water recapture in the various hydrologic regions of the State, given the pace of development of low impact development solutions and the differences in water source use, and determine to what extent this can play a role in future water supply and energy savings.
- Examine different land use patterns densities for various hydrologic or MPO regions around the State (existing as well as planned or potential development), and estimate the water consumption (and wastewater treatment/disposal) footprint of those patterns, as well as the overall level of energy consumption associated with water use and disposal/treatment.
- Analyze the various ways energy can be extracted from the water infrastructure including such possibilities as generation of bio-gas from wastewater treatment facilities and co-generation of heat (or cooling) and electricity from wastewater or water treatment processes. Analyze projects and studies worldwide for these technologies.
- Using various existing studies of water pricing, consumption and conservation in different regions of the State, evaluate what types of pricing structures would engender alternative levels of conservation and energy reduction, and develop appropriate policy choices.
- Develop a uniform and low cost/user friendly methodology for calculating the full, life cycle energy implications of the water systems typically used in urban areas in California.
- Determine the institutional, political, practical, and legal barriers to full cost water supply pricing.
- Examine the institutional complexities and constraints for providing water and wastewater services in various hydrologic regions around the State, and assess the potential for uniform approaches to quantifying the energy implications of water infrastructure.
- Calculate the energy demands from water consumption in the rural and agriculture sectors in different hydrologic regions around the State and the potential for agricultural conservation to reduce energy demand.

This research agenda should be refined through consultation with the Department of Water resources, the major water purveyors of the state, expert organizations such as the Pacific Institute, engineering firms, sanitation departments and key academics.

4.6. Materials Flows, Consumption, and Waste

Overview of the Issue

The flow of materials into cities, the consumption of materials in cities, and the flow waste out of cities all contain substantial embedded energy. Careful accounting of these flows, will provide significant information about energy use in California communities, including implications for waste disposal.

The Governor's 2007 Goods Movement Action Plan, prepared by the Business Transportation and Housing Agency and the California Environmental Protection Agency, offers an excellent platform on which to build an energy use research agenda for this sector. The Plan is comprehensive relative to concerns about GHGs and community pollution impacts, the need for greater efficiencies, but adding metabolism perspective will assist the Plan in meeting its goals by drawing attention to the energy use in goods movement by transportation sector. Further, targeted life cycle analysis of sectors of goods movement will assist in identifying inefficiencies in goods movement (hauling empty containers for example), that the Plan does not address.

The identification and analysis of route networks to and from each MPO will be useful and will serve to underpin the life-cycle assessment of the energy embedded in goods movement for each MPO in California. The study will examine vehicles (trucks, trains, planes and ships, including fuel), rights of way (highways, railroad tracks, shipping lanes), and terminals (distribution centers, warehouses, cargo hangars, parking lots, ports).

The study will analyze goods movement for industrial, agricultural and consumer products, categorized by NAICs code. It will include international, interstate and intrastate imports and exports.

The studies should be able to identify areas supply chain where efficiency can be improved, and where energy and cost savings could be most easily achieved. Multiple players in the supply chain will benefit from this information, including manufacturers, transportation companies and consumers. Policy makers and planners at the state, regional and local levels will also benefit from better land use and energy planning policy decisions.

Research Recommendations

- Uncover the embedded energy costs in alternative transportation systems: rail, truck, air, beyond emissions.
- Sectoral goods movement: conduct life-cycle analysis on recycling in the major MPOs and the recycling materials exported out of the state to track the full costs and benefits on energy use and the environment, and identify opportunities for increased efficiency in the supply chain. Analyze the energy balance of different recycling techniques used in California; examples include exporting recyclable goods, increased recycling of different materials, reduced consumption.

- Determine the life-cycle impacts and energy costs of goods movement for communities within each MPO, and identify opportunities for increased efficiency in the supply chain.
- Determine where to locate key goods movement infrastructure, including distribution centers and warehouses in a strategic, coordinated manner.
- Quantify the movement of industrial vs. consumer goods.
- Quantify the flows of materials into urban areas and waste streams and their partitioning between recyclables and landfill waste.
- Quantify flow of manufactured consumption goods outside of food.

This research program would best be refined with the participants in Governor Schwarzenegger's Goods Movement Action Plan, which had a broad representation of stakeholders. The program could also benefit from the presence of researchers working on life cycle cost of goods movement and materials flows

4.7. Energy System Management and Institutional Structure, Distributed Energy Generation, Transmission, and Distribution

Overview of the Issue

Many factors are converging to increase interest in, and reliance on, renewable energy. Climate change, energy security, pollution and other environmental damage, the finite nature of fossil fuels and volatile energy prices have all motivated policymakers to seek cleaner, longer-lasting and more stable forms of power. But increasing our use of renewable energy will have land-use implications, and environmental implications beyond simply reducing the air pollution associated with burning fossil fuels. Wind farms, for instance, can have impacts on migratory birds, solar arrays can impact desert ecosystems and endangered species, and the rights of way needed for high voltage transmission lines can run through sensitive habitat and urban communities.

The CEC's California Distributed Energy Resources Guide is a public benefit site containing a wealth of information regarding distributed energy resources (DER). Distributed energy resources is the generation of electricity from many small energy sources. Additional research on the effects of developing distributed energy resources themselves is required. Distributed energy sources such as rooftop solar photovoltaics are becoming more viable. Concomitantly, new policies are emerging that are meant to create efficiencies in the energy system, incentivize the adoption of distributed generation, and manage these new sources and uses of electricity. Further, there are innovative models for increasing the installation of distributed renewable energy generation. Community solar power and community wind power, where multiple owners cooperatively install and benefit from a local renewable energy generator, is one such strategy that is supported in California by certain policies such as the Multifamily Solar Housing program and programs run by Sacramento Municipal Utility District and the Los Angeles Department of Water and Power. However, myriad barriers exist to widespread adoption of this strategy, which research indicates may result in greater affordability, access, and equity in installing distributed renewable power (Farrell 2010). Research should be undertaken to address issues including access to tax incentives, securities regulations that prevent community renewable power, siting of community installations, and the ownership or lease status of cooperative members.

When electricity generation becomes more distributed, one result is often that the source of electricity is physically closer to the user (i.e., closer to homes or businesses, and sometimes in homes or businesses). As a result, there will be an increased need for new policies that simultaneously enable this deployment, and maintain its functionality over the long term and the security of electricity supply. The institutional management side of a shift toward DER is an area that requires thought and investigation. Currently, reliance on centralized power generation enables centralized regulation. The roles of the Energy Commission and the Public Utilities Commission in permitting, overseeing, and regulating these power plants is reflective of the current needs in policy and regulation. As individual homeowners and businesses become energy producers in their own right, often with increased capacity to manage the storage and consumption of that electricity, many, and/or other agencies and officials will be responsible for oversight.

Researchers are only beginning to consider the broader implications of the new technological and policy options for related aspects of the integrated energy system including personal transportation (e.g. electric vehicles), energy consumption tools (e.g. smart meters), energy transmission (e.g. smart grids), building design (e.g. green design), and industrial production. State and local policy makers and utilities would benefit from further study of the implications of shifting to distributed and renewable electricity.

There are several critical issues that distributed electrical generation raise that will have to be addressed by local planners and decision-makers.

Research Recommendations: Distributed Power Generation

- Installation of distributed generation, particularly solar photovoltaics .
    - What building code changes are necessary for roof top solar panels?
    - What community regulations (e.g. aesthetic codes) impede the installation of small-scale wind or solar generation?
    - How are small-scale power generating facilities likely to be geographically distributed? How will this distribution impact local grids? How might this distribution correlate with energy consumption patterns, including increased adoption of electric vehicles (which may co-occur with increases in residential solar power installations)?
    - How can community (multi-owner) distributed renewable power generation projects be incentivized or supported through local and state policy?
    - Will there need to be new land use zoning or land use configurations to accommodate either the power source (photovoltaics) or storage?
- Transmission and regulation of distributed power
    - What are the geographic patterns of energy consumption? Do these correlate with the likely geographic patterns of distributed energy generation?
    - How do local rules governing electricity metering influence the adoption and economic viability of distributed power?

    - In locales where distributed generation and new storage or consumption devices (such as electric vehicles) are installed, what rights do those citizens/businesses have to govern their generation and use independent of utilities or state regulators?
- Storage of distributed power
    - Where will power generated from renewable sources be stored? Will it be stored at the site of generation, in local aggregators, or at the substation?
    - What types of energy storage devices are likely to be used? How will this impact the local environment and local communities?
    - What are the size, location, and number of storage facilities that will be needed in different communities?
    - What are the environmental justice implications of decisions associated with the location of the storage devices? Do these implications depend at all on the type of technology the storage devices use? .
    - What are the environmental and health impacts of different types of storage device (both in manufacturing and employing the devices)?
    - How will storage devices be disposed of or recycled? What are the energy and environmental costs associated with the disposal of different types of storage?
- Consumption of distributed power
    - Will new technologies be employed differently across the grid? Will these rely more or less often on concomitantly installed distributed power?
    - How will electric vehicles serve as both consumers and storage sites of electricity? What is the structure for ownership and regulation of EV batteries by owners and utilities?
    - Does the existing grid support the equitable distribution of new technology deployment?

Changes in the way we supply energy will pose challenges for current energy providers. The existing institutional actors are fragmented, and the institutions were built to manage an energy system that is relatively simple compared to the energy systems being built. Large power plants, for example, generally burn fossil fuels (and some nuclear and hydro in California), which are then transmitted across a transmission grid managed by private and publicly owned utilities and finally to consumers. The advent of less centralized technologies to produce and distribute energy places these institutional actors in a new and uncharted position. The Energy Commission has a role to play in assisting these actors to manage an increasingly complex energy system.

Research Recommendations: Energy System and Institutional Structure

- Identify the institutional actors—utilities, regulators, industries, technology producers—responsible for key sections of the energy market and their capacity to manage an electricity system that includes new players at different scales, from the individual home owner up.

- Investigate the role that regulators, including the CEC and the CPUC, play in enabling or hindering the adoption of new energy production technologies.
- Analyze the capacity for existing utilities to manage distributed electricity generation, with special attention to customer ownership of energy across jurisdictions.
- Examine how utilities might be able change their organizational structure from a hierarchical one to a more integrated one, much like how a smart grid differs from the traditional grid.
- Determine how utilities will manage increased use of electric vehicles in order to account for different rates of adoption, problems arising around the ownership of batteries, protection of privacy of vehicle owners, and customer vs. utility control.
- Determine how regulators can manage the distribution of electricity as more electricity generation facilities (including small-scale distributed renewables) feed into the grid. This will include grid capacity.
- Identify what environmental impacts must be considered in the reorganization of energy management institutions.

Developing this research agenda will require assembling a diverse group of stakeholders, from CEC experts to practitioners and land use planners—both urban and rural, to engineers, major utilities and technology developers. Distributed energy implementation is a research frontier, from the technologies to the infrastructure for its support. Life-cycle metabolism will add depth to this enterprise, and allow for the identification of possible unintended consequences.

4.8. Natural Resources and Ecosystem Services

Overview of the Issue

California has been at the forefront in conserving endangered species, habitat and open space. The state's commitment to conservation is a result of federal and state endangered species acts, and also of public support for the protection of the state's natural beauty and biodiversity. Conservation programs have shaped land uses in some parts of the state, by setting aside some areas as protected while enabling development in other places. Developers have also funded a great deal of land preservation through development fees. This fee-based protection approach has implications for urban form as well as for the future of ecosystem health in the state as ecosystems are impacted by pollution—heavy metals deposit on soils for example—and serve as pollution sinks as well as serving as reservoirs of resources such as water, timber, minerals, recreation opportunities and other socially important functions. The supporting and supplying roles that natural resources and ecosystems service have received insufficient analysis, in their functions for urban areas from a metabolic perspective.

This area of research is perhaps the most challenging of the roadmap, because natural resources and ecosystem services have not been considered in metabolic analyses and thus require new methods. The realization that ecosystems provide indispensible services to humans, both in urban environments and from the lands that provide water, fuel and the many inputs necessary to cities, has been captured in the United Nations Millennium Assessment (MEA) framework.

MEA categories were developed in response to concern about the decline of ecosystems and their life sustaining role. The Millennium Ecosystem Assessment (2003) identified three types of direct societal benefits provided by ecosystems, which collectively are called ecosystem services: provisioning services supply food, fiber, fuel, or other material goods; regulating services modify aspects of the physical environment such as air quality, water quality, and climate; and cultural services provide health, aesthetic, spiritual, recreational, or psychological benefits. In addition, supporting services are the fundamental ecological processes that contribute to the three types of direct societal benefits as illustrated in the figure below and are therefore more indirect aspects of ecosystem services.

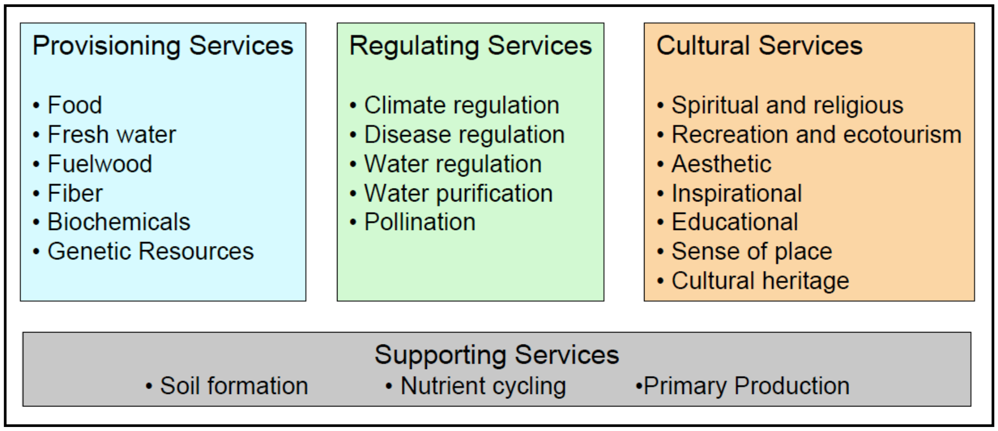

Figure 10. Classification of types of ecosystem services. Source: United Nations Millennium Ecosystem Assessment (2003).

What the MEA recognizes is that natural resources provide the materials that are transformed into the products human use, as well as water, air, and other life-supporting functions. Nature is also an important pollution sink. Our energy pricing discounts future scarcity and does not even reflect the other services nature provides like carbon sinks, however, as these services are impacted by further growth, depletion of resources, and pollution, the costs to our energy system may become more obvious. Examining how natural resources and ecological services contribute to the urban metabolism of California communities will assist in policy making by identifying the resources and inputs into our urban areas.

Ecosystems within urban boundaries have been studied relatively more than how remote ecosystems are captured and transformed into products that sustain urban systems (Grimm et al. 2000, Pickett et al. 2001). In order to incorporate ecosystem services and disservices into a research framework that will benefit California, it will be necessary to consider both urban greenspace as well as the remote ecosystems that are influenced by the urban footprint. Land use policies that maximize urban ecosystem services may adversely affect remote ecosystem services and vice versa; for example, while irrigating urban greenspace may provide several important ecosystem services within an urban area (like maintaining urban tree canopy cover that reduces the urban heat island), the water used in urban areas might have negative environmental consequences in remote riparian or wetland ecosystems. Similarly, increased urban expansion into fire-prone landscapes can have negative effects on both the urban development and the surrounding hinterland.

To understand these tradeoffs, it will be necessary to improve our knowledge of ecosystem processes along the urban to wildland gradient. For example it will be important to quantify the carbon sequestration capacity of greenspaces in and surrounding California's major MPOs, and to examine how different land management strategies might affect that capacity (even if any changes are minor). Southern California's mountains receive high levels of rainfall that recharge regional aquifers. How significant is this rainfall for local water supplies? The answer might depend on land use policy for managing alluvial fans, rural development and local water availability.

Many land use policies and decisions that do not directly address ecosystem services still have important and sometimes unintended effects on these services. Changes in land use that impact vegetation, fauna, and/or soils inevitably have consequences for ecosystem services. It may be intuitive that urbanization and other forms of land use change have impacted the ability of ecosystems to regulate air and water resources, but it is very hard to determine how much of an impact they have. The effects that lost habitat and land use change might have on human cultural values and perceptions are even more uncertain.

Recommendations

- Examine Habitat Conservation Plans (HCPs) in the state's regions and how they affect urban form and infrastructure development. For example, often an HCP must be passed to ensure species are protected before transportation infrastructure can be constructed.
- Document the funding for infrastructure projects that are expended once the endangered species act concerns are met by HCPs per HCP.
- Document the funding for HCPs per development area created when HCPs are passed.
- Identify and develop metrics of urban ecosystem services and disservices, such as urban tree canopy cover urban cooling vs. water use, bioswales water capture and purification vs. cost to reconfigure urban morphology.
- Identify the impacts of urban growth on regional ecosystem services in the "urban/wildland" interface (fire, degradation of ecosystems, water use, air quality, runoff, infrastructure provision) and the costs associated with those impacts.
- Determine the capacity of soils to filter wastewater in the major MPOs.
- Determine how much CO2 the major ecosystems surrounding the MPOs absorb within each urban region.
- Determine the potential of ecosystems adjacent and surrounding major MPOs to contribute to local water supplies.
- Determine the potential of alluvial fans in the state near major MPOs to serve as fire buffers, infiltrate water for groundwater supplies, and prevent flooding.

As with the other research areas, the research topics suggested in should be refined with experts involved in ecosystem services, including biologists and other scientists, land developers, land managers, and experts in municipal finance and infrastructure finance. The research program should also involve the state's Resources Agency, CAL EPA, major land management agencies, and nonprofit organizations involved in land conservation.

4.9. Energy Implications of Demography and Socioeconomics

Overview of the Issue

California's population continues to grow even if at a slower rate than in the past several decades. More people live in cities in CA than in most of the other states. In the 21st century, no single ethnicity will dominate and today the white population accounts for less than half of the population. Thirty-five percent of the state's residents are Hispanic, twelve percent are Asian, and six percent are African-American. Foreign immigration continues and there are nearly 10 million immigrants in the state. The majority of immigration continues to be from Mexico, followed by the Philippines, China, Vietnam and El Salvador. Nearly 60% of the population lives in Southern California and 30% of all Californians live in Los Angeles County.

Such a dynamic population is likely to have significant implications for current and future energy use in California communities. Therefore research in the energy field should not be limited to technological advances and hardware fixes, but should also include the socio-economic aspects of the energy system. Linking socioeconomic and demographic factors to energy use is crucial to designing the policy options that will work best to meet the energy goals of the state. This will require finely grained analysis of population clusters and integration of socio-economic indicators with energy use data.

Such knowledge will help state and local planners and policy makers understand the potential economic and social issues related to current and potential future energy technologies and energy planning, barriers to behavior change, and the acceptability and implementation of new technologies and policies as well as their environmental, economic and social sustainability. It may also prevent unintended consequences of policy decisions on different groups of Californians. As immigrant groups, for example, become wealthier, they may increase energy use, for instance many immigrants today cannot afford automobiles and ride public transit. Will this behavior change with more wealth?

For future energy forecasting and potential for energy conservation, the examination of socioeconomic and demographics factors and energy consumption will be useful as will parsing out effects of income relative to ethnicity. Researching the socioeconomic, cultural and demographic factors that affect energy use in each community is crucial to designing the policy options that will work best to meet the energy goals of each community.

This research will help state and local policy makers connect economic and social factors to the state's current energy profile, develop future planning scenarios, construct incentives to change behavior, and evaluate the acceptability new technologies and policies.

Research Recommendations

- Determine the relative energy use of communities with different fiscal capacities to correlate the impact of fiscal flows impact on urban form, energy use, economic activity and energy consumption (for example, does energy consumption track with the affluence of the city?).
- Develop data on household energy and water use and waste production by socioeconomic and demographic categories, including income, education, ethnicity, immigration status (recent immigrants compared to first generation immigrants) and for age of housing and location.

Developing the specific questions for this research area will require the participation of demographers, utilities and builders who together can determine what data sources exist and how best to approach the spatial and social dimensions of connecting energy use to socio-demographics in the state.

5.0 Keys to Success

5.1. 4.0 Data Gathering and Curation

Performing the research outlined in this road map will require the gathering of new data and pulling together already existing data in new ways. The research will require common metrics for comparing energy use. The Energy Commission already is the repository for an immense amount of data, and is therefore in an ideal position to lead this additional data curation effort. To accomplish this, the Energy Commission will need to focus on two elements of data in particular:

1. Gathering the data. The CEC should gather existing data, increase systematized data reporting by local and state agencies, and create a mechanism to facilitate data identification and reporting.
    - Data reporting may need to be facilitated by identifying and developing more data reporting requirements.
    - Data gaps may be revealed that will need to be filled.
2. Curating the data. The CEC should craft appropriate databases that make the data accessible to researchers and decision-makers in readily-usable formats.
    - Commensurability should be an overriding concern.
    - The more finely-grained databases must protect privacy, in accordance with prevailing research standards.

5.2. Prioritizing Research

An urban metabolism research program is a novel undertaking, as relatively few such programs exist. As such, the priorities identified in this road map should not be considered set in stone, but rather should be periodically evaluated and if necessary adjusted or changed. The initial research funding priorities in this roadmap were determined based on several criteria:

- Importance in determining energy consumption and use
- Lack of existing data on the processes that govern energy systems
- Relevance to other aspects of the energy system
- Ability to provide fundamental insight into energy system dynamics
- Applicability to existing Energy Commission program areas and research
- Likelihood of providing greater ability to prioritize and fund future research

This final criterion is based on the logic that as a research program is built, greater knowledge of how to conduct research will be generated. Thus it is important to begin with research that provides fundamental analyses of California's energy systems and will be able to generate further research questions that may enter more deeply into the complexity of these systems.

Because the process of setting research priorities will be ongoing and dynamic a process that will allow for this continuous priority setting will have to be created. The process may involve the reporting out of the research experts assembled for each of the areas discussed above and the determination of the feasibility of the research, and its urgency. To summarize the points made throughout the roadmap:

- Short-term
  - Conduct workshops with academic researchers and policy-makers (sometimes separate, sometimes together) and other experts to determine and prioritize specific research agendas.
  - Engage the research community to help identify data gaps, policy priorities, and methods for interdisciplinary research
  - Identify data gaps in energy generation and energy consumption for California communities, including both explicit energy and socioeconomic metrics as a disaggregated level (need to be able to identify energy use with uses and places, not energy use at an MPO or city level).
  - Develop common metrics for reporting data across sectors and places.
  - Identify major policy factors that condition energy use such as revenue needs, fiscal mechanisms, land use priorities, transportation planning, etc.
- Medium-term
  - Create accessible databases for research and decision-making
  - Begin synthesizing data to characterize the metabolism of the state's major MPOs
  - Integrate complex methods and models, such as PECAS and new LCA approaches
- Long-term
  - Create decision support systems that will allow the urban metabolism research to be used for fostering sustainable energy systems
  - Design urban system level energy accounting methods that assemble appropriate data and allow effective assessment and forecasting of energy needs
  - Analyze natural experiments around the state where different policy or planning steps were taken and quantify the energy and sustainable impacts of those different paths

5.3. Interdisciplinary Research

PIER has recognized the need for an interdisciplinary research approach. Interdisciplinary research, however, 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, recounts how it took nearly 40 years 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 a way that can influence policy (Van der Sluijs et al. 1998; Hodgson and Smith 2007).

Integrated research for creating sustainable energy systems in California communities will require the collaboration of multiple disciplines. As the climate science example shows, interdisciplinary work requires dedication and vision, and an ability to build a broad and welcoming tent for traditionally disparate sets of research inquiries. The ability to think in interdisciplinary ways, to forge integration among different approaches requires time and effort. Trust among researchers from different disciplines will need to be actively created as well as 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.

Working across disciplines is a challenge for researchers. There are several barriers within disciplines as well as between fields, particularly when the research involves physical sciences, social sciences, and applied research (Lélé and Norgaard). Interdisciplinary research requires clarity in the research process to create appropriate cooperation within and across realms (Hodgson and Smith). This activity must be built on:

- 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.

6.0 Conclusion

To help California become more sustainable and reduce its energy consumption, the Energy Commission should engage in the examination of how Californians live on the land and how they conduct their daily life. As California implements new policies and technologies that change the sources and uses of energy, researchers and policy makers will have to re-evaluate the entire energy system and begin planning in a more integrated manner. The relationship between energy consumption and land use is the impetus behind California's forward looking land-use planning legislation, SB 375, although SB 375 addresses only one aspect of the state's unsustainable foundation of current land use and energy patterns. Urbanization and energy use 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), but many more factors are at play. Unfortunately, the state has little empirical data on the relationship between different types of land use and energy throughputs, including waste. The state also has little empirical data about how different regulations, fiscal incentives, and jurisdictional scales influence land use and therefore energy consumption. Consequently, California's population, including its decision-makers, cannot sufficiently see the interactions between the state's current forms of urbanization, human health, agricultural land viability, ecosystem health, water resources availability, equity, and the global climate system.

Urban metabolism is a method that can help the understanding of the complexity of communities and the interactions among the parts that make communities whole systems. The research program recommended in this roadmap will require an unprecedented commitment to integrating domains of research into a systemic body of knowledge about energy use in California communities, including the relationship between energy use and community populations and policy factors. It calls for the examination of the complex underpinnings of energy use in California communities, which are driven by multiple—and sometimes contradictory—policy directives, rules, incentives and decisions at all levels of government. Private decision-making also shapes California communities and their energy use. Decisions by lenders, for example, often dictate what kinds of development styles and patterns can be constructed in the state. And the state's diverse and growing population is another important factor to take into account when attempting to explain or forecast energy use.

PIER is in a unique position to guide such an integrated research initiative. Over time, incrementally, data gaps will be identified that require greater research and/or better reporting processes or rules. Provided the UM research framework, information will be correlated and assembled in novel ways to provide new insights into land use patterns and energy use in California, as well as a set of other important and contingent energy flows and their pollution outputs.