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PREFACE

The California Energy Commission Energy Research and Development Division 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 Energy Research and Development Division conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

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- Renewable Energy Technologies
- Transportation

Los Angeles County Regional Baseline Pilot is the final report for the Methodology to Develop Energy Baselines for California’s Regions project (500-10-033) conducted by The Regents of the University of California, Los Angeles. The information from this project contributes to Energy Research and Development Division’s Transportation Program.

For more information about the Energy Research and Development Division, please visit the Energy Commission’s website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.
ABSTRACT

California is a leader in the country in using less energy per capita, advanced building standards, and efficient industrial and commercial technologies. The next decades will require even more changes and innovations to meet 2050 greenhouse gas emissions goals, improve air quality and ensure that water supplies are sufficient. This research provides a new framework, to analyze energy use in the state. Urban metabolism is the total of the technical and socio-economic processes that occur in cities resulting in growth, the production of energy and the elimination of waste. This study attempted to improve the policy relevance of urban metabolism by refining the scale of the analysis to reveal the actual flows at the census block scale, and to address the economic, equity and environmental issues associated with the urban metabolism of Los Angeles County. The preliminary results presented in the report provide novel insights into the relationships between built environment characteristics, census characteristics, jobs, wages and environmental impacts, and they identify significant data gaps. The level of detail presented in this report should help policymakers, cities, and local governments better understand patterns of energy consumption and assist in their future planning of conservation and efficiency investments, rate and tariff adjustments, economic development strategies, and more. This approach, with its mixed methods, will provide a new analytical framework for other regions in the state in the future.

Keywords: California Energy Commission, urban metabolism, energy use, greenhouse gas accounting

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EXECUTIVE SUMMARY

The next decades for California will require even more changes and innovations to meet 2050 greenhouse gas emissions goals, improve air quality (regulated under different rules and regulations), and ensure that water supplies are sufficient. This research investigates a new framework to analyze energy use in the state. Urban metabolism is the total of the technical and socio-economic processes that occur in cities resulting in growth, energy production and the elimination of waste (Kennedy et al 2007). Humans use approximately 60 billion tons of material every year. Urban metabolism studies quantify material flows into cities or communities (such as electrons, water, wood, air, other materials, and food), flows out of these entities (pollution, other waste, losses as heat and distribution), and what remains inside. To date, urban metabolism analyses have largely been conducted at a city level – including Los Angeles, Hong Kong, and Paris – or at the neighborhood scale.

This study attempts to improve the policy relevance of urban metabolism by refining the scale of the analysis to how flows are used at a fine granular scale. Previous studies of city metabolism have been at a highly aggregated level, making it more difficult to both discern who is using the various resource flows where to do what, and then to reduce them through conservation measures or other policies. In this work the census block scale is used with a level of aggregation that protects the privacy of individuals and businesses but reveals patterns of resource use across Los Angeles County. Address-level electricity and natural gas data was obtained from the Energy Commission and electricity data was obtained from the Los Angeles Department of Water and Power, both under non-disclosure agreements. This initiative took over two years and the analysis presented below is constrained due to the lack of time to conduct the full analysis.

This research project also drew on a novel set of research collaborators across different disciplines – including engineering, transportation planning, and employment economics (conducted by a research nonprofit) – directed and coordinated by the California Center for Sustainable Communities at UCLA’s Institute of the Environment and Sustainability. This unusual collaboration led to some methodological challenges particularly for the reconciliation of data sets, agreement on the setting of boundaries, and vocabulary. However, the preliminary results presented in the report provide novel insights into the relationships between built environment characteristics, census characteristics, jobs, wages and environmental impacts, and they identify significant data gaps. The level of detail presented in this report should help policy makers, cities and other local governments better understand patterns of energy consumption and assist in their future planning of conservation and efficiency investments, rate and tariff adjustments, economic development strategies, and more. This approach, with its mixed methods, will provide a new analytical framework for other regions in the state in the future. It can significantly improve the accuracy of greenhouse gas accounting, create a pathway to establish real baselines of energy use so that improvements can be assessed accurately, and identify programs that are not achieving desired outcomes.
The results of this analysis can be briefly summarized as follows:

- There is a strong correlation between energy use and wealth throughout Los Angeles County.

- The relationship between building age, construction type and energy use varies depending on the type of building and decade in which it was built.

- It is important to correlate the urban morphology of county cities (types of buildings and their heights and sizes) with energy use to determine the appropriate thresholds for new energy disclosure policies.
  - Accounting for embedded energy through a life cycle analysis of buildings and roadways can provide new insights about the tradeoffs between new infrastructure investments or the reinvestment and repurposing of existing infrastructure. This issue is also related to and interacts with urban morphology.

- There is a strong relationship between high paying jobs and high greenhouse gas (GHG) emissions in the region’s industrial sectors such as petrochemical refining and energy production.

- High paying jobs in commercial and professional occupations are much less greenhouse gas emissions intensive.

- Very little is known about the composition of solid waste and diverted recyclables by sector and geography in the region, and even less is known about those relationships and wealth, size of firm and so forth.

- Water use data is lacking and should be collected and analyzed.

Finally, it is important to acknowledge that current urban form and energy use is a product of soft and hard infrastructures that co-produce the urban environment. Soft infrastructures are rules, laws, codes, procedures and norms. Hard infrastructures are the buildings, roads, pipes and wires that are deployed for urban life. Unraveling the soft infrastructures and the ways in which they both create and are then constrained by the hard infrastructures are important next steps for urban metabolism analysis. Some of this is implicit in this report – zoning codes, building codes, traffic codes and the conventions about road widths clearly are developed by regulators and professional associations, and enforced through regulations. These are at the heart of the region’s urban form and much of its energy use, but they are also dependent on the fact that today’s energy remains primarily carbon-based. That fossil (or carbon-based) fuels have been so abundant, inexpensive, flexible in their application, and easy to transport where they are needed have deeply shaped contemporary urbanization. Rules have been created to facilitate their development and subsidize their utilization. All of this needs to be factored into strategies that foster a transition to more sustainable energy sources that have less negative impacts. The urban metabolism approach presented in this report is one method that can help in that transformation by providing unprecedented empirical data about how energy is used, and how to measure the effectiveness of alternatives.
CHAPTER 1: 
Introduction and Purpose

California is a national and international leader in energy policy and initiatives, particularly with respect to the reduction of GHG emissions. These include well-known legislation such as AB 32 and SB 375, and more recent regulatory initiatives by the Energy Commission, requiring zero net energy buildings by 2020 for all new residential construction and 2030 for all new commercial construction. GHG emissions accounting is increasingly a matter of course for every local government in the state, and the major industrial sectors must report their GHGs. The state’s renewable energy standards set high goals of 33 percent of total procurement by 2020, and AB 32 sets a goal of reducing GHG emissions by 80 percent below 1990 levels by 2050. AB 32 also launched a cap-and-trade program to reduce GHG emissions. Yet the state’s multiple forward-thinking initiatives tend to operate in independent spheres; they are insufficiently integrated and do not inform or reinforce one another or create coordinated programs. For example, the state’s renewable energy portfolio and clean energy goals operate independently from utility energy conservation and efficiency programs and/or analysis of life cycle impacts of buildings and roads. GHG emissions reductions goals are not examined or strategically integrated with policies focusing on jobs, wages and economics, and the relationship between GHG emissions and air pollution is often disregarded. As this report will highlight, some of the Los Angeles region’s best-paying jobs happen to be in the fossil fuel industry, an industry that also manufactures a product that creates significant criteria pollutants and GHG emissions.

This report applies a new approach to understanding and accounting for energy flows called urban metabolism (UM), which reveals the interacting relationships of energy, materials and other resource flows into urban systems and pollution out of them. This research implements a novel methodology that can be replicated throughout the state. UM is applied to understanding energy and resource flows into and out of Los Angeles County, the most populous county in the United States. This kind of analysis and study provides insights into energy use that have not existed heretofore and new insights into potential energy use reduction policies and programs.

Urban metabolism is “the sum total of the technical and socio-economic process that occur in cities, resulting in growth, production of energy and elimination of waste” (Kennedy et al 2007). Fundamentally, urban metabolism is about the accounting and analysis of how humans alter the biophysical landscape through the application of energy, which, in contemporary society, is fossil fuel-based. It tracks the inputs into cities and the waste outputs; where possible, it identifies how and by whom those inputs are used, and where in the urban landscape it takes place (Pincetl 2012, 2014). Due to the impacts of burning fossil fuels on the earth’s atmosphere, and the concomitant effect on air, soils and public health, it is critical to delve into how energy is used in cities in order to develop policies and programs that reduce fossil fuel energy dependencies and the waste stream that results. This includes accounting for embedded energy within the urban fabric – the energy used or expended to build buildings, roads and other infrastructure. The existing urban infrastructure – the hard infrastructure -- was made from
materials extracted from the earth through energy expenditure that contributed GHGs and air pollutants to the atmosphere, used water in materials transformation processes, used energy in transport and construction, and created environmental impacts at the places of origin (Chester et al 2013). All this is important to consider, particularly when policy makers are confronted with decisions about the redevelopment and densification of already-built areas, or building anew. Such accounting is known as Life Cycle Analysis (LCA) and is an integral part of urban metabolism in this application. The research also investigates GHG per wage per job in the county as a novel approach in UM and in GHG accounting. Such analysis directs attention to the intimate relationships between economic activity, wages and GHG emissions, showing in stark terms the articulation of current economies and fossil fuels.

Energy use and the driving factors (soft infrastructures of rules, codes, conventions, laws and expectations) that create energy consumption patterns are critical for California communities to unravel and to account for in order to substantially reduce fossil fuel-based energy use. This includes examining the age and shape of cities, building types and ages, transportation systems, energy use and employment. The work in this report reflects this analysis, implementing an approach to urban metabolism that goes beyond questions of energy efficiency and conservation to build an integrative analysis that more completely and synthetically depicts the energy metabolism of communities. It asks the question of who is using what energy where to do what, and includes the built environment, transportation and employment factors of the urban economy. This study applies a ground-up approach, quantifying the actual use at the most detailed level of specificity obtainable by researchers and overlaying that information onto a number of characteristics, as elaborated below and chapter-by-chapter.

Figure 1.1: Life Cycle Assessment and Nested Urban Metabolism

Source: Chester et al. 2012
1.1 Methodological Innovations: Multiple Data Sets and Ground-up Data

The approach to urban metabolism used in this report goes beyond most UM studies for a number of reasons, from methodological innovations to the unique opportunity for disaggregated data acquisition. It overlays county tax assessor parcel information (size and type of building, building age and construction), census sociodemographic data, address-level electricity and natural gas data (aggregated to the census block group to protect customer privacy), economic data (IMPLAN, as described below, as well as sector employment and wage data), ATHENA building energy software tools, and Life Cycle Analysis. The ATHENA building energy software tools enabled researchers to account for building shell energy expenditures and to determine how much energy is embedded in existing building stock in Los Angeles County. The same exercise was conducted for roadways using the Pavement Life-cycle Assessment Tool for Environmental and Economic Effects (Horvath, 2003). The analysis incorporates economic data using IMPLAN (Impact Analysis for Planning), which enables the quantification of energy flows in the economy and GHG emissions from different sectors. IMPLAN provides state-level input-output data in combination with ZIP codes (postal code of the U.S. Post Office of five decimal numerical digits), and uses annual national economic data. This study combines IMPLAN economic data for 2008 with the Carnegie Mellon Economic Input Output-Life Cycle Analysis that is California-specific, but based on 2002 IMPLAN data. Additionally this study benefited from parcel-level electricity and natural gas data over seven years by customer class, obtained through a nondisclosure agreement with the California Public Utilities Commission for the Investor-Owned Utilities (IOUs), and with the Los Angeles Department of Water and Power (LADWP) for the City of Los Angeles.

The combination and overlying of these different data sources allows for an unprecedented “thick” description of the urban metabolism of Los Angeles County enabling the examination of how different levels, sectors and dynamics create the region’s energy metabolism. In this research, maps are combined with tables, charts and statistical analysis to create multidimensional descriptions of the County’s metabolism, showing how the different elements affect and interact with each other. Through this work, the role of the region’s hard and embedded infrastructure and land use patterns becomes evident not only in current flows, but in expended energy used to build and maintain what exists today. At the same time, each of these patterns is guided, and, sometimes even dictated, by rules and codes. For example, the zoning code, which is a soft infrastructure, essentially constrains the types and uses of buildings that can be built in the different parts of the city. Building codes then dictate certain measures for health and safety or energy conservation that inform the construction of hard infrastructures. Green building codes and low-impact development codes are all part of the soft infrastructures of governance and government that affect hard infrastructure deployment and change. Clearly, once the hard infrastructures are in place, they constrain soft infrastructure development – for example, a rule that would require all lots to retrofit to low-impact development is unlikely due to the difficulty and cost of doing so physically, as desirable as it might be.
Nonetheless, energy use at the city and neighborhood scale is poorly documented and data is difficult to obtain. In a paradox of policies, metropolitan planning organizations (MPOs) and cities (through general plan updates) are required to do environmental and climate change planning, yet they are not equipped with the appropriate scale of data necessary to target mitigation efforts around energy consumption. Not only do cities and counties generally not have energy consumption data at the address-level – even for their own buildings – but water consumption data is almost non-existent at this scale. Both are critical, given future climate impacts that are projected to increase the number of high-degree heat days and California’s historical drought cycles. Furthermore, there is the well-known but poorly-documented embedded energy in water in southern California.

An important research finding is that geographically-disaggregated energy use data greatly improves the understanding of a community’s energy use. Address-level energy billing data, by month, by year and by customer class – matched to building characteristics such as type, age, size, shell, climate zone, industrial classification code or sociodemographic profiles – provides the ability to develop multivariate regressions to understand what the drivers of energy use are among income, size of building, location, type of activity, and others characteristics that much research has not yet addressed. This level of understanding can then allow targeted, verified and precise energy conservation and efficiency interventions. In addition, it allows the creation of baselines of energy use over time, where energy use by various characteristics can be tracked to determine change. Thus, in a number of years hence, policy makers, regulators, utilities, researchers and others, will be able to access this analysis and see if there has been change at all, and if so, what the change looks like.

This leads to a policy recommendation that such analysis should be conducted for all of California, and that energy use data should be housed consistently and over time in a centralized library, allowing such research to be conducted. Such a program – establishing an energy data repository – will also enable research to take place over time such that in a decade or two from now, researchers will be able to analyze temporal trends. Currently, such longitudinal analysis is not possible. It is not possible to know the effectiveness of programs and policies with any specificity. Such lack of analysis means that efficiencies are lost in targeting programs – knowing specifically what works where, for whom and over time can enable far more effective use of funds and programs.

While this study pushes the envelope of urban metabolism methods and is unique in its use of disaggregated energy use date and employment data, given the quality and status of the data, UM must remain somewhat opportunistic and will not be as methodologically homogeneous as would be most optimal. For example, researchers were not able to obtain data from the same baseline year – rather, the EIO-LCA data is from 2002, IMPLAN from 2008, and the Pavement Assessment tool from 2007. Researchers chose to use eGRID2012 values, reflecting California-wide average emissions for electricity generation that do not reflect the actual emissions from different regions, not fully taking into account that the City of Los Angeles uses coal as part of its generation. The analysis was concluded before the closure of the San Onofre Nuclear Generating Station, so the report does not reflect the additional use of natural gas that will be and has been coming on line for electricity generation. These issues are unfortunate, but an
artifact of current data availability and the use of multiple expert teams that did not always agree on methods and data. Other areas that were difficult to reconcile among teams were the industrial classification codes that different teams compressed at different scales as well as the range of building types. In the future, a greater emphasis should be put on insisting on similar metrics across all research teams, something that is easier to accomplish when teams work together over longer periods of time.

Importantly, this work points to the need for updating EIO-LCA, an intensive but critical enterprise. This study of Los Angeles County is the first of its kind and has clear methodological weaknesses – as have been laid out above – but it is a template of what is possible with good data. However, there is no doubt that it can and will be improved upon in the future.

Using urban metabolism in this manner is critical for sustainability planning. This report addresses the three-legged stool of sustainability by looking at the environment through GHG emissions, waste flows and air pollution, life cycle analysis, and energy use across the region; the economy, by analyzing economic viability based on size and growth of firms, as well as by pointing toward the need to decouple economic growth from GHG emissions in order to find other types of economic activity that are not fossil fuel-intensive and/or to develop non-fossil energy sources; and social sustainability based on wages for workers. This inclusive framework for assessing sustainability draws on the concept of three pillars of sustainable development that was put forward by the United Nations Brundtland Commission in 1987.

The analysis presented in this report provides the foundation for being able to do so, but importantly points to the major components of a region’s metabolism. Researchers are able to show, for example, the relationship between building age, its embedded energy and energy use today. This coupled analysis is important as it provides insight into the impacts of life cycle energy expenditures when older buildings with greater embedded energy but potentially lower current energy use (an empirically verifiable question with the data collected under the aegis of this project) are replaced by newer buildings that have less embedded energy due to more efficient materials extraction and processing, but potentially higher – or lower – energy use. Similarly, the analysis of GHG emissions in the economy points to the need to research and understand the relationship between a specific region’s economy and fossil fuels. Furthermore, there is an important link between transportation-related GHGs, air pollution and embedded energy in the road infrastructure (which are highly GHG-intensive, especially freeways) that this research highlights for further analysis.

Clearly, with population growth and demographic composition dramatically changing in the state, better and more disaggregated information about existing energy use, how that energy is used (by whom, where, and for what), and the social impacts in California communities over time will allow the Energy Commission to both plan for prospective energy needs and to develop policies that can impact energy use, the environment and society. The research in this report should provide the Energy Commission, stakeholders such as local governments, and policy makers with new information, data, and methods for implementing integrated energy planning.
1.2 Los Angeles County

Los Angeles County encompasses 4,750 square miles of Southern California and, as of 2013, it is estimated to house over 10 million residents (Los Angeles Almanac, 2014; U.S. Census Bureau, 2014). This means that Los Angeles County contains just over one-quarter of California’s 38 million people (U.S. Census Bureau, 2014). The county contains 88 cities: Los Angeles is the county’s largest city with nearly four million people, followed by Long Beach and Glendale, which as of 2010 had populations of approximately 462,000 and 192,000 respectively (U.S. Census Bureau, 2014). In contrast, Vernon is L.A. County’s least populated city with only 112 people (U.S. Census Bureau, 2014). Los Angeles County is projected to increase to a population of more than 11.5 million people (an 18 percent increase) over the next 50 years, while the State of California is expected to increase to nearly 52.7 million people (a 41 percent increase) over the same time (California Department of Finance, 2013).

Los Angeles County is located within the Southern California Association of Governments (SCAG) MPO. SCAG is the largest MPO in California and has five subregion councils: Gateway Cities Council of Governments, Las Virgenes-Malibu Council of Governments, San Gabriel Valley Council of Governments, South Bay Cities Council of Governments, and Westside Cities Council of Governments (Southern California Council of Governments, 2014). These councils allow smaller cities within Los Angeles County to coordinate and work toward common goals and governance.

Figure 1.2: Los Angeles County regions

1.2.1 Geography and Climate

Los Angeles County contains mountains, beaches, deserts, and islands. The county is bordered by the Pacific Ocean to the west, and contains two of the Channel Islands, including Santa Catalina—one of the largest islands off the coast of California. The Santa Monica Mountains and San Gabriel Mountains are both located in the county and Mount San Antonio is its highest peak at over 10,000 feet (Los Angeles Almanac, 2014). There are four rivers—the Los Angeles River is the longest with nearly 100 miles in its stream—and various lakes, of which Castaic and Pyramid Lake are the largest (Los Angeles Almanac, 2014).

Los Angeles County’s climate ranges from dry Mediterranean in the Los Angeles basin to much more arid conditions in the eastern portion of the county. The average daily maximum temperature in Los Angeles County is around 76 degrees Fahrenheit, while the minimum is around 58 (Los Angeles, Almanac, 2014). The average monthly temperature high ranges from 84 degrees in August to just under 68 degrees in December while the record highest and lowest temperatures were 113 degrees in 2010 and 25 degrees in 1911, respectively (Los Angeles, Almanac, 2014).

1.2.2 Demographics

As shown in the pie chart to the right, just under half (48 percent) of Los Angeles County’s population is of Hispanic or Latino descent. Forty-eight percent of the county’s population is white, 14 percent are Asian, 9 percent black, and less than 1 percent of the population identifies as American Indian (U.S. Census Bureau, 2014).

The median household income from 2008-2012 for the county is approximately $56,000 (U.S. Census Bureau, 2014). The highest median household income for neighborhoods and cities within Los Angeles County is Bel Air at nearly $208,000, while the lowest is downtown at only $15,000 (Los Angeles Times, 2014A).

1.2.3 Transportation

Many interstate highways including the I-5, I-10, I-110, I-405, and the U.S. route 101 serve Los Angeles County. In addition, many well-known streets such as east-west thoroughfares Wilshire and Santa Monica Boulevard, as well as famous shopping and tourist streets like Hollywood Boulevard, Sunset Boulevard, and Rodeo Drive are located in the county. In regards to public transportation, the largest transit provider is Los Angeles County Metropolitan Transportation Authority (LACMTA), also shortened to Metro, which provides bus and rail transit to county residents. The county also has Amtrak stations that allow residents to travel outside the county and state.

Los Angeles County also houses one of the busiest airports in the world, the Los Angeles International Airport (LAX), located in the Westchester district (Airports Council International, 2014). Other airports in the county include Bob Hope Airport in Burbank, Long Beach Municipal Airport, and the Santa Monica Airport that serves chiefly non-commercial air traffic.

Two major seaports serve Los Angeles County: the Port of Los Angeles and the Port of Long Beach. While the two ports are independently-operated and compete for business, combined
they rank sixth busiest in the world by the volume of cargo containers shipped and are the busiest in the United States of America (Port of Long Beach, 2014).

1.2.4 Economy and Jobs

Los Angeles County is known for its entertainment industry, and groups such as Warner Bros. Studio, Walt Disney, Sony Pictures Entertainment, and FX Networks LLC all rank among the county’s top employers (State of California Employment Development Department, 2014A). However, despite its reputation, the entertainment industry makes up a relatively small portion of the job market with an estimated 200,000 jobs classified between the Information and Leisure & Hospitality industries (U.S. Census Bureau, 2014). Some of the county’s public universities are also considered major employers, including UCLA, Santa Monica College, and California State University. Public service institutions such as the Long Beach City Hall, Los Angeles County Sherriff’s Department and Los Angeles County Police Department also rank among the county’s top employers. Health care institutions, including Cedars-Sinai Medical Center, UCLA Health Systems, Providence Holy Cross Cancer, Pomona Valley Hospital Medical Center, and Long Beach Memorial Medical Center, also provide thousands of L.A. County residents with employment.

Figure 1.3: Job Industry breakdown in L.A. County

This chart presents a breakdown of industries that provide the most jobs in Los Angeles County as of June 2014.

Source: Economic Roundtable 2014

Trade, Transportation, and Utilities, Education and Health Services, Government, and Leisure and Hospitality provide the most jobs in the county (State of California Employment Development Department, 2014B).
When expanding from Los Angeles County to the entire Los Angeles-Long Beach-Santa Ana Metropolitan Statistical Area (MSA), the area is the largest manufacturing workforce in the country with 510,900 manufacturing workers as of July 2014 (Los Angeles Times, 2014B). However, because of the large population within the Los Angeles area, manufacturing makes up only 9.1 percent of employment in the MSA and only 8.4 percent within Los Angeles County. As the next sections of the report will show, economic activities in the region show a wide difference in energy use and GHG emissions. Building energy use, for each of these sectors, varies as well, depending on the building characteristics themselves and their activities. When economic activity is analyzed by GHG emissions by wage, the environmental impacts of the region’s economy become apparent, especially since GHGs are closely linked to criteria pollutants..

Los Angeles is a world metropolis situated in a fragile air shed that provides homes and jobs for a transnational labor force. The region’s future will emerge out of an economy deeply intertwined with both environmental and socio-economic realities. Achieving sustainability requires an industry structure that provides enough jobs for the labor force, pays sustaining wages to workers, and sharply reduces the ratio of greenhouse gas emissions to jobs.
CHAPTER 2:
Urban Metabolism Flows Overview

2.1 Overview

The following sections consist of in-depth reporting of each component of the urban metabolism analysis. It includes embedded energy and GHG emissions profiles for every building present in the 2008 Los Angeles Assessor database and all of the roadways. This establishes the background context of the energy in the existing urban fabric, excluding some of the infrastructure such as the pipes and wires in buildings and those that supply the region (for example, transmission wires, the pipes that bring in, and distribute water and dispose of waste water and so forth). It shows the pulse of development of Los Angeles County over time, and that single-family homes are found to be the most significant sinks of embedded energy use and GHG emissions despite their comparatively lower prototype factors that is they tend to be smaller buildings that each individually do not have high embedded energy. For roadways, despite comprising nearly 76 percent of the network, local roads account for 41 percent and 39 percent of the cumulative construction impact for energy use and GHG emissions. In contrast, while only comprising 2 percent of the entire network, freeways/highways are responsible for 29 percent and 34 percent of the cumulative construction impact for energy use and GHG emissions. This has policy implications for further investment in transportation infrastructure.

The embedded energy analysis offers a description of the existing built environment, the expended and in-place energy upon which the flows of current energy use are draped. This is essentially the city’s skeleton, the hard infrastructure within which activities occur. It too, however, required building, and continues to require maintenance. It has an energy and GHG history that is part of our current emissions levels, and created supply chain impacts as materials were extracted, processed and transported for use in Los Angeles County. Thus it is important to take this hard structure and its needs into consideration in understanding a community/city/region’s metabolism as it conditions what activities take place, it creates path dependencies and emergent behavior (Chester et al 2012). Emergent behavior includes such manifestations as wider roads facilitating faster automobile traffic, inhibiting, for example, bicycling, walking, or neighborhood stores. Undoing, reconfiguring, urban infrastructure to achieve different goals then requires the expenditure of energy and materials, causing further GHG emissions and supply chain impacts. To date, neither urban metabolism or GHG accounting includes embedded infrastructure energy, thus inadvertently neglecting costs of new development compared to changing already existing infrastructure, and/or remodeling and retrofitting compared to demolition and new construction. Of course, any major hard infrastructure changes require concomitant changes in soft infrastructure (or vice-versa), and changing roads, say from a 12 foot width to a 10 foot width, as is now being recommended for traffic calming, needs both to come together to facilitate change toward more bicycle and pedestrian friendly neighborhoods.

The report therefore begins by accounting for building and transportation embedded energy in Los Angeles County. Such analysis also reveals the timing and patterns of development over
the region’s history, and the associated energy and GHG impacts. Importantly it reveals the disproportionate costs of maintaining freeways and highways in contrast to surface streets.

Patterns of electricity and natural gas use across the region are then presented. Using here-to-fore unavailable address level consumption data (as of 2014 such data are available upon request to the Independently Owned Utilities (IOUs) by University of California Los Angeles researchers), researchers mapped usage, aggregated to census block group to protect customer privacy. Overlaid with census socio-demographic data, county tax assessor parcel data (age of structure, size, building shell), climate zone and industrial classification code, the maps reveal the energy use patterns of the region. Further analysis shows energy use by building class, building age, building size, as well as by different socioeconomic groups and by industry.

The report then turns to examining the GHG emissions of the different sectors of the economy and then the social sustainability of those sectors in terms of wages per GHG emissions. For the region to become more sustainable in the classic sense of sustainability – environment, economy and society – such understandings are critical. It is clear in the Los Angeles region, that its rich inheritance of fossil fuel extraction and processing currently provides well-paying jobs, but at the cost of environmental quality and health. Older traditional industries, such as manufacturing of different types, also show greater energy use and GHG emissions. This is scarcely surprising, but it points to the heavy legacy of fossil fuel energy sources that need to be addressed to reduce these emissions. Simply importing those manufactured goods does not change global GHG emissions; the problem is the fuel mix. Analysis also shows the significant amount of natural gas used to create electricity, a situation that will be exacerbated by the closing of the San Onofre Nuclear Generating Station (SONGS). Over 1,800MW of replacement energy is considered necessary over the medium term in Edison territory alone, possibly more over the longer term. Replacement energy is 400 MW of non-fossil fuel energy for Edison; the rest is conventional fossil fuel energy. Given the high energy use of traditional manufacturing, and much of the economy, this situation is a kind of an energy path lock-in.

Further analysis also shows that service sector jobs, among the least well paid, generate a disproportionate amount of transportation GHGs, and their geographical locations show the impacts of suburbanization and the passage of the property tax reduction measure Proposition 13. Newer suburbs have zoned land for commercial, sales tax producing land uses. These land uses attract shoppers who generally are automobile dependent, but the jobs themselves pay poorly. Moreover, while the jobs and activities themselves do not generate a lot of GHGs or even criteria pollutants, they rely on products produced elsewhere and off shored GHG production. They do generate GHGs due to transportation requirements that result from segregated land uses.

Thus contemporary urban life in this region is predicated on energy and energy use. Understanding it in more geographically specific ways, matched up with other factors, and using a mixed methods approach, has produced new knowledge that can be actionable.

Specific methods are found for each section and type of analysis. Overall, however, another innovation of this research has been to imagine the partnering of different disciplines, bringing
different methods, models and data sources. Urban planning and geography constructed the analysis from a perspective of urban systems and urban morphology – looking at connections between how cities are laid out, the spatial patterns of income and economy, and an interest in supply chain impacts on the supplying regions. From engineering come life cycle analysis and the use of engineering models to estimate GHGs by different building types and roads as well as VMT and travel behavior models. From economics comes the use of several economic activity models couples with life cycle economic input output data. These methods and disciplinary approaches were combined to provide a very different type of analysis of a region’s interdependence with energy. It is hoped it will lead to novel understandings and further research of this type to advance the state’s sustainability (Pincetl et al 2014).

To fully understand a region’s urban metabolism, a number of additional categories must be analyzed. In the following sections we discuss transportation energy use and GHG emissions at a schematic level as the research did not focus on this issue, as well as solid waste and criteria pollutants. Criteria pollutants are included to illustrate the need to address air emissions beyond GHG emissions and the focus on transportation GHGs that have occluded the impacts of criteria pollutants associated with fossil fuel energy use. While researchers conducted specific research on solid waste, data was so sparse that the analysis remains very aggregated. The report does not explore wastewater and water pollution. Transportation emissions, as discussed in the previous two chapters, are significant by-products of the economy and economic activity, they are well-documented in other studies—notably by the Southern California Association of Governments and the state Air Resources Board—but they are also an important aspect of how the regional economy works, embedded in each sector as the previous chapter shows.

2.2 Transportation

2.2.1 Overview

Los Angeles’ built environment exemplifies 20th century growth and development patterns. Population migration and settlement in the region began in the late 1800s and developed concurrently with the Los Angeles streetcar system. In many ways, the streetcar system created the backbone for Los Angeles’ sprawled development and land use speculation patterns while distributing electricity through the streetcar cables to new development (Jones, D 1985). Large amounts of capital were not invested until the early 1900s—the same time the private automobile became available. Los Angeles’ urban landscape differs from many other large urban areas in that it not only accommodates private automobile travel, it was designed for it.

Travel plays many roles for Angelenos by connecting and moving people, goods, and ideas. The transportation system creates access to opportunities, social interactions, and economic exchanges. There are many utilities of travel, and the transportation system plays an integral role in helping (or hurting) the economy. While there are many benefits associated with travel, it can also result in negative externalities such as air pollution and greenhouse gas emissions. As discussed in the previous sections, Los Angeles has already expended enormous amounts of emissions on the built environment. Los Angeles County has 915 freeway and highway miles (Caltrans District 7 2014), 87.8 miles of fixed rail and 40 miles of bus rapid transit right of way.
These investments come at a high price in terms of the environment and economics. It is critical to keep in mind the embedded energy required to build the transportation system’s existing infrastructure as the region considers options to follow the aims of SB 375 to reduce per capita emissions.

2.2.2 On-Road Vehicle Emissions

On-road transportation emissions come from two major vehicle sub-groups (light/medium duty vehicles and heavy-duty trucks) and make up nearly 34% of Los Angeles County’s total greenhouse gas emissions (LARC 2013). For 2010, total GHG emissions from on-road transportation in LA County were 32.2 million MTCO2e, with nearly 90 percent of these emissions originating from light/medium-duty vehicles (Figure 2.1).

![Figure 2.1: On-Road Transportation Emissions](source: SCAG and LA County GHG Inventory)

According to the 2010 Highway Performance Monitoring System report from Caltrans, over 211.9 million vehicle miles were traveled daily within Los Angeles County. In 2012, annual VMT per capita in LA County was 7,869 miles (Caltrans Highway Performance Monitoring System; Metro Sustainability Report 2012).

According to the LA County 2010 Inventory, light-duty and medium-duty vehicles have the most vehicles miles traveled within LA County and comprise a majority of on-road GHG emissions. However, they proportionally emit fewer GHGs per mile traveled in comparison to heavy-duty trucks. Even though heavy-duty trucks travel only 6 percent of vehicle miles in Los Angeles County, they emit 11 percent of the on-road transportation GHG emissions (Figure 2.2).

---

1 LA County Regional 2010 GHG Inventory: Executive Summary
2.2.3 Heavy-Duty Trucks and Goods Movement

Goods movement is an integral part of the regional, state, and national economy. Combined, the Port of Long Beach and Port of Los Angeles (collectively known as the San Pedro Ports) are the largest in the nation, and sixth largest in the world (AAPA, 2010). In 2010, 14.1 million twenty-foot equivalent units (TEUs) of containerized cargo travelled through the San Pedro Ports, accounting for 33 percent of all port container movement in the United States.

Freight movement via heavy-duty trucks and railways are a central part of logistics and the role of transportation will increase as businesses increase their reliance of just-in-time delivery practices. SCAG, Metro, and many other regional southern California agencies project the San Pedro Ports will accommodate 40 million TEUs by 2035 (Southern California Multi-County Goods Movement Action Plan 2008; SCAG RTP/SCS 2012). Additionally, the ports contribute to the SCAG region’s relative strength in the manufacturing sector, with Los Angeles County ranked 1st, Orange County ranked 10th, and the San Bernardino-Riverside area ranked 15th nationally (SCAG RTP/SCS 2012).

2.2.4 Transit Operation Emissions

Public transit provides an important service to the region. Not only does it provide mobility to residents without access to passenger vehicles, it also offers the opportunity to displace private automobile travel and divert greenhouse gas emissions from these trips. Figure 2.3 displays transit emissions for LA County public transit operations, which account for 1 percent of total transportation emissions for LA County.
There are over 20 transit agencies that directly operate within Los Angeles County, three of which rank within the nation’s 50 largest transit agencies by ridership (LA County Metro, LADOT, and Long Beach Transit) (NTD 2010). Additionally, there are over 60 transit agencies that serve Los Angeles County residents in some capacity (Metro “Other Carriers” 2014). The transportation plan prioritizes funding for transportation projects for all modes throughout the region and develops a long-term vision for growth. Table 2.1 lists the largest agencies that serve Los Angeles County.

### Table 2.1: L.A. County Transportation Agencies and Primary Service Areas

<table>
<thead>
<tr>
<th>Agency Name</th>
<th>Primary Service Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antelope Valley Transit Authority</td>
<td>Palmdale and Lancaster, with service into Downtown LA</td>
</tr>
<tr>
<td>Arcadia Transit</td>
<td>Arcadia</td>
</tr>
<tr>
<td>Culver City Transit</td>
<td>Culver City and surrounding areas</td>
</tr>
<tr>
<td>Foothill Transit</td>
<td>East LA County</td>
</tr>
<tr>
<td>Gardena Municipal Bus Lines</td>
<td>Gardena and Hawthorne</td>
</tr>
<tr>
<td>Agency Name</td>
<td>Primary Service Area</td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>--------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>LADOT Dash and Commuter Express</td>
<td>Local circulators throughout Downtown LA and commuter buses throughout LA County into and out of Downtown LA</td>
</tr>
<tr>
<td>Long Beach Transit</td>
<td>Long Beach and surrounding areas</td>
</tr>
<tr>
<td>Metro</td>
<td>LA County</td>
</tr>
<tr>
<td>Montebello Bus Lines</td>
<td>Montebello</td>
</tr>
<tr>
<td>Norwalk Transit</td>
<td>Norwalk and surrounding areas</td>
</tr>
<tr>
<td>Santa Clarita Transit</td>
<td>Santa Clarita and surrounding areas</td>
</tr>
<tr>
<td>Santa Monica's Big Blue Bus</td>
<td>Santa Monica and Los Angeles</td>
</tr>
<tr>
<td>Torrance Transit</td>
<td>Torrance and surrounding areas</td>
</tr>
</tbody>
</table>

Source: Go 511; http://www.go511.com/transit/default.aspx retrieved 2014

LA County Metro’s bus and rail service is the most extensive service in the Los Angeles region, covering nearly the entire urbanized area of LA County (south of the San Gabriel Mountains) and serving 8.6 million residents (Metro Sustainability Report 2012; NTD 2010). In 2010, Metro provided system-wide service for over 2 billion passenger miles and 463 million unlinked passenger trips (Metro 2010; NTD 2010). Over the past 25 years, Metro has developed over 80 miles of urban rail, two bus rapid transit routes, and the nation’s largest fleet of very-low emissions busses (Metro Sustainability Report 2012). Metro retired its last diesel fuel bus in 2011 and has transitioned to Compressed Natural Gas (CNG) (Metro Sustainability Report 2012).

2.2.5 Reducing VMT throughout Los Angeles County

Los Angeles County is polycentric, meaning that it has many dense areas throughout multiple areas in the region. Dense areas such as downtown Los Angeles, Santa Monica, Century City, Long Beach, and Pasadena will require a very different approach to reducing VMT in comparison to less dense locations. Metro’s Countywide Sustainability Planning Policy and Implementation Plan (2012) recognizes that a “one size fits all” approach to transportation planning will not work due to the differing land use characteristics throughout Los Angeles County. Through local analysis, Metro identified that high residential density and employment centrality result in lower household VMT (Figure 2.4).
Metro identified four accessibility clusters, which have appropriate context-specific strategies to reduce per capita vehicle miles traveled (Figures 2.5 and 2.6). The clusters reflect current land use patterns and do not correspond with projections of future growth. However, they do provide incremental steps to increase job and housing density in each cluster when transportation projects are developed.

Figure 2.5: 2009 Snapshot: Accessibility Clusters Across Los Angeles County

Source: Metro Countywide Sustainability Planning Policy and Implementation Plan 2012
2.2.6 Conclusion

Transportation, which accounts for one-third of Los Angeles County’s greenhouse gas emissions, provides a critical role to the region for economic and social sustainability. The urban metabolism framework helps provide a more complete picture of lifecycle investments that already exist within the current built environment. It is imperative to integrate the previous
chapter’s findings into the decision-making process when considering transportation priorities and SB 375 opportunities.

SB 375 aims to reduce regional greenhouse gas emissions through coordinated transportation, housing, and land use planning. It requires metropolitan planning organizations (MPOs) to develop a new section of their Regional Transportation Plan called the Sustainable Communities Strategy (SCS) but falls short of providing regulatory authority to enforce implementation of the strategies. Furthermore, it does not currently have enforcement mechanisms or consequences if regions do not achieve their reduction targets. The 2012 SCS/RTP, developed jointly by SCAG and Metro, aims to maximize existing voluntary local efforts that support SB 375 goals and synchronize projected growth with future transportation plans to reduce per capita emissions by 16 percent per capita by 2035 (which is more than the required 13 percent) despite an increasing demand to move goods and people. To do this SCAG plans on increasing job and housing density near high-quality transit and expanding the existing transportation system. The MPO projects that by 2035 over twice as many households will live near high-quality transit. The 2012 RTP/SCS also integrates regional economic impacts and opportunities provided by the transportation plan in terms of direct gains from job creation as well as efficiency gains from productivity.

2.3 Air Pollution and Criteria Pollutants

One of the important waste flows of the region is air pollution. While the research did not explicitly address criteria pollutants emitted in the region, it is important to add this flow to the analysis, if only to draw attention to its importance and to point out that criteria pollutants are important co-pollutants of GHGs and directly affect public health and ecosystems.

2.3.1 Los Angeles County air quality overview

In 2012, Los Angeles ranked as one of the most polluted counties in the U.S., according to the American Lung Association (American Lung Association 2014). This is a trend that has a long precedence, with the County habitually violating EPA regulations of the six primary criteria air pollutants—carbon monoxide, ozone, sulfur oxides, nitrogen oxides, particle pollution (or particulate matter) and lead. For the 13th time in 14 years, Los Angeles topped the list for worst ozone pollution in the country, and in 2012, it ranked third in the nation in year-round particle pollution and fourth in short-term particle pollution. These figures are particularly important considering both ozone and particle pollution can have severe human health impacts, including asthma, heart and lung diseases and premature death. Los Angeles County also continues to rank as one of the dirtiest in the country for toxic air pollutants, which are associated with high risks of cancer (Scorecard 2002).

The county’s historically poor air quality ratings can be explained by the region’s topography and weather conditions, as well as its socio-economic structure and sprawled land use patterns, historically predicated on automobile travel. The combined presence of heavy industry, considerable activity emanating from both ports, as well as the over 12 million vehicles on the road, create difficult conditions for improvement (Hricko et al 2008). However, important progress has been made in air quality over the past 20 years. Despite a growing population and
an increase in average daily miles travelled, unhealthy ozone days have been reduced by over one third over the past 15 years, and toxic air pollutants have been cut nearly in half since 1990 (CAPCOA 2014). The California Air Pollution Control Officers Association (CAPCOA) attributes statewide improvements to tight restrictions on fuel standards and vehicle emissions, as well as Air Districts’ industrial source emissions restrictions. (CAPCOA 2014).

**Figure 2.7: LA County 2012: Summary of Estimated Annual Average Emission in tons per day**

<table>
<thead>
<tr>
<th>STATIONARY SOURCES</th>
<th>TOC</th>
<th>ROG</th>
<th>CO</th>
<th>NOX</th>
<th>SOX</th>
<th>PM</th>
<th>PM10</th>
<th>PM2.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Combustion</td>
<td>30.59</td>
<td>6.33</td>
<td>35.59</td>
<td>37.38</td>
<td>6.43</td>
<td>7.40</td>
<td>5.37</td>
<td>4.48</td>
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<tr>
<td>Waste Disposal</td>
<td>233.84</td>
<td>2.35</td>
<td>0.76</td>
<td>1.61</td>
<td>0.39</td>
<td>0.76</td>
<td>0.29</td>
<td>0.14</td>
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<td>Cleaning and Surface Coatings</td>
<td>53.83</td>
<td>23.63</td>
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<td>0.01</td>
<td>1.49</td>
<td>1.43</td>
<td>1.38</td>
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<td>Petroleum Production and Marketing</td>
<td>100.75</td>
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<td>4.55</td>
<td>1.14</td>
<td>2.14</td>
<td>2.57</td>
<td>1.64</td>
<td>1.41</td>
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<tr>
<td>Industrial Processes</td>
<td>6.62</td>
<td>5.68</td>
<td>0.96</td>
<td>0.34</td>
<td>0.28</td>
<td>26.63</td>
<td>14.31</td>
<td>4.65</td>
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<td>TOTAL STATIONARY SOURCES</td>
<td>425.63</td>
<td>68.27</td>
<td>42.21</td>
<td>40.88</td>
<td>9.26</td>
<td>38.84</td>
<td>22.74</td>
<td>12.05</td>
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<th>NOX</th>
<th>SOX</th>
<th>PM</th>
<th>PM10</th>
<th>PM2.5</th>
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<tr>
<td>Solvent Evaporation</td>
<td>80.60</td>
<td>67.86</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
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<tr>
<td>Misc. Processes</td>
<td>18.38</td>
<td>7.44</td>
<td>47.46</td>
<td>13.34</td>
<td>0.47</td>
<td>101.42</td>
<td>55.63</td>
<td>18.33</td>
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<td>TOTAL AREAWIDE SOURCES</td>
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<td>75.30</td>
<td>47.46</td>
<td>13.34</td>
<td>0.47</td>
<td>101.43</td>
<td>55.64</td>
<td>18.34</td>
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<table>
<thead>
<tr>
<th>MOBILE SOURCES</th>
<th>TOC</th>
<th>ROG</th>
<th>CO</th>
<th>NOX</th>
<th>SOX</th>
<th>PM</th>
<th>PM10</th>
<th>PM2.5</th>
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<tbody>
<tr>
<td>On-Road Motor Vehicles</td>
<td>91.97</td>
<td>83.89</td>
<td>860.64</td>
<td>188.71</td>
<td>1.26</td>
<td>-</td>
<td>16.72</td>
<td>8.83</td>
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<tr>
<td>Other Mobile Sources</td>
<td>65.97</td>
<td>59.84</td>
<td>456.25</td>
<td>112.08</td>
<td>5.24</td>
<td>6.32</td>
<td>6.15</td>
<td>5.43</td>
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<td>TOTAL MOBILE SOURCES</td>
<td>157.94</td>
<td>143.73</td>
<td>1316.89</td>
<td>300.79</td>
<td>6.50</td>
<td>6.32</td>
<td>22.87</td>
<td>14.26</td>
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<table>
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<tr>
<th>GRAND TOTAL FOR L.A. COUNTY</th>
<th>TOC</th>
<th>ROG</th>
<th>CO</th>
<th>NOX</th>
<th>SOX</th>
<th>PM</th>
<th>PM10</th>
<th>PM2.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>682.50</td>
<td>287.29</td>
<td>1406.57</td>
<td>355.00</td>
<td>16.22</td>
<td>146.59</td>
<td>101.25</td>
<td>44.66</td>
<td></td>
</tr>
</tbody>
</table>

This figure summarizes the average annual emissions by source and by pollutant in tons per day in Los Angeles County in 2012 (CARB Almanac 2014). It gives a snapshot of the level of emissions and their sources, providing insight into the county’s energy landscape from which these sources emanate.

Source: Almanac Emission Projection Data ARB 2014

Carbon Monoxide is the most important pollutant released into the atmosphere in Los Angeles County, with an average total of 1406.57 tons emitted per day (Figure 2.7). These emissions come predominantly from on-road vehicles traversing a sprawling county heavily dependent on automobile use. Mobile sources are the largest polluters by large, emitting 1969.25 tons per day, that is nearly three times as many criteria air pollutants emitted on average by all stationary sources (659.88 tons per day) and five times as many as all area sources (410.96 tons per day).
Total Organic Gases (TOG), which includes Methane, are the second largest type of pollutants at 682.50 tons emitted per day. These are primarily released via waste disposal at stationary sources. It is important to note that these emissions are measured at their point source and do not give an accurate description of how and where air pollution travels, nor how such pollutants affect communities on the ground. A preliminary study demonstrates that while communities immediately adjacent to major transportation corridors and other important air pollution sites are indeed heavily impacted by resultant pollution, criteria pollutants, such as ozone, can be tracked in areas much further away than their original sources, such as in the San Gabriel Mountains and even in Utah and Colorado (Ryerson et al. 2013). Just as greenhouse gasses, it is important to understand and study in greater depths the impacts at all levels—local, regional, statewide, national, global—of air pollutants on air quality and community health.

2.3.2 Cumulative Impact tools

In April 2014, the California Environmental Protection Agency (CalEPA) released census track pollution data for the first time, providing granular detail of levels and variations across the state. Using this data, the CalEnviro tool was created in association with CalEPA and the Office of Environmental Health Hazard Assessment (OEHHA) to map multiple pollutants across census tracks, providing a more complete picture of how and where communities are most impacted by, and most sensitive to, multiple air pollutants (CalEPA and OEHHA 2014). This study compliments previous work, such as the Environmental Justice Screening Method (EJSM) (Sadd et al. 2011), the 2013 Health Atlas for the City of Los Angeles (County of Los Angeles Public Health 2013) and the Los Angeles Equity Atlas (Reconnecting America 2013), which all take a more integrated view of air pollution and its inter-linkages with land use patterns and human health impacts across neighborhoods.

These are important developments, considering current legislation largely addresses air pollution by tightening restrictions pollutant-by-pollutant, facility-by-facility and sector-by-sector (Sadd et al. 2011)—such as cleaner cars (AB 1493, SB 1275), fuels (AB 8, AB 118), and diesel regulations (AB 923). Policies still lack a more holistic approach to tackling how multiple pollutants compound to affect communities differently. Rather than examining criteria air pollutants together, for example, different pollutants are measured at facilities above a certain threshold and their resulting impacts are isolated. These are also calculated separately from other similar airborne concerns, such as toxic pollutants—with for example the “Toxic Air Program” that only targets small areas with specific toxics above a certain level—and greenhouse gas emissions. While certain criteria air pollutants fall under GHGs—such as CO2 and NO2—policies separate out the two and focus more heavily on greenhouse gas emissions even though criteria air pollutants have more immediate and localized impacts than GHGs, which are felt on a global level. In part this is due to epidemiological science that has not found adequate methods to understand the ways in which multiple exposures lead to disease across geographical space, time, different age groups and ethnicities. Furthermore, air pollution in the policy and regulatory realms is separated from larger land use practices and energy use patterns. Pollution does not happen in a vacuum, rather it is brought on by economic activity (such as industry and trade) as well as land use practices that have segregated land uses and...
been predicated on car-dependence and the abundance of fossil fuels. These various Cumulative Impact tools are important developments in linking all these elements together.

Environmental justice activists and researchers have long understood the detrimental impacts of air pollution and varied environmental health hazards on communities. These historically have had a disproportionate effect on low-income communities and communities of color, who are more likely to live in areas with higher hazard risks and industrial activity, alongside major transportation corridors and on or near polluted sites. The various analytic tools mentioned above—such as the CalEnviro tool and the Environmental Justice Screening Method—confirm these concerns and provide important insight into the articulation between land use practices, pollution and human health. Each of these tools employs different scales, metrics and scores, but all have been created to enable a shift towards policies that tackle air pollution in a more integrated and holistic manner. Several of these tools as well as some of their findings are summarized below to add a layer to the urban metabolism assessment and provide insight into the impacts of criteria pollutants across the county.

2.3.2.1 The CalEnviro tool

The CalEnviro tool uses a range of data to map population characteristics—which include “sensitive population” characteristics and socioeconomic factors, such as age, educational attainment, poverty and unemployment rates—alongside pollution burdens—which include exposure to and environmental effects related to a range of pollutants such as ozone, diesel particulate matter, pesticide use, facilities, traffic, solid waste sites, cleanup sites and groundwater threats. Each indicator is mapped individually at census track level across the state and subsequently combined to create a cumulative score, which gives a visual illustration of each neighborhood’s compounded pollution and socioeconomic burdens. Figure 2.8 demonstrates the CalEnviro score for the 20 percent statewide tracts across the Los Angeles area. Areas in red have higher CalEnviro scores, demonstrating higher levels of combined pollution and socioeconomic burdens.
2.3.2.1 The Environmental Justice Screening Method (ESJM)

The Environmental Justice Screening Method (ESJM) provides a complimentary and more qualitative analysis to these issues (Sadd et al 2011). Created by Sadd, Pastor and Morello-Frosch in 2011, the ESJM creates a cumulative score by tracking hazard proximity, exposure to air pollution, and socio-demographic characteristics over land use data across the South Coast Air Quality Management District territory. This analysis is conducted at the census tract level, and uses residential land use data as well as locations of schools, senior centers, day care centers, parks and playgrounds, to calculate higher exposure to environmental and health risks. Using existing land use data and verifying results on the ground with stakeholders as these researchers have done, has enabled a much finer definition of problem areas.
Figure 2.9: Environmental Justice Screening Method (EJSM)

This figure demonstrates the results of the EJSM. Scores for Southern California. Scores range from 3 to 15, with higher scores indicating closer proximity to hazards, higher levels of exposure, and a higher degree of social vulnerability

Source: Screening for Justice

The EJSM yields similar results to the CalEnviro tool: neighborhoods which score highest in cumulative impact tend to be low-income and with higher ethnic minority populations. These areas are concentrated around industrial areas (Ports of Los Angeles/Long Beach, the Los Angeles International Airport) as well along transportation corridors running from the ports to downtown Los Angeles (Alameda Corridor and 710). High hazard areas tend to have denser populations and are clustered around industrial areas or along major transportation corridors. The neighborhoods with the highest health risk and exposure scores can be found in industrial areas in central and East Los Angeles, as well as in Baldwin Park and east of Ontario Airport (Sadd et al 2011).

2.3.3 Benefits
2.3.3.1 Policymaking
This kind of multivariate analysis has multiple benefits. First, these kinds of cumulative assessment tools enable policymakers to fine-tune legislation to specific communities and to understand land use practices, energy use, environmental impacts—such as air pollution—and health as interlinked and reinforcing. The EJSM and the CalEnviro tool have already inspired lawmakers to adopt similar tools, such as CARB’s Proposed Screening Method for Low-Income
Communities Highly Impacted by Air Pollution for AB 32 Assessments. It should be noted that the EPA has recently developed a federal environmental justice screening—the Environmental Justice Strategic Enforcement Screening Tool (EJSEAT)—but presently it is used to conduct preliminary assessments as an internal tool for EPA (Sadd et al 2011).

2.3.3.2 Climate change

These cumulative impact tools can also help connect air quality problems with climate policy, which has primarily focused on greenhouse gas emissions. At present, GHGs take center stage of the climate debate and are largely unlinked with air quality problems on the ground. However, climate change, air quality and human health impacts are intricately linked. According to the California Air Pollution Control Officers Association, “While dramatic progress has been made in reducing air pollution and meeting air quality standards over the years, the effects of climate change threaten to reverse this progress and diminish decades of investments made to improve air quality.” (CAPCOA 2014). Climate change will bring about more severe urban heat island effects, poorer air quality and smoke resulting from wildfires, which in turn will increase adverse health impacts on residents, such as respiratory and cardiovascular diseases, heat stroke and exhaustion, asthma, and permanent damage to the lungs and heart. These impacts can be traced geographically across Los Angeles County, according to a recent UCLA study (Hall et al 2014) that calculates heat increases resulting from climate change across county neighborhoods. The analysis demonstrates an increase in annual average temperatures between 3.7°F and 5.4°F across the County, with higher temperature increases in the mountains and desert areas, and lower increases in the coastal areas (Hall et al 2014). These warming temperatures will also lead to increased levels of ground-level ozone as well as particulate pollution, which will result in increased respiratory illness. (Union of Concerned Scientists 2012). These higher temperatures and resulting air quality and health impacts will be felt largely in areas not currently experiencing high environmental and socio-economic burdens, but rather in the surrounding mountain and desert areas—Porter Ranch, Antelope Valley and in the San Fernando Valley—often in more affluent neighborhoods.

2.3.3.3 Sustainability

Air quality, climate change, socio-economic vulnerabilities must be tackled holistically and such analysis will reveal unanticipated impacts and complex interactions. Integrated and cross-sectoral legislation such as AB 32, SB 375 and SB 372 that specifically target GHGs could be a first step in this direction. AB 32 mandates that greenhouse gas emissions reduction targets take into consideration communities heavily burdened by air pollution problems. Cumulative impact (CI) tools such as the ESJM can help guide policymakers into the areas most heavily impacted by air pollution and in turn use multi-pronged approaches to address the compounded problems demonstrated above. This means using not just pollutant specific levers as is presently done—such as supporting more electric trucks and heavy-duty vehicles (SB 1204)—but incorporating sustainability measures such as building denser and combining job, housing and transportation goals—to reduce inequalities across the board. Such an approach could be used, for example, when directing funds allocated by the recently signed SB 535, which invests nearly $300M from the Greenhouse Gas Reduction Fund into disadvantaged...
communities, or for those neighborhoods, such as Porter Ranch, that will be most heavily burdened by climate change-related temperature rises.

2.3.3.4 Fossil Fuel dependence

Finally, moving beyond mapping vulnerable populations with current and future air quality scenarios, a larger and more important question must be addressed that is the driving force behind our air pollution problems: the continued reliance on the burning of fossil fuels. In order to decrease health impacts, climate change and air quality problems, a much greater shift towards renewable energy is necessary. The air quality debate as well as its policies must be framed in this light to achieve true advances in this domain. A UM framework which analyzes socioeconomic drivers as well as policy measures and various incentives, could be an important step forward in this regard, as it could enable policymakers to understand where path-dependencies to fossil fuels are, what kinds of regulations and policies are contributing to continued reliance, so that they may begin to unravel some of these connections.

Among these, the focus on carbon with regards to GHGs has created a complex interplay between air pollution and greenhouse gas emissions targets. Legislation aimed at reducing criteria air pollutants has concomitantly decreased GHGs as a result of transitioning to cleaner fuels that are less carbon intensive. However, transitioning to natural gas for transportation fuel is creating a path dependency that will make it harder to achieve other state air quality goals. While natural gas is said to be less carbon-intensive than either coal or oil, with regards to total lifecycle emissions of GHGs, natural gas does not necessarily outperform coal, and can in fact be much worse when it is extracted by hydrofracturing (Bulls, 2010). Furthermore, one study shows that “transitioning” to natural gas is in fact only greenwashing the problem and it is in fact legitimizing more carbon-intensive natural gas development (Stephenson et al. 2012).

A UM undertaking of the life-cycle analysis of natural gas production combined with analysis of policy and socioeconomic drivers, can help guide the way towards a “post-carbon” future, by unraveling some of the lock-in and path dependencies generated by current practices reliant on fossil fuels. Additionally, while CI tools are important first step in understanding interlinked issues related to air quality, health, socioeconomic vulnerabilities, a UM framework allows for a more expanded analysis of this sort, connecting these to wider land use patterns and institutional frameworks that make up the county’s energy use trends. Utilizing an urban metabolism framework opens the potential to have a cross-sectoral analysis, linking air pollution to its associate energy use patterns and to the wider energy use landscape of the county.

2.4 Solid Waste Flows

This section of the report is an analysis of solid waste flows in Los Angeles County. Waste flows, like air pollution, solid waste and sanitation flows are important parts of a full urban metabolism, as these are the most immediate local waste flows from a region’s metabolism. The analysis conducted was unable, however, to take life cycle impacts into account, in part due to the lack of available data, especially at a regional level. Such data needs to be developed in order to fully account for the region’s metabolism and impacts.
The following discussion is based on Murphy and Pincetl 2013 that investigated waste flow management in the county of Los Angeles, and in Los Angeles City and attempted to determine the quantities of waste produced in the different areas of the region, and the types. In 1989, California adopted AB 939 that set statewide diversion targets for local jurisdictions of 5 percent by 2000. In 2011 the legislature approved AB 341 that increased the diversion objective to 70 percent by 2020 (advanced by 75 percent by a 2013 mayoral directive) and required recycling services be provided to large multi-family residential properties and commercial properties generating more than 4 cubic yards of waste per week. Los Angeles was the first city to institute a co-mingled recycling program and in 2014 the city implemented a ban of single-use plastic bags. The city has the highest diversion rate among the 10 largest cities in the U.S., achieving 72 percent in 2012. Waste disposal trends are shown in Figure 2.10.

**Figure 2.10: Annual solid waste disposal, City of Los Angeles 1995-2012 (metric tons)**

The city is one of several dozen cities and counties in the U.S (Zero Waste International Alliance 2013) that has established a long-range zero waste goal of 93 percent diversion by 2030 and has implemented a franchise system to streamline waste collection. The recently created exclusive franchise collection system limits the number of haulers providing city service to the non-residential sectors (and apartment buildings larger than 4 units), and provides for further investment in waste processing infrastructure. The Bureau of Sanitation separately collects trash, co-mingles recyclables and green waste from the city’s 540,000 single-family homes and 220,000 small multi-family complexes. According to the city, commercial properties are responsible for generating 69 percent of the city’s waste sent to disposal facilities: 20 percent from large multi-family residential properties and 49 percent from non-residential properties (City of Los Angeles 2002, 2009a, 2009b). Haulers are required to report total source-separated and mixed tonnages of waste and recyclable materials delivered to each transfer and disposal
facility and to pay a state AB 939 compliance fee of 10 percent of gross receipts if they collect more than 1000 tons of waste per year. This level of reporting makes it impossible to determine what is in the waste stream, where it is initiated, and its energy content. Adequately quantifying the GHG or other energy embedded in waste flows is therefore not currently possible. It is also not possible to ascertain whether the recyclable materials are reprocessed and reused, or whether they end up as waste. The current system is aimed at diverting waste from landfills, but not to quantitatively reduce waste, other than perhaps green waste, which is increasingly composted.

The franchise system that has now been implemented may enable greater transparency and accountability if the city then requires the franchisers to report commercial sector waste generation by franchise area, quantifies types of recyclable materials processed in recycling facilities and by geographic area of generation. Separating domestic waste flows from commercial properties seems important as well, since likely the types of waste will be significantly different. To reduce waste flows, it is critical to know what the composition is, and where it is generated, two factors that remain unknown.
CHAPTER 3: Embedded Energy

Dr. Chester, Arizona State University

This section presents the joining of UM and LCA to establish a connection between how infrastructure systems have been deployed and managed and the activities in the city that are thus enabled (see Chester et al. 2012 for further discussion of these methods, underlying data, and assumptions). Building and road infrastructure condition how people move and use buildings (Parrish and Chester 2013). Broad streets encourage automobile use, single-family neighborhoods do as well, and each type of building and road is the result of energy expenditures and induces more energy expenditures. These investments frame what emergent behavior can result. That is, in places built for automobile transportation, walking or biking is implicitly discouraged and often difficult. The emergent behavior is driving a car. A methodology was developed to quantify the life-cycle impacts of building infrastructure and paved surface areas (roadways and parking) across the county and over time (additional methodological detail for these analyses are available in Fraser and Chester, 2013 and Reyna and Chester, 2013) that have shaped current, and constrained future, behavior.

The analysis considers major development of the city starting in the early to mid-1900s through the present. It was performed at the individual building (using County Assessor parcel data) and roadway link (determined by categorizing and measuring all the road of the county based on the Thomas Brothers map of the county). Prototypical building models were developed for three time periods (pre-1950, 1950-1990, and 1990 to 2012) and the corresponding material requirements, energy, and environmental outcomes for each were estimated (Reyna and Chester 2013; Athena 2012). A historical construction, maintenance, and reconstruction model was developed for roadways and highways (see Fraser and Chester 2013 for additional methodological detail) (Pincetl et al 2014). What this analysis raises is the importance of accounting for the built environment as it exists. It raises questions of trade-offs between building a new or retrofitting regarding GHG emissions and energy use; it also raises questions about roads and freeways, and the amount of energy expended in their mere maintenance. While AB 32 aims to reduce GHGs from vehicular traffic, and SB 375 is aimed to reduce driving by bringing housing and jobs closer together, neither approach considers the energy and GHGs expended in current infrastructure, nor what new building will create. All in all, these are important new insights that need to be added to the regulatory framework to understand the GHG impacts of urban activities.

3.1 Summary of Findings

Buildings: The granular spatial-temporal assessment of embedded flows reveals inefficiencies in the rapid expansive growth of the county during the past 30 years. Older (and more centrally located) neighborhoods have larger embedded impacts per unit of land area due to their higher building densities, while per capita impacts in these high-density neighborhoods tends to be low. However, sprawling residential outward growth has led to the embedding of low
population density impacts at the county fringe, which is dominated by large residential detached single-family homes. The net effect is that across the county the average embedded energy and GHG emissions per unit of floor area has remained fairly constant. This has occurred while the manufacturing of raw materials and construction practices have become more efficient. Approximately 70 percent of embedded building energy and GHG emissions occurred between 1930 and 1980. This implies that since 1980 Los Angeles has been deploying new building infrastructure at a slowing pace and has instead focused on using and upgrading existing building infrastructure (Pincetl et al 2014).

Roadways: Results from the roadway assessment show that energy use and GHG emissions from initial construction are dwarfed in the long run by resurfacing activities that replace the wearing layers every 5 to 30 years. Thus freeways have much higher embedded energy per mile than other roadways (Pincetl et al 2014).

3.1.1 Buildings

3.1.1.1 Methodology

Forty-two building prototypes (14 prototype categories for 3 time periods of construction) were developed to give a unique embedded energy and GHG emission profile for every building present in the 2008 Los Angeles County Assessor database.

3.1.1.2 Temporal Modification of Athena Factors

Modifications were made to Life Cycle Analysis software outputs to account for differences in the energy use and GHG emissions from historic building construction. Athena Impact Estimator estimates location-specific impacts for current building construction practices. For all prototype categories, modifications to energy use and GHG emissions during material manufacturing of steel, concrete, and aluminum were applied for each of the two historic time periods (pre-1950 and 1950-1990) based on the available literature. Energy efficiency penalties of 61 percent, 29 percent, and 152 percent were applied to pre-1950 buildings for steel, concrete, and aluminum respectively. The GHG penalties for this time period and these materials were 56 percent, 40 percent and 152 percent, respectively. For buildings constructed between 1950 and 1990, energy penalties of 39 percent, 14 percent and 117 percent for steel, concrete, and aluminum were applied. For GHG emissions, these penalties were 25 percent, 20 percent, and 17 percent, respectively (Martin et al. 1999; US Department of Energy 2007; Worrell et al. 2001).

Because of the prevalence of single-family homes in the Los Angeles building stock, differing material inventories were used for the two earlier time periods. The contribution of these material inventory changes and the technology efficiency penalties are presented in Figure 3.1. Together these material and technology changes increase the embedded energy use factor by nearly 11 percent for pre-1950 homes compared to the post-1990 baseline.
The results of applying the technology efficiency penalties to all prototype categories and the material modification to the single family residential category show the variation between building categories, time periods of construction, and life cycle processes (Figure 3.2). This study was a cradle-to-gate assessment, encompassing the energy used and the greenhouse gases emitted in order to enable functionality of the building stock. This includes manufacturing the materials, transporting them to the site, and physically constructing the building. For all of the prototypes, material manufacturing was the dominating contributor to the embedded energy use and GHG emissions, suggesting that reducing impacts from materials should be the focus of future efforts. LCA is an important tool for identifying the drivers of environmental impacts of infrastructure systems. For example, in the 2008 building stock, concrete and steel material manufacturing are responsible for approximately 43 percent and 35 percent, respectively, of the embedded greenhouse gases emissions in Los Angeles. This means that the transportation and construction phases combined with the manufacture of all other building materials contributes less than 22 percent of embedded GHG impacts, and that any GHG emission reductions in the production processes of concrete or steel will substantially reduce the embedded contribution of new construction.
The post-1990 prototypes are validated based on previously published LCA building studies (Figure 3.3). The existing LCA literature is most applicable to the post-1990 prototypes since there are no identified LCA studies of buildings before this time. All of the prototypes were within the range of other published values with the exception of two multi-family buildings and the industrial buildings. No studies were identified on industrial buildings. The two identified multi-family studies had a narrow range of GHG emission values. The R2 (multi-family large) category was the furthest out of the range, and perhaps more closely resembles a tall commercial building. The R2 GHG emission quantity falls within the commercial range of published values, many of which are office buildings.
The Athena results for post-1990 construction were validated against existing literature studies. The circles represent prototypes from this work and the lines represent the range of values present in the literature. The dashes on the line represent the averages from each published study. The numbers of the study correspond to 1) Ochsendorf et al. 2011, 2) Ochoa Franco 2004, 3) CWC 2011, 4) Lippke et al. 2004, 5) Eaton and Amato 1998, 6) Junnila and Horvath 2003, 7) Guggemos and Horvath 2005, 8) Jonsson et al. 1998, 9) Johnson 2006, and 10) Chester et al. 2013.

3.1.1.3 Temporal Results

The majority of buildings in Los Angeles County are residential, and studying the vintage breakdown of the 2008 building stock shows historic patterns of infrastructure deployment (Figure 3.4). The vintage distribution is dependent on historic events in Los Angeles history. For example World War I (1914-1918), the Great Depression (1930s), and World War II (1941) all coincide with fewer buildings of those vintages appearing in the 2008 stock. Similar trends can be seen in the types of residential buildings being constructed. Starting with the Federal Housing Administration’s preferential financing of single-family detached residences in 1934, the share of these homes rose until the 1960s, when space constraints shifted new construction to higher density dwelling units (Whittemore 2012). This trend is visible in the types of buildings surviving to 2008. This urban morphology greatly impacts such new policies such as building energy disclosure policies that attempt to nudge energy use reductions in buildings by requiring building owners to disclose energy use, as is discussed in Chapter 6.
The floor area distribution between prototype categories provides insight into where embedded materials have been placed (Figure 3.5). Commercial and industrial buildings in the current stock are larger, on average, than residential buildings, and thus have a larger share of the floor space. Larger buildings and floor space correspond to larger amounts of materials used in creating these spaces.
Embedded energy use and GHG emissions were quantified for every building in the 2008 building stock of Los Angeles County (Figure 3.6). These totals are a combination of the count of the buildings, the size of the buildings (floor area), and the prototype factors. The embedded GHG emissions, subdivided by building vintage and prototype classification, are presented in Figure 3.2. Industrial buildings are a larger contributing category than the building count would indicate (Figure 3.4) because of the large amount of floor area per industrial building. The majority of the embedded GHG emissions in the current day building stock are the result of buildings constructed between 1945 and 1990. The post-1990 buildings contribute relatively little to the total embedded GHG footprint. When examined by prototype category, there are distinct differences in the vintages of embedded GHG emissions; for example, industrial buildings have more embedded GHG emissions in newer buildings whereas residential buildings tend to have higher contributions to the embedded GHG emissions from older vintages. This could be due either to differences in mixes at the time of initial construction (i.e. there was more construction of industrial buildings during more recent decades than residential buildings) or that the ratio of floor area between industrial and residential buildings has changed over time (i.e. industrial buildings grew more rapidly in size by vintage than did residential buildings). The embedded energy use from material manufacturing and construction activities displays a similar profile to embedded GHG emissions, because the majority of the energy consumed during these activities was fossil energy, which has a direct correlation between energy, expended and GHG emitted. When this analysis is matched with building energy use, as is done below, a full picture of the contribution of the building stock to GHG emissions emerges in a way that has not been possible before.

Figure 3.6: GHG Emissions by Vintage and Type
The embedded GHG emissions in the building stock are large compared to the total annual GHG emissions from the county. In a 2010 regional inventory, Los Angeles was estimated to have emitted ~99 teragrams (Tg) of GHG from all activities within the county boundary (ICF 2013). The total 2008 embedded GHG emissions (~120 Tg) are 20 percent larger than those that occurred in 2010. The embedded GHG emissions have accumulated from over a century of construction activities, but it is still a non-negligible quantity. Single-family homes are found to be the most significant sinks of embedded energy use and GHG emissions despite the comparatively lower prototype factors. Further, since residential buildings account for over 50% of the embedded impacts of Los Angeles County, their current energy use should be the primary focus of future construction efficiency improvements, but prioritized by combining this finding with current energy use.

3.1.2 Roadways

There are energy use and greenhouse gas emissions (GHGs) associated with the deployment and rehabilitation of a roadway network and over time these embedded effects may be significant. These impacts are the result of upstream processes including the mining and processing of materials used in roadway construction, transportation of those materials to the site, and the on-site processes during construction and rehabilitation operations. The life-cycle impacts of a road are defined by two distinct phases: i) activities related to the initial construction, and ii) activities related to the lifetime maintenance and rehabilitation. Impacts can be allocated to the: i) traveled way, and ii) non-traveled way (shoulders).

The paved portion of the Los Angeles County Roadway Network (like other networks) is comprised of four primary roadway types: local, collector, arterial, and freeway/highway. There are approximately 24,000 paved road miles within the county (Thomas Brothers Map Company, 2009). Local roads make up a majority (76 percent) of the network road miles at 18,240. Collector and Arterial road miles account for 10 percent with 2,400 road miles respectively. Freeway/Highway miles are the smallest portion of the overall network, 530 miles (2 percent). In addition to roadway length, embedded impacts associated with each roadway type are also a function of roadway width and cross-sectional design. Embedded energy use and GHG emissions (CO2e) for each roadway type are detailed in Table 1 and were determined using the Pavement Life-cycle Assessment Tool for Environmental and Economic Effects (Horvath, 2003). The total embedded energy use and GHG emissions resulting from the initial construction of the county network are approximately 255,000 terajoule (TJ) and 20,900 gigagram (Gg) CO2e. Despite comprising nearly 76 percent of the network, local roads account for 41 percent and 39 percent of the cumulative construction impact for energy use and GHG emissions. In contrast, while only comprising 2 percent of the entire network, freeways/highways are responsible for 29 percent and 34 percent of the cumulative construction impact for energy use and GHG emissions.
<table>
<thead>
<tr>
<th>Road Type</th>
<th>Los Angeles County Length [miles]</th>
<th>Embedded Energy [TJ/mile]</th>
<th>Embedded GHG Emissions [Gg CO2e/mile]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local</td>
<td>18,240</td>
<td>5.8</td>
<td>0.4</td>
</tr>
<tr>
<td>Collector</td>
<td>2,400</td>
<td>8.0</td>
<td>0.6</td>
</tr>
<tr>
<td>Arterial</td>
<td>2,400</td>
<td>19.4</td>
<td>1.5</td>
</tr>
<tr>
<td>Freeway/Highway</td>
<td>530</td>
<td>142.1</td>
<td>13.3</td>
</tr>
</tbody>
</table>

For both asphalt roads (local, collector, arterial) and concrete based freeways/highways, material production is the dominant contributor to life-cycle impacts. For asphalt roads, aggregate, bitumen, and hot-mix asphalt production account for 73 percent of the total embedded energy use and 74 percent of the total GHG emissions. For concrete freeway/highway, ready-mix concrete, cement, concrete additives, and steel production result in 93 percent of the life-cycle embedded energy use and 95 percent of GHG emissions. Among the asphalt roads, the differences in construction impacts are related to width and cross sectional differences resulting in increased material demand. The pronounced difference between freeway/highway and the three other types of roads is a function of the energy use and GHG emissions intensities of concrete, cement, concrete additives and steel production relative to bitumen and hot mix asphalt. For spatially-equivalent road segments, concrete-based roadway construction requires 5.8 times more energy and results in 7.0 times more GHG emissions across the life-cycle. For asphalt roads, material transportation accounts for 25-26 percent of the total energy use and GHG emissions and while only contributing 5-6 percent for concrete freeway/highway. Localized impacts resulting from the construction process and equipment are small, less than 1.5 percent, for all road types. At the same time, local roadways only carry 10 percent of total traffic, as explained below.
Figure 3.7: Embedded Energy (TJ) per Mile of Construction by Road Type

![Embedded Energy (TJ) per Mile of Construction](image)

- Local
- Collector
- Arterial
- Freeway

- Virgin Aggregates
- Hot-Mix Asphalt Process
- Concrete Additives
- Steel Reinforcing Bars
- Gravel
- Transportation
- Asphalt Bitumen
- Cement
- Water
- Ready-mix Concrete
- Sand
- Construction Process
The energy use and GHG emissions associated with initial construction of roadways is a small portion of life cycle impacts when life-time maintenance and rehabilitation are included. Because construction impacts are largely the result of materials associated with the wearing layer, efforts to rehabilitate and resurface roadways contribute significantly to the life-cycle impacts of a network. Maintenance and rehabilitation efforts continually embed energy and GHGs into the network as new material inputs are used during each cycle.

The Los Angeles County roadway network was largely deployed between 1940 and 1970 with 99 percent of the total network deployed by 1990 (Fraser & Chester, 2013). As a relatively mature network it has undergone extensive maintenance and rehabilitation. The total maintenance and rehabilitation experienced on a given roadway link is primarily a function of its age. A network deployment model was developed and used to assign approximate year of construction to each network link. Each roadway link was then assigned a standard maintenance and rehabilitation schedule. The impact of wearing layer rehabilitation is so large
that following two rehabilitation cycles the impacts associated with maintaining the roadway link are greater than the impacts associated with its initial construction. Figure 3.9 depicts the annual energy associated with construction and maintenance and rehabilitation activities. When the impacts associated with maintenance and rehabilitation are included the cumulative embedded impacts are 3.9 times greater for energy use (1010 petajoule [PJ]) and GHG emissions (82,100 Gg CO2e). Future maintenance activities will continue to increase the embedded impacts in the network.

Figure 3.9: Annual Energy Use for Construction and Maintenance

3.1.2.1 Traveled Way vs. Non Traveled Way

In addition to vehicle travel, the roadway infrastructure also facilitates vehicle parking. Curb-side vehicle parking, metered and non-metered, can be found along nearly all of Los Angeles County’s local, collector and arterial roadways. Roadway design guidelines and the scale of the Los Angeles County roadway network has resulted in significant investment in the non-traveled way portions of roadways. The environmental impacts associated with roadway shoulders should be considered separately from the portions of roadways that are dedicated to vehicle travel. Local roads dedicate the largest proportion of total roadway surface area to shoulders at 33 percent. Increased roadway widths in collector and arterial roads, which facilitate additional vehicle travel, result in smaller fractions of total roadway dedicated to the non-traveled way (25 percent and 15 percent respectively). Cumulatively, the non-traveled way
portion of the network is responsible for 23 percent of the total embedded energy use (230,000 TJ) and GHG emissions (19,000 Gg CO2e).

3.1.2.2 Transportation
In 2008, travel in Los Angeles County was estimated at 82 billion vehicle miles of travel (VMT) of which approximately 94 percent can be attributed to light duty vehicles and heavy-duty vehicles responsible for the remaining 6 percent (Southern California Association of Governments, 2008). In total, vehicle travel in 2008 required 598,000 TJ of energy and resulted in 43,000 Gg CO2e emissions. The impacts associated with vehicle operation, sometimes referred to as “tailpipe emissions”, represent 72 percent if the total annual energy use and 68 percent of the total GHG emissions associated with vehicle travel. The upstream life-cycle stages related to vehicle travel, which includes fuel refining and vehicle manufacturing, contribute 21 percent and 23 percent respectively. Despite representing only 6 percent of the total annual VMT, heavy-duty vehicles are responsible for a disproportionate share of annual energy use (21 percent) and GHG emissions (23 percent) due to lower average fuel economies and increased manufacturing intensities. The results are shown in Figure 3.10.

**Figure 3.10: 2008 Energy Use and Greenhouse Emissions Associated with Vehicle Travel (2008)**
3.2 Conclusion

The cumulative embedded energy use and GHG emissions associated with the roadway network are roughly equivalent to two times the annual environmental impacts that result from vehicle travel. For all roadway types, material inputs dominate the overall impacts and the maintenance stage is a greater contributor to the cumulative impact than initial construction. Efforts that increase the cycle times between wearing layer rehabilitations and the utilization of recycled and low-carbon materials may significantly reduce the future environmental impacts associated with the network. The assessment finds that local roadways account for greater than 50 percent of the total impacts despite carrying less than 10 percent of total vehicle travel (Federal Highway Adminstration, 2012). This suggests that the potential for a more efficient distribution of transportation infrastructure through integrated transportation and land use policies exists. This analysis also highlights the impact of fossil fuel dependent vehicles and the disproportionate impact of heavy-duty vehicles in both operation and upstream life cycle impacts. Heavy-duty vehicles are important components of the economy in the region, transporting goods in and out of the region’s combined ports, and moving goods around. Decarbonizing transportation fuels will be important to reduce vehicle GHG emissions, though will do little to reduce road infrastructure GHGs. Relationships between the roadway network and transportation modes need to be investigated further, as well as the relationships between the transit system, housing and LCA. Chester et al (2010) conducted a separate study comparing life cycle impact of light rail, bus rapid transit and the automobile in Los Angeles, pointing to the importance of the fuel mix for life cycle impacts as well as criteria pollutants. Electrified light rail, even at current ridership numbers has the least impacts, and coupled with greater ridership could greatly reduce roadway maintenance GHGs.

The embedded energy that makes up the urban fabric – the accreted materials used to create the built environment – enables (or constrains) the activities of the county and is the county’s hard infrastructure. An urban area’s hard infrastructure creates path dependencies, inscribing land use decisions in geographical space: single family neighborhoods in one area, industry in another, offices in yet other places, all linked by road networks. Economic activity within that geographical space is a result of geographical location (such as port activities, mining or petroleum refining), history (such as the movie industry or aerospace manufacturing), and a multitude of other factors. Economic activities interact with the hard infrastructure, reinforcing it (as in transportation networks for goods movement) and subject to it (for example, the dependence on the automobile for transportation to jobs and other activities, as public transportation hard infrastructure is currently insufficient to accommodate that substitution). Thus hard infrastructure and the energy and materials used to create and to maintain it are an important aspect of understanding a city’s urban metabolism and its evolution. It is also obdurate, meaning changing hard infrastructure is expensive and often difficult because of the path dependencies and cultural expectations that have evolved around existing patterns.
CHAPTER 4:
Building Energy

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4.1 Overview

On average California generates more than 200,000 gigawatt-hours of electricity annually,
which is transported over the state’s 32,000 miles of transmission lines. According to the
California Energy Almanac, in 2011, California produced 70 percent of the electricity it uses; the
rest was imported from the Pacific Northwest (10 percent) and the U.S. Southwest (20 percent).
Natural gas is the main source for electricity generation at 45 percent of the total in-state electric
generation system power.2 California imports over 90 percent of its natural gas and
approximately 40% of all natural gas is used to generate electricity.3 The rest is used for
industrial, commercial and residential purposes with a small portion used for transportation.

Reducing electricity and natural gas consumption is integral to meeting California’s greenhouse
gas reduction goals. While upstream changes to the fuel mix are important to reducing the
overall carbon intensity of the system, reducing downstream consumption is essential to
making new technologies (e.g. solar and wind) viable. While the Energy Commission reports
annual countywide electricity and natural gas consumption, this is the first study to analyze
building energy consumption using ground-up address level data across Los Angeles County.
This is particularly significant because Los Angeles is the largest and most populous county in
the state and consumes more electricity than any other county, at 25 percent of the state’s total.

Address level consumption of electricity and natural gas data are highly protected due to
California’s privacy rules. It took researchers over two years to acquire access to the address
level consumption from the three largest utilities in Los Angeles County—Los Angeles
Department of Water and Power (LADWP), Southern California Edison (SCE) and the Southern
California Gas Company (SoCal Gas). This significantly curtailed the amount of time available
for analyzing the data and the results throughout this report should be considered preliminary.
Researchers at the California Center for Sustainable Communities will provide updated results
in the form of an interactive energy atlas in Spring 2015.

These early results show:

1. Disaggregated data reveals residential consumption patterns masked by aggregated
data. That is higher users use considerably more energy than lower users.

2 http://energyalmanac.ca.gov/electricity/index.html

3 http://energyalmanac.ca.gov/naturalgas/index.html
2. Urban morphology impacts the cost and overall effectiveness of energy policies, particularly building energy disclosure policies. That is the physical structure of the city high rises vs. low rise buildings – affects the building energy use profile. Smaller, low rise buildings use less energy compared to bigger high rise buildings. The Los Angeles region is characterized by lower rise buildings.

3. Communitywide greenhouse gas accounting can be improved through centralized data collection and analysis of ground up energy data.

4. Coupling building end use energy consumption with life cycle analysis of the embedded energy of building and transportation infrastructure provides important insights into how to improve the built environment overtime.

4.2 Methodology and Data

As stated above, this building energy analysis uses address level energy consumption data to show variation in energy patterns across space, building type and socio-demographics. This work relies on three main data sets: utility data, Los Angeles County Assessor data and census data. Each data set and the methodologies used for analysis are described below.

4.2.1 Utility Data

Through non-disclosure agreements (NDAs) with the Los Angeles Department of Water the California Public Utilities Commission, researchers obtained six-years of monthly electricity and natural gas consumption from the three largest utilities in of Los Angeles County, Southern California Edison (SCE), the Los Angeles Department of Water and Power (LADWP) and the Southern California Gas Company (SoCal Gas).

Research on this aspect of the urban metabolism study was delayed as it took researchers over 2 years to obtain data for the investor owned utilities (IOUs), thus only a limited analysis of this dataset was completed in time for this report. Through additional funding, research on this data continues and updated analyses will be available at the California Center for Sustainable Communities Website (http://www.californiasustainablecommunities.com) in Spring 2015.

4.2.2 Assessor Data

The publicly available 2008 Los Angeles County Assessor’s database is foundational to this work. It contains dozens of variables describing built space at the parcel level. Researchers used three of the most significant available variables for this analysis: built space, year built and use type.

- Built Space
  - In instances where there was more than one building on a parcel, researchers summed the square feet for each building and worked with the summed total for the parcel.

- Use Type
To enable researchers to overlay energy consumption data and embedded energy data, researchers use the same simplified parcel use codes described in the life cycle assessment section above.

Future research will go investigate the significance between embedded energy and energy consumption. This report describes preliminary observations only.

Researchers took several steps to standardize, prepare and analyze the data, each of which are described below.

1. Recordize Consumption Data

   Consumption data exports provided by each of the utilities consisted of rows of address information and monthly meter readings for each non-residential and residential account active during a given year. Data was not organized in a searchable way and had many inconsistencies. CCSC researchers developed customized software to process electricity, gas, and water use data coverage of Los Angeles County. This program converts heterogeneous addresses and readings data into a standardized record format of usage data and a standardized address format for address data allowing for storing the standardized data in a PostGIS database. This program also logs where problems occur when processing the data.

2. Geocode Service Addresses

   The utility data contained latitude and longitude data for each service addresses, the majority of this geocoding however was not precise enough to match to the parcel level data. In order to match service addresses to associated use type and square footage, the service addresses were geocoded into shapefiles using ArcGIS and a parcel-level locator provided by Los Angeles County. Due to the size and complexity of the data this process was done programmatically using customized Python scripts. Inconsistencies in the data and errors in the locator, led to manual geocoding of significant sections of data.

   To link energy consumption built space characteristics, researchers aligned site address of energy consumption to the County Assessor tax parcel information. Throughout this report, the term parcel is synonymous with County tax parcel. The one exception to the parcel level analysis occurs when multiple parcels share identical spatial geometry. This is the case for roughly 13 percent of parcels in Los Angeles County and happens when a single building has multiple parcels, for example in a condominium complex. This further complicates the use of the spatial join tool to link parcel-geocoded service addresses to their correct parcels. To address this potential problem, parcels with shared geometry were transformed into “mega-parcels”, meaning these overlapping parcels, including the total square-footage, use types, and consumption, were summed into one mega-parcel. By creating mega-parcels, the chance for error in over-counting consumption is reduced by over-assigning service addresses to parcels via the spatial join.
Across all years of electricity data, researchers were able to accurately match 97 percent of addresses to the street level and 89 percent of service addresses to the parcel level. Street-geocoded addresses accounted for 83 percent of total consumption within the Los Angeles Department of Water and Power (LADWP) and Southern California Edison (SCE) service areas. Further statistical analysis revealed that the 17 percent of countywide electricity consumption, not geocoded to the parcel level, occurs randomly likely due to errors in address fields that could not be fixed. Researchers removed this consumption from the analysis without impact to the final outcome.

For natural gas across all years 92 percent of service addresses were geocoded to the parcel level, which accounted for approximately 85 percent of countywide consumption. Natural gas consumption is highly skewed and statistical analysis of the un-geocoded consumption suggests that the distribution is not random, meaning that if geocoding the remaining portion of the data were possible, the results could shift. Researchers are continuing to develop ways to correct this bias for future analysis.

3. Create and Load Database

An energy database was created in PostgreSQL with PostGIS spatial extension with separate tables for consumption, service addresses, parcels with building attributes, and related data such as climate zones and city boundaries. Residential and non-residential consumption data were loaded from CSV outputs of the standardization program into respective tables using custom Python scripts with Psycopg, a PostgreSQL adapter for Python. Shapefiles for address points, parcels and other spatial data sets were loaded using the shp2pgsql program included with PostGIS. This command line tool converted a shapefile into Structured Query Language (SQL) syntax suitable for automated import into the database based on user-defined configuration parameters such as spatial reference identifiers and character encoding.

4. Query Database

SQL queries to the database for summarized information were performed using the psql command line interface. Initial queries categorized parcels by building size and use code, while subsequent queries summarized energy consumption for each of these categories as well as by city, neighborhood, and climate zone. Database queries utilized the spatial capacities of PostGIS to find all accounts within a given parcel grouping or other spatial boundary and sum the monthly electricity and natural gas consumed. The queries necessary to answer the research questions involved computationally intensive joins of service addresses with consumption as well as spatial joins of service addresses within parcels. Prior to conducting queries, researchers prepared indexes on account number and geometry columns to optimize performance. Given the size and complexity of the database, queries often took several hours to days to complete.

Analysis by building size was conducted at the parcel level, where each parcel may contain one or more buildings. In the case of multiple buildings per parcel, the sum of square footage of the first five buildings on the parcel was used (five buildings per
A parcel is a limitation of the County Assessor’s data. In addition, since parcels are assessed by owner, some buildings contained multiple parcels. Parcels data were obtained from the Los Angeles County Assessor’s Office and only included taxable properties.

4.2.3 Consumption Discrepancies
Researchers found discrepancies between the total consumption provided by LADWP and the total consumption the utility reports publicly. This is because CCSC data does not include the electricity consumption associated with water conveyances or street light consumption data. Unfortunately, Southern California Edison (SCE) and Southern California Gas Company (SoCal Gas) do not report consumption at the county level and so researchers were not able to verify total consumption numbers with a public source. The data set is from a large data set developed by consultants to the California Public Utilities Commission (CPUC) who undertook extensive quality checks of the data to confirm completeness. Researchers are thus fairly confident in the completeness of the IOU data.

4.2.4 Limitations
There are three important limitations to the analysis at this time:

A. **The results are at the parcel level.** The County Assessor’s data compiles information at the parcel level. In some instances there are multiple buildings on one parcel and in some instances buildings span more than one parcel. With the exception of condos, which are aggregated up to the buildings in which they exist, the results shown for this analysis are for built space at the parcel level, not for individual buildings. In cases where there is more than one building on a parcel, the database sums the square footage for all buildings. In cases where a very large building spans more than one parcel, the data is reported for the built space occupying each individual parcel.

B. **Data on non-taxable land is limited.** The County Assessor’s data set provides information on building square footage for taxable land. Information regarding non-taxable land (e.g. churches and government buildings) is limited and less accurate. Going forward CCSC researchers will refine the analysis to provide a better accounting of non-taxable land, but at this time the data for these parcels remain limited.

C. **The assessor’s data undercounts square footage.** In part due to the reasons outlined above, CCSC researchers estimate that the County Assessor’s data set underestimates total built space in the County of Los Angeles by about 4 percent. Researchers are developing methods to address this limitation.

4.3 Findings
The findings of this preliminary analysis are:

1. Disaggregated data reveals consumption patterns masked by aggregated data. Both residential and non-residential consumption is skewed towards higher users.

2. Urban morphology impacts the cost and overall effectiveness of energy policies, particularly building energy disclosure policies.
3. Communitywide greenhouse gas accounting can be improved through centralized data collection and analysis.

4. Coupling building end use energy consumption with life cycle analysis of the embedded energy of building and transportation infrastructure could provide important insights into how to improve the built environment overtime and this relationship should be investigated further.

Each of these is discussed in more detail below.

4.3.1 Finding 1: Disaggregated Consumption Data

Disaggregated Consumption Reveals Residential Consumption Patterns Masked by Aggregated Data.

As discussed in the embedded energy section above, “single-family homes are found to be the most significant sinks of embedded energy use and GHG emissions despite the comparatively lower prototype factors.” Because of their prominence in the landscape, single-family homes represent an important place to target conservation efforts. An earlier report in this project, Los Angeles County Building Energy Use and GHG Baseline Assessment, shows that residential energy patterns vary significantly across space. The findings below display this, variation, within LADWP territory, in greater detail and underscore the importance of policies and programs that take into the account differences in consumption that occur due to land use, population size, building characteristics and sociodemographics.

In a future report, the LA Energy Atlas (available Spring 2015), researchers will further drill down into these patterns by linking energy consumption, geography, building type, building size, sociodemographics and industrial classification.

The maps below show residential energy consumption in the City of Los Angeles at three levels of aggregation: 1) city council district, 2) neighborhood and 3) census tract. The following section shows that disaggregated energy consumption patterns, generally masked by aggregated data – for example total energy use for the city. With fiscal year 2010-2011 residential LADWP electricity data, and adhering to the 15/15 guidelines established to protect confidentiality, significant shifts in understanding energy use occur with more granular data.

Figures 4.1 through 4.3 display median annual residential electricity consumption for the City of Los Angeles by city council district, neighborhood, and census block group, respectively. Darker areas represent higher median annual consumption and suggest priority areas for targeting energy efficiency/conservation programs to maximize cost-effectiveness. Results could also inform Tier restructuring. Maps showing total electricity consumption by geographic area can provide important information for targeting efforts to relieve consumption hotspots.
Figure 4.1: Electricity Use by City Council District

Electricity use by city council district
FY 2011-2012, LADWP

Source: University of California Los Angeles using 2010 LADWP billing data and 2010 Census Sociodemographic information

Figure 4.2: Electricity Use by Neighborhood

Electricity use by neighborhood
FY 2011-2012, LADWP

Source: University of California Los Angeles using 2010 LADWP billing data and 2010 Census Sociodemographic information
For each map the ratio of upper bounds for the highest and lowest tiers were computed to report a simple metric that quantified variation displayed in each. By city council district (Figure 4.1) this ratio was 2.2 (with a range of 4,170 kWh); by neighborhood (Figure 4.2) the ratio was 5.6 (with a range of 17,800 kWh); and by census block group (Figure 4.3) the ratio was 26 (with a range of 39,000 kWh). The census block group map thus unlocked significant variation in consumption masked by city council district and even by neighborhood, and helps to demonstrate the value of disaggregating energy data. White spaces in Figure 4.3 indicate a lack of residential population in a given census block group. This series of figures also demonstrates that data aggregation levels affect the understanding of areas of high and low consumption—note how the darkest areas shift depending on the level of data aggregation. To fully understand the diversity in consumption across Los Angeles, more information is needed regarding the relationship between land use, sociodemographics and building characteristics. The energy drivers section below discusses some of these key relationships.

The LA Energy Atlas will build off of this work to assess the geographic variation in these relationships.

### 4.3.2 Finding 2: Urban Morphology and Building Energy Policies

Urban morphology impacts the cost and overall effectiveness of energy policies, particularly building energy disclosure policies.
Throughout California, cities are considering implementing energy disclosure policies. These policies rely on setting a threshold above which building owners must publicly report their energy consumption. Researchers conducted an analysis of electricity and natural gas consumption for the city of Los Angeles in 2010, to see how much energy consumption different building thresholds would capture.

Table 4.1: Electricity Use by Account Class

<table>
<thead>
<tr>
<th>Account Class</th>
<th>kWh</th>
<th>Percent of kWh</th>
<th>Number of Accounts</th>
<th>Percent of Accounts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>6,726,000,156</td>
<td>37.63%</td>
<td>1,195,785</td>
<td>87.63%</td>
</tr>
<tr>
<td>Non-Residential</td>
<td>11,147,850,710</td>
<td>62.37%</td>
<td>168,763</td>
<td>12.37%</td>
</tr>
<tr>
<td>Totals</td>
<td>17,873,850,866</td>
<td>100%</td>
<td>1,364,548</td>
<td>100%</td>
</tr>
</tbody>
</table>

Source: University of California Los Angeles using County Assessor’s 2008 database

LADWP parcel-level analysis of built square footage by customer class shows that while the majority (90 percent) of accounts are residential, non-residential accounts consume more total energy (63 percent), (Table 4.1) and that most energy is used on parcels with less than 5,000 square feet of built space (Table 4.2). Table 4.3 reports the proportions of parcels and service addresses in each of the built square footage categories used throughout this analysis. Note that while this table shows a maximum of 25 percent for each bin, parcels and service addresses in the under 5,000 square feet category make up a far greater proportion of the total (90 percent and 61 percent, respectively) (Table 4.3). The patterns of building energy consumption revealed by this analysis reflect the City Los Angeles’ urban morphology. The City has a small proportion of large buildings compared to older American cities such as New York. In fact, 90 percent of parcels in the City of Los Angeles have built space of less than 5,000 square feet. As a result, both energy consumption and, as described above, the embedded energy within the built environment is less concentrated than in some other large urban regions. In other words, a large number of small buildings have a significant impact on the environment and urban landscape, despite a relatively low impact per square foot.

In total, residential customers consume 34 percent of total electricity and make up 87 percent of accounts. Non-residential properties consume 66 percent of electricity and make up 13 percent of accounts. While New York City was able to achieve its energy disclosure objectives – capturing 74 percent of the City’s building GHG emissions and nearly half of the New York City’s total floor space4 – with a 50,000 square foot threshold, researchers found that in the City of Los Angeles parcels with a built space above 50,000 square feet represent only 34 percent of total energy consumption and greenhouse gas emissions. Not until the reporting threshold is reduced to 10,000 square feet would the City capture more than half of total energy consumption (52 percent).

Table 4.2: Electricity Use by Parcel

<table>
<thead>
<tr>
<th>Built Sq. Ft.</th>
<th>kWh</th>
<th>Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 5k*</td>
<td>7,938,398,103</td>
<td>44.41%</td>
</tr>
<tr>
<td>5 - 10k</td>
<td>1,511,815,564</td>
<td>8.46%</td>
</tr>
<tr>
<td>10 - 15k</td>
<td>768,166,496</td>
<td>4.3%</td>
</tr>
<tr>
<td>15 - 20k</td>
<td>576,855,660</td>
<td>3.23%</td>
</tr>
<tr>
<td>20 - 25k</td>
<td>478,607,038</td>
<td>2.68%</td>
</tr>
<tr>
<td>25 - 30k</td>
<td>356,840,135</td>
<td>2%</td>
</tr>
<tr>
<td>&gt; 30k</td>
<td>6,243,167,872</td>
<td>34.93%</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>17,873,850,866</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

Source: University of California Los Angeles using County Assessor’s 2008 database

Table 4.3: Proportions of Parcels and Accounts in Each Built Square Footage Category

<table>
<thead>
<tr>
<th>Built Sq. Ft</th>
<th>Number of Parcels</th>
<th>Percent of Total Parcels</th>
<th>Number of Accounts</th>
<th>Percent of Total Accounts</th>
<th>Number of Non-Residential Accounts</th>
<th>Percent of Non-Residential Accounts</th>
<th>Number of Residential Accounts</th>
<th>Percent of Residential Accounts</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 5k*</td>
<td>733,398</td>
<td>92.15%</td>
<td>829,811</td>
<td>60.81%</td>
<td>62,658</td>
<td>37.13%</td>
<td>767,153</td>
<td>64.15%</td>
</tr>
<tr>
<td>5 - 10k</td>
<td>36,145</td>
<td>4.54%</td>
<td>166,825</td>
<td>12.23%</td>
<td>40,240</td>
<td>23.84%</td>
<td>126,585</td>
<td>10.59%</td>
</tr>
<tr>
<td>10 - 15k</td>
<td>9,007</td>
<td>1.13%</td>
<td>70,186</td>
<td>5.14%</td>
<td>17,801</td>
<td>10.55%</td>
<td>52,385</td>
<td>4.38%</td>
</tr>
<tr>
<td>15 - 20k</td>
<td>4,635</td>
<td>0.58%</td>
<td>49,391</td>
<td>3.62%</td>
<td>10,531</td>
<td>6.24%</td>
<td>38,860</td>
<td>3.25%</td>
</tr>
<tr>
<td>20 - 25k</td>
<td>2,923</td>
<td>0.37%</td>
<td>36,589</td>
<td>2.68%</td>
<td>7,007</td>
<td>4.15%</td>
<td>29,582</td>
<td>2.47%</td>
</tr>
<tr>
<td>25 - 30k</td>
<td>1,885</td>
<td>0.24%</td>
<td>29,078</td>
<td>2.13%</td>
<td>4,787</td>
<td>2.84%</td>
<td>24,291</td>
<td>2.03%</td>
</tr>
<tr>
<td>&gt; 30k</td>
<td>7,893</td>
<td>0.99%</td>
<td>182,668</td>
<td>13.39%</td>
<td>25,739</td>
<td>15.25%</td>
<td>156,929</td>
<td>13.12%</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>795,886</strong></td>
<td><strong>100%</strong></td>
<td><strong>1,364,548</strong></td>
<td><strong>100%</strong></td>
<td><strong>168,763</strong></td>
<td><strong>100%</strong></td>
<td><strong>1,195,785</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

Source: University of California Los Angeles using County Assessor’s 2008 database
Not surprisingly, non-residential electricity consumption is skewed significantly toward larger buildings. Non-residential accounts on parcels with a built space over 30,000 square feet consume just over half (51 percent) of total non-residential electricity consumption and represent 15 percent of non-residential accounts. Non-residential accounts on parcels with a built space above 10,000 square feet consume nearly two thirds (66 percent) of non-residential consumption and make up 39 percent of total non-residential accounts. For residential accounts, parcels with a built space over 30,000 square feet capture only 9 percent of total residential consumption and make up 13 percent of total residential accounts. Even requiring reporting for residential accounts in parcels with a built space above 5,000 square feet would capture just one quarter of total residential electricity consumption despite covering 36 percent of total residential accounts.

**Figure 4.4: Non-Residential Electricity Consumption**

Source: University of Los Angeles California using County Assessor and LADWP 2010 billing data
For energy disclosure policies to be effective, they must be applied to enough of the building stock such that energy conservation or efficiency measures will make a difference. Knowing building uses by category, their general locations, building age and shell will enable the development of appropriate programs and measures to address the variations among high-energy buildings and building uses. The City of Los Angeles, for example, will be able to develop efficient policy measures based on this analysis. Interestingly, in contrast to cities with denser downtowns, like New York, it may also mean it is likely that implementing an energy disclosure project will be more expensive in the City of Los Angeles than in New York and could lead to less information about energy use.

4.3.3 Finding 3: Centralized Data Collection and Analysis

Communitywide greenhouse gas accounting can be improved through centralized data collection and analysis.

An unanticipated finding of this work is that consolidating and curating building energy data in a single repository that is maintained overtime can provide a valuable resource for community greenhouse gas accounting.

Municipalities throughout the state are actively seeking ways to reduce building energy consumption in their jurisdictions. Access to building energy data, which is fundamental to their efforts, is, however, often unavailable. Those municipalities who are able to gain access to the data, often lack the resources to fully analyze it. The database developed in part for this project, provides a flexible and responsive way to analyze large amounts of energy consumption data. It can provide sophisticated and policy relevant energy and GHG information to city and regional planners. This data when combined with the VMT outputs from Metropolitan Planning Organizations can be used to accurately and consistently quantifying the majority of GHG emissions for communities across the state. Not only will this tool improve the reliability and usability of community GHG inventories, it will greatly cut
down on costs. To maximize the benefits of the State’s investment in this project, researchers at the California Center for Sustainable Communities at UCLA, are actively seeking ongoing funding for this database.

4.3.4 Finding 4: Coupling Building Energy Consumption with Embedded Energy

Coupling building end use energy consumption with life cycle analysis of the embedded energy of building and transportation infrastructure could provide important insights into how to improve the built environment overtime and this relationship should be investigated further.

Electricity consumption is only a portion of a small portion of a building’s environmental footprint. As discussed in the embedded energy section the full impact of a building begins with the manufacturing of materials and continues into construction, maintenance and operations. Further, land use patterns of a city impact the type of construction, which then plays a large part in dictating consumption patterns. In Los Angeles’s relatively flat landscape, single-family homes dominate the built environment, in terms of absolute numbers and represent the largest portion of embedded energy by anyone building type. Residential buildings also consume a significant portion, 44 percent of all electricity in the City of Los Angeles (based on 2010 consumption). Further, housing people in single family homes requires more land than housing people in multi-story apartment buildings. A spread-out flat city requires expansive roadway infrastructure to support travel between distant destinations. As described above, the materials, construction and maintenance of these roadways are highly energy intensive. This makes implementing certain policies, such as building energy disclosure more expensive and possibly less effective.

Further, coupling analysis of end use consumption with analysis of embedded energy patterns provides important insights into both building retrofits and new construction. The embedded energy section of this report emphasizes the importance of concrete and steel manufacturing within the building life cycle. Together these two processes are responsible for 78 percent of the embedded energy within Los Angeles County buildings. If AB 32 is successful in reducing the emissions of cement and steel manufacturing in California, it could significantly decrease the energy embedded in future buildings. The findings of this report, thus lend additional support to efforts to reduce upstream sources of pollution.

At the same time, end use building energy consumption drives demand for upstream electricity generation and as shown in Chapter 6, electricity generation is a major source of emissions in Los Angeles County. Thus upstream efforts to clean up the supply chain must be combined with downstream efforts to reduce overall demand. Disaggregated data, such as that discussed here, can improve such efforts by informing policy design to best target programs to maximize reduction potential.

4.4 Policy Relevance

This analysis brings to bear previously unavailable insights into energy use by a multitude of important variables to design targeted energy management programs, create appropriate
building energy disclosures, and to optimize energy investments and appropriate energy
disclosure policies for city building profiles. With access to customer-level data, matched to
parcel data and census data, energy consumption and related metrics can be related at various
politically relevant geographic aggregations to provide insights that can improve city and the
servicing utility’s ability to target energy conservation efforts. For example, portfolios of cost-
effective energy efficiency measures could be developed for each census block group in a
service territory using median annual consumption and income and linked to GHG emissions
reductions. This approach to understanding energy use can also, and should be, coupled with
energy efficiency and conservation program information to establish baselines for evaluation of
program investments.

The next sections explore greenhouse gas emissions and economic activities in the region, as
well as jobs and greenhouse gas emissions. These analyses add a dimension to understanding
the connection between the economy and the region’s fossil fuel intensive economy. However,
Los Angeles County is not unique in depending heavily on fossil fuels for economic activity,
this is characteristic of all urban economies today. What this analysis provides is a deeper and
more disaggregated look into that relationship in order to account for that dependence at the
county scale. This can help develop strategies and pathways to begin to decarbonize the
economy, keeping in mind the hard infrastructure constraints and conditions, as well as the
impacts on jobs and wages. Coupling the analysis of hard infrastructure and greenhouse gas
emissions from economic activity is an important step in reducing GHG emissions over time.
For example, Los Angeles County’s current hard infrastructure inhibits the use of public
transportation to jobs and services, policies and practice allow roads to prioritize automobiles
and single-family passenger vehicles over other forms of transportation. Additionally, fixed-
route public transportation must be retrofitted into the existing hard infrastructure, an
expensive and complex task. From the analysis presented below, GHG emissions to and from
jobs and services are significant across the board, reinforced by zoning that segregates land
uses. Additionally, this region also depends on high GHG emitting economic sectors such as
petroleum refining that also serves the rest of the state and beyond.

The economic analysis presented is subject to the several data limitations that are highlighted in
each section. Greenhouse gas emission factors for industries do not exist at the regional scale.
The Carnegie Mellon Economic Input Output-Life Cycle Analysis (EIO-LCA) database is a
national one based on 2002 economic data. Updated to reflect California’s unique energy mix,
the EIO-LCA still relies on 2002 economic data. Further, because of privacy guidelines both for
employers and other customers, researchers have aggregated results such that no employer or
customer can be identified. Within these limits, however, the following analysis is far more
regionally specific than others, showing the variation across industries and employment
characteristics in a novel and more detailed manner than before. That being the case, there is an
important contrast between the more aggregated level of analysis presented below and the
address-level up approach discussed above. Much of this gap is due to data privacy
considerations that do not allow for a closer matching or detailed understanding.
CHAPTER 5:
Greenhouse Gas Emissions and Energy Consumption and Economic Activity and Commodity Flows

Giovanni Circella, University of California Davis and Georgia Institute of Technology

5.1 Introduction

Most urban metabolism studies to date are based on the analysis of aggregated economic and resource data inside city boundaries. This approach, which generates an aggregated overview of the urban metabolism impact of human activities in complex urban systems, provides limited information on the environmental impact and the consumption of resources associated with (1) the various groups of economic activities, (2) the specific patterns of spatial locations and (3) the impact of local policies (Kennedy et al., 2007).

In order to overcome some of the limitations to connecting urban metabolism to economic activities and their environmental impacts, contemporary approaches have proposed the use of more advanced modeling tools that can allow greater spatial and temporal resolutions in the analysis of the impact of economic activities and the impact on energy and resource consumption. For instance, Keirstead and Sivakumar (2012) used an activity-based model to compute non-transport energy demand resulting from changes in commuting patterns and activity schedules. The application of a modeling approach increases the depth of the analysis of the urban metabolism and allows for more detailed spatial and temporal resolution.

This section of the report discusses the adoption of an economic input-output modeling approach to estimate the energy consumption and greenhouse gas (GHG) emissions associated with the direct and lifecycle effects embedded in commodity flows and economic activities in Los Angeles County to spatially represent energy consumption and GHGs. The approach uses data for economic activities using the input-output IMPLAN economic model, aggregated by economic sectors. Energy consumption and GHG emissions are computed for both direct and indirect effects of the economic activities using California-specific energy consumption and GHG emission factors obtained from the California Air Resource Board (CARB) environmental input-output LCA model (CA-EIO-LCA). The methodology allows the quantification of the lifecycle energy consumption and greenhouse gas (GHG) emissions associated with production, consumption and export of commodities, goods and services, and it supports the identification of areas where policies should address increased efficiency and GHG emission reductions in more energy-intensive sectors of the economy.

The results from this portion of the study help identify spatial patterns in energy consumption and GHG emissions in the area of study, and allow researchers to analyze the different trends in specific economic sectors. In particular, the analysis highlight some important findings related to the need to account total supply-chain environmental effects in the evaluation of the impact from economic activities. As discussed in the following sections, the environmental effects of some sectors of the economy, more than others, largely vary depending on the methods of GHG
accounting. In particular, some sectors are associated with very small (in magnitude) direct environmental impacts. However they are an important source of energy consumption and GHG emissions, if the entire lifecycle activities are considered. The difference between direct vs lifecycle (which include the entire supply chain) effects is important. Since GHG emissions are global, having low direct GHG emitting activities in the area of study is often linked to supply-chain GHGs being generated elsewhere, but the aggregate impact on the planet remains the same. Thus, for longer term sustainability, the identification of the total GHG-emissions effects of the activities (and their spatial distribution) is important, in order to properly assess the role of the various economic activities that are active in a region in affecting environmental disruption.

5.2 Methodology

Researchers applied a modeling approach to estimate the resource and energy consumption associated with the direct and lifecycle effects embedded in commodity flows and economic activities in the area of study. The primary objective of this part of the project was to establish a comprehensive platform for estimating the lifecycle energy and GHG impacts of economic activity within Los Angeles County for the base year 2008. This entailed the evaluation of the patterns of production, consumption and export of economic commodities by economic sector in the County. The results were then combined with the estimation of the lifecycle energy and GHG associated with the output of each economic sector to compute the resulting lifecycle impacts associated with economic activities and then mapped.

Researchers used 2008 IMPLAN (Impact Analysis for Planning) data for Los Angeles County and commodity flows aggregated to 49 economic sectors. IMPLAN data capture the production, consumption and export of commodities exchanged among industries and between industries and consumers for the entire US at the county level. They are available for 440 economic sectors,5 which are defined as functional aggregations of North American Industry Classification System (NAICS) codes. Researchers combined the outputs of the commodity flow estimation with the emissions factors (estimated for the same aggregations of industry sectors) derived from the California-specific environmental input-output LCA model (CA-EIO-LCA) created for the California Air Resources Board (Masanet et al., 2012). CA-EIO-LCA tables allowed the estimate of energy resources required for, and the environmental emissions resulting from, economic activities. County-level energy and GHG estimates were computed for the 49 economic sectors and were assigned to a more disaggregated level of spatial aggregation.

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5 In 2000, IMPLAN had 528 categories. Starting in 2005, later versions of IMPLAN aggregated economic sectors to 509 economic sectors, which were further reduced to 440 categories starting from the modeling year 2007. Using documentation available from IMPLAN, the researchers built complete crosswalks to convert economic results among the 528 categories of IMPLAN 2000, the 509 categories of IMPLAN 2005, the 440 categories of IMPLAN 2007 (and more recent years) and the 52 categories used in the California PECAS model, of which 49 were used in this study for the quantification of energy consumption and GHG emissions by economic sector.
using the distribution of employment by economic sector for land use zones (LUZ) 6 and transportation analysis zones (TAZ). 7 The methodology used in this study allowed the quantification of the life cycle energy consumption and GHG emissions associated respectively with the production, consumption and export of commodities, goods and services in Los Angeles County. It used California-specific energy consumption and emission factors computed from the lifecycle analysis of the environmental impacts of economic activity, in coordination with the activities developed by the other research units participating in the project, in order to generate the estimates of the lifecycle analysis by each economic sector.

The researchers opted for the use of a quantitative approach that could be integrated with a computable general equilibrium (CGE) modeling approach to complete the estimation of the commodity flows in Los Angeles County. This allowed the estimation of the energy and environmental impacts associated with the current activities. CGE models have been developed to provide guidance on the effects of large-scale events impacting economic activity at the level of individual commodity groups and industry types.

The data for the commodity flows in the 2008 base year scenario were computed using IMPLAN data associated with production, consumption and export patterns for Los Angeles County for the aggregated 49 economic categories. Economic sectors and commodity types were aggregated by similarity, starting from the NAICS sector information. Researchers developed detailed analysis to build extensive comparisons and internal and external consistency checks to review the aggregation of economic categories from the IMPLAN and matched these to TREDIS (http://www.tredis.com) (a suite of tools that assesses economic impacts, benefits and costs of transportation policies, plans and projects) categories. Data were examined in spreadsheet and database format to identify possible internal inconsistencies in the data for commodity flows. Data were also examined to identify possible gaps in the analysis of economic activities, which would affect the quality of the estimation of energy consumption and GHG emissions associated with each economic sector. Results were computed separately for the categories of production, consumption and export of commodity flows in Los Angeles County.

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6 The LUZs were previously defined during the development of the California PECAS model (at the UC Davis Urban Land Use and Transportation Center) as smaller areas of spatial aggregation that can be considered rather homogenous in terms of economic patterns and sociodemographics. Los Angeles County is divided in 57 LUZs.

7 The TAZs were created as part of the development of the California PECAS and CSTDM models, in order to analyze the distribution of households, workplaces and transportation activities for modeling purposes. 1301 TAZs are located in Los Angeles County.
Researchers then used the commodity flow data obtained from the modeling framework to compute the overall direct and life-cycle environmental patterns associated with each economic sector in 2008. Commodity flow data for the 2008 base year are measured in 2008 US$ by economic sector. These commodity flow data are combined with the results from the California-specific environmental input-output LCA model (CA-EIO-LCA) created for the California Air Resources Board. As the results of the CA-EIO-LCA analysis are referenced to the year 2002, using 2002 US$, the researchers converted commodity flow data to 2002 dollars to assure consistency of the data in the computation of the final lifecycle energy and environmental impacts.
Figure 5.2: Estimation of Direct and Indirect Impact of Economic Activities on Energy Consumption and GHG Emissions

The CA-EIO-LCA model assesses the economy as 428 sectors, each corresponding to a cluster of standardized industrial classification codes (NAICS). The joining of economic flows with CA-EIO-LCA impacts produces a region-specific assessment of environmental outcomes from economic activities. The outcome shows how industries and other economic activities in Los Angeles County produce impacts directly and indirectly (i.e. in the supply chain). For example, the impacts of a manufacturing process may release emissions at the manufacturing plant itself but also trigger supply chain activities that may occur outside of the county, state, or even country. Figure 5.1 summarizes the commodity flows, energy and GHG emissions flows that are analyzed in this part of the study.
The results from the modeling framework were aggregated to the land use zone (LUZ) level of spatial aggregation for the analysis of spatial economic patterns and the distribution of economic activities and environmental impacts in the regions, using employment data by economic sector obtained from InfoUSA. In this part of the analysis, we used the employment data to spatialize the analysis, and assign the data computed for energy consumption and GHG emissions to the geographical areas where the activities actually take place. Combining these approaches enables a strong visual understanding of energy use and GHG emissions in the County. Los Angeles County is divided into 57 LUZs. As part of the study, energy and environmental impacts of economic activities are also analyzed at the more detailed Transportation Analysis Zone level of spatial aggregation. There are a total of 1301 TAZs in Los Angeles County (about 23 TAZs are contained on average in each LUZ). TAZs nest perfectly into land use zones. Figure 5.2 shows the process of data aggregation that was used for the estimation of the direct and indirect impacts on energy consumption and GHG emissions by
economic sector, and the creation of the related datasets and maps. Figure 5.3 shows the distribution of land use zones and transportation analysis zones in Los Angeles County.

5.3 Results

Researchers integrated the input-output modeling approach with the California-specific environmental input-output Life-Cycle Analysis model (CA-EIO-LCA) as a platform for assessing the volume of economic activity, by sector, and the related impact in terms of energy consumption and GHG emissions in Los Angeles County. This allowed creating a baseline assessment of the direct (local) vs. indirect (included in the lifecycle) energy consumption and GHG emissions from production, consumption and export of commodities (goods and services) in the area of study and the mapping of the data.

Such an approach provides decision-makers with better information associated with the environmental impact of economic activities (and their spatial distribution in the area of study). The more easily-measurable direct effects of economic production are, in fact, only a limited portion of the entire environmental effects associated with economic patterns of consumption in an important metropolitan area. Figure 5.4 shows an example with the comparison of total economic value in the fields of food production and food consumption for Los Angeles County. Large metropolitan areas are associated with very intense consumption patterns, which are – for many reasons, including available land -- usually only partially met by local production. Moreover, the effects of this large consumption (on the economy, as well as on the environment) are often felt in terms of externalities very far away in the increasingly extended and internationally-integrated supply chains, some of which are captured in the EIO-LCA model.

![Figure 5.4: Comparison of Total Economic Volume (in 2008 US$) of Food Production and Food Consumption in Los Angeles County, and the Associated Direct and Lifecycle Effects](image)

Source: University of California Davis and Georgia Institute of Technology

Building a methodology that allows understanding the relationships between production and consumption patterns and the total direct and lifecycle effects associated with these flows of goods and services provides decision-makers with information that can better support the development of policies targeted at improving the total efficiency of the system. It can support the identification of specific targets and encourage reduced environmental effects and increased social equity in the access to goods and services, as well as in understanding and governing the
spatial distribution of their effects in terms of energy consumption and other environmental externalities.

Figure 5.5 summarizes the results for the amount of economic demand (consumption), supply (production) and export for the top 20 sectors in the area of study, in term of their direct environmental impacts (measured in Tons of CO2 equivalent) included in the analysis for the entire Los Angeles County. For a complete list of all 49 economic sectors, see Appendix A.

Figure 5.5: Total Economic Activity (Production, Consumption, Export) in 2008 for the 20 Economic Sectors Responsible for the Largest Direct CO2 Emissions in Los Angeles County

Depending on the specific sector and the characteristics of economic activities, the direct GHG emissions might be significantly larger than the indirect emissions. The differences are illustrated in Figure 5.6, which reports the ranking of the top 20 sectors in the area of study, in term of their direct environmental impacts (measured in Tons of CO2 equivalent), and compares the direct and lifecycle GHG effects associated with each sector.
The following table demonstrates the direct and lifecycle energy associated with the corresponding amount of economic output (by top 10 sectors) that was consumed in Los Angeles County, and the corresponding direct and lifecycle GHG emissions (expressed in tons of CO2 equivalent). This table only lists the top 10 economic sectors responsible for the largest direct CO2 emissions. For a complete list of all 49 sectors, see the appendix at the end. As previously mentioned, consumption patterns in large metropolitan areas, such as Los Angeles, might largely depend on goods and services that are not locally produced, and whose environmental effects are often experienced by others, sometimes also a far distance from the place of consumption. The results in this table provide information on the overall environmental effects associated with the consumption, production and export patterns in Los Angeles County, by sectors, which are often only partially linked to local production. For GHG accounting into the future, these types of analyses are critical as they reveal the importance of fossil fuels in consumption, production and export. Such understandings can inform economic development strategy in the region, but also more widely.

The assessment of the direct and indirect energy consumption and GHG emissions from economic activities allowed creating a database that includes detailed information for all
economic activities in the area of study, measured in terms of the amount of commodity flows by economic sector in Los Angeles County, and the associated energy consumption and GHG emissions, for both the direct local effects and in their lifecycle effects, after the entire supply chain impacts are accounted for.
Table 5.1: Total economic activity (production, consumption, export) by sector (in 2008 $Millions) and direct and lifecycle effects associated with economic sector and by activity in Los Angeles County in 2008 (Sources: IMPLAN; CA-EIO-LCA)

<table>
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</tr>
</thead>
<tbody>
<tr>
<td>ELECTRIC UTILITIES</td>
<td>5,219.74</td>
<td>12,463.20</td>
<td>1,185.01</td>
<td>471,035.53</td>
<td>484,119.85</td>
<td>38,467,901.87</td>
<td>40,866,693.94</td>
</tr>
<tr>
<td>MANUFACTURING Petro-Chemicals</td>
<td>29,337.83</td>
<td>21,734.80</td>
<td>13,712.86</td>
<td>292,898.02</td>
<td>711,714.82</td>
<td>26,147,961.36</td>
<td>64,225,930.08</td>
</tr>
<tr>
<td>WHOLESALE TRADE</td>
<td>58,126.30</td>
<td>42,937.04</td>
<td>30,135.43</td>
<td>267,563.31</td>
<td>474,027.58</td>
<td>17,651,375.35</td>
<td>33,593,143.04</td>
</tr>
<tr>
<td>TRANSPORTATION SERVICES</td>
<td>12,949.95</td>
<td>12,581.64</td>
<td>6,209.16</td>
<td>247,628.20</td>
<td>342,470.28</td>
<td>16,879,510.91</td>
<td>24,274,091.79</td>
</tr>
<tr>
<td>MANUFACTURING Paper Chemicals</td>
<td>33,089.88</td>
<td>44,588.68</td>
<td>21,416.07</td>
<td>244,048.36</td>
<td>672,989.59</td>
<td>16,332,337.03</td>
<td>47,141,647.38</td>
</tr>
<tr>
<td>State and Local GOVT Services</td>
<td>41,603.08</td>
<td>41,603.08</td>
<td>7,481.24</td>
<td>146,812.13</td>
<td>222,130.11</td>
<td>8,783,235.32</td>
<td>16,998,688.91</td>
</tr>
<tr>
<td>ONSITE BUSINESS SERVICES</td>
<td>21,199.09</td>
<td>23,607.27</td>
<td>6,343.66</td>
<td>10,893.65</td>
<td>65,450.47</td>
<td>5,388,593.36</td>
<td>9,423,451.27</td>
</tr>
<tr>
<td>MINING AND EXTRACTION</td>
<td>6,485.08</td>
<td>32,502.01</td>
<td>1,764.79</td>
<td>61,512.24</td>
<td>117,187.04</td>
<td>4,892,111.93</td>
<td>9,591,120.66</td>
</tr>
<tr>
<td>MANUFACTURING Metal Steel</td>
<td>16,260.09</td>
<td>19,423.67</td>
<td>11,633.52</td>
<td>66,356.76</td>
<td>239,167.11</td>
<td>4,100,371.53</td>
<td>17,114,601.58</td>
</tr>
<tr>
<td>MANUFACTURING Food</td>
<td>24,155.55</td>
<td>28,777.91</td>
<td>13,551.43</td>
<td>71,528.79</td>
<td>310,452.96</td>
<td>3,266,294.99</td>
<td>30,927,756.64</td>
</tr>
</tbody>
</table>

Source: University of California Davis and Georgia Institute of Technology
In the remainder of this section, the spatial distribution of the energy and environmental impacts associated with the economic activity in Los Angeles County are explored. As discussed in the methodology section, employment data by economic sector from InfoUSA is used to disaggregate the information spatially. In this way, economic activities (and the related energy and environmental impacts) were assigned to the Land Use Zones (LUZs) in Los Angeles County as InfoUSA indicates where employment centers in different sectors are located. A similar process was used to assign economic activities to an even more detailed level of spatial aggregation, the Transportation Analysis Zones (TAZs).

This part of the study allowed researchers to identify specific patterns in the distribution of economic activity, and the associated environmental impacts at a more detailed level of spatial aggregation. For instance, Figure 5.7 graphically represents the spatial distribution of the activities in the field of “metal/steel production” in Los Angeles County. The map was created using information about the total economic output for this sector in Los Angeles County and projecting it to a more detailed level of spatial aggregation (TAZ level, in Figure 5.7) using information about the spatial location of employment in this field in the county. This pattern is based on the assumption that the amount of economic output (and the associated energy consumption and environmental impacts) can be assumed to be constant, for each economic sector, across different parts of the study area as more disaggregated data would disclose confidential energy use. This is also a simplification of the reality that does not account for the presence of specific differences across various businesses in the same economic sector.
The information about the location of employment by economic sector was used to assign the respective energy and environmental impacts associated with economic production inside Los Angeles County.8

The approach was used to build a geo-spatial database for Los Angeles County, which included information on the spatial distribution of economic activities, and the associated energy consumption and environmental effects in the area of study, by economic sector. This allowed the generation of detailed analysis and spatial maps of the distribution of economic activities and associated environmental impacts, which were developed both at the LUZ and TAZ levels of spatial aggregation.

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8 This study focuses primarily on the direct and lifecycle energy consumption and GHG emissions associated with production activities, given that the employment data that were used in the process of spatial disaggregation are a measure of the distribution of production activities, by economic sector, in a region. Consumption patterns might differ substantially in their spatial distribution as centers of consumption could be located far away from where production activities (and employment) are located.
The following Figure 5.8 presents an example of the spatial distribution of the environmental effects associated with heavy industry activities for metal/steel production (and related transformational activities) in Los Angeles County (generated by the production activities in this sector represented in the previous Figure 5.7). The data mapped in Figure 5.8 represent the spatial distribution of the direct GHG emissions associated with the production activities in this economic sector. As a comparison, Figure 5.8 reports the spatial distribution of the indirect (lifecycle) GHG emissions associated with the same sector (using the same scale for measuring the environmental effects of the economic activity). Understanding the difference between direct and indirect GHG emissions is an important aspect of reducing them. Indirect GHG emissions are either produced in infrastructure development (as in building stock, roadways), or emitted out of the region. Either way, they are still GHGs associated with the sector that need to be better tracked and accounted for.

**Figure 5.8: Spatial Distribution of the Direct GHG Emissions (in CO2 Equivalent) of Steel/Metal Production**

Source: University of California Davis and Georgia Institute of Technology
The results from this portion of the study help identify spatial patterns in energy consumption and GHG emissions in the area of study, and they allow researchers to analyze the different trends in specific economic sectors. In particular, the analysis can highlight the environmental effects of some sectors of the economy that are not associated with very large (in magnitude) direct environmental impacts, but that might represent an important source of energy consumption and GHG emissions if the entire lifecycle activities are considered.
For example, Figure 5.10 reports the direct (left part of the figure) and lifecycle (right part of the figure) GHG emissions associated with media production, an economic sector that is particularly important in Los Angeles County. Even if media production is usually found to have rather low direct CO2 emissions, if the total lifecycle effects are accounted for, the relevance of this sector increases significantly in comparison with the rest of economic activities. In other words, the media production activities located in Los Angeles County are responsible for a much larger impact in terms of total GHG emitted in the environment, even if these effects are not perceived locally (but they are equally harmful for the environment). This should be appropriately considered, for instance, when developing policies that regulate (e.g. limit, or tax) GHG emissions, attributing the full damages caused to the environment to the activities that caused them (see the right part of Figure 5.10) even if the emissions do not necessarily happen there (but rather the companies that are responsible for them are located there). Chapter 6 of this report discusses the GHG emissions associated with jobs in the media sector, and the transportation GHGs of production as well, but also transportation GHGs created by driving to movie theaters.

Even if the media production sector of economic activity does not produce many environmental externalities locally, its total contribution to the larger processes of environmental pollution (and climate change) is much larger. Effective policies designed to limit the environmental impacts of economic activities should therefore consider these indirect impacts (some of which are not produced in the local area) too, to reduce environmental externalities associated with economy activity, and to target overall increased energy efficiency. In this sector, much of the administrative and business end of media production takes place in Los Angeles, while the
actual production takes place across the globe. Those GHG emissions involved in making of films, are not produced locally.

This part of the research focused on the estimation of the energy consumption and GHG emissions associated with economic production, consumption and export flows in Los Angeles County. The next section of the report discusses the relationship between employment and GHGs. Here, the use of EIO-LCA to estimate the direct and indirect energy consumption and greenhouse gas (GHG) emissions from economic sectors for Los Angeles County are integrated. The integration enables insights into the energy and GHG impact associated with these economic patterns, including the embedded energy from indirect effects through the inclusion of supply chain energy and resource flows. This enhances the understanding of the environmental impacts in complex regions and cities (Chester, Pincetl, Allenby 2012; Pincetl, Bunje, Holmes 2011). EIO-LCA has been increasingly used for sustainability assessments of economic production and as a tool for the evaluation and ranking of the environmental impact and eco-efficiency of different economic sectors (Egilmez et al. 2013).

The approach used in this part of the study used a limited number of aggregations – 49 -- economic sectors to represent functional aggregations of economic sectors. This allows assisting policy-makers in identifying the contributions to the total energy and environmental impacts of the various economic sectors, and it supports the evaluation of policies that tackle increased efficiency in specific sectors.

**Figure 5.11: Estimated Direct (left) and Lifecycle (right) Effects for the Top Five Economic Sectors Responsible for the Highest direct GHG Emissions in LA County**

For instance, the left part of Figure 5.11 summarizes the direct GHG effects (measured as percentages of the total tons of CO2 equivalent emitted in the area of study) and identifies the five economic sectors responsible for the highest amounts of GHG emissions in Los Angeles County.
County. These sectors are attributed (jointly) approximately 72 percent of the total direct emissions in the area of study. However, when the entire lifecycle effects are accounted for in the analysis, the relevance of these five sectors (right part of Figure 5.11) is reduced, as other economic activities have stronger indirect impacts and supply-chain effects. If the goal of policy-making is the reduction of the total environmental impacts associated with economic activities, and not only the portion that is locally produced and measured, the larger the difference between direct and lifecycle effects is for a sector, the larger any needed adjustment in the policy should be. Eventually, different rankings among economic sectors are observed, and different policies should be developed, if the purpose of the policies is to address the most polluting sectors across the entire lifecycle.

The next step in the economic analysis of GHG emissions in Los Angeles County is to examine the relationship between GHGs and employment. This discussion is important as it shows the relationship between wages and GHGs a relationship that has insufficiently been explored. It is important to consider in economic planning and moving toward a lower carbon, or post carbon economy.
CHAPTER 6:
Industrial Greenhouse Gas and Wage Sustainability, A Baseline Analysis for Los Angeles County

Daniel Flaming and Patrick Burns, The Economic Roundtable

6.1 Overview

A baseline profile of Los Angeles County industries is developed using three dimensions of sustainability: greenhouse gas emissions, social sustainability based on wages for workers, and economic viability based on size and growth, with primary emphasis on the first two factors. The metric for assessing greenhouse impacts in different industries and geographic areas is the ratio of jobs to emissions indexed three ways: direct emission from establishment activities, direct emissions from gasoline consumed by customers driving to establishments in private light duty vehicles, and the full life cycle emissions from the supplier chain linked to activities at each establishment as well as from establishment activities. This analysis provides another dimension to the previous one that showed greenhouse gas emissions per industrial sector. Here the focus becomes the knowledge needed to plan for a less greenhouse gas intensive job sector that maintains living wages. Progress toward sustainability requires an industry trajectory that 1) adds higher levels of value to the economy for each terajoule that is consumed, 2) cleaner sources of power that release less greenhouse gas per terajoule consumed, and 3) higher wages so that all workers are paid enough to support a minimum standard of living.

Similar to the methods utilized to determine GHG emissions in each industrial sector, for GHG emissions per job, direct establishment emissions are estimated using the California multi-regional input-output (MRIO) life-cycle assessment (LCA) model. Life cycle emissions are estimated using the U.S. Economic Input-Output Life Cycle Assessment (EIO-LCA) model. Correction factors for calibrating the models to Los Angeles County are derived from county-level California Energy Commission data breaking out energy consumption by industry as well as from annual changes in the ratio of industry energy consumption to the amount of value added by industries.

In this section of the report industry development and job growth options are identified that can make the region more environmentally and socially sustainable. This baseline profile of Los Angeles County industries uses three dimensions of sustainability: greenhouse gas emissions, economic viability based on size and growth, and social sustainability based on wages for workers. This inclusive framework for assessing sustainability draws on the concept of three pillars of sustainable development that was put forward by the United Nations Brundtland Commission in 1987.

Emission reduction targets for both the United States and California converge on reducing greenhouse gas emissions by 83 percent in 2050. The baseline evidence presented in this report indicates that the amount of energy consumed by Los Angeles’ industries has remained roughly constant and has not yet shifted into the steep downward trajectory required to meet 2050 goals.
Local government can help achieve the goals for reducing greenhouse gas emissions by making land use decisions and enacting development policies that encourage a regional industry structure that adds growing value to the economy and employs growing numbers of workers while releasing decreasing amounts of greenhouse gases. Information in this report can be used in assessing trade-offs for achieving both social and environmental sustainability.

6.2 Ranking Industries – GHGs per Job

This analysis of the baseline relationship between energy, greenhouse gases and wage sustainability draws on multiple data sets to produce estimates of greenhouse gas and wage outcomes from each type of industry in each sub-region of the county. Data sources include:

1. Longitudinal establishment data for each employer in the county with addresses, industry classifications, employment levels, and payroll amounts for each facility (this data is covered under a non-disclosure agreement and all analysis presented in the report is aggregated to protect the confidentiality of establishments).
2. Annual data from the California Energy Commission identifying the amount of electricity and natural gas consumed by each industry in Los Angeles County.
3. The California multi-regional input-output (MRIO) life-cycle assessment (LCA) model provides direct energy consumption and greenhouse gas emission factors for each industry.
4. The U.S. Economic Input-Output Life Cycle Assessment (EIO-LCA) model provides life cycle energy consumption and greenhouse gas emission factors for each industry.

This combination of data sources means that industry employment and payroll data is accurate and specific to each sub-region, however greenhouse gas emission factors represent statewide averages for each industry in the case of direct emission estimates using the MRIO-LCA model, and national averages for each industry in the case of life cycle estimates using the EIO-LCA model as in the estimates of GHG emissions per industrial sector discussed in the previous section. An additional limitation is that both the MRIO-LCA and EIO-LCA models are derived from the Bureau of Economic Analysis’ 2002 benchmark Input-Output Make and Use tables. Correction factors for the time lag built into these models comes from annual energy consumption data provided by the California Energy Commission, which are applied to direct emission estimates produced using the California MRIO-LCA model, and annual changes in the amount of value added per worker in each industry in Los Angeles, which are incorporated into both the MRIO-LCA and EIO-LCA models.

Three key strengths of MRIO-LCA and EIO-LCA models are their comprehensiveness, their consistency, and their use of very rich, complex and reliable data from the Bureau of Economic Analysis. The 2002 benchmark Input-Output Make and Use tables describe each industry separately, covering the entire industry structure. A single framework of industry relationships is used to produce energy and emissions factors for every industry, covering the entire economy. These models made it possible for this analysis to link employment at each
establishment with standardized industry factors for energy consumption and greenhouse emissions in order to estimate the environmental impact of each establishment.

Overall consumption of electricity and natural gas by industries in the county has remained constant since 2008, with slight progress in increasing the amount of value added to the economy per terajoule of energy consumed. Extracting and refining petroleum for transportation uses (leaving out the impacts of burning the fuel in transportation uses) accounts for nearly a third of the greenhouse gasses emitted by industries in Los Angeles County.

Measured against environmental benchmarks, the county’s industries have not yet made visible progress in meeting the federal target for 2020 of reducing greenhouse gas emissions 17 percent below 2005 levels.

Measured against social benchmarks, employment is increasingly concentrated in the service sector, with a large segment of employment in low-wage service industries. Los Angeles County lags behind the state and nation in median levels of earned income, and the city of Los Angeles lags behind the county.

The metric for assessing greenhouse impacts in different industries and geographic areas was the ratio of jobs to emissions indexed three ways: direct emission from establishment activities, direct emissions from gasoline consumed by customers driving to establishments in private light duty vehicles and the full life cycle emissions from the supplier chain linked to activities at each establishment as well as from establishment activities.

The three industries with the highest greenhouse gas emissions per job in 2011 were petroleum refining (12,292 tons), air transportation (1,442 tons), and utilities (941 tons). These high emissions in a small number of basic industries skewed the overall average upward. The entire industry base of the county emitted an average of 33 tons of greenhouse gases per job in 2011. At the low end of the spectrum, office-based industries had direct greenhouse gas emissions of roughly one-twentieth of a ton per job.

Customer trips are estimated to account for a metric ton or more annually of greenhouse gas emissions per employee in 20 major industries, and account for more emissions per job than establishment activities in 18 major industries. The emission profile of a number of industries shifts from negligible to significant emissions per job when the impact of gasoline consumed for customer trips is taken into account.

Industries in each sub-region of Los Angeles County are ranked on two scales, wage sustainability and greenhouse gas sustainability based on both direct emissions from establishment activities and emissions from gasoline consumed for customer trips to establishments. The quintile benchmarks used for ranking were derived by dividing Los Angeles County’s labor force in 2011 into wage quintiles and greenhouse gas quintiles, with an equal number of employees in each quintile on each scale. In many instances the ranking for environmental sustainability differs from the ranking for wage sustainability. In the near-term, these rankings differences identify trade-offs. In the long-term, they identify sustainability
weaknesses that need to be improved to increase industry sustainability and long-term prospects for viability.

A summary of these quintile rankings for wage and greenhouse sustainability for Los Angeles industries is shown in the following table. Only five of the rolled-up industries shown in the table, representing 26 percent of total employment, both pay at least average wages (wage tiers 3 to 5) and emit less than 2.2 metric tons of greenhouse gasses per job each year (GHG tiers 4 to 5). Three-quarters of the county’s industry base pays less than average wages, has average or higher emissions, or both.

Table 6.1: Quintile Ranking of Los Angeles County Industry Sectors

<table>
<thead>
<tr>
<th>Industry</th>
<th>Employment 2011</th>
<th>Wage Tier 5 = Best</th>
<th>Annual Average Wage 2011</th>
<th>MT GHG per Job from Establishment Activities &amp; Customer Trips 2011</th>
<th>GHG Tier 5 = Best</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>5,720</td>
<td>1</td>
<td>$28,679</td>
<td>35</td>
<td>1</td>
</tr>
<tr>
<td>Petroleum Extraction &amp; Refining</td>
<td>6,269</td>
<td>5</td>
<td>$148,884</td>
<td>8,231</td>
<td>1</td>
</tr>
<tr>
<td>Electric Power Generation &amp; Distrib</td>
<td>16,560</td>
<td>5</td>
<td>$109,316</td>
<td>1,439</td>
<td>1</td>
</tr>
<tr>
<td>Other Utilities</td>
<td>12,684</td>
<td>5</td>
<td>$81,520</td>
<td>6,238</td>
<td>1</td>
</tr>
<tr>
<td>Construction</td>
<td>107,683</td>
<td>3</td>
<td>$53,360</td>
<td>0.08</td>
<td>5</td>
</tr>
<tr>
<td>Food &amp; Apparel Manufacturing</td>
<td>104,947</td>
<td>2</td>
<td>$38,487</td>
<td>4.52</td>
<td>2</td>
</tr>
<tr>
<td>Wood, Chem, Plastic, Cement</td>
<td>64,274</td>
<td>3</td>
<td>$47,889</td>
<td>14</td>
<td>1</td>
</tr>
<tr>
<td>Metal &amp; Other Durable Mfg.</td>
<td>197,727</td>
<td>4</td>
<td>$69,723</td>
<td>2.18</td>
<td>4</td>
</tr>
<tr>
<td>Wholesale Trade</td>
<td>208,856</td>
<td>3</td>
<td>$55,451</td>
<td>0.11</td>
<td>5</td>
</tr>
<tr>
<td>Retail Trade</td>
<td>396,780</td>
<td>1</td>
<td>$30,596</td>
<td>8.88</td>
<td>2</td>
</tr>
<tr>
<td>Air Transportation</td>
<td>18,033</td>
<td>4</td>
<td>$63,155</td>
<td>1,445</td>
<td>1</td>
</tr>
<tr>
<td>Trucking &amp; Couriers</td>
<td>44,029</td>
<td>2</td>
<td>$42,763</td>
<td>290</td>
<td>1</td>
</tr>
<tr>
<td>Other Transportation</td>
<td>102,650</td>
<td>3</td>
<td>$52,287</td>
<td>35</td>
<td>1</td>
</tr>
<tr>
<td>Information</td>
<td>197,255</td>
<td>5</td>
<td>$94,125</td>
<td>0.60</td>
<td>4</td>
</tr>
<tr>
<td>Finance, Insurance, Real Estate</td>
<td>215,407</td>
<td>5</td>
<td>$81,127</td>
<td>4.02</td>
<td>2</td>
</tr>
<tr>
<td>Prof., Scientific, &amp; Tech. Srv.</td>
<td>314,693</td>
<td>5</td>
<td>$87,794</td>
<td>0.27</td>
<td>5</td>
</tr>
<tr>
<td>Admin. Support &amp; Waste Mgmt.</td>
<td>239,952</td>
<td>2</td>
<td>$33,574</td>
<td>2.24</td>
<td>3</td>
</tr>
<tr>
<td>Education</td>
<td>351,631</td>
<td>3</td>
<td>$49,837</td>
<td>2.50</td>
<td>3</td>
</tr>
<tr>
<td>Industry</td>
<td>Employment 2011</td>
<td>Wage Tier 5 = Best</td>
<td>Annual Average Wage 2011</td>
<td>MT GHG per Job from Establishment Activities &amp; Customer Trips 2011</td>
<td>GHG Tier 5 = Best</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>----------------</td>
<td>-------------------</td>
<td>--------------------------</td>
<td>---------------------------------------------------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>Health Care &amp; Social Assistance</td>
<td>469,446</td>
<td>3</td>
<td>$52,070</td>
<td>2.42</td>
<td>3</td>
</tr>
<tr>
<td>Arts, Entertainment, &amp; Recreation</td>
<td>78,751</td>
<td>5</td>
<td>$90,451</td>
<td>2.84</td>
<td>3</td>
</tr>
<tr>
<td>Hotels &amp; Restaurants</td>
<td>334,825</td>
<td>1</td>
<td>$19,395</td>
<td>17</td>
<td>1</td>
</tr>
<tr>
<td>Personal &amp; Repair Services</td>
<td>256,118</td>
<td>1</td>
<td>$24,849</td>
<td>2.48</td>
<td>3</td>
</tr>
<tr>
<td>Public Administration</td>
<td>151,279</td>
<td>4</td>
<td>$75,553</td>
<td>17</td>
<td>1</td>
</tr>
</tbody>
</table>

Source: Economic Roundtable 2014

The very highest levels of greenhouse gas emissions are from cornerstone industries that provide energy and movement that are essential for the economy: petroleum extraction and refining, electric power generation and distribution, air transportation, and trucking.

The lowest wages are predominantly in routine service industries – retail, restaurants, hotels and personal services.

Some industries are both socially and environmentally sustainable when seen individually, however, all industries are dependent on the energy and transportation sectors of the economy, which are emission-intensive. The long-term sustainability of all industries is dependent on cleaner sources of energy and higher levels of value added to the economy per unit of energy consumed.

Progress toward environmental sustainability requires improved technologies and industry processes for producing electricity and petroleum and for moving people and goods much more efficiently and with much less dependence on fossil fuels. To become more socially, economically and environmentally sustainable, Los Angeles County must move its industry base toward:

1. Higher levels of value added to the economy for each terajoule that is consumed.
2. Cleaner sources of power that release less greenhouse gas per terajoule consumed.
3. Higher wages so that all workers are paid enough to support “the minimum standard of living necessary for health, efficiency, and general well-being.”

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9 These criteria for the minimum level of worker compensation are from Section § 202 - Congressional finding and declaration of policy, The Fair Labor Standards Act of 1938.
6.3 Tools for Assessing Sustainability

Data from this study is operationally relevant for informing land use decisions in Los Angeles County, Los Angeles City and each of the nine Southern California Association of Governments (SCAG) sub-regions within LA county. This includes detailed data for assessing sustainability strengths and weaknesses of industries in each region:

- Direct and life cycle energy consumption per job by industry
- Direct and life cycle greenhouse gas emissions per job by industry
- Direct greenhouse gas emissions from gasoline consumed for customer trips
- Average wages in each industry in each region

Policy relevant information includes identification of industry sectors that:

1. Support a growing economy that is socially and environmentally sustainable, or
2. Provide significant labor force benefits but at an unsustainable environmental cost and should be targeted for energy efficiency investments to increase competitiveness, or
3. Provide jobs with low associated greenhouse gas emissions but do not pay sustaining wages and should be targeted for wage improvements, or
4. Have significant carrying costs for both the social safety net and the environment.

6.4 Electricity and Natural Gas Consumption

Electricity and natural gas provide most of the energy that enables workers to add value to the economy, and are therefore essential prerequisites for the jobs of most workers in Los Angeles County’s labor force. The relationship between energy consumption and concomitant greenhouse gas (GHG) emissions, and value added to the economy provides a starting point for investigating industry sustainability.

6.4.1 Electricity Consumption by Industry Sector

Detailed data about electricity consumption by different industries in Los Angeles County is available from the California Energy Commission from 1990 onward. Electrical power consumption for uses other than residences and street lighting, that is, for commercial-industrial and governmental activities, peaked in 2001 at 184,880 terajoules, as shown in Figure 6.1. Electricity consumption dropped following the 2001 recession, increased from 2004 until the 2008 recession, although not to the 2001 level, and then declined through 2011.10 Industry

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10 Terajoules are used as the unit of measure in this discussion so as to provide a common framework for describing all forms of energy used by industries, including electricity, natural gas and petroleum. Natural gas and petroleum are primary forms of energy and electricity is a secondary form, however both the MRIO-LCA and EIO-LCA models used in chapter 2 and the discussion of the overall industry profile of Los Angeles County industries, as measured by natural gas and electricity consumption, require this integrated frame of reference. Care has been taken to avoid double counting natural gas used to generate electricity when discussing the combined consumption of natural gas and electricity.
electricity consumption increased in 2012, from 166,064 terajoules in 2011 to 172,192 terajoules in 2012. This suggests an overall pattern of fluctuation that follows business cycles within a consumption band of 160,000 to 180,000 terajoules of electricity a year to power the county’s industries.

**Figure 6.1: Annual Terajoules of Electricity Consumed by Industries in Los Angeles County**

Electricity consumption by industries has remained fairly stable over the 23-year time window shown in Figure 6.1. The greatest rates of change were an average annual decline of 2.7 percent for durable manufacturing and an average annual growth of 2.4 percent for other commercial – a catch-all category made up mostly of technical and professional services.11

The distribution of electricity consumption among industries in 2012 is shown in Figure 6.2. Offices were the largest consumer (17 percent), followed by other commercial (12 percent), retail (11%), and petroleum extraction and refining (11 percent). Petroleum-related electricity consumption is primarily for refineries.

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11 This is labeled “miscellaneous” by the California Energy Commission and includes: Gasoline stations, Motion picture and recording, Information services, Data processing services, Commercial and industrial leasing, Architects and engineers, Other professional and technical services, Technical and trade schools, Arts, entertainment and recreation, RV parks, Repair and personal services, Religious organizations, Civic organizations, Justice and public safety.
6.4.2 Natural Gas Consumption by Industry Sector

In 2012, industries in Los Angeles County consumed roughly 2.4 times as many terajoules of natural gas as they did of electricity. However, 37 percent of the natural gas consumed by industries is used to generate electric power, and thus is double-counted when it reappears in this study as electric power. When natural gas used to generate electric power is left out of the calculation, industries consume 1.5 times as many terajoules in the form of natural gas as in the form of electricity.
A breakout of natural gas consumption by industry sectors from 2008 through 2012 is shown in Figure 6.4.12. In 2012, 69 percent of the natural gas consumed by industries was used to extract and refine petroleum (32 percent) and to generate electricity (37 percent).

The time window for data breaking out natural gas consumption in Los Angeles County by industry is shorter than the comparable breakout for electric power. The natural gas breakout covers 2008 to 2012.
Double counting of natural gas energy used to generate electricity is avoided by removing it from the natural gas inventory in this section of the baseline analysis (Figure 6.4). This is necessary because GHG emission factors for electricity include the impacts of consuming natural gas to generate electricity. There is a related issue with natural gas as it is consumed at petroleum refineries to produce transportation fuel. However, unlike electricity, the consumption of natural gas at refineries is not included as a direct impact when computing greenhouse gas emissions, so it does not result in double counting. The natural gas energy that is embedded in refined petroleum appears only in life-cycle computations of emission impacts.

When the industry uses of natural gas that transform it into other forms of energy, i.e., electricity and petroleum, are removed from the mix, the remaining 31 percent of the inventory is consumed for the establishment-based uses.

Nondurable manufacturing accounts for 27 percent of establishment-based consumption, followed by hotels and restaurants, which consume 14 percent. Heating commercial buildings, the use encompassed by two categories, other commercial and offices, accounts for a total of 19 percent of establishment-based consumption of natural gas.

### 6.5 Electricity and Natural Gas

There is less year-to-year variation in the combined consumption of electricity and natural gas by the county’s industries (excluding consumption of natural gas for electric power generation) than there is when electricity or natural gas consumption are studied individually (Figure 6.5). Over the five years of 2008 to 2012, industries in Los Angeles Counties consumed an annual
average of 421,000 terajoules of natural gas and electricity. In 2012, total consumption of these two forms of energy slightly exceeded the 2008 level. Throughout the five-year interval shown in Figure 6.6, industry consumed 41 percent of the combined energy provided by electricity and natural gas in the form of electricity and 59 percent in the form of natural gas (excluding natural gas used for electric power generation).

6.5.1 Value Created in the Economy per Terajoule of Electricity and Natural Gas

A critical metric for assessing energy consumption is the amount of value that is added to the economy through the use of energy. Value is added almost entirely through the work done by the labor force. The economy and the jobs of workers become more environmentally sustainable when more value is created per unit of energy, and even more so, when more value is created per unit of greenhouse gas emitted.

**Figure 6.6: Value Created in All Industry Sectors per Terajoule of Electricity and Natural Gas**

From 2008 through 2011, all industries combined added an average of $1,175,000 to the economy for every terajoule of electricity and natural gas that they consumed (excluding natural gas used to generate electricity), as shown in Figure 6.6.13 There was a 1 percent increase from 2008 to 2011 in the amount of value added per terajoule of energy consumed by industries. This hints at slight progress toward increased energy efficiency.

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13 Energy consumption data is from the California Energy Commission, value added data for Los Angeles County is from IMPLAN data for the county in each year.
The amount of value added per terajoule of energy consumed in 2011 is broken out by broad industry sector in Figure 6.7, with electric power and natural gas each shown separately. Looking first at natural gas consumption, offices add the most value to the economy ($20,733,129) per terajoule of natural gas consumed and petroleum extraction, refining add next to the least ($97,619), and electric power generation added the least ($37,895). The low amount of value added per terajoule of natural gas consumed in producing petroleum and electric power represents the outcomes for energy-intensive industrial activities that produce comparatively inexpensive commodities – refined petroleum and electricity.

**Figure 6.7: Amount of Value Added per Terajoule of Electricity and Natural Gas Consumed by Industry Sectors in 2011**

Looking now at the amount of value added per terajoule of electricity consumed, many industries consume more energy in the form of natural gas than electricity, but the industry ranking based on energy-intensity is the same as for natural gas except for the combined sectors of agriculture, mining and construction. This sector added the most value to the economy per terajoule of metered electricity - $10,404,698. In the cases of agriculture and mining this reflected high reliance on petroleum (which is not shown in this figure) as an energy source. Offices added the next highest amount of value to the economy per terajoule of electricity consumed - $7,275,797. Utilities added the least value to the economy per terajoule of electricity consumed - $367,441 for utilities except electric power and $0 for electric power. This reflects the large amount of energy required to produce and move low-cost commodities, for example...
water. In the case of electric utilities it reflects incorporation of utility electricity consumption as part of overall energy loss in producing and distributing electric power.

**Figure 6.8: Tons of CO2e Emitted from Direct Industry Consumption of Electricity and Natural Gas Consumed in 2012**

6.5.2 GHG Emissions from Industry Consumption of Electricity and Natural Gas

In 2012, electricity and natural gas directly consumed by industries in Los Angeles County produced an estimated 27.5 million tons of greenhouse gas emissions, as shown in Figure 6.8. Extracting and refining petroleum accounted for nearly a third of these emissions – 8.7 million tons, followed by nondurable manufacturing – 2.9 tons and offices – 2.9 tons. Combining the impacts of electricity and natural gas for all industries, 64.4 tons of greenhouse gases were emitted for every terajoule of energy consumed.

These emissions estimates provide a benchmark for estimating the trajectory of reductions needed to meet federal targets for reducing overall production of greenhouse gas.

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14 This estimate is based on United States Environmental Protection Agency eGRID2012 Version 1.0 factor of 77.6 tons of CO2 equivalent emissions for every terajoule of electricity generated in California and the Greenhouse Gas Equivalencies Calculator factor of 50.3 metric tons or 55.4 short tons of CO2 equivalent emissions for every terajoule of natural gas consumed.
6.6 Reductions in GHG Necessary to Meet State and Federal Targets

California Assembly Bill 32, the Global Warming Solutions Act of 2006, establishes a comprehensive program to reduce greenhouse gas emissions from all sources throughout the state.

Table 6.2: California Greenhouse Gas Emission Trajectory

<table>
<thead>
<tr>
<th>Year</th>
<th>Millions of Metric Tons of CO₂ Equivalent for California</th>
<th>Total Emissions as % of 1990 Level</th>
<th>Total Emissions as % of 2005 Level</th>
<th>Metric Tons of CO₂ Equivalent per Person</th>
<th>Per Capita Emissions as % of 1990 Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>427</td>
<td>100%</td>
<td>88%</td>
<td>14.3</td>
<td>100%</td>
</tr>
<tr>
<td>2000</td>
<td>452</td>
<td>106%</td>
<td>93%</td>
<td>13.3</td>
<td>93%</td>
</tr>
<tr>
<td>2005</td>
<td>487</td>
<td>114%</td>
<td>100%</td>
<td>13.3</td>
<td>93%</td>
</tr>
<tr>
<td>2010</td>
<td>522</td>
<td>122%</td>
<td>107%</td>
<td>13.3</td>
<td>93%</td>
</tr>
<tr>
<td>2020</td>
<td>422</td>
<td>99%</td>
<td>87%</td>
<td>9.6</td>
<td>67%</td>
</tr>
<tr>
<td>2030</td>
<td>284</td>
<td>67%</td>
<td>58%</td>
<td>5.8</td>
<td>41%</td>
</tr>
<tr>
<td>2040</td>
<td>185</td>
<td>43%</td>
<td>38%</td>
<td>3.4</td>
<td>24%</td>
</tr>
<tr>
<td>2050</td>
<td>85</td>
<td>20%</td>
<td>17%</td>
<td>1.4</td>
<td>10%</td>
</tr>
</tbody>
</table>


The scoping plan for AB 32 that was adopted in 2008 uses 1990 as the benchmark year and sets out the goals for reducing total emissions as well as per capita emissions through 2050, as shown in Table 6.2. The goal for 2050 is to reduce the states total greenhouse gas emissions by 80 percent from what they were in 1990 or 83 percent of what they were in 2005. The goals anticipate population growth and call for reducing per capita emissions by 90 percent in 2050, with a 7 percent reduction achieved by 2000 and holding through 2010. That translates into reducing greenhouse gas emissions by:15

- 2020: 17 percent below 2005 levels
- 2025: 30 percent below 2005 levels
- 2030 42 percent below 2005 levels
- 2050: 83 percent below 2005 levels

These targets have not yet been adopted by Congress and signed into law but they provide federal benchmarks for reductions in greenhouse gas emissions. Emission reduction targets for both the United States and California are shown in Figure 6.9. Both sets of goals converge on reducing greenhouse gas emissions by 83 percent in 2050.

Achieving the goals set out by the state and federal governments will be an extraordinary feat, and if realized, a notable accomplishment.

The baseline evidence presented in this report indicates that the amount of energy consumed by Los Angeles’ industries has remained roughly constant and has not yet shifted into the steep downward trajectory shown in Figure 6.9.

Local government can help achieve the targeted reductions in greenhouse gas emissions through land use and development policies that encourage a regional industry structure that adds growing value to the economy and employs growing numbers of workers while releasing decreasing amounts of greenhouse gases. Such actions need to also ensure that GHG emissions are not exported outside of the region as, in fact, they will accrue to global GHGs and thus add to the global challenge.
6.7 Economic and Wage Sustainability of Los Angeles County Industries

This section of the analysis addresses two non-environmental dimensions of industry sustainability. The first dimension is wage sustainability – does an industry pay its workers enough to support “the minimum standard of living necessary for health, efficiency, and general well-being?” The second dimension is economic sustainability – is an industry large enough to be significant and is it growing or declining? These non-environmental dimensions of sustainability are integrated, with wages given triple weight to create an index of economic performance.

Three factors are being combined in this index: employment size, change in employment size, and average industry wage. A higher score on the index indicates higher performance. Each of the 23 industry sectors was ranked based on each of the three factors. The index was created by adding together an industry’s ranking on these three factors, after the wage ranking had been multiplied by three to give it triple weight. With three factors being combined and the wage factor triple weighted, wage levels accounted for 60 percent of the overall ranking, industry size 20 percent, and change in industry size 20 percent.

6.7.1 Wage Sustainability

Wages are central to the well-being of workers. Annual average wages in Los Angeles County’s formal economy are shown in Figure 6.10. Thirty-five percent of jobs are found in seven industries, where the average wages for all workers (managers through janitors) are under $40,000. At the bottom are hotels and restaurant jobs, paying under $20,000 a year. This low-wage cluster tops out with food and apparel manufacturing industries with average wages of about $39,000 a year.

16 These criteria for the minimum level of worker compensation are from Section § 202 - Congressional finding and declaration of policy, The Fair Labor Standards Act of 1938.
The middle cluster of industries starts with education, paying an average of about $51,000 a year, and extends through metal and machinery manufacturing, paying average wages of about $71,000 a year. This cluster of nine industries accounts for 41% of employment.

The highest paying cluster of industries starts with public administration, paying an average of about $77,000 a year, and extends to a small employment cohort in utilities earning an average of about $99,000 a year and an even smaller cohort in mining and petroleum extraction earning an average of about $159,000 a year. This cluster of the eight highest paying industries accounts for 24% of Los Angeles County’s employment in the formal economy.
The hourly wage distribution of Los Angeles County’s entire labor force, including workers in both the formal and informal economies, is shown in Figure 6.11. Informal workers typically have lower wages, pulling down the earnings levels for formal workers shown in Figure 6.10, but providing a more complete picture of earnings. 43% of workers are paid less than fifteen dollars an hour. This hourly wage is approximately 200% of the poverty threshold, representing a minimum living wage in a high-cost region like Los Angeles. The large number of low-wage workers means that many households do not have enough income to pay for basic life necessities.

Median earnings of the entire labor force, including informal workers, are shown in Figure 6.12. This time series from 1979 through 2011 shows earned income of the median worker, the typical worker who is in the middle of the wage distribution. Los Angeles City and County have lower median earnings than California and the United States. Median earnings in Los Angeles City are particularly low – in 2011 they were 11 percent less than in the county, 16 percent less than in the United States, and 19 percent less than in California. Moreover, while the income of the median worker has increased for California and the United States over time, it is not noticeably different in 2011 compared to 1979 for workers in Los Angeles County and Los Angeles City.
Figure 6.12: Los Angeles County Industry Employment Size 2011

Source: California Employment Development Department Establishment Database for Los Angeles County

Figure 6.13: Median Earned Income 1979 to 2011

Source: U.S. Census Bureau 1980, 1990 and 2000 Decennial Census and 2005 to 2012 American Community Survey Public Use Microdata Samples and tables
6.7.2 Economic Sustainability

6.7.2.1 Industry Size

A summary view of Los Angeles County’s industry structure at the 2-digit NAICS classification level is shown in Figure 6.13. Only 12 percent of employment is in goods-producing industries. This is the industry super-sector whose primary product is making tangible things – growing food, extracting minerals, making and distributing electric power and other utilities, constructing buildings, and manufacturing consumable and durable goods. Many goods-producing industries are comparatively small. Mining and agriculture each account for only a tenth of one percent of employment. Utilities and construction each account for only one percent.

Service-producing industries account for the other 88 percent of employment. This includes transportation (4 percent), wholesale trade (6 percent), retail trade (10 percent), information (5 percent), finance (6 percent), professional services (8 percent), health and education (21 percent), leisure and hospitality (11 percent), other services (13 percent), and public administration (excluding schools and health care 4 percent).

![Figure 6:14: Change in Los Angeles County Industry Employment 1996 to 2011](source: California Employment Development Department Establishment Database for Los Angeles County)

6.7.2.2 Industry Growth Trajectory

Change in the employment size of industry sectors from 1996 to 2011 is shown in Figure 6.14. The six industries with the highest rates of job growth are in the service sector. The four industries with the highest rate of job loss are in the goods-producing sector. Decline in
construction can probably be explained by the highly volatile nature of the industry. Low employment in 2011 was the result of the recent recession.

6.7.3 Index of Economic Performance

An overall ranking of industries’ economic performance is shown in Figure 6.15. This index was derived by averaging the rankings of each industry based on size in 2011, change in size from 1996 to 2011, and average wage in 2011. The average wage was given triple weight when computing the rankings because of the central importance of earnings for social sustainability.

Industries that rank highest on the economic performance index are knowledge-intensive, for example professional services, finance, information and health care, or capital-intensive, for example, petroleum extraction and utilities.

Industries that rank lowest on the index pay low wages, for example, agriculture, food and apparel manufacturing, retail, courier and storage services, paper and chemical manufacturing, janitors and security guards, and hotels and restaurants.

6.8 Greenhouse Gas and Economic Outcomes from Industries in Sub-regions of Los Angeles County

In this section the relationship between environmental impacts and job opportunities in Los Angeles in the context of energy use, greenhouse gas emissions and climate change, and future urban sustainability is explored. It describes the energy intensity and economic sustainability of industry activity in the city and county of Los Angeles. For further insight into each of SCAG’s nine sub-regions in the county, see the Economic Roundtable’s full report (Economic Roundtable 2014). The most frequently used metric is the ratio of jobs to greenhouse gas emissions estimated through three frameworks:

1. Direct emission from establishment activities
2. Direct emissions from estimated gasoline consumed by customers driving to establishments in private light duty vehicles
3. Life cycle emissions from the supplier chain linked to activities at each establishment as well as from establishment activities

Activities that severely stress the environment represent areas in which more efficient industrial processes are needed to preserve jobs as constraints on greenhouse gas emissions become increasingly severe. Activities with a light environmental footprint that provide a significant number of jobs represent win-win opportunities for economic growth. Similarly, jobs that pay less than living wages identify sectors where the wage floor is too low to pay for basic expenses. Jobs that pay living wages represent social sustainability strengths of the region.

This analysis of the baseline relationship between energy, greenhouse gases and wage sustainability draws on multiple data sets to produce estimates of greenhouse gas and wage outcomes from each type of industry in each sub-region of the county. (Some data sources are specific to individual establishments, and others that are specific to the county, the state or the
nation. For a detailed discussion of the methods used, see Economic Roundtable 2014. A partial list of data sources includes: IMPLAN; the California multi-regional input-output (MRIO) life-cycle assessment (LCA); annual data from the California Energy Commission for electricity and natural gas consumed by sector in Los Angeles County; the U.S. Economic Input-Output Life Cycle Assessment (EIO-LCA) model; data from the Air Resources Board on annual gasoline consumption by vehicle type; data from Argonne National Laboratory’s GREET 1 model for vehicle emission factors.

This combination of data sources means that industry employment and payroll data is accurate and specific to each sub-region, however greenhouse gas emission factors represent statewide averages for each industry in the case of direct emission estimates using the MRIO-LCA model, and national averages for each industry in the case of life cycle estimates using the EIO-LCA model. An additional limitation is that both the MRIO-LCA and EIO-LCA models are derived from the Bureau of Economic Analysis’ 2002 benchmark Input-Output Make and Use tables as noted before. Correction factors for the time lag built into these models comes from annual energy consumption data provided by the California Energy Commission, which are applied to direct emission estimates produced using the California MRIO-LCA model, and annual changes in the amount of value added per worker in each industry in Los Angeles, which is obtained from IMPLAN and incorporated into estimates made using both the MRIO-LCA and EIO-LCA models. For additional discussion about the MRIO-LCA and EIO-LCA models, see Economic Roundtable 2014. The 2002 benchmark Input-Output Make and Use tables describe each industry separately, covering the entire industry structure. A single framework of industry relationships is used to produce energy and emissions factors for every industry, covering the entire economy.

These models made it possible for this analysis to link employment at each establishment with standardized industry factors for energy consumption and greenhouse emissions in order to estimate the environmental impact of each establishment. These establishment-level estimates were aggregated by industry for each sub-region of the county, thereby protecting establishment confidentiality and also populating industry classifications with sufficiently large numbers of firms as to be statistically reliable.

6.9 Direct Energy Consumption and GHG Emissions per Job

6.9.1 Energy Consumption

There is great variation in the amount of energy required for the activities that workers carry out in their jobs. The estimated number of terajoules consumed from all sources per job in each industry is shown in Figure 6.16. Petroleum refineries consumed 153 terajoules for each person they employed in 2011.
Other industries that consumed large amounts of energy per job include utilities (47), air transportation (6.2), pipeline transportation (2.8), petroleum extraction (2.7), and truck transportation (1.5). Industries that produce energy or move things are energy-intensive.

The countywide average was 0.63 terajoules per job per year.

At the low end of energy consumption, finance and insurance establishments consumed 0.01 terajoules per job. Other office-based jobs have similarly low levels of energy consumption. (The methods used to produce this data are described in greater detail in Economic Roundtable 2014.)

6.9.2 Greenhouse Gas Emissions

Energy consumption correlates closely with greenhouse gas emissions, with some variation in this correlation based on variation in energy source among industries. Natural gas produces
50.3 metric tons of CO2 equivalent emissions for every terajoule consumed, electricity produces 70.4 tons, and vehicle gasoline produces 83.9 tons.17

The three industries with the highest direct greenhouse gas emissions per job in 2011 were petroleum refining (12,292 tons), air transportation (1,442 tons), and electric power generation (1,439 tons), as shown in Figure 6.17.

The overall industry base of the county directly emitted 33 tons of greenhouse gases for each job in 2011.

At the other end of the spectrum, office-based industries had direct GHG emissions of roughly one-twentieth of a ton per job.

Figure 6.16: Metric Tons of Greenhouse Gases Directly Emitted per Job, Los Angeles County 2011

Source: California Employment Development Department Establishment Database; California MRIO-LCA

17 This estimate is derived from United States Environmental Protection Agency eGRID2012 Version 1.0.
6.9.3 Direct Emissions per Job from Gasoline Consumed for Customer Trips
The trip generation models used for land use planning were used in this analysis to estimate greenhouse gas emissions from customer trips.\textsuperscript{18} Land use planners currently estimate the level of vehicle traffic that will be generated by new developments in determining parking and road improvement requirements.

Customer traffic also creates greenhouse gas emissions from combustion of gasoline.

\textsuperscript{18} These estimates were derived from the California Emissions Estimator Model, Table 4.3 Mobile Trip Rates, South Coast Air Quality Management District, 2011, and for industries not covered by that model, from the ITE Trip Generation Handbook - 2nd Edition. Industries such as manufacturing that do not have public customer traffic are not assigned a trip generation factor.
Table 6.3: Metric Tons of Direct GHG per Job in 2011 from Establishment Activities and Customer Gasoline

<table>
<thead>
<tr>
<th>Industry and NAICS Code</th>
<th>Establishment Activities</th>
<th>Customer Gasoline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bakeries (3118)</td>
<td>3.6</td>
<td>1.0</td>
</tr>
<tr>
<td>Retail Trade (44-45)</td>
<td>0.1</td>
<td>7.0</td>
</tr>
<tr>
<td>Air Transportation (481)</td>
<td>1,442.0</td>
<td>2.2</td>
</tr>
<tr>
<td>Water Transportation (483)</td>
<td>76.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Passenger Transit (485)</td>
<td>126.8</td>
<td>0.3</td>
</tr>
<tr>
<td>Sightseeing Transportation (487)</td>
<td>10.1</td>
<td>0.6</td>
</tr>
<tr>
<td>Postal Servicer (491)</td>
<td>2.4</td>
<td>3.9</td>
</tr>
<tr>
<td>Couriers (492)</td>
<td>210.9</td>
<td>3.7</td>
</tr>
<tr>
<td>Finance &amp; Insurance (52)</td>
<td>0.1</td>
<td>4.2</td>
</tr>
<tr>
<td>Rental &amp; Leasing (53)</td>
<td>0.3</td>
<td>1.0</td>
</tr>
<tr>
<td>Motion Picture Theaters (5121)</td>
<td>0.0</td>
<td>52.3</td>
</tr>
<tr>
<td>Legal Services (5411)</td>
<td>0.1</td>
<td>0.3</td>
</tr>
<tr>
<td>Accounting (5412)</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Architecture &amp; Engineering (5413)</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Specialized Design Srv (5414)</td>
<td>0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>Veterinary &amp; Misc Prof Srv (5419)</td>
<td>0.1</td>
<td>1.2</td>
</tr>
<tr>
<td>Employment Services (5613)</td>
<td>0.0</td>
<td>0.2</td>
</tr>
<tr>
<td>Copying &amp; Mail Service (5614)</td>
<td>0.1</td>
<td>2.3</td>
</tr>
<tr>
<td>Travel Agencies (5615)</td>
<td>3.4</td>
<td>0.3</td>
</tr>
<tr>
<td>Educational Services (61)</td>
<td>1.0</td>
<td>1.2</td>
</tr>
<tr>
<td>Ambulatory Health Care (621)</td>
<td>0.5</td>
<td>1.9</td>
</tr>
<tr>
<td>Hospitals (622)</td>
<td>0.5</td>
<td>1.1</td>
</tr>
<tr>
<td>Nursing Care Facilities (623)</td>
<td>2.1</td>
<td>1.0</td>
</tr>
<tr>
<td>Social Assistance (624)</td>
<td>0.5</td>
<td>0.9</td>
</tr>
<tr>
<td>Arts &amp; Entertainment (71)</td>
<td>0.2</td>
<td>2.1</td>
</tr>
<tr>
<td>Hotels (721)</td>
<td>4.0</td>
<td>2.3</td>
</tr>
<tr>
<td>Restaurants (722)</td>
<td>2.1</td>
<td>13.5</td>
</tr>
<tr>
<td>Other Services (81)</td>
<td>0.9</td>
<td>1.3</td>
</tr>
<tr>
<td>Public Administration (92)</td>
<td>15.6</td>
<td>1.5</td>
</tr>
<tr>
<td><strong>Los Angeles County Average</strong></td>
<td><strong>32.7</strong></td>
<td><strong>2.5</strong></td>
</tr>
</tbody>
</table>

Source: Economic Roundtable model for estimating GHG emissions from vehicle operations for customer trips.

Trip generation data were calibrated to employment and linked with the amount of gasoline consumed for customer trips by the public to business and government. This methodology is described in greater detail in Economic Roundtable 2014. Impacts of commercial transportation, including commercial vehicle fleets, are included in the direct industry impacts shown by the California MRIO-LCA model. Including impacts from customer traffic adds a missing piece to estimates of industry greenhouse gas emissions generated by industry activity.
Emissions from both establishment activities and customer trips are shown in Table 6.3. Customer trips account for a metric ton or more of GHG emissions per employee in 20 industries. Motion picture theaters lead this list with 52 tons per year per employee, followed by restaurants with 13 tons, and then retail trade with 7 tons.

The emission profile of a number of industries shifts from negligible to significant emissions per job when the impact of customer traffic is taken into account. Gasoline consumed for customer trips accounts for more emissions per job than establishment activities in 18 industries, as shown in Figure 6.18.

6.9.4 Life Cycle Emissions per Job

Life cycle emissions include all of the embedded greenhouse emissions released through industry activities of upstream suppliers. The estimated life cycle greenhouse gas emissions per
job in Los Angeles County in 2011 are shown in Figure 6.19. The method used to produce these estimates is described in Economic Roundtable 2014.

The life cycle average for all industries in 2011 was an estimated 136 metric tons of greenhouse gases per job. Life cycle estimates are less reliable than those for direct emissions, but they have two important uses. First, they provide an index of the comparative life cycle impacts of different industries. Second, they identify industries with high life cycle impacts that may well face increasing competitive hurdles as carbon taxes are imposed and prices charged by upstream suppliers increase.

The ranking of industries based on life cycle emissions (Figure 6.19) is roughly similar to the ranking based on direct emissions (Figure 6.17). In both the direct and life cycle rankings, energy sources and transportation have the highest emissions per job.

Electric power generation is the high-emission outlier based on life cycle impacts, whereas petroleum refining is the outlier based direct impacts. Electric power generation and distribution has far greater life cycle impacts than any other industry — 15,326 metric tons of greenhouse gas emissions per job per year.

Government activities have above average life cycle impacts 145 annual metric tons of greenhouse gases compared to an overall average of 136 tons.

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19 The correction factor used to bring U.S. EIO-LCA life cycle factors into alignment with actual impacts in Los Angeles County was annual changes in the ratio of energy consumed by individual industries to the value added by industries in the county. This correction factor improves the reliability of the estimates but is not as robust as the actual quantities of energy consumed by each industry that were used to correct MRIO-LCA factors in estimating direct emissions.

Because of anomalies in life cycle GHG estimates from the EIO-LCA model compared to direct GHG estimates from the MRIO-LCA model, five life cycle data for five industries has been removed from estimates shown in this chapter.
6.9.5 Ratio of Life Cycle to Direct Emissions

For all industries in the county, life cycle GHG impacts are roughly four times greater than direct impacts (136 vs. 33 metric tons of emissions per job per year), but this ratio varies widely among industries. A rough rule of the thumb is that industries with low direct impacts often have proportionately larger upstream impacts in their supply chain, and industries with high direct impacts often have proportionately smaller upstream impacts in their supply chain. The ratio of life cycle to direct GHG emissions per job is shown below for a sample of industries.

This difference – direct vs. supply chain – is important to acknowledge in GHG accounting as in the previous section. Since GHGs are global, having low direct GHG emitting jobs in the basin most likely means the supply chain GHGs are being generated elsewhere, but the aggregate impact on the planet remains the same. Thus, longer term, the goal is to transition from a fossil fuel dependent economy to other sources of energy.
6.9.6 Average Direct Emissions per Job in Each Region

The estimated energy consumption and greenhouse emissions per job are the same for industries throughout the county, but there are substantial differences in the industry structure of different regions, producing wide variation in the amount of energy consumed and greenhouse gas released per job in different regions of the county.

The highest energy consumption per job (1.1 terajoules) is in Metro Los Angeles, which is the urban core of the region with a high concentration of manufacturing and utility establishments. The South Bay Cities are next with 0.9 terajoules per job in 2011, as shown in Figure 6.20. The lowest energy consumption per job is in Las Virgenes (Malibu sub-region) and Arroyo Verdugo (a small sub-region made up of La Canada Flintridge and Montrose) with 0.08 terajoules consumed per job. This low level of energy consumption is attributable to industry structures in these areas that are heavily tilted toward retail and services.

The pattern shifts with greenhouse gas emissions. The South Bay Cities are the regional hub for petroleum refining and have the highest greenhouse gas emissions per job, as shown in Figure 6.21. This includes 71 metric tons of GHG per job from establishment activities and almost 3 tons from customer trips. Given the regional service petroleum refining provides, this type of accounting is always difficult and focuses attention on the host cities, but masks the regional (and even beyond) importance of the economic activity. Such issues have not been well resolved yet in GHG accounting. Further, for many firms, their energy choice is constrained, so their energy use GHGs is predetermined, and the materials embedded energy is also determined by decisions outside of their scope. Thus GHG per job is more or less an end-of-the-pipe outcome.

Los Virgenes (Malibu) has a small, service-based economy and the lowest emissions per job – 3 tons from establishment activities and almost 3 tons from customer trips.

A different pattern emerges for customer trip emissions. The highest level of emissions from customer trips is in Arroyo-Verdugo – 5.2 tons per job, followed by North Los Angeles County with 3.7 tons per job. This is the result of industry structures in these sub-regions that are skewed toward retail and consumer service industries, including restaurants. Here they benefit from being late comers to the development of the region, creating economic activities that have high tax revenue (sales tax), but providing jobs that tend to be more poorly paid and generate GHG emissions from customer trips. These areas benefit, therefore, economically but do not contribute to mitigating the impact that results from the land use zoning. The historical development of the region has created this distribution of GHG emissions.
6.10 Environmental and Economic Sustainability Trade-offs

6.10.1 Sustainability Benchmarks

The benchmarks used to rank industries and geographic areas are shown in Table 6.4 below. Higher wages and lower GHG emissions are represented by higher scores (tier 5 – the best tier), while lower wages and higher GHG emissions have lower scores (tier 1 – the worst tier). The ranking benchmarks were derived by dividing Los Angeles County's labor force in 2011 into wage quintiles, each with an equal number of employees, and also direct greenhouse gas emission quintiles, each with an equal number of employees.

The greenhouse gas rankings include both direct establishment emissions and gasoline emissions from customer trips per employee. Because of the importance of wage levels, the social sustainability rankings in the following tables are based solely on this factor.

Industries and geographic sub-regions are ranked twice – first based on greenhouse gas emissions per job and second based on average wages. In many instances the ranking for environmental sustainability differs from the ranking for wage sustainability. In the near-term, these rankings differences identify trade-offs. In the long-term, they identify sustainability
weaknesses that need to be improved to increase industry sustainability and long-term prospects for viability.

The ranking process uses average greenhouse gas emissions and wages to place industries within interval categories that each represent equal numbers of workers. Consequently, a small number of workers with high emissions per job or high wages sometimes skews the overall average for a geographic area. This sometimes results in lowering the overall environmental ranking or raising the wage ranking for a geographic area.

Table 6.4: Emission and Wage Benchmarks for Each Tier

<table>
<thead>
<tr>
<th>Tier</th>
<th>Bottom of Tier</th>
<th>Top of Tier</th>
<th>Metric Tons of Direct GHG per Job 2011 (Establishment &amp; Customer Gasoline)</th>
<th>Average Annual Wage 2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best</td>
<td>5</td>
<td>0.00</td>
<td>0.49</td>
<td>$80,000</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.50</td>
<td>2.19</td>
<td>$55,600</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2.20</td>
<td>3.49</td>
<td>$47,000</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>3.50</td>
<td>9.99</td>
<td>$30,500</td>
</tr>
<tr>
<td>Worst</td>
<td>1</td>
<td>10.00</td>
<td>Highest</td>
<td>$1</td>
</tr>
</tbody>
</table>

6.10.2 Geographic Aggregation

This analysis uses employer data from the California Employment Development Department, which provides establishment-level employment and payroll data for every employer in Los Angeles County from 1996 through 2011—a total of 1,011,707 employers. This information provides a practical tool for evaluating trade-offs to identify the most sustaining workforce employment and job creation opportunities.

Information provided by these time-series records for the approximately 400,000 employers that are active in Los Angeles County in any given year includes:

- Address
- Six-digit North American Industry Classification System (NAICS)
- Monthly employment
- Quarterly payroll

This highly disaggregated data is aggregated into the nine Southern California Association of Governments (SCAG) sub-regions shown in Figure 6.22.
Employment and payroll information in the data set was used to calculate average wages. Factors for greenhouse gas emission for each industry from the California multi-regional input-output (MRIO-LCA) model and for gasoline emission from customer trips were linked to employment at each establishment to estimate direct greenhouse gas emissions.

Figure 6.20: Nine SCAG Sub-regions in Los Angeles County

In the ranking tables, employment numbers for sub-regions and industries fall about 1 percent short of total employment shown in each table for three reasons. First, a small number of establishments do not have accurate address data, so they cannot be assigned to a sub-region. Second, if industries have five or fewer establishments in a geographic area, data are suppressed. Third, establishments whose industry classification is not determined are included in total employment but not in industry breakouts.
6.10.3 Overall Ranking of Geographic Areas in Los Angeles County

The city and county of Los Angeles and each of the nine SCAG sub-regions are given overall sustainability rankings in Table 6.5. All but two geographic areas have the lowest greenhouse gas ranking (1), as a result of the skewing effect of high-emission industries in each area. However, there is wide variation within this “worst” ranking, ranging from 10.20 metric tons of greenhouse gas emissions per job in the San Fernando Valley to 74.06 tons per job in the South Bay. Los Virgenes and Arroyo Verdugo, with most employment in service-producing industries and therefore fewer emissions per job, are in the second-worst tier (2) for greenhouse gas emissions.

Table 6.5: Overall Ranking of Geographic Areas

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Los Angeles County</td>
<td>3,954,626</td>
<td>$53,434</td>
<td>3</td>
<td>32.58</td>
<td>2.48</td>
<td>35.06</td>
<td>1</td>
</tr>
<tr>
<td>Los Angeles City</td>
<td>1,572,622</td>
<td>$57,512</td>
<td>4</td>
<td>42.62</td>
<td>2.40</td>
<td>45.02</td>
<td>1</td>
</tr>
<tr>
<td>San Fernando Valley</td>
<td>789,782</td>
<td>$51,266</td>
<td>3</td>
<td>7.79</td>
<td>2.41</td>
<td>10.20</td>
<td>1</td>
</tr>
<tr>
<td>North Los Angeles County</td>
<td>74,297</td>
<td>$40,241</td>
<td>2</td>
<td>11.37</td>
<td>3.66</td>
<td>15.03</td>
<td>1</td>
</tr>
<tr>
<td>Los Angeles Metro Area</td>
<td>1,121,339</td>
<td>$60,982</td>
<td>4</td>
<td>57.03</td>
<td>2.29</td>
<td>59.31</td>
<td>1</td>
</tr>
<tr>
<td>Arroyo Verdugo</td>
<td>9,108</td>
<td>$39,547</td>
<td>2</td>
<td>3.68</td>
<td>5.19</td>
<td>8.86</td>
<td>2</td>
</tr>
<tr>
<td>San Gabriel Valley</td>
<td>618,163</td>
<td>$44,434</td>
<td>2</td>
<td>18.64</td>
<td>2.77</td>
<td>21.41</td>
<td>1</td>
</tr>
<tr>
<td>Westside Cities</td>
<td>221,915</td>
<td>$72,979</td>
<td>4</td>
<td>9.39</td>
<td>2.34</td>
<td>11.73</td>
<td>1</td>
</tr>
<tr>
<td>South Bay Cities</td>
<td>360,558</td>
<td>$58,594</td>
<td>4</td>
<td>71.45</td>
<td>2.61</td>
<td>74.06</td>
<td>1</td>
</tr>
<tr>
<td>Gateway Cities</td>
<td>681,367</td>
<td>$43,099</td>
<td>2</td>
<td>26.03</td>
<td>2.50</td>
<td>28.53</td>
<td>1</td>
</tr>
<tr>
<td>Las Virgenes</td>
<td>42,168</td>
<td>$64,458</td>
<td>4</td>
<td>3.11</td>
<td>2.58</td>
<td>5.69</td>
<td>2</td>
</tr>
</tbody>
</table>

Sources: California Employment Development Department; California MRIO-LCA model; California Energy Commission; IMPLAN; U.S. EIO-LCA model; SCAG; California Emissions Estimator Model; California Department of Motor Vehicles; California Air Resource Board; Argonne National Laboratory

The City of Los Angeles and four of the SCAG sub-regions have average wage levels that place them in the next to the highest tier (4) for wage sustainability. The county and the San Fernando Valley are in the middle range (tier 3). Four sub-regions are in the next to the lowest wage tier (2): North Los Angeles County, Arroyo Verdugo, San Gabriel Valley, and Gateway Cities.
6.10.4 County of Los Angeles Industry Rankings

Sustainability rankings for all of the industries in Los Angeles at a high level of aggregation is shown in Table 6.6. Most industries present trade-offs between environmental and wage sustainability strengths. Of the 46 industry categories shown in Table 6.6, only 13 industries are in the same tier for both environmental and wage rankings; 36 industries have different environmental and wage rankings.

6.10.4.1 Low Wage Industries

Seven industries that employ 29% of the labor force have average wages of $30,000 a year or less. This average includes all workers in the industry, from manager to janitors. To become socially sustainable these industries need to raise wage levels.

- Restaurants and Bars $17,905
- Other Services (personal and repair services) $24,673
- Employment Services (temporary employment agencies) $27,294
- Agriculture, Forestry $28,803
- Nursing Care Facilities $29,945
- Hotels $30,069
- Retail Trade $30,586

Four of these seven very-low-wage industries are in the lowest two quintiles based on greenhouse gas impacts and thus are doubly challenged to both raise wages and reduce emissions. These four industries are restaurants and bars, agriculture and forestry, hotels, and retail trade. The other three industries have average or above average greenhouse gas rankings – nursing care (tier 3) other services (tier 4) and employment services (tier 5).

6.10.4.2 Low Wage, High Emission Industries

Nine industries are in the first or second tier for both greenhouse gas emissions and wages. Average annual wages and greenhouse gas emissions per job are:

- Restaurants and Bars $17,905 15.56 metric tons
- Agriculture, Forestry $28,803 35.66 metric tons
- Hotels $30,069 6.31 metric tons
- Retail Trade $30,586 7.19 metric tons
- Sightseeing Transportation $32,188 10.75 metric tons
- Bakeries $33,692 4.56 metric tons
- Food and Apparel Manufacturing $39,369 4.5 metric tons
- Passenger Transit $39,697 127.14 metric tons
- Truck Transportation $41,948 343.18 metric tons
To become sustainable these industries are challenged to both raise wages and decrease greenhouse gas emissions, and both are predicated, often, on larger societal shifts: increase of the minimum wage in the state and nationally, and decarbonizing fuels.

Table 6.6: County of Los Angeles Industry Rankings

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<thead>
<tr>
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<td>Agriculture, Forestry (11)</td>
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<td>1.48</td>
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<td>3</td>
<td>32.58</td>
<td>2.48</td>
<td>35.06</td>
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Sources: California Employment Development Department; California MRIO-LCA model; California Energy Commission; IMPLAN; U.S. EIO-LCA model; SCAG; California Emissions Estimator Model; California Department of Motor Vehicles; California Air Resource Board; Argonne National Laboratory
6.10.4.3  **Very High Emission Industries**

Ten industries have 100 or more metric tons of direct greenhouse gas emissions per employee per year from establishment activities and customer trips.

- Petroleum Refining  12,275 metric tons
- Air Transportation  1,444 metric tons
- Electric Power Generation and Distribution  1,439 metric tons
- Natural Gas Distribution  394 metric tons
- Truck Transportation  343 metric tons
- Mining, Petroleum Extraction  278 metric tons
- Water, Sewage and Other Systems  222 metric tons
- Couriers  215 metric tons
- Pipeline Transportation  137 metric tons
- Passenger Transit  127 metric tons

These very-high-emission industries provide energy and transportation for the entire industry structure of the region. These services are indispensable for the economy, however these ten industries are estimated to produce over 90 percent of all direct greenhouse gas emissions released by industries in Los Angeles County. Progress toward environmental sustainability requires improved technologies and industry processes for producing electricity and petroleum and for moving people and goods much more efficiently and with much less dependence on fossil fuels.

A strength of these industries is that seven of them pay above average wages. The three surface transportation industries, truck transportation, couriers and passenger transit pay below average wages and are in tier 2. Air transportation is in wage tier 4, paying above average wages. And five of the industries are in the highest wage tier (5): petroleum refining, electric power generation and distribution, natural gas distribution, mining and petroleum extraction, water and sewage systems, and pipeline transportation.
CHAPTER 7: Conclusions and Recommendations

There is little time to lose for California to become less dependent on fossil fuels and to meet its 2050 goal of reducing GHG emissions by 80 percent below 1990 levels (EO S-3-05). The state is likely to meet its goal of reducing GHG emissions to 1990 levels by 2020, but the next reductions will require a broad and massive transition across economic sectors, land uses, transportation modes and uses, water use, energy supplies, and distribution, waste collection and treatment, and much more. Indeed the transformation will be multi-dimensional and not less revolutionary than the changes wrought by the industrial revolution, the introduction of the railroad, rural electrification, the creation of massive water works in the west, and the extraordinary development of centralized energy systems. The harnessing of fossil energy over the past two hundred years has enabled the intensification of human’s ability to transform the planet, including increasing agricultural productivity, enabling unprecedented urbanization and ultimately globalization of trade and economic activity. Fossil fuels have been the key to this success; they are also its Achilles heel.

This research project offers both granular accounting from the ground-up depicting who uses what energy where to do what, and understanding from the top-down of the interactions and interdependences of this complex urban system. This is accomplished through the layering of attributes such as census data, energy infrastructure, solid waste flows, historic embedded energy in the urban fabric and economic activity. Building energy use (ground-up) can pin-point which use most energy, and matched to county assessor building age and construction type (shell) data can indicate how much energy was used to create them and is now part of our GHG legacy. This type of analysis enables the development of more refined building and energy codes informed by life-cycle building accounting. The life cycle analysis of buildings and road GHGs presented in this report should be important information relative to investments in future infrastructure going forward and are relevant for both ground-up analysis as well as top-down trend analysis.

GHG emissions are linked to economic activities, but also to wealth. Matching residential building energy use with census data and parcel data that describes building size, vintage, and age, shows the wealth effect in energy use. In Los Angeles County, wealthier neighborhoods use considerably more residential energy than less wealthy neighborhoods. This is taking into account climate zones and per capita energy use. For the region to reduce its energy use, high users need to be targeted and this analysis allows policy makers to do so. Policy tools are multiple, from energy pricing to mandatory conservation standards. Equity issues are implicit in this situation as to date, ratepayer funds have been used to fund conservation and efficiency programs. Whether ratepayers who, on the whole, use less energy than the wealthy, should fund these programs is an important question that needs to be considered.

The links between economic activity and GHG emissions are also enormously important to unpack for the local and state economies to thrive. From a top down perspective, this report points to the fundamental way in which fossil energy underlies the economy and the jobs that
pay well. And if life cycle GHG analysis is done, acknowledging that a GHG emitted outside of California to create a product or a good that is imported is part of California’s GHG inventory, shifting to a service economy that relies on the importing of goods, will not reduce the state’s GHG footprint. If California’s policies simply lead to exporting emissions, rather than reducing emissions all of the efforts will be in vain. Moreover, while currently each service sector job in itself does not produce high GHGs, this sector tends to have lower wages, and since the customers of those service sectors (retail, restaurants and so forth) generally use automobiles to access those services, this ultimately yields a high GHG emitting sector. Because of its geology, the County has had a history of oil extraction and production. Many of the best paying jobs in the County are in the energy sector, whether oil refining or energy production. The County is still dependent on fossil energy for transportation, natural gas manufacturing and many other uses including increasingly for electricity generation. The recent closure of the San Onofre Nuclear Generating Station has increased the dependence on natural gas for electricity generation. More and more evidence shows that with more use (and abundance) of natural gas the reduction effect on GHG emissions are small. That is, the increased use of natural gas simply maintains our current trajectory of increasing GHG emissions (Shearer et al 2014).

Transportation fuels remain the sector that emits the most GHG emissions of any other sector. SB 375 notwithstanding, the transformation of the urban fabric to enable greater use of public transportation, more able to be fueled by non-carbon fuels that will release less CO2, and less criteria pollutants is one of the most important goals. This report did not specifically analyze land use as a driver of GHG emission and the use of fossil fuels, but land use is implicit in the report. Driving to shop or to entertainment is what causes high GHG emissions from those sectors. The disaggregated land use patterns that segregate uses drive automobile traffic and underlie the enormous embedded energy in the road infrastructure. This road infrastructure is indispensable to the combined Los Angeles and Long Beach ports and to the regional and national economy. Goods transport is reliant on fossil fuels. The GHG emissions from transportation are coupled with criteria pollutants that cause significant health impacts to the region’s residents. Burning fossil fuels to transport goods and people are intrinsic to the current economy. A shift to clean transportation fuels and a different transportation infrastructure – renewable electric rail, for example – seems inexorable to change this impact.

Yet the report also points to many other contributing sectors to the region’s GHG profile and consequences of cheap fossil fuels, inexpensive materials, expansive urban fabric, and high reliance on consumption in this economy. Solid waste flows that are not reused are an example of this situation. Not only are the flows poorly accounted, but the amount of recycled materials that are exported are not well known, and little is known about what sector produces how much and what types of solid waste. Here is an important flow that has unquantified embedded energy and materials that is indicative of one the fundamental changes needed. Just like sanitation water is a resource, so is solid waste. To curb and constrain further resource extraction, waste needs to be not only sorted and recycled, but also reused. Municipal composting is becoming more common, but is only one step. Linking materials to manufacturing is yet another important one. Urban metabolism is a method that uncovers the missing links that are necessary to construct to shift toward a recycling and reuse economy that
aims to reduce energy and materials flows to reduce embedded energy in those flows. For the state to embrace a low carbon future, this approach is unavoidable.

The report validates the utility of accurate ground-up energy data to understand energy use by multiple sectors and how they interact. With good data, specifically targeted programs can be developed, taking equity impacts into consideration, and policies can be developed that will, step-by-step, actually ensure the state meets its 2050 GHG emissions reductions. To do so will require this type of in-depth understanding of how fossil fuels are used in the region, to do what, where, and by whom. The next steps are developing the specific alternatives appropriate to each sector. This can range from implementing distributed solar generation with battery storage to replace natural gas electricity generation, and solar hot water systems to replace natural gas water heaters, to targeting other high energy sectors such as sewage treatment, and substitution of renewable biogas for natural gas. Understanding how the grid is deployed throughout will also point to the low hanging fruit for distributed generation opportunities. Better analysis of building energy and embedded building energy will help determine where retrofit and reinvestment makes more sense than new construction. Most importantly, this research, which is on-going and will be publicly available, should generate discussion, debate and greater transparency about patterns of energy use across Los Angeles County. It should engender further questions and research that will help in moving the region, and the state, toward greater fossil fuel energy independence and more healthy and livable places.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<td>ACS</td>
<td>American Community Survey</td>
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<td>CDPH</td>
<td>California Department of Public Health</td>
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<tr>
<td>CEEM</td>
<td>California Emissions Estimator Model California Energy Commission</td>
</tr>
<tr>
<td>CEIDARS</td>
<td>California Emission Inventory Development and Reporting System</td>
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<tr>
<td>CPUC</td>
<td>California Public Utilities Commission</td>
</tr>
<tr>
<td>CALSIM</td>
<td>California Statewide Integrated Model of Statewide Land Use</td>
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<td>CSTDM</td>
<td>California Statewide Travel Demand Model</td>
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<td>TJ</td>
<td>Terajoules</td>
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<td>TPY</td>
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Appendix A

Total economic activity (production, consumption, export) by sector (in 2008 $Millions) and direct and lifecycle effects associated with economic sector and by activity in Los Angeles County in 2008 (Sources: IMPLAN; CA-EIO-LCA).

<table>
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<tr>
<th>Activity</th>
<th>Production</th>
<th>Consumption</th>
<th>Export</th>
<th>Energy (TJ; Supply)</th>
<th>CO2 Equivalent (ton; Supply)</th>
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<td>Direct</td>
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<td></td>
<td></td>
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<td>12.36</td>
<td>837.4</td>
<td>9.45</td>
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