ARIZONA STATE UNIVERSITY

SCHOOL OF SUSTAINABLE ENGINEERING AND THE BUILT ENVIRONMENT

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Smart Growth Along the Proposed Light Rail Expansion Lines Can Reduce Future Urban Energy Consumption and Environmental Impacts

Mikhail Chester, Assistant Professor
Civil, Environmental, & Sustainability Engineering
Affiliate Faculty, School of Sustainability
chester.faculty.asu.edu
mchester@asu.edu

Roberta Bosfield
Amelia Celoza
Keith Christian
Gilbert Flores
Nick Francis
Andrew Fraser
Ryan Furcini
Venu Garikapati
Sam Johnson
Andrew Kaehr
Mindy Kimball
Matthew Nahlik
Valentina Prado
Drew Rostain
Minghao Xu
Andy Yu

SSEBE-CESEM-2012-CPR-013
Course Project Report Series

December 2012

ASU Ira A. Fulton Schools of Engineering

SMART GROWTH ALONG THE PROPOSED PHOENIX LIGHT RAIL EXPANSION LINES CAN REDUCE FUTURE URBAN ENERGY CONSUMPTION AND ENVIRONMENTAL IMPACTS

Course Project Report
Urban Infrastructure Anatomy and Sustainable Development, CEE 494/598, CON 598, SOS 598
Arizona State University, Fall 2012

Dr. Mikhail Chester, Assistant Professor, mchester@asu.edu

Student Authors:

Roberta Bosfield	Amelia Celoza
Keith Christian	Gilbert Flores
Nick Francis	Andrew Fraser
Ryan Furcini	Madhav Garikapati
Sam Johnson	Andrew Kaehr
Mindy Kimball	Matt Nahlik
Valentina Prado	Drew Rostain
Minghao Xu	Andy Yu

December 17, 2012

urbansustainability.lab.asu.edu

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INTRODUCTION

Phoenix, Arizona is the center of a major metropolitan area in the desert southwest United States, with a population of 4.2 million and an urban land area of over 16,000 square miles. Current projections estimate that the area will continue to grow with the population more than doubling by 2050 (Morrison Institute for Public Policy, 2011). Valley Metro, Maricopa Association of Governments, and the Arizona Department of Transportation are planning to extend the current 20-mile light rail transit line to meet future transportation demands and help manage growth. The proposed locations for system expansion traverse urban areas with many vacant and dedicated surface parking lots that could accommodate new growth in the form of transit-oriented development (TOD). The existing light rail system exceeded initial ridership forecasts and has become a beacon for urban revitalization in the core of the Phoenix Metropolitan Area. The planned light rail extensions have the potential to improve the transportation and land use sustainability footprint of Maricopa County in tandem with inevitable regional growth.

During the Fall of 2012, an interdisciplinary course project assessed the energy, environmental, and social benefits from future growth along the planned light rail extensions in Maricopa County, and proposed transition strategies to facilitate the implementation and use of three proposed TOD locations. Students from engineering, sustainability, urban planning, and public affairs worked together in the course titled "Urban Infrastructure Anatomy and Sustainable Development" to analyze and synthesize the effects from placing TOD commercial and residential units in vacant lots that have easy access to the proposed light rail stations. During the project, students used state-of-the-art building, energy, and transportation resources to tailor the results for each location and consulted with members of the Phoenix community, transportation and land use planners, university faculty, and local decision-makers.

Students assessed the potential benefits in avoided energy consumption and environmental impacts that would occur from TODs on vacant lots near three new light rail stations as opposed to single-family home and dispersed commercial development without access to the light rail. Each of the three site locations are on a different section of the proposed extension: a predominantly residential TOD in eastern Phoenix along the Interstate-10 corridor, a predominantly commercial TOD in northern Phoenix along 19th Avenue, and a more even mix of residential-commercial TOD in Mesa along Main Street. The benefits from these TODs include reduced automobile travel, more efficient building construction and energy use, and less land consumption for new development. The barriers that may prevent cities from achieving these benefits, and the corresponding solution recommendations, are categorized as political and institutional, economic, and social. These transitional strategies address both the successful TOD implementation and the sufficient use of the TODs once they are constructed.

PUBLIC TRANSIT IN THE PHOENIX METROPOLITAN AREA

The history of publically financed mass transit in the Phoenix Metropolitan area is relatively short. The growth of the region has been tied to the automobile and is deeply embedded within the culture (Collins, 2005; Gober, 2005; Heim, 2001). However, the cities of Phoenix, Mesa and Tempe are currently planning and expanding public transportation due to greater demand (Valley Metro RPTA, 2012). Current and future plans for public transportation are closely tied to voter-approved tax increases in Maricopa County and participating municipalities (Goddard, 2012).

Public transportation in the Phoenix metropolitan area is run by Valley Metro Public Transportation Authority (VMPTA). Valley Metro serves a population of roughly 3.8 million people in over 25 cities (Valley Metro, 2012). The transit system includes services such as local bus routes, regional bus routes, vanpools and light rail transit (LRT). Specifically the light rail services almost 20 miles in the cities of Phoenix, Tempe and Mesa, and operates from 4:30 am to midnight on weekdays and weekends 5:00 am to 3:00 am (Valley Metro 2012).

In 2004, Maricopa County voters approved Proposition 400 to be used specifically for transportation funding. The result was a reauthorization of a half- cent sales tax passed in 1985. Proposition 400 also extended the tax to 2025 and increased the amount of funding for public transportation (from 2 percent to roughly 33 percent of total sales tax revenues) approximately $2.8 billion over the 20 years. The local funding is expected to be matched by Federal funds. The combined funds will provide bus and light rail transit improvements, adding an increase of 17 miles of addition service to the original 20 miles of light rail system. These improvements include a 3.1 mile light rail extension in central Mesa on Main Street from Sycamore to Mesa Drive, a 3.2 mile extension north from the current end-of-line at Montebello to Dunlap Avenue, and a 11 mile extension from downtown Phoenix through the State Capitol area to approximately 79th Avenue and the I-10 West freeway (Valley Metro, 2012).

Although the construction of light rail and its expansion is celebrated by Valley political leaders, securing public financing for mass transit projects has not always been successful. In March 1989, the Regional Public Transit Authority, the predecessor of Valley Metro, proposed plans for a regional transportation initiative, Proposition 300, which came to be known as the ValTrans proposal. It included a comprehensive approach to addressing mass transit needs with 7-day a week local bus service, 27 miles of bus-only lanes, regional Dial-A-Ride service, vanpool and rideshare services, a commuter rail plan that would connect Chandler to Phoenix and Phoenix to Wickenburg, and 103 miles of elevated trains designed to emulate those used in Vancouver, British Columbia. The system was engineered to service the entire Valley, with a major crossing underneath Terminal 4 of Sky Harbor Airport. The proposal would have required a half-cent increase in the county's sales tax to be matched by federal funding. Although initially met with approval, as measured by opinion polls at the time, the proposal was voted down by 61% of county voters (Arizona Rail Passenger Association, 2012).

The defeat of Proposition 300 by Valley voters was followed by rejections of similar mass transit proposals throughout the 1990's. In November 1994, voters in Maricopa County turned down a ¼ cent increase to city sales taxes intended to fund the completion of highway projects begun a decade before. The initiative failed, with 54% voting against. In September 1997, voters in Phoenix narrowly defeated a plan to raise the city sales tax by ½ cents to fund Sunday bus service and an expanded Dial- A-Ride system. The referendum failed by 126 votes out of 110,000 cast. In the same year, Scottsdale voters rejected a local sales tax of ½ cent for expanded bus service by a majority of 64%. Chandler did the same by 58%, defeating an initiative to expand bus service that would have required raising the city's sales tax by 3/8 cents. Finally, the City of Phoenix voters passed "Transit 2000" with a 65-35% majority, giving the green light to 24 miles of light rail construction and expanded bus service. Once this funding was matched by the approval of Proposition 400 in 2004, funding for the light rail system was secure (Arizona Rail Passenger Association, 2012).

FUTURE TRANSPORTATION DEMAND IN THE PHOENIX METROPOLITAN AREA

To increase ridership and public involvement, there is significant interest in deploying transit-oriented development (TOD) in conjunction with proposed future light rail extensions. TOD can be an important factor in transitioning neighborhoods from automobile-dependent households to "…compact, mixed-use communit[ies], centered around a transit station that, by design, invites residents, workers, and shoppers to drive their cars less and ride mass transit more" (Bernick & Cervero, 1997). While TOD is not a complete solution, it is valuable in ensuring that transit is accepted by the local community. TOD projects attract more civic and public spaces, affordable housing units, and greater community walkability (Bernick & Cervero, 1997).

METHODOLOGY

This study uses a sustainability approach, assessing environmental, social, and economic aspects of urban growth issues in the Phoenix metropolitan area. The environmental assessment analyzes the effects from land use changes (building types and land use) and transportation (passenger travel behavior and modes of travel). The social and economic assessment evaluates the barriers that prevent TOD growth in the first place, and the actions or policy changes that must take place for new TODs to be successful once they are designed and constructed.

In order to calculate the environmental effects from buildings and transportation, life-cycle assessment (LCA) methods are employed. LCA is a framework for evaluating the raw material extraction, processing, use, maintenance, and end-of-life energy and environmental impacts of products, processes, services, activities, or the complex systems in which they reside. In this study, the buildings analysis focuses on building construction processes, electricity feedstock production (the primary fuel extraction and processing combined with transmission of electricity), and electricity use (emissions and energy from electricity generation at the power plant). The transportation analysis focuses on vehicle manufacturing, gasoline production feedstock (crude oil extraction and refining), and vehicle operation (gasoline combustion). The specific methodologies for each process analysis will be described in both the buildings and transportation sections.

To calculate all probable variations of future transportation and land use processes, different scenarios for urban growth were designed. TOD growth scenarios (placing new development within walking distance of proposed new light rail transit stations) are compared to the same amount of growth at the "fringe" of the city where automobiles are used for most travel because there is no easy access to public transit. The low-density automobile-dependent growth is named business-as-usual (BAU), and is always compared to the TOD scenario to evaluate the change in energy and environmental effects rather than just the sole impacts of TOD development.

This study only evaluates a small subset of the potential LRT expansion (i.e. three stations, each on a different section of the expansion and each with unique development designs). The methodology can logically be employed at all proposed light rail stations in Valley Metro's plans, but as an initial investigation this study provides a proof-of-concept for stakeholders and decisionmakers. The three future light rail stations considered in this study are slated for construction as part of the expansion of the existing line west along the I-10 corridor in Phoenix, north along 19th Ave in Phoenix, and east along Main Street in Mesa. The specific locations are indicated on the map at FIGURE 1.

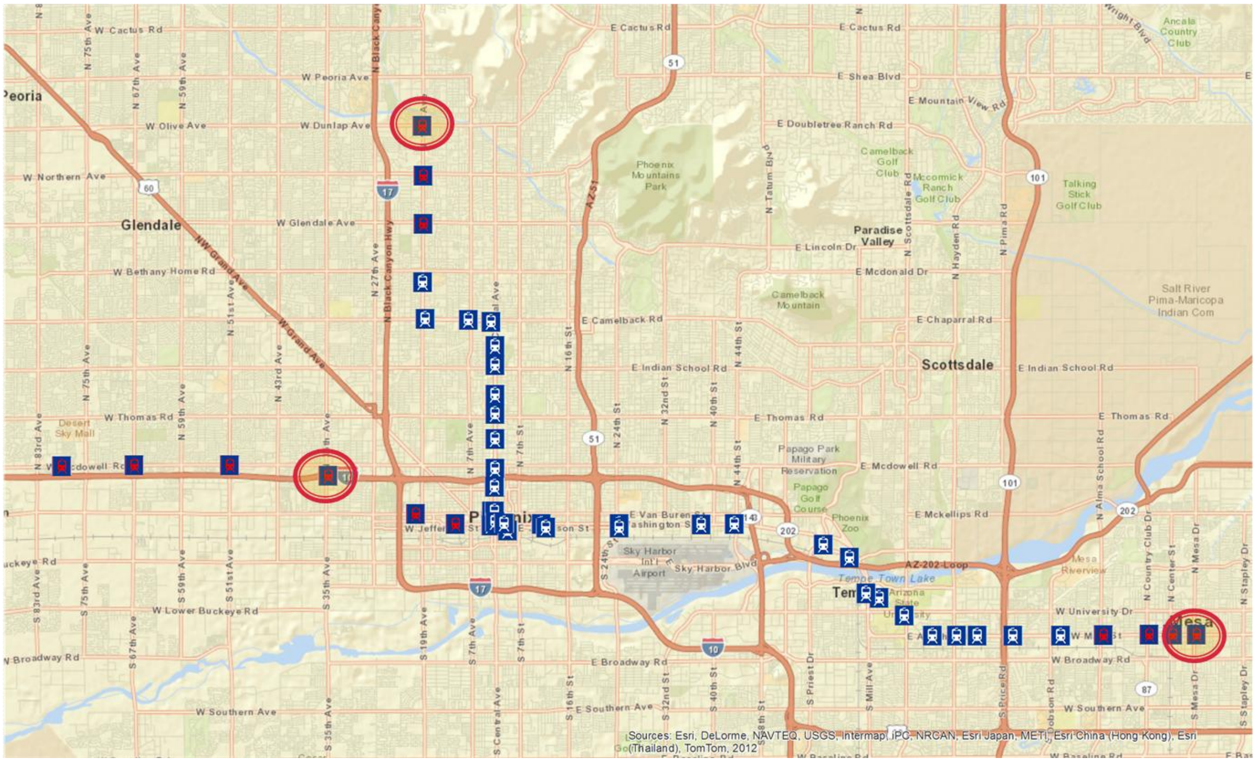

Figure 1. Site locations circled in red. The current light rail line stations are marked in blue and white, and the proposed stations along the future light rail expansions are marked in blue and red.

EVALUATING SOCIAL AND ECONOMIC FACTORS FOR SUCCESSFUL TOD TRANSITIONS

Effective planning is needed to ensure successful implementation and use of TODs and future public transit expansion. Potential barriers must be identified. This section will outline and discuss barriers which can impede implementation of new TOD projects along the light rail extension. Solutions will be provided to overcome these barriers, and transition strategies appropriate to the Phoenix region will be proposed to encourage and promote TOD projects.

The research framework used for transitions analysis was modeled after the sustainability transitions strategy (Wiek, Binder, & Scholz, 2006) which addresses the difficulty of managing transitions in sustainable development. In particular, this method generates knowledge of three types: systems knowledge which describes systems structure and processes, target knowledge which describes the future goals and objectives of the system, and transformational knowledge which describes constraints and strategies when transitioning from the current state to the target state. Transformational knowledge also describes the barriers to any project's implementation.

Methodology for Evaluating Sustainable Transitions

The goal of this analysis is to provide detailed suggestions that will improve upon the current TOD model in the Phoenix metropolitan area. This improvement may require a shift from previous planning methods. To identify barriers and corresponding solutions, the team gathered information pertinent to many aspects of the planned LRT expansion. Subsequently, barriers and solutions were identified using three categories: political/institutional, economic, and social. They were then analyzed within the context of two development scenarios: Density, whereby the goal is to maximize residential and commercial density within ½ mile of each light rail station; and TOD, wherein the goal is to increase density while encouraging and maximizing mode-shifts in transportation choices. One of the primary contentions of this analysis is that while production of density around light rail stations is important for successful TOD, density alone does not ensure transit use. Changes in the behavior of the people using TOD services – commuters, shoppers, residents - are just as important as the maximization of density around TOD sites.

Representatives from Valley Metro, the City of Mesa and Phoenix were contacted as a means of gaining a perspective as to the knowledge and approach of professionals working most closely with these projects - what do they see, and how do they see it? These conversations helped the Transition Team consider solutions to barriers in a realistic, feasible manner. Some of the topics discussed helped illustrate the roles each city's Mayors and Council Members play in promoting and securing the success of light rail and TOD projects. Our conversations with city planners, city staff and Valley Metro staff also clarified many of the political and economic barriers to implementing TOD projects (Dayal, 2012; Goddard, 2012; Graves, 2012; Tetreault, 2012).

Developing a fuller understanding of the governance structure for each municipality's transit system was also an early priority. Understanding the strategies, tools and needs of elected officials proved beneficial for devising more realistic TOD implementation strategies. Zoning laws were also researched and analyzed based upon their ability to promote growth in TOD corridors.

Identifying Barriers and Solutions

The following section provides a description and an analysis of each identified barrier and solution, presented in two tables divided by barrier category (political, economic, and social). Table 1 details barriers to increasing urban density, and Table 2 details barriers to successful implementation and use of TOD.

TABLE 1. BARRIERS AND SOLUTIONS FOR MAXIMIZING DENSITY

Type	Barrier	Solution
Political / Institutional	Proposition 207 / Eminent Domain	Robust and flexible form-based code.
	Political Organization / Stakeholder Interest	Education campaign of the benefits of public transportation, high-density living, and mixed-use development.
	Tax Incentives	Revenue fund sources.
Economic	Financing / Funding TODS	Public-private partnerships.
	Fringe Urban Growth	Affordable housing near light rail and at TODs.
Social	Urban Sprawl Culture	Urban growth boundaries.
	Public Transportation Perception	Visible marketing campaign and incentives.

TABLE 2. BARRIERS AND SOLUTIONS FOR SUCCESSFUL TOD

Type	Barrier	Solution
Political / Institutional	TOD zoning and Proposition 207	TOD zoning in response to Proposition 207
	TOD zoning not written to fulfill the purpose of TODs.	TOD zoning written to fulfill the purpose of TODS
Economic	TOD and public transportation adoption costs	Promote benefits of public transportation. Ensure TODs are developed with multi-use purpose.
Social	Accessibility inequality	Public engagement and involvement.
	Socioeconomic TOD mix	TOD planning for multiple income levels.

Barriers and Solutions for Maximizing Density

Political Barriers

PROPOSITION 207

Proposition 207 was passed in 2006. This amendment is referred to as the "Private Property Rights Protection Act" (Arizona, 2006). Cities frequently support the development of projects by assisting in land assembly through eminent domain or by paying for infrastructure such as parking structures, road improvement, or enhanced streetscapes. In Phoenix, these options are limited due to Proposition 207 because cities are no longer allowed to exercise eminent domain when acting on behalf of a private party. Additionally, Proposition 207 requires that the government reimburse landowners when regulations cause a property's value to decrease.

Land acquisition is an important component to any development and it is especially important in transit-oriented development because the land must be in close proximity to transit stops to ensure a neighborhood's walkability. Eminent domain can no longer be a way for government to acquire land. However, government agencies are allowed to provide financial assistance for land assembly. When defining property value and its decrement due to regulation, the statute is unclear when discussing the burden of proof necessary to prove the impact on the fair market value of a property. The statute protects the use of eminent domain for public health and safety purposes, leading to the solution of overlay zoning to promote TOD, as it would be exempt from the compensation aspect of the statute (EPA, 2009a). Phoenix and Mesa could use this exemption when developing TODs as these developments promote a mode shift away from the private automobile, which encourages biking and walking. Promoting a more active lifestyle could be considered protecting public health, which allows for Phoenix to implement overlay zoning at TODs.

Proposition 207 allows for waiver agreements, stating that "nothing in this section prohibits the state or any political subdivision from reaching an agreement with a private property owner to waive a claim for a diminution in value" (Arizona, 2006). This language permits landowners to opt-in to overlay zoning. Phoenix and Mesa can utilize this language to promote transit-oriented development and it can be used to overcome zoning related barriers.

POLITICAL ORGANIZATION AND STAKEHOLDER INTERESTS

Phoenix's form of government is a council-manager plan, which has three main positions - mayor, council member, and city manager. This form of government is also known as a weak mayor form of government. The mayor and council are elected, and council members represent interests of council districts. The mayor and council hire the city manager, who oversees the city's employees. The mayor and council are the legislative branch, the city manager is the executive branch, and the municipal court acts as the judicial branch (City of Phoenix, 2012a). Barriers arise from this form of government due to conflicts in interest of council members. This is known as political complexity, with "stakeholders striving to achieve their ambitions and protect their interests" (Mayer, Van Buren, Bots, & Vander Voort, 2005).

The council-manager form of government often leads to conflict because each council member represents the interests of their own council-district and a lack of coordination between government and transit agencies (Robert Cervero, Ferrell, & Murphy, 2002). "Not in my Backyard," or NIMBY-ism is an attitude held by individuals or organizations that can prevent TOD from occurring. This can occur in the City of Phoenix due to the governing system, which relies on different council members serving in eight council districts. Only the mayor is elected at-large and the mayor's vote is merely one vote among nine. At times, council members may be hesitant to support TOD if the improvements are not located in their district.

The Council must define goals and propose policies and programs to work toward those goals. Educational campaigns can be used to highlight the benefits of public transportation, high density living, and mixed-use developments. Emphasis should be placed on the economic developments of the region and the positive impact these developments can have on the Phoenix Metropolitan Area as it continues to grow. San Jose, California operates under a council-manager form of government, similar to the form of government in Phoenix, but has been able to gain approval from the city council to implemented TOD successfully. The San Jose City Council approved a housing initiative in 1989, which encouraged high-density housing near public transit facilities. The Council developed objectives including promoting transit as an alternative to driving, increasing housing opportunities for various economic levels, "supporting economic development by providing housing near job centers," and several others (City of San Jose, 1989). Phoenix's City Council can propose plans similar to this one that contribute to the economic growth of Phoenix and promote transit.

There are a variety of approaches to combat the NIMBY attitude held by politicians and citizens. With regard to politicians, an effective way to combat the notion that TOD is undesirable, local supporters can be mobilized to demonstrate the true beliefs of a district. These supporters belong to many different groups: direct beneficiaries, indirect beneficiaries, potential project users, and special interest groups (Noto, 2010). With organization, these various groups can voice their support for TOD projects. Studies show that individual attitudes toward aspects of TODs, like affordable housing, can be swayed by humanizing the perceived issue (Machell, Reinhalter, & Chapple, 2009). Furthermore, communicating the interior and exterior designs of buildings in TOD can greatly impact NIMBY attitudes held by community members. Brochures produced by the Non-Profit Housing Association emphasize the "who, what, how, and why" of projects and the importance of effectively communicating these to community members (Machell et al., 2009). It is important to reframe community issues in a manner that asserts the positive impacts that TODs can have towards a community. One example of this type of communication is a myth-fact pair: "Myth: high density and affordable housing will cause too much traffic; Fact: people who live in affordable housing own fewer cars and drive less" (Machell et al., 2009). Overall, when faced with resistance from community members, it is important to provide an explanation of why TODs are necessary to aid in more efficient growth of the Phoenix metropolitan area and to articulate who benefits, both directly and indirectly, from the development.

TAX INCENTIVES

Legal and political constraints exist that limit the ways in which municipalities can participate in TOD projects. Using eminent domain for land assembly is not possible (see discussion above on Proposition 207). Extending tax breaks to encourage favored projects is not possible. Tax Increment Financing (TIF) Districts are either frowned upon or explicitly forbidden by the Arizona State Legislature. These tools are commonly used to promote TOD projects in other jurisdictions, yet are not available in the Phoenix metropolitan region.

Local municipalities can participate in TOD projects by using existing non-general fund revenue sources. Federal programs such as Low Income Housing Tax Credits and New Market Tax Credits are available for mixed-use projects. The Local Initiatives Support Collaborative (LISC) and the Raza Development Fund manage a $25M pool of pre-development funding for TOD projects (Mineta, 2000). Municipalities can concentrate recurring funding such as Community Development Block Grants, scheduled infrastructure improvements and funding for expanded services for such things as libraries and parks around TOD development projects.

Economic Barriers

WEAK MARKET DEMAND FOR URBAN INFILL

Thirty years of urban sprawl followed by five years of depressed housing prices and an economic recession has weakened the demand for density at or near the urban core. Market studies completed for Valley Metro to measure the development potential of properties near stations along Camelback Road and 19th Ave show limited to no demand for owned housing, commercial office space and large-scale retail (Smith & Gray, 2008). The best mix for these neighborhoods is recommended as rental housing with no parking structures and small retail shops accompanied by modest quantities of office space. These recommendations are seen as the most sound, most easily financed, and least likely to fail. Fee simple condominiums, commercial office buildings, strip malls and large-box retail are not recommended - they are deemed not supportable by the market at this time, in that neighborhood.

Although the other locations in this study have not been specifically analyzed, existing developments indicate that market conditions are worse in those locations than at the Camelback/19th Ave site. The assumption is that the same recommendations would apply at all three sites in this study.

Although sprawl has diluted the demand for density at the urban core, it has also produced countervailing economic trends that may assist the development of TOD projects. Over the last decade, the combination of housing and transportation costs has risen relative to the annual income of moderate- income households. With moderate-income households defined as 50-100 percent of area median income, Figure 2 below ranks the total burden of housing and transportation costs in the nation’s eight most burdensome metropolitan statistical areas (Hickey, Lubell, Haas, & Morse, 2012). Phoenix is now the eighth, with housing and transportation costs comprising 62% of moderate-income families’ budgets.

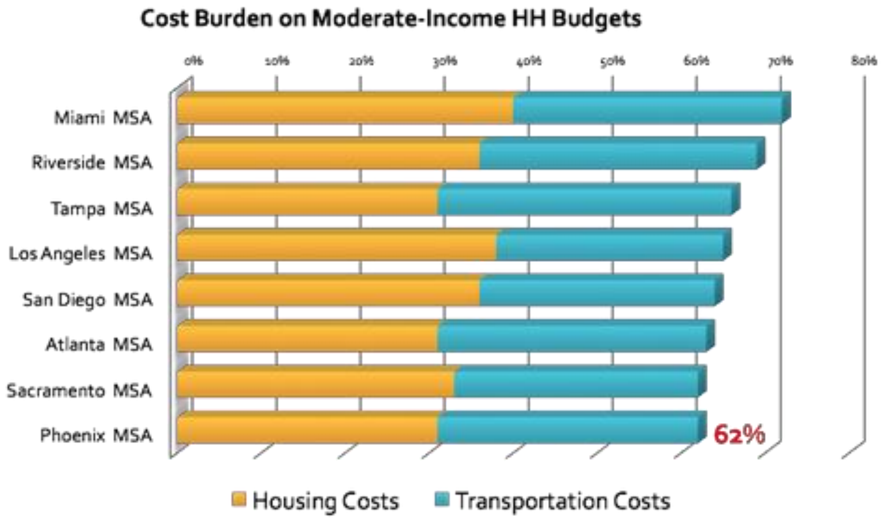

FIGURE 2. TOP EIGHT METROPOLITAN STATISTIC AREAS (MSA) FOR HOUSING AND TRANSPORTATION COST BURDENS WITHIN HOUSEHOLD BUDGETS (HICKEY, LUBELL, HAAS, & MORSE, 2012)

The second countervailing economic trend that may assist the development of TOD projects is that transportation costs have risen, producing a corresponding increase in demand for affordable housing. Table 3 lists results from a market study commissioned by the Phoenix-based nonprofit, the Local Initiative Support Collaborative (LISC), in 2010 (BAE Urban Economics, 2012). The LISC report measured the demand for affordable housing near light rail stations. It shows that the Phoenix market can absorb up to 130,699 affordably priced units located ½ mile from light rail. Over 25,000 of those units can be built for families making 80-120% of the Area Median Income (AMI).

TABLE 3. DEMAND FOR AFFORDABLE HOUSING UNITS NEAR TRANSIT IN THE PHOENIX METROPOLITAN AREA (BAE URBAN ECONOMICS, 2012)

Household Income Category	# Housing Units in Demand by Income Category	% of Total Units in Demand
0-30% AMI	46,399	36%
30-50% AMI	30,611	23%
50-80% AMI	24,634	19%
80-100% AMI	8,398	6%
100-120% AMI	6,343	5%
120%+ AMI	14,314	11%
Total	**130,699**	

Phoenix MSA (Metropolitan Statistical Area) Area Median Income = $65,500

Creating mixed-use, mixed-income rental housing targeted to families earning from 30-120% of AMI with a mix of small retail and limited commercial office space is a viable solution to increasing density. The federal Low-Income Housing Tax Credit program provides funding for such projects (HUD, 2012). Units for individuals or families making 80-120% of AMI can be constructed for nurses, teachers, police and firemen and marketed as community-oriented workforce housing. A marketing campaign highlighting the cost savings of residing or working near mass transit, driving less and, perhaps, giving up one's automobile will be an enticing message for customers from many income brackets throughout the Valley. Although 30 years of uninterrupted sprawl has created market conditions that have weakened the demand for projects near the urban core, countervailing economic patterns are creating a second wave of conditions that provide a competitive advantage to communities that have had the foresight to invest in transit-oriented infrastructure.

FRINGE URBAN GROWTH

Political barriers mentioned above also pose financial and economic barriers to completing TOD projects. Many transit authorities purchase excess land around stations. Surplus parcels are purchased with the expectation that they will be developed as the project matures. By that time, the demand for residential and commercial properties will have risen and values will have increased. The revenues expected from the development, through sales or, more commonly, land-lease payments, are built into the long-term modeling of the project, and play an important part in ensuring the transit authority's long-term financial viability. With Metro Light Rail, Valley Metro plays no role in land assembly - they acquire only the land needed for the construction of stations. They rely upon municipalities to provide incentives for projects. Proposition 207, in turn, limits municipalities from using imminent domain to acquire land: they must work with owners to purchase properties as they become available on the open market.

Cities in the Valley are also restricted in the number of ways they can participate in the development of projects. City tax breaks are a common approach in other areas of the country and a recommended best practice. That practice came to a halt in 2009 when a local non-profit, the Goldwater Institute, invoked the gift clause of the Arizona constitution to sue the City of Phoenix for its participation in CityNorth, a large mixed-use housing, commercial office and retail development project now partially built in the northern section of Phoenix. The city granted the developer a phased, multi-year sales-tax abatement and paid a portion of the project's parking costs. The Arizona Supreme Court ruled that the value of what the city received was not equivalent to the "gift" it had given. As one of the defense lawyers, development attorney Grady Gammage said at the time, the CityNorth ruling may fundamentally change how all Valley municipalities participate in development projects (Gammage, 2010).

Valley cities must be creative in how they participate in commercial and residential development projects. When general funds are scarce funding from federal and state programs may be accessed. Depending on the location and nature of a project, a city's Community Development Block Grants (CDBG) may be used. Affordable housing can be financed with Low-Income Housing Credits and commercial projects can use New-Market Tax Credits. Beyond financing, cities may also add value by helping to market a neighborhood or a project (through information campaigns, for instance), or by placing a community amenity such as a library or park nearby.

Social Barriers

URBAN SPRAWL CULTURE

The Phoenix metropolitan area's growth is tied to the automobile (Collins, 2005; Gober, 2005; Heim, 2001). The growth and prosperity of Phoenix has also been somewhat segregated in the past (Bolin, Grineski, & Collins, 2005). If the value of urban density and socioeconomic diversity is to be realized in the future then the mindset and behaviors of individuals must be changed.

According to Brueckner (2000), remedies to sprawl can be market-based (taxes and fees) or planning based (urban growth boundary). However, in many situations market-based solutions are easier and more palatable to implement. The cities of Phoenix, Tempe and Mesa can implement market-based measures to discourage automobile use near the TOD. The cities can build shared parking facilities and they can also encourage developers to reduce parking demand through incentives. Shared parking facilities can consolidate parking needs in a specific location rather than at individual establishments (Shoup, 2005). To reduce the demand for parking, developers (or employers) can give incentives (cash, passes, etc.) to their employees. These incentives encourage public transportation use thereby reducing the need for parking. Partnerships between employers and transportation agencies, such as trip reduction programs, can also contribute to reduced vehicle traffic.

PUBLIC TRANSPORTATION PERCEPTIONS

To some, the idea of public transportation (including TODs) is seen in a negative light. Arguments against supporting public bond initiatives for transportation projects, for instance, can revolve around voters' "sticker shock" reaction to the large budgets transportation projects require, and around the apparent bias some projects seem to display by serving the interests of select segments of the population- minorities, the poor, or commuters. These perceptions can create points of conflict between a regions' fiscally conservative constituents whose support is needed for public financing to be approved, and elected officials, who might agree with the long-term goals of mass transit strategies, but can't secure the financing needed to implement them without voter-approved bond financing (Mineta, 2000). Many arguments are values based on fiscal responsibility, where an unwillingness to pay for someone else's commute becomes a topic of contention. Maintenance and operations costs for existing and new transit investments are often not the first priority for the general taxpayer, especially when faced with other budgetary and social priorities, like education and healthcare. Public transit perceptions sometimes include discriminating ideas that public transit exists primarily to serve the poor, minorities, and youth.

In order to garner public support for TOD projects and increase the likelihood of voters approving future bond initiatives needed to expand existing mass transit infrastructure, TOD projects must be presented as critical economic development initiatives, important to the city's and the region's long-term economic growth. Secondly, the many social benefits of creating attractive, active, dense, walkable neighborhoods must be explained to and clearly understood by the public. Safety, health, and environmental indicators can all be vastly improved within well- designed and well-functioning TOD neighborhoods (Duany, Plater-Zyberk, & Speck, 2010). These benefits accrue to the general public, not just those using TOD services. Creating a visible marketing campaign that promotes these characteristics as well as societal values like social equality and economic diversity may have promising results in overcoming the public's misperceptions about mass transit. However community enthusiasm must be activated by including community input throughout the entire project. One such example took place in Pasadena, California where the developer of Mission Meridian Village solicited inputs from the residents of a historic single family home neighborhood before building what was a relatively high density, mixed-use TOD. Soliciting public input by the developers resulted in a highly successful TOD that not only won over approval of local residents, but acted as a catalyst for activating the entire neighborhood, smoothing the way for approval of more like-minded developments (Seattle Department of Transportation, 1998). In other words, clearly articulating the benefits of smart growth and densification, improved transport options, increased housing options, and community cohesion, are all great topics to point to for any TOD marketing campaign, but including the community in the design and build process will ultimately make it make the biggest difference in community adoption any such project (Litman, 2012).

Barriers and Solutions for Successful and Increased TOD

Political Barriers

TOD ZONING AND PROPOSITION 207

The City of Phoenix recognized Proposition 207 as a potential barrier to achieving the purpose of TOD and offered that existing property owners within the new TOD Overlay could opt-in to the new TOD (EPA, 2009a). This approach may create an overlay where an insufficient number of property owners choose to be included. Implementation of TOD overlay zones may cause claims by property owners to be brought against the cities of Phoenix and Mesa. Cities such as Phoenix and Mesa may choose to implement new TOD overlay zones through an opt-in method as a more conservative approach to avoiding Proposition 207 claims (EPA, 2009a). Without a critical mass of included parcels, such overlays will be less effective (EPA, 2009b).

To attract a sufficient number of property owners cities must take an incentivized approach (EPA, 2009b). These approaches could include: fast track development review, land use intensity tools such as density bonuses, tax exempt bonds, tax abatement, joint development programs, land acquisition loan funds, and funds for buying available parcels in the open market. Cities must conduct outreach and education for existing property owners, future developers, local business leaders and community development corporations. The TOD Overlay Zoning Ordinances 662 and 663 need to support the target sectors of the economic development strategic plan, bio-life sciences, advanced business services, sustainable industries and enterprises, higher education, world business, trade, and established and emerging enterprises (City of Phoenix, 2012b).

TOD ZONING IS NOT WRITTEN TO FULFILL THE PURPOSE OF TOD

TOD zoning that does not address the purpose of TODs, becomes a barrier to a successful TOD. TOD zoning must be written to promote higher development densities for successful TOD implementation. TOD zoning as written does not provide a balanced mix of land uses and will not generate 24-hour ridership of light rail transit. Zoning must fully address places to work, live, learn, relax, and shop for daily needs. Creating a sense of place generates buildings that shape and define memorable streets, squares, and plazas, while allowing their uses to change over time. Successful zoning should not overestimate minimum parking requirements. Zoning should limit the block perimeter to encourage a fine-grained network of streets, dispersed transit routes, and allowance for the creation of quiet and intimate thoroughfares. Finally, zoning should institute maximum parking requirements instead of minimum, e.g. for every 1,000 workers, no more than 500 spaces and as few as 10 spaces are provided (Tumlin, Millard-Ball, Zuckeer, & Siegman, 2003).

The City of Phoenix could encourage property owners to opt-in for the overlay by making the uses and requirements of the overlay zoning as attractive as possible while achieving the goals of the TOD (EPA, 2009b). TOD-1 and TOD-2 zoning as written currently defines what building types are permitted within the zone (City of Phoenix, 2011). It needs to be refined to define the balanced mix. Overlay zoning as written is not a form-based zoning. Suggest that Phoenix amend the zoning to a form-based zoning for the overlay zones (EPA, 2009b). Minimum parking has not been abolished (Tumlin et al., 2003). Instead Phoenix is allowing a percentage reduction in parking related to new building types. It is allowing the existing parking requirements to remain for those properties developed before January 1, 2014 (City of Phoenix, 2008). Phoenix should abolish the minimum parking standards (Tumlin et al., 2003). The City of Phoenix did not set a standard for average block perimeter in the code, and it needs to be amended to reflect such. Additionally, lot coverage is not a guarantee of producing the mixed-use density that describes a TOD. The City of Phoenix did not base maximum parking requirements based on workers. This needs to be addressed. Instead the City of Phoenix solution was to provide reduced parking in relationship to distance to light rail station. The parking reductions apply to new developments within the TODs. Existing parking requirements prior to the overlay remain in place. The code should be amended to achieve parking reductions to support TOD overlays include redevelopment of existing properties (Tumlin et al., 2003).

Economic Barriers

TOD AND PUBLIC TRANSPORTATION ADOPTION COSTS

When faced with a choice to move to TODs, users might think about the convenience of a personal vehicle and potential time lost when using public transportation. Incentives for current automobile owners to shift and use public transportation might me the only way to change driver behavior. Also, the public most impacted by denser development around light rail stations must be informed of the benefits of transit-oriented, walkable neighborhoods.

Market Incentives should be used to encourage usage of TODs. City and state government might consider incentives similar to the United Stated cash-for-clunkers program in 2009. Multiple credits can be given if users sell a car and move to an address within the light rail corridor. Another incentive to encourage TOD usage is amenities. Valley Metro should track the number of services (government and health) available along the entire LRT line. They should track the placement of key amenities like grocery stores and other retail amenities so that programs that encourage intra- modal travel such as bike-sharing or Zip Cars could be placed where services and amenities are farther than mile from LRT stations. Public agencies can work closely with neighborhood groups and resident-led committees to track each TOD neighborhood's worker/resident ratio and walkability score. Leakage analyses and market studies can be combined with resident surveys to understand what businesses are in demand along the light rail system, meet residents' needs, and raise walkability scores.

Social Barriers

ACCESSIBILITY INEQUALITY

Urban sprawl limits the accessibility of necessary amenities for urban living. For most residents, automobile usage is a prerequisite to complete daily tasks outside of their home. Zoning laws, which set strict requirements for separating residential and commercial development, have resulted in the existence of entire neighborhoods that are completely removed from accessible amenities needed for day-to-day activities.

Separation of residences from amenities is doubly as harmful in the creation of spaces for public engagement. Residents have become accustomed to neighborhoods devoid of public interaction and space. Public space becomes allocated solely to sidewalks lining these neighborhoods, which are underutilized due to the prevalence of automobile commuting.

Public involvement and engagement is crucial to solving accessibility and inequality issues. Successful communities incorporate spaces for public engagement that build strong community and interdependence. The Project for Public Spaces (PPS) utilizes four key principles to aid in the creation of functional public spaces. These elements are: accessible, activity driven, comfortable, and sociable to ensure successful public space utilization (Project for Public Spaces, 2009). Each TOD should be subject to these key elements which can be qualitatively and quantitatively measured by specified parameters in the Place Diagram at figure

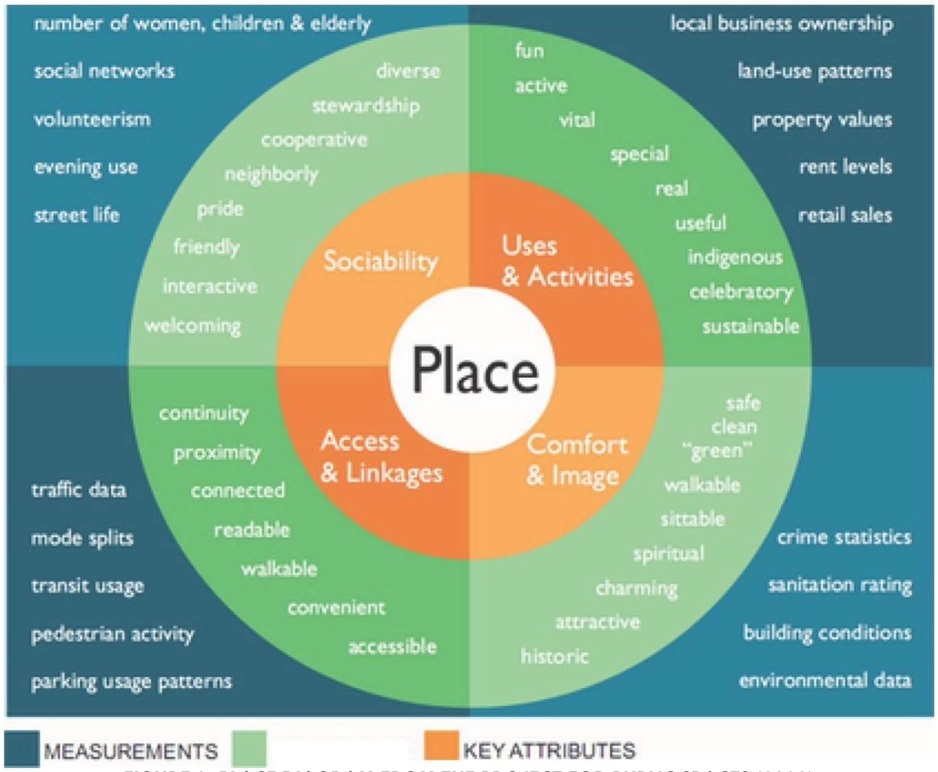

FIGURE 3. PLACE DIAGRAM FROM THE PROJECT FOR PUBLIC SPACES (2009)

One example of a measurable indicator is the Walkability Score. Each location is awarded points based on the distance to amenities in each category; these categories vary across a wide array of common daily destinations: restaurants, grocery stores, parks, schools, entertainment, etc. Amenities within .25 miles receive maximum points and no points are awarded for amenities further than one mile. Like this example illustrates, each TOD development should be devised so that each location implements measures to increase accessibility to all residents of a neighborhood with minimal automobile dependence.

TOD FOR DIVERSE SOCIO-DEMOGRAPHIC PROFILES

Large scale housing developments have inadvertently resulted in the socio-economic segregation of entire populations because homes built in many of these developments are constructed to the same specifications: size, quality, etc. Home prices all have similar baseline costs, resulting in homogenous income distribution for entire neighborhoods.

Another form of housing segregation is the public's perception of good and bad neighborhoods. Records of sanitation ratings, crime rates, school quality, environmental data, and building conditions are all important quantifiable factors that can be used to determine the difference between good and bad neighborhoods. These factors generally get better when moving from lower to higher income neighborhoods and any pre-existing deficiencies in the proposed TOD neighborhoods will be a challenge to overcome for creating mixed income neighborhoods.

Cities should actively seek ways to diversify socio-demographic profiles in neighborhoods. Mixed use developments are an opportunity for neighborhoods to diversify the socio-economic background of its residents (Brophy & Smith, 1997; Duany et al., 2010). The key to any great, successful place is a diversity of people. Older cities likely achieved this because there were no zoning laws for developers to adhere to when these cities were being built. Because of this, neighborhoods often included a mix of different income levels all living within the same block. The benefits to neighborhood densification include the following.

- "The behavior patterns of some lower income residents will be altered by emulating those of their higher income neighbors. The quality of the living environment, not housing quality alone, leads to upward mobility" (Brophy & Smith, 1997)
- "Non-working low-income tenants will find their way into the workplace in greater numbers because of the social norms of their new environment (for example, going to work/school every day) and the informal networking with employed neighbors" (Brophy & Smith, 1997)
- "The crime rate will fall because the higher income households will demand a stricter and better enforced set of ground rules for the community" (Brophy & Smith, 1997)
- "Low-income households will have the benefit of better schools, access to jobs, and enhanced safety, enabling them to seize the same opportunities as higher income families" (Brophy & Smith, 1997)

BUILDINGS AND LAND USE ANALYSIS

Methodology for evaluating changes in buildings and land use

Land use development in the Phoenix metropolitan area consists primarily of low density suburban housing at the fringe of the city. The expansive low density developments have led to a "sprawling" urban landscape. Sprawl is problematic because the extension of services outside city centers is expensive (Bruckner, 2000). The scattered population contributes to traffic, which requires extensive transportation infrastructure and maintenance while also leading to the degradation of urban city centers (Duany et al., 2010). The increased vehicle traffic from sprawl contributes to air quality issues (Gober, 2005). In addition, sprawl introduces social justice challenges to public services for high-income development on the fringe that are subsidized by all residents, including the urban poor (Duany et al., 2010). Although social impacts and transportation impacts are part of the greater scope of the study, this section focuses on the energy consumption and environmental impacts resulting from land use alone.

This study assesses the energy consumption and environmental impacts from multiple densification scenarios related to Transportation Oriented Developments (TODs) located in Phoenix, Tempe, and Mesa. Various scenarios were developed for land use changes within 0.5 mile radius of the three sites selected for this study (see FIGURE 1). For each TOD infill scenario there is a Business-as-Usual (BAU) scenario that places the same amount of growth away from public transit and in low density configurations. The BAU scenario place single family homes on the "fringe" of the city to imitate current construction practices. The densification scenarios focused on infilling vacant land and land to be repurposed with an ultimate goal to eliminate fringe development. A carefully selected array of mixed-use, commercial, and residential buildings, of varying densities were modeled and allocated to each TOD station area, based on the needs of the local community at that location.

This study uses life-cycle assessment methods to evaluate energy consumption and environmental impacts associated with the proposed building types, including construction and use phase. The environmental impacts of the two scenarios quantify potential greenhouse gas emissions (GHG, in CO_2 equivalents), human respiratory impacts (in $PM_{2.5}$ equivalents), smog potential (in O_3 equivalents), and actual energy use (in mmBTU) associated with the construction and use over a 60 year life span. The sensitivity analysis considers possible variations in projections for Arizona's electric mix over the next 60 years (through 2073).

Existing land use assessment

Vacant lots and underutilized areas at each TOD site are identified and characterized using the Maricopa Assessor database (Russell, 2012). Two types of available land are considered; 1) the vacant lots with no existing construction, and 2) lots which are underutilized and could be repurposed in the near future to accommodate increased TOD growth. To evaluate the effects of different levels of development, this study creates two scenario categories, "conservative" and "aggressive". Both scenarios take place in a 0.5 mile radius around each selected LRT station. The "conservative" scenario develops only vacant lots and the "aggressive" scenario develops both vacant and underutilized lots (Table 1). In the BAU scenario all available land is filled with single-family homes and single-story commercial space on the fringe of the city. Alternatively, in the TOD infill scenarios, the land was filled with mixed-use, commercial, and residential buildings, of varying densities. A more detailed explanation and insight on how the buildings were allocated at each station can be found at the end of this methodology section ("Allocating building types in unique designs at each site location").

TABLE 4. AREA COVERED BY THE CONSERVATIVE AND AGGRESSIVE SCENARIO CATEGORIES AT EACH TOD LOCATION

	Conservative (acres)	Aggressive (acres)
19th and Dunlap, Phoenix	5.85	10.84
Main St and Mesa Dr, Mesa	32.2	59.6
I10 and 35th, Phoenix	23.8	26.3

Individual building design

This study models seven types of buildings: single-family home, residential 3-story apartment building, single story commercial space, 4 and 6-story mixed-used apartment buildings, 6-story commercial, and 12-story mixed-use high rise (see Table 5). The BAU scenarios place low-density (automobile-dependent) single-family homes and single story commercial space away from LRT access, while the TOD scenarios place combinations of residential and commercial development according to the needs identified at that site.

TABLE 5. BUILDING TYPOLOGY

Building Type	Single-family home	Single Level Commercial	6-story commercial building	3-story residential apartment building	4-story mixed use apartment building	6-story mixed use apartment building	High rise mixed-use apartment building
Ground footprint (acres)	0.036	0.25	0.25	0.25	0.25	0.25	0.25
Residential floors	1	-	-	3	3	5	10
Commercial floors	-	1	6	-	1	1	2
DU/Commercial floor	-	8	8	-	8	8	8
DU/Residential floor	1	-	-	8	8	8	8
Total DU	1	8	48	24	32	48	96
Net DU/acre[a]	27.8	32	192	96	128	192	384
Parking spots/DU	2	1.5	1.5	1.5	1.5	1.5	1.5
Total parking spaces	2	48	288	153.6	192	288	576
Parking space total (ft^2)[b]	324	7,776	46,656	24,883.2	31,104	46,656	93,312
Surface area of parking lot, ft^2 (incl. access)[c]	324	11,664	69,984	37,324	46,656	69984	139,968

[a]Net DU/acre does not include parcel lot nor parking space.
[b]Each parking space at 9 ft by 18 ft = 162 ft^2 (Mikhail Chester, Horvath, & Madanat, 2010)
[c]For large parking spaces, access area is one and a half times more than that of the parking space except for the single family home (Mikhail Chester et al., 2010)

BUSINESS-AS-USUAL SCENARIO BUILDINGS:

- Single-Family Home: The single family home represents a generic low-density residential unit of 1,600 ft^2.
- Single level commercial: This unit represents a typical single-story commercial space at a shopping plaza. Each unit has a footprint of 0.25 acres.

TOD INFILL:

- Single-Family Home: The single family home represents a generic low-density residential unit of 1,600 ft2.
- Single level commercial: This unit represents a typical single-story commercial space at a shopping plaza. Each unit has a footprint of 0.25 acres.
- 3-story residential apartment building: This building has a footprint of 0.25 acres with eight residential dwelling units in each floor, for a total of 24 residential dwelling units.
- 6-story commercial building: This building has a footprint of 0.25 acres with six levels of solely commercial/office space.
- 4-story mixed-use apartment building: This building has four floors of mixed use, and a ground footprint of 0.25 acres. The bottom floor is commercial, and the remaining three floors above are of residential use with eight dwelling units each for a total of 24 residential dwelling units.
- 6-story mixed-use apartment building: Same structure as the 4-story mixed-use building. The bottom floor is commercial use, and the remaining five floors above are of residential use with eight dwelling units each for a total of 40 residential dwelling units.

- High rise mixed-use apartment building: 12-story mixed-use high-rise apartment building. The bottom two floors are for commercial use, and the remaining 10 floors are apartment units with eight residential dwelling units per floor, for a total of 80 residential dwelling units.

Parking allocations for each TOD and BAU location were calculated by adding 1.5 spaces per dwelling unit, 12 spaces per floor of commercial space, and a 400 square foot concrete driveway for each single family home. Emission estimates for each parking space were based on Chester et al (2010) study on environmental impacts of parking infrastructure. The emissions for the concrete driveways were derived from modeling within PaLATE (M. Chester, 2012; Horvath, 2012). While parking space impacts can be viewed separately, impacts associated with the concrete driveways are part of the construction impacts of the single family home. Additional parking spaces were modeled at the Dunlap TOD locations in order to meet parking demand of the proposed park and ride.

Figure 4 portrays the seven building types. The floors highlighted in red represent commercial space and the yellow highlighted floors represent residential space.

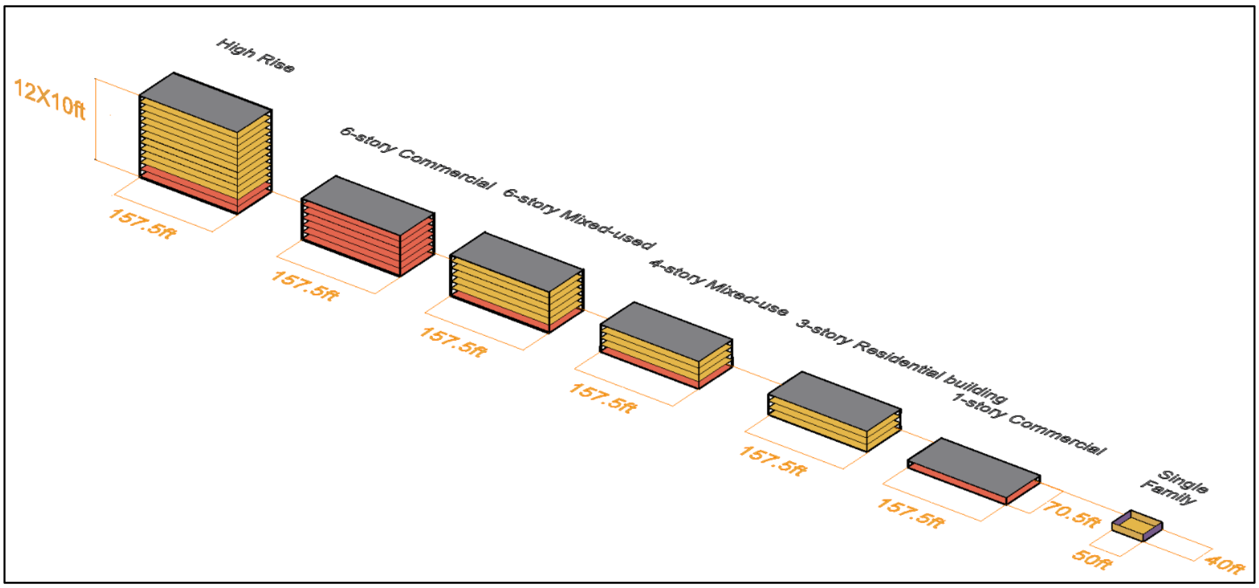

FIGURE 4. BUILDING TYPE SCHEMATIC

All of the buildings have the same footprint and internal layout (see floor plan at Figure 5), except for the single family home. This model was selected using a representative typical apartment building (Manor Park One, 2012). Each dwelling unit within the residential building models included 2 bedrooms, 1 bathroom unit with a space of approximately 1,200 ft^2. For the commercial floors the area was left open for the designation of the future tenet.

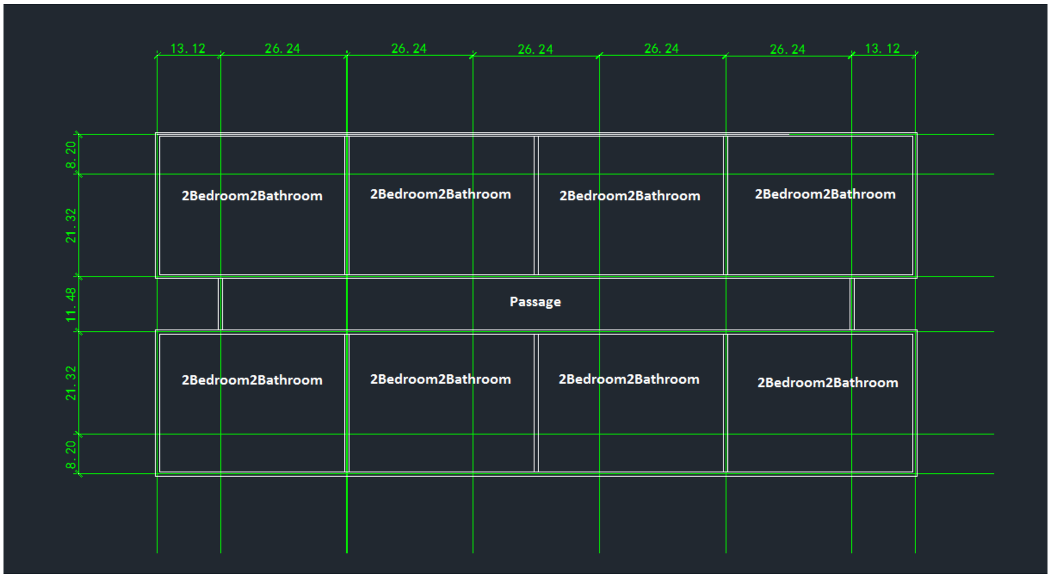

FIGURE 5. GENERIC FLOOR PLAN OF APARTMENT BUILDINGS. DIAGRAM DIMENSIONS ARE IN FEET.

Calculating environmental impacts from materials and construction of buildings

Environmental and human health impacts (GHG, human respiratory and smog) for the construction, maintenance, materials transport, and end-of-life for each of the individual buildings were modeled using Athena Impact Estimator (Athena, 2012). The construction materials for each building were calculated from RS Means guides (Reed Construction Data, 2007). Many assumptions are included in these construction, design, and modeling estimates given the use of RS Means and Athena, but they offer a standard that is representative of typical new construction. The Athena results were developed using a 60-year building life expectancy (Aktas & Bilec, 2011; Athena Sustainable Materials Institute, 2011; Ochsendorf et al., 2011) and a project location of Los Angeles. The Athena software does not have a location option for Phoenix, so Los Angeles was chosen to represent a typical urban area in the southwest United States. Each building's major construction characteristics are listed below.

- <u>Single Family Home:</u> The single story homes were modeled with wood stud framing, concrete slab foundations, conventional stucco siding and fiberglass insulation, wooden trusses for the pitched roof, and concrete tile shingles.
- <u>Single Floor Commercial Building:</u> The commercial building was modeled with a concrete slab on grade, concrete block exterior walls, steel stud interior framing, and steel joist roofing. This building varied from the apartment buildings and the mixed use buildings because it had large window areas, the height of the exterior walls was increased to 15 feet, and the length of interior walls was reduced.
- <u>3 and 4-Story Apartment Building:</u> The apartment building was modeled using a concrete slab on grade foundation, wood stud exterior and interior framing, wood joist flooring for the upper levels, and wood joist parallel roofing.
- <u>6-Story Mixed-Use and 6-Story Commercial Buildings:</u> These buildings were modeled using a concrete slab on grade foundation, concrete block exterior walls, steel stud interior framing, open web steel joist flooring for the upper levels, and steel joist parallel roofing.

- High Rise Building: The high rise building was modeled with a concrete foundation and slab on grade, concrete columns, steel stud exterior and interior framing, suspended slabs for each level, and steel joist roofing for the uppermost roof.

The Athena outputs for air emissions can then be assessed as environmental impacts using the U.S. Environmental Protection Agency's (EPA) Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) (Bare, Norris, Pennington, & McKone, 2002). The air emissions that are converted to greenhouse gases (in carbon dioxide-equivalent, or CO_2e) are CO_2, N_20, and CH_4. The emissions that have the potential to cause human health respiratory effects (in equivalence of particulate matter of 10 microns or less in size, or $PM_{10}e$) are particulate matter (PM_{10}), SO_x, and NO_x. The emissions that have the potential to cause smog (converted to ozone-equivalent, or O_3e) are CH_4, CO, VOC, and NO_x. Table 6 summarizes the environmental impacts from building construction, materials manufacturing, materials transport, and end-of-life for the 60-year lifetime of each building type.

TABLE 6. ENVIRONMENTAL IMPACTS FROM CONSTRUCTION, MATERIALS, AND END-OF-LIFE FOR BUILDINGS OVER THE 60-YEAR LIFETIME

	Single Family	3-story residential building	4-story mixed-sue apartment building	6-story mixed-use apartment building	Single Floor Commercial	6-story commercial building	High Rise mixed-use
Global Warming Potential (kg CO_2 eq)	31,966	864,515	1,266,496	1,820,343	391,913	1,820,343	3,714,990
Human Health Respiratory Effects Potential (kg PM_{10} eq)	109	2,808	4,232	5,438	1,105	5,438	13,757
Smog Potential (kg NO_x eq)	122	2,459	3,578	5,034	1,127	5,034	11,863

Modeling the use-phase energy consumption of buildings

The energy measured during the use-phase of each building type was modeled using the U.S. Department of Energy's (DOE) EnergyPlus energy modeling software (DOE, 2012). The energy use-phase software replicated weather conditions of the Phoenix Metropolitan area to provide results that were appropriate for our site locations. EnergyPlus models the annual energy use of buildings based on the size, number of floors, use (commercial, residential, office, etc.), building occupancy, materials, windows, lighting fixtures, and heating & cooling units. The outputs were used to estimate the electricity consumption of seven building types over the 60-year lifetime. Table summarizes the annual electricity use for each building type.

TABLE 7. ANNUAL ELECTRICITY USE PER BUIILDING TYPE

	Use-phase Energy (kWh/yr)		
Building type	Commercial	Residential	Total
Single Family Home	-	24500	24500
Single level Commercial	97508.33	-	97508.33
3-story residential	-	375411.1	
6-story commercial building	479599.99	-	479599.99
4-story mixed use apartment building	79933.33	375411.1	455344
6-story mixed use apartment building	79933.33	664916.65	744849.98
High rise mixed-use apartment building	159866.66	1310555.52	1470422.18

These energy consumption rates were used to calculate the total energy consumption for all of the buildings proposed as new construction at all of the sites over the 60-year lifetime from materials manufacturing and transport through construction, use, and end-of-life. The air emissions from this energy consumption were calculated using Argonne National Laboratory's (ANL) Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) fuel cycle model (ANL, 2011). These total life-cycle environmental effects are reported in the results section below ("Results for building energy consumption and environmental effects").

Sensitivity analysis of electricity grid mix in Arizona over the next 60 years

Annual energy consumption values are assumed to remain the same over the 60-year lifetime of the selected buildings. However, the energy mix composition changes according to the future renewable energy standards (APS, 2009). Therefore, pollutants generated from the changing Arizona grid mix are modeled through individual annual changes. Figure 6 illustrates three sensitivity scenarios: pessimistic, base case, and optimistic.

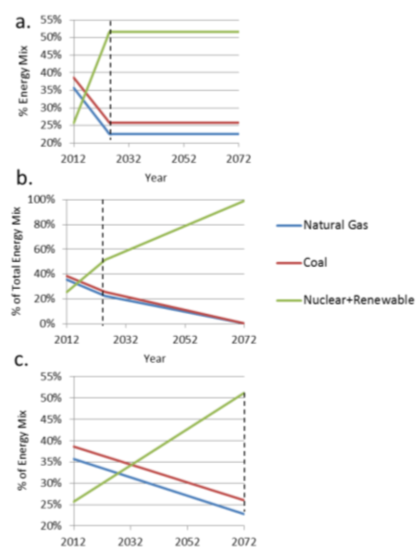

FIGURE 6. SENSITIVITY SCENARIOS FOR VARYING ENERGY MIX IN ARIZONA

The proposed Arizona renewable energy standards (outlined in the APS energy plan (2009)) is marked by the dashed lines. The base case scenario (a) reaches the proposed renewable standards by 2025, but does not make further improvements. The Optimistic scenario (b) also reaches the renewable energy standards by 2025, but continues to improve until it reaches 100% renewables and nuclear by 2072. The pessimistic scenario (c) reaches the 2025 energy goals by 2072.

Allocating building types in unique designs at each site location

Building types were placed in TOD locations by taking into consideration the area limitations of individual parcels. Recall that Scenario 1 simply places single-family homes in the available land, while Scenario 2 proposes higher density mixed-use development. For Scenario 2, the development design considered the number of vacant parcels complementing the type and the quality of the surrounding buildings, and the city planners' views on what should be built. Each of the three sites presented different needs (see Table 8). The TOD at Dunlap and 19th Ave is the new end-of-line stop and is located in a heavily-developed area which left the least amount of available land to develop compared to the other sites. It is composed of a few single-family homes and 4-story mixed-used apartment buildings. The TOD infill in Mesa has an abundance of vacant parcels. The TOD in west Phoenix (Interstate-10 corridor) has many small vacant lots that cannot accommodate anything other than single-family homes. Recall that each site used two different approaches to assessing the amount of "usable" land for new TOD developments: a conservative approach that just used vacant lots, and an aggressive approach that used vacant lots as well as underutilized parcels and aging structures that could be repurposed in the near future.

TABLE 8. BUILDING ALLOCATION FOR EACH TOD SITE LOCATION (IN SCENARIO 2, MIXED-USE DEVELOPMENT)

	Dunlap and 19th Ave		Main St. and Mesa Dr.		I-10 and 35th Ave	
Building Type	Conservative	Aggressive	Conservative	Aggressive	Conservative	Aggressive
Single Family Homes	5	5	7	11	26	26
4 Floors (3 Residential, 1 Commercial)	8	16	8	42	34	39
6 Floors (5 Residential, 1 Commercial)	0	0	0	7	0	0
12 Floors (10 Residential, 2 Commercial)	0	0	10	10	0	0
3 Floors (3 Residential)	0	0	10	10	9	9
Commercial Space (1 Commercial)	0	0	0	0	3	3
Medium Commercial (6 Commercial)	0	0	16	25	0	0
Parking Spots	627	1004	3223	5919	1958	2193
Available Land at Site (acres)	5.8	11	32	60	24	26
Total New Dwelling Units	200	390	1200	2100	1100	1200
Total New Commercial Space (square feet)	89000	180000	310000	690000	410000	470000

SPECIFIC DESCRIPTIONS OF CONSERVATIVE AND AGGRESSIVE LAND USE DESIGNS AT EACH SITE

The 19th and Dunlap stop is the new proposed end of line for the north end of the light rail. This TOD is located within a highly developed area with limited available vacant land. Considering the need of an end-of-line park and ride and the limited space, a phased plan was created. The goal for this site is to create a 4 floor park and ride parking structure for when the stop is built. Our design is to create a parking structure to have 627 spaces, this will provide the necessary parking required for the heavy load the end of the line stop is expected to have. Future expansions propose that this section of the light rail will be further expanded in the near future. We have designed the new TOD development at the park-and-ride location to be flexible in order to accommodate redevelopment many decades from now when 19th and Dunlap is no longer the end of line station (however, the future redevelopment is not considered in any of the construction calculations of this report). When this occurs, we propose a mixed-use apartment be built at the stop, much like the Gregio Metro at the McClintock & Apache station in Tempe. The park-and-ride and apartment complex could share the parking structure, which is designed to handle the apartment parking requirements as well as leaving 300 stops for a park-and-ride. Transitioning from a park-and-ride to a mixed-use apartment complex with a park-and-ride allows for the space to be developed to a higher potential. This creates a plan that will bring residents closer to the light rail and discourage creating a large surface lot on the minimal available vacant land at this location. For the purposes of this study, only the park-and-ride parking structure is included in the building construction, building use, and transportation analyses.

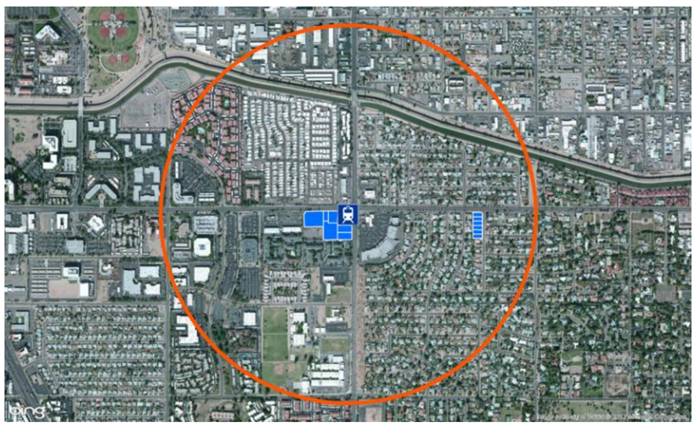

FIGURE 7. CONSERVATIVE LAND USE DESIGN FOR TOD AT 19TH AVE AND DUNLAP

A more aggressive plan for 19th and Dunlop would be to phase in the mixed-use apartment complex as described and also redevelop the strip mall located next to the proposed station. We consider rebuilding this area with more mixed-use apartment units. The first floor would be commercial, allowing for current businesses to remain in their location but create more living opportunity by creating another 3 floors of apartments above. Although 19th and Dunlop does not have the amount of vacant land opportunity that the other stops have, effectively phasing in a mixed-use apartment creates an opportunity to make a significant difference to the land and increase ridership.

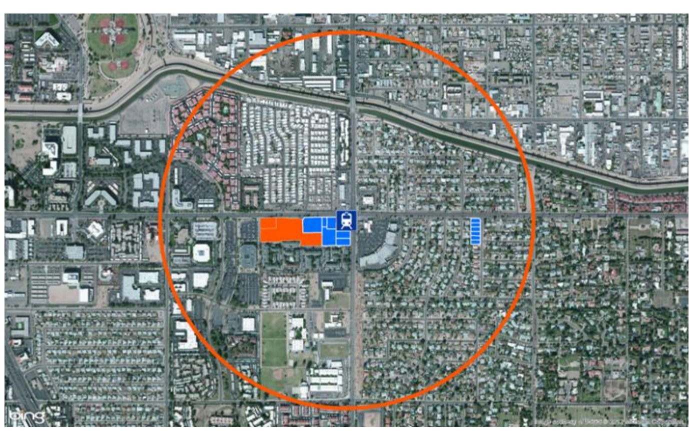

FIGURE 8. AGGRESSIVE LAND USE DESIGN FOR TOD AT 19TH AVE AND DUNLAP

The Mesa Dr. and Main St. station has the greatest amount of vacant land available to develop. Focus for this TOD was placed heavily on the large 18 acre vacant land north of the station as well as redeveloping buildings located along Main St. that would extend downtown Mesa. When considering development for this TOD, proposed Mesa city plans were used when determining building allocation (City of Mesa, 2012; Gowri & Huang, 2011; Graves, 2012). The City of Mesa places a high value on the 18 acre vacant piece of land and has a goal to use it for bringing jobs to downtown Mesa in the form of higher education location, hospitals, or similar technology and innovation businesses. Considering this goal, the design at this site includes several large 6 story commercial buildings that have the potential to meet Mesa's future plans. Also located within this area is a 12 story residential apartment complex where the bottom two floors are left for retail or business use. Parking for business and residential use is provided as well as several acres left for community or green space. This combination of high-rise residential living and commercial units takes advantage of this large area without limiting it to just one specific use.

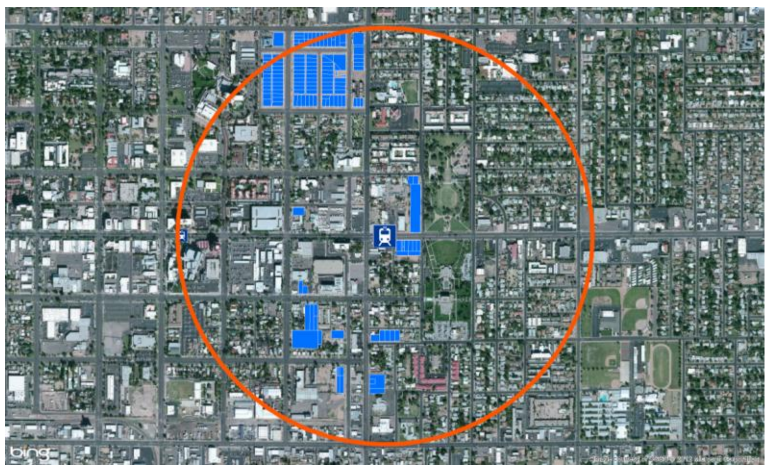

FIGURE 9. CONSERVATIVE LAND USE DESIGN FOR TOD AT MESA DR. AND MAIN ST.

The Mesa site has many older buildings, however just west of the half-mile radius is the edge of downtown Mesa, which has new buildings and many local businesses. The design for this area will extend downtown Mesa to and past this LRT station. The aggressive version of the scenario would redevelop most of the land located along Main St. Redevelopment would contain many small and medium sized mixed-use apartments that would connect downtown Mesa to this LRT station.

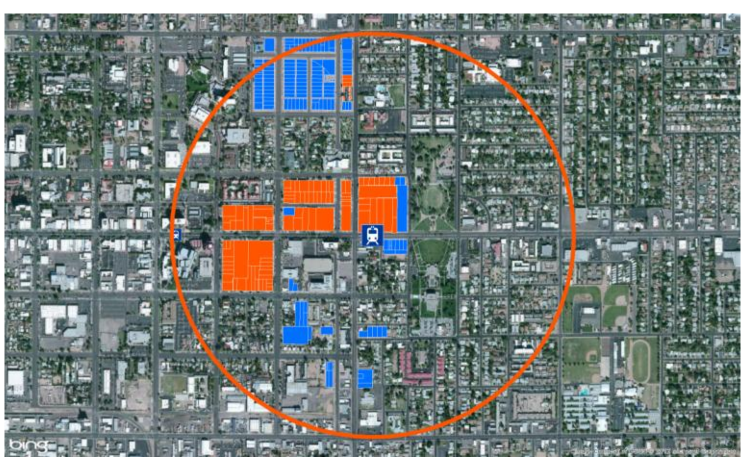

FIGURE 10. AGGRESSIVE LAND USE DESIGN FOR TOD AT MESA DR. AND MAIN ST.

The I-10 & 35th Ave station has several small vacant parcels available for development and only a few large vacant areas that could effectively be used for mixed-use apartments. The majority of the development infills small parcels with single-family homes, single story commercial buildings, and small 3 story apartments. However, on the north side of I-10 is a large 7-acre parcel that could accommodate a large mixed-use apartment complex. This apartment complex will be the largest change to the area and may encourage similar development when land becomes available. Located on the south side of the I-10 is an old un-used U.S. Navy building which could be repurposed into a center for community engagement.

FIGURE 11. CONSERVATIVE LAND USE DESIGN FOR TOD AT I-10 AND 35TH AVE

The difference between the conservative and aggressive land use scenarios for the I-10 location is very minimal. Only one developed parcel would benefit from future repurposing to a small mixed-use apartment complex. The rest of the land and developed areas are not good choices for change. However, as the buildings continue to age and the LRT line is put into operation, buildings will need to be replaced and hopefully follow the example made by the mixed-use apartment complex infilled on the north side of I-10.

FIGURE 12. AGGRESSIVE LAND USE DESIGN FOR TOD AT I-10 AND 35TH AVE

Results for building energy consumption and environmental effects

The 60-year life-cycle energy consumption and environmental impacts for the TOD and BAU scenarios at the three sites are graphed in Figure 13, Figure 14, Figure 15, and Figure 16. The uncertainty bars represent the electricity grid mix sensitivity analysis (see Figure 6). The lower bound of the uncertainty bar is the optimistic grid scenario which reaches 100% renewable and nuclear at the end of 60 years, while the upper bound represents the pessimistic scenario where the grid mix reaches 2025 energy goals by 2073.

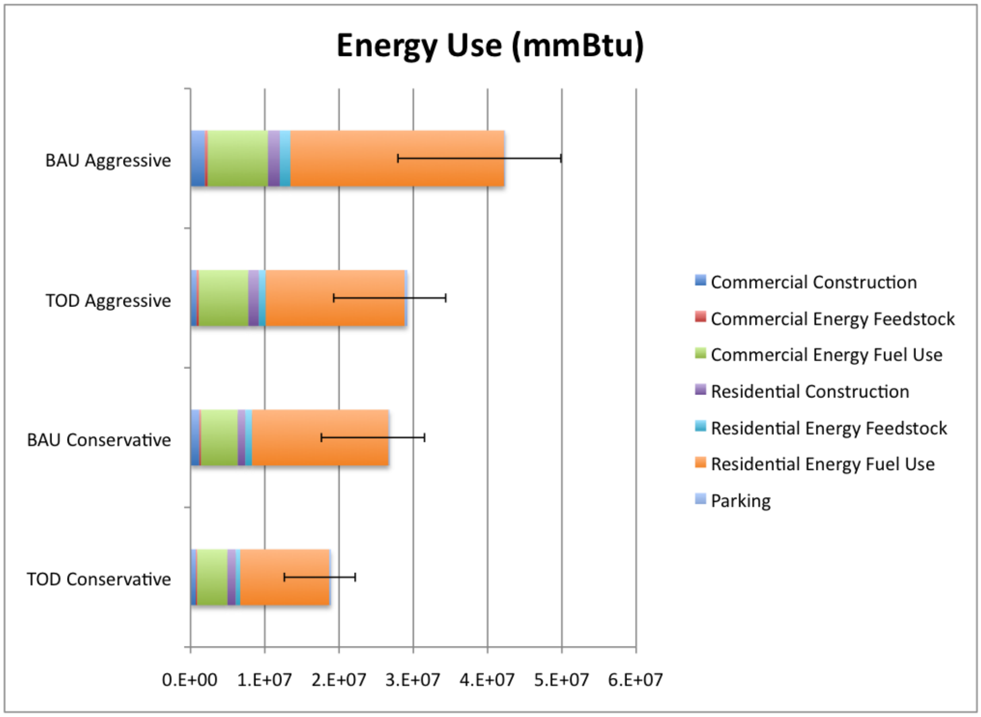

FIGURE 13. TOTAL ENERGY CONSUMPTION FOR BUILDINGS, BY LIFE-CYCLE PHASE

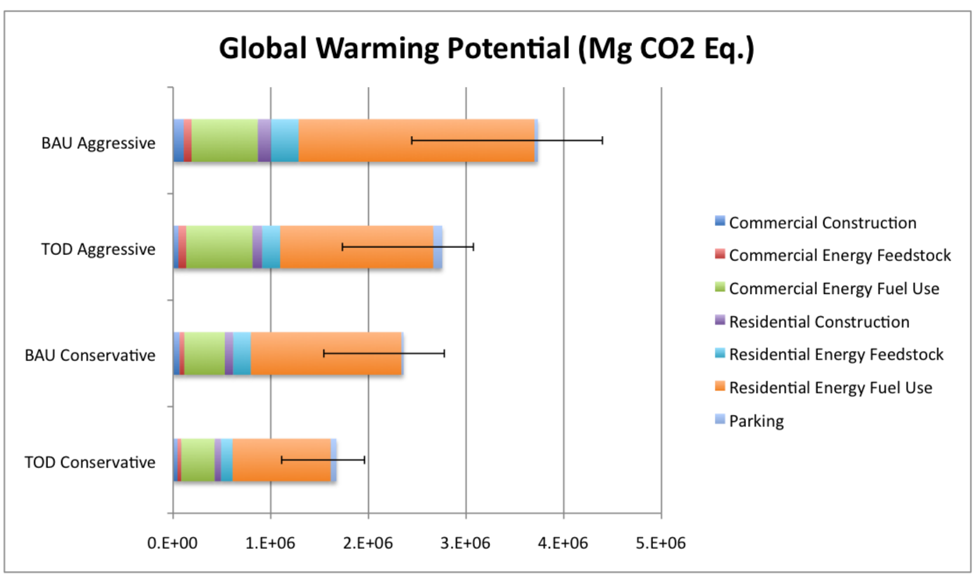

FIGURE 14. TOTAL GREENHOUSE GAS EMISSIONS FOR BUILDINGS, BY LIFE-CYCLE PHASE

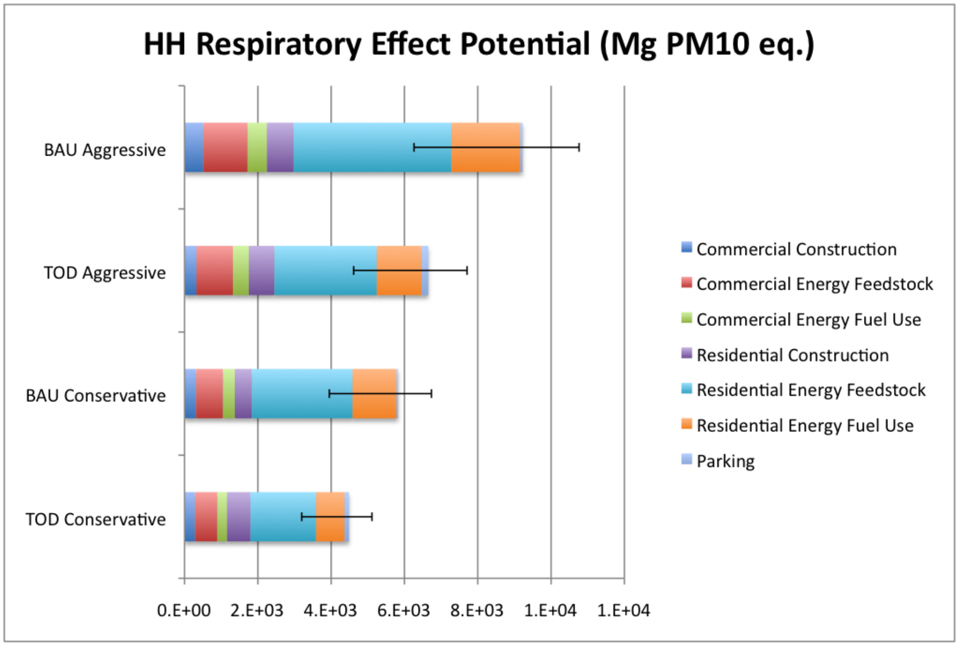

FIGURE 15. TOTAL HUMAN HEALTH RESPIRATORY POTENTIAL IMPACTS FOR BUILDINGS, BY LIFE-CYCLE PHASE

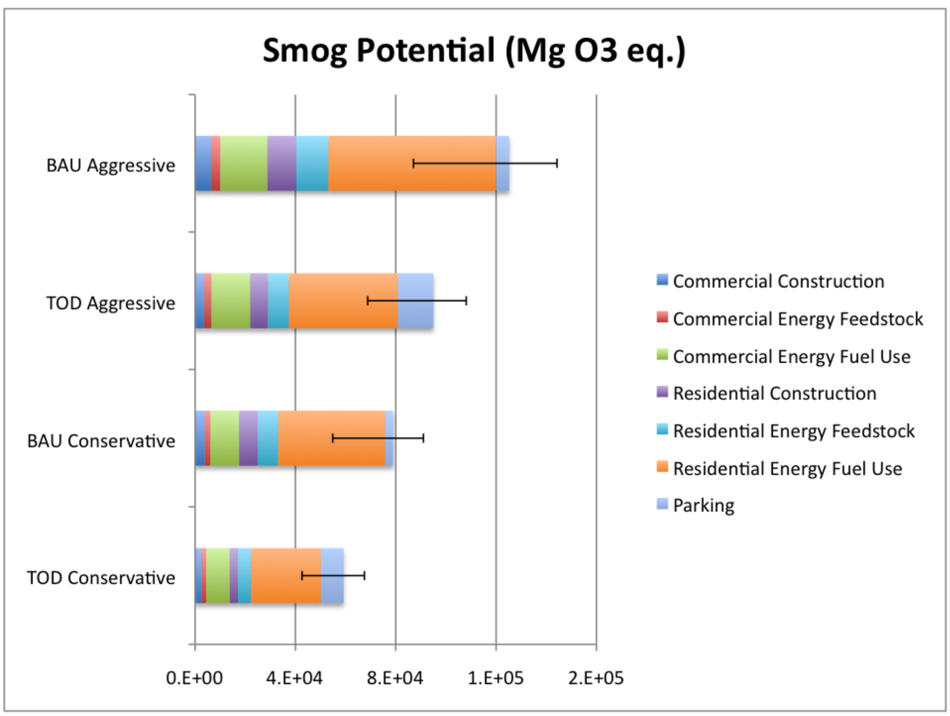

FIGURE 16. TOTAL SMOG FORMATION POTENTIAL FOR BUILDINGS, BY LIFE-CYCLE PHASE

Across the board, TOD infill consumes less energy and produces fewer air emissions than its BAU counterpart scenario. Ranging between 25-30% of the totals, these reductions indicate that there are significant benefits to urban densification when compared to the typical sprawl growth pattern seen in the Phoenix Metropolitan

Area. These reductions are likely due to the economies of scale that result from multi-dwelling unit buildings and the combination of residential and commercial space in mixed-use buildings (TRB, 2009).

It is important to note that not all phases of life-cycle impacts are lower in the TOD scenarios. The human health respiratory impact potential emissions associated with residential construction are higher for TOD than BAU by nearly 30% in the conservative scenario. This is a direct result of the increased use of concrete, steel and other building materials when building high-rise mixed-use buildings. However, the total human health respiratory impact potential for TODs (considering all phases of the life-cycle) are significantly less than the total impacts associated with BAU. The total savings over a building's 60-year life-cycle should be considered when making judgments regarding future development.

The building use phase for residential and commercial buildings dominate the results of total energy consumption, greenhouse gas emissions potential, and smog formation potential emissions. Because Arizona is a net exporter of electricity these impacts will be felt at the state and local level. Densification greatly reduces the electricity use footprint of both residential and commercial space. This is likely a result of the shared wall effect, energy savings resulting from a centralized HVAC system, or other savings associated with economies of scale (TRB, 2009).

The total results for human health respiratory impact potential are primarily dominated by commercial and residential energy feedstock (the energy consumed while generating electricity and the raw material extraction, processing, and transmission). This is largely due to emissions associated with surface coal mining. While Arizona does not produce much of the coal it uses, there are still operating coal mines within the state and it is important to consider the reductions produced by TOD both locally and nationwide. Because TOD reduces the electricity use footprint, the impacts associated with electricity production feedstock will also be reduced when compared to the BAU scenario.

The building typologies associated with TOD result in considerable impact savings in every measured category across the buildings lifecycle when compared to low density fringe growth. Urban densification strategies should be stressed as a means to reduce energy consumption and environmental impacts and to transition towards sustainable cities.

TRANSPORTATION ANALYSIS

Travel analysis can assess the transportation benefits of TODs, taking into consideration the travel characteristics of urban residents and fringe residents. National Household Travel Survey (NHTS) data for Maricopa Association of Governments (MAG) is used to compute these average travel characteristics (US Department of Transportation, 2011). The intent of the transportation analysis is to quantify the number of automobile trips that can potentially be reduced because of the introduction of TODs, then to calculate the resultant energy consumption and air emissions (environmental impact). The analysis mirrors the buildings analysis by comparing a Business As Usual (BAU) scenario where developments take place on the fringe to a TOD mixed-use development with access to a new light rail transit (LRT) station. Within the TOD developments, a bounding analysis was conducted by varying the percentage of travel mode-shift (automobile to public transit).

Methodology for evaluating transportation changes

The transportation analysis uses five steps to assess the comprehensive impacts from changes in travel behavior when growth happens as TOD rather than BAU scenarios.

Modeling Travel behavior

Spatial analysis tool ArcGIS was used to compute the average trip rates and trip lengths of people residing near the existing light rail stations, based on the NHTS data. The travel characteristics of residents in the proposed TODs are assumed to be synonymous with people living near the current light rail stations. This assumption was necessary because data for TOD developments does not yet exist for the Phoenix Metropolitan Region. To obtain the average trip rates and trip lengths, the household travel characteristic file from the 2009 National Household Travel Survey (US Department of Transportation, 2011) for Maricopa County was overlaid on the Maricopa Region Traffic Analysis Zone (TAZ) shape file in ArcGIS. Existing light rail stations were marked on the map and a 0.75 mile buffer was drawn around the current station locations. The households falling within the buffer were selected for analysis. The buffer is larger than the 0.5 mile radius used in the land use analysis because the NHTS data does not contain enough data points within the 0.5 mile radius to be statistically significant. All 28 LRT stations of the current transit line were considered in order to obtain the maximum number of data points for analysis. Travel characteristics such as the average trip rate per household, average trip distance traveled by a household in a day, etc., were calculated for the selected households. The summaries are presented in Table 9.

TABLE 9. HOUSEHOLD STATISTICS FOR RESIDENCES WITHING 0.75 MILE RADIUS OF EXISTING LRT STATIONS (AUTOMOBILE TRIPS ONLY)

Variable	Data Points	Minimum	Maximum	Mean	Std. Deviation
Household Size	72	1	8	2.21	1.42
Trip Length(miles)	72	0.24	407.97	54.58	72.12
Trip Duration (minutes)	72	10	487	122.2	96.47
Number of Trips	72	1	29	7.72	5.75

The same analysis is at Table 10 for people living on the urban fringe of the Phoenix Metropolitan Area. The fringe was constructed by carefully observing the sprawl pattern of the area using Google Earth and identifying the demarcation boundary from the city where developments were sparse and clustered.

TABLE 10. HOUSEHOLD STATISTICS FOR RESIDENCES OUTSIDE THE FRINGE BOUNDARY (AUTOMOBILE TRIPS ONLY)

Variable	Data Points	Minimum	Maximum	Mean	Std. Deviation
Household Size	2221	1	10	2.49	1.29
Trip Length(miles)	2221	0.22	2076.26	75.27	103.82
Trip Duration (minutes)	2221	2	1125	146.2	131.86
Number of Trips	2221	1	57	7.73	5.46

The average trip rates of households on the fringe and near the existing light rail stations are in line with the national averages. The average distance traveled by a household on the fringe is about 20 miles higher than that of the average urban residence. This clearly indicates that more dense urban developments can have less impact on the environment by reducing household vehicle travel.

Determine population statistics for site locations

The next step in the analysis determined the current development densities at the selected TOD locations. To quantify the number of people per dwelling unit and in turn the number of trips per typical household, census block group data (Arizona Department of Administration, 2010) was filtered for households within 0.5 miles of the three proposed TOD sites. Each site was evaluated separately and summaries can be seen in Table 11, Table 12, and Table 13.

TABLE 11. POPULATION AND DWELLING UNIT CHARACTERISTICS WITHIN 0.5 MILES OF THE 19TH AVE AND DUNLAP STATION

Variable	Data Points	Minimum	Maximum	Sum	Mean	Std. Deviation	Area (acres)	Characteristic /Acre
Total Population	46	1	1133	5787	125.8	243.32	502.4	11.52
Total Dwelling Units (Occupied)	46	1	446	2443	53.11	105.6	502.4	4.86
People per Dwelling unit	46	1	3.7	105.3	2.29	0.68	502.4	

TABLE 12. POPULATION AND DWELLING UNIT CHARACTERISTICS WITHIN 0.5 MILES OF THE MESA DR. AND MAIN ST. STATION

Variable	Data Points	Minimum	Maximum	Sum	Mean	Std. Deviation	Area (acres)	Characteristic /Acre
Total Population	51	3	278	3962	77.69	67.94	502.4	7.89
Total Dwelling Units (Occupied)	51	1	136	1369	26.84	25.13	502.4	2.72
People per Dwelling unit	51	1.44	6	155.5	3.05	0.89	502.4	

TABLE 13. POPULATION AND DWELLING UNIT CHARACTERISTICS WITHIN 0.5 MILES OF THE I-10 AND 35TH AVE STATION

Variable	Data Points	Minimum	Maximum	Sum	Mean	Std. Deviation	Area (acres)	Characteristic /Acre
Total Population	59	20	746	5106	86.54	92.8	502.4	10.16
Total Dwelling Units (Occupied)	59	6	231	1277	21.64	28.75	502.4	2.54
People per Dwelling unit	59	3.13	5.79	248.6	4.21	0.65	502.4	

To calculate the number of trips at each TOD location and its BAU counterpart, the census data analysis is combined with the NHTS data analysis. Low density fringe development will considerably increase trip distances, and hence increase emissions. To calculate the savings in trips as a result of developing commercial and office establishments in the TODs, this study assumes that a percentage of automobile trips generated by the commercial establishments will be reduced as a result of TOD residents accessing these establishments using non-motorized transportation modes.

Sensitivity analysis of travel mode-shifts

There are a total of 16 scenarios in which vehicle miles traveled (VMT) were computed and compared. Figure 17 shows the schema of the transportation analysis scenario development.

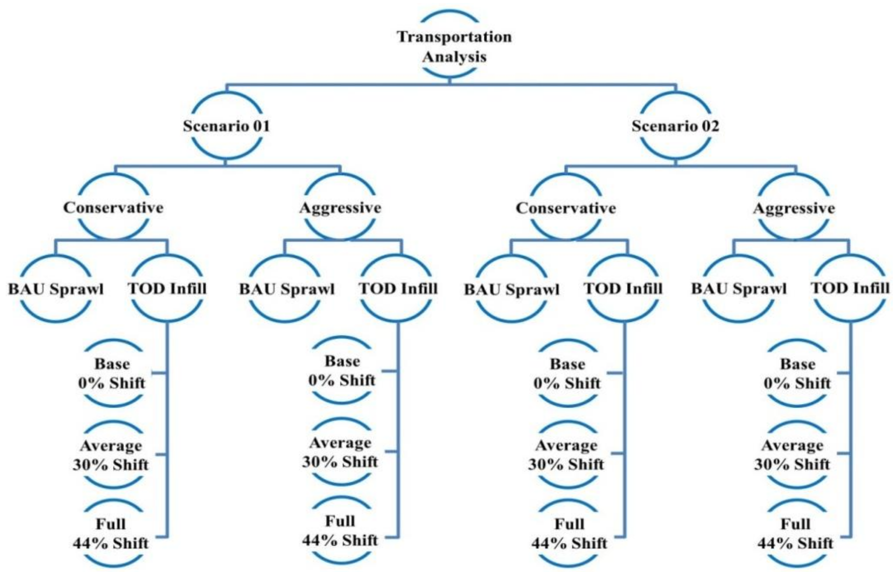

FIGURE 17. VARIATIONS ON SCENARIOS FOR SENSITIVITY ANALYSIS OF VEHICLE MILES TRAVELED AND TRAVEL MODE-SHIFT

The scenarios and development variations match with the scenarios assessed in the buildings analysis. Scenario 1assumes that all of the vacant lots are developed as single-family dwelling units, while Scenario 2 infills the TODs as higher-density mixed-use residential and commercial development. Within each scenario, a "conservative" land use scheme is planned where only the vacant lots are used for development, whereas in the "aggressive" land use scheme more land is considered based on aging or under-utilized spaces. Within each scenario, the TOD is compared to a "BAU" case where development happens on the fringe instead of at the TOD site. Each TOD variant of the scenarios has three different possibilities for travel mode-shift: the base shift assumes no LRT ridership from the new TOD residents and the only VMT savings come from shorter household trips (i.e. shorter commute distances). The average shift assumes that a 30% mode-shift to public transit is realized in addition to the savings from shorter trip lengths. Full mode-shift assumes a that 44% of the trips shift away from automobiles and to public transit. These mode-shift assumptions are also used in the next step of the analysis while calculating non-commercial trip reductions ("Calculating changes in travel").

Calculating changes in travel

Travel reduction in the proposed TOD locations will happen in two ways. First, TOD residents will reduce the number of non-commercial trips. Second, shopping and work trips will be reduced due to commercial and workspace development in proposed TODs.

NON-COMMERCIAL TRIP REDUCTION

The number of trips made by the residents in the TODs is computed by using the trip rates from travel behavior analysis and the population statistics for the scenario. Shopping and work trips were calculated and subtracted from the total trips (see Table 9 and Table 10) and then the remainder of the trips are considered non-commercial trips. The same numbers are computed for residents on the fringe. The total distance travelled by a household in the TODs is approximately 20 miles less than the average household living on the fringe. Simply by placing the new developments as TOD infill rather than BAU (with base mode-shift), there will be savings in the form of reduced impacts from transportation. For the full benefit scenario, the 44% mode-shift was considered from a study that looked at trip reduction in 17 TOD locations across the United States (R. Cervero & Arrington, 2008). The rationale behind choosing the 30% “average” mode-shift is that it matches the current percentage of transit riders in the Valley Metro Transit Survey (Dayal, 2012).

REDUCTION IN TRIPS DUE TO COMMERCIAL AND OFFICE DEVELOPMENTS

Shopping and work trip rates and trip lengths were computed for people in the TODs and the fringe (BAU). The people on the fringe had longer trip lengths for shopping and work trips. By developing shopping and commercial spaces in the TODs, it was assumed that half of the shopping/work trips made by TOD residents will now be done by non-automobile modes. In the BAU scenarios, all trips are assumed to be taken in automobiles with longer trip lengths. The resulting VMT are computed and compared between BAU and TOD scenarios, and the mode-shift variants (base, average, and full) are computed as uncertainty in the totals.

POTENTIAL FOR FURTHER TRIP REDUCTION

This travel analysis also the Institute of Transportation Engineers trip generation manual (ITE, 1991) to calculate the total VMT generated by the commercial and office establishments being built these TODs. The resulting VMT generated were very large because the customers and workers traveling to these establishments come from the entire regional population and not just the new TOD residents. However, the savings in VMT are also significant due to a portion of the travel to these developments happening within the TODs. These savings can be considered additional benefits for infilling mixed-use TOD developments.

TRAVEL REDUCTION RESULTS (TRIPS AND VMT)

In order to report the results with adequate resolution, this section details separate analyses for travel by TOD/BAU residents only, and then travel conducted by both TOD/BAU residents and all of the people patronizing new commercial spaces. Table 14 and Table 15 list trip and VMT reductions in commercial and non-commercial travel by TOD residents, as compared to the BAU scenario travel. Keep in mind these tables are represented as the travel savings (the difference between BAU travel and TOD travel).

TABLE 14. TRIP REDUCTIONS DUE TO DIFFERENT INFILL SCENARIOS (NEW RESIDENTS TRAVEL ONLY)

Scenario Breakdown			Daily Non-Commercial Trip Reduction	Daily Commercial Trip Reduction	Total Daily Trip Reduction	Reduction from BAU
Single-Family Home Infill	Conservative Land Use	0% mode-shift	4	0	4	0.1%
		44% mode-shift	1243	0	1243	44.1%
	Aggressive Land Use	0% mode-shift	6	0	6	0.1%
		44% mode-shift	1935	0	1935	44.1%
Dense Mixed-Use Residential and Commercial Infill	Conservative Land Use	0% mode-shift	19	3297	3316	15.6%
		44% mode-shift	6436	3297	9733	45.9%
	Aggressive Land Use	0% mode-shift	30	5163	5193	15.6%
		44% mode-shift	10080	5163	15243	45.9%

TABLE 15. VMT REDUCTIONS DUE TO DIFFERENT INFILL SCENARIOS (NEW RESIDENTS TRAVEL ONLY)

Scenario Breakdown			Daily Non-Commercial VMT Reduction	Daily Commercial VMT Reduction	Total Daily VMT Reduction	Reduction from BAU
Single-Family Home Infill	Conservative Land Use	0% mode-shift	7552	0	7552	27.5%
		44% mode-shift	16317	0	16317	59.4%
	Aggressive Land Use	0% mode-shift	11752	0	11752	27.5%
		44% mode-shift	25393	0	21052	59.4%
Dense Mixed-Use Residential and Commercial Infill	Conservative Land Use	0% mode-shift	30183	48623	78806	42.0%
		44% mode-shift	71763	48623	120386	64.2%
	Aggressive Land Use	0% mode-shift	47271	79696	126967	43.2%
		44% mode-shift	112392	79696	192088	65.4%

Figure 18 and Figure 19 graph the results for scenario 1 of this study (all single-family home residential development). These charts include uncertainty bars which show the values for the base case (0% travel mode-shift) and full benefits case (44% travel mode-shift).

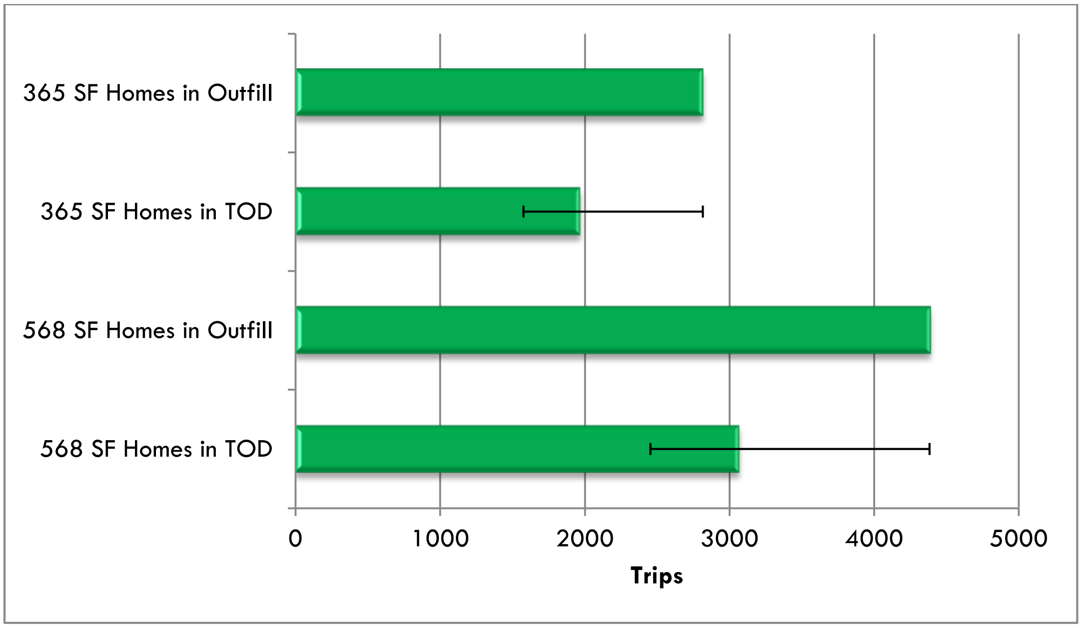

FIGURE 18. AUTOMOBILE TRIPS TOTAL FOR ALL TRIPS IN SCENARIO 1

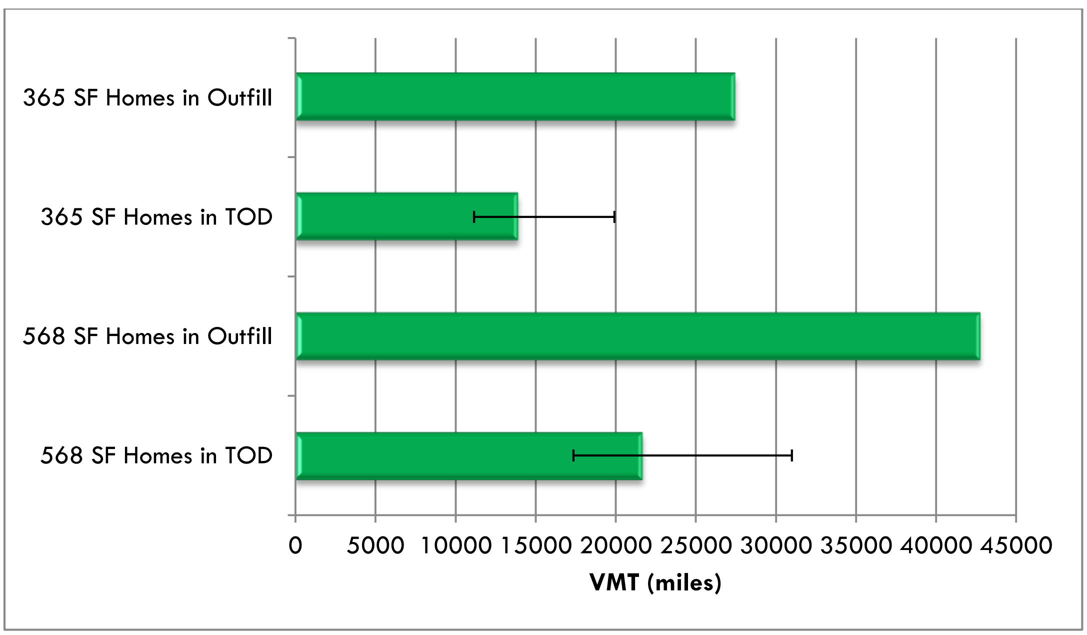

FIGURE 19. AUTOMOBILE VMT TOTAL FOR ALL TRAVEL IN SCENARIO 1

Graph the trip and VMT reduction results for Scenario 2 (where single-family homes and single-story commercial is assumed to be built in the BAU growth, and the TOD growth infills high-density mixed-use residential and commercial buildings with access to public transit). These charts also include uncertainty bars for the base case mode-shift (0% shift) and the full benefits mode-shift (44% shift).

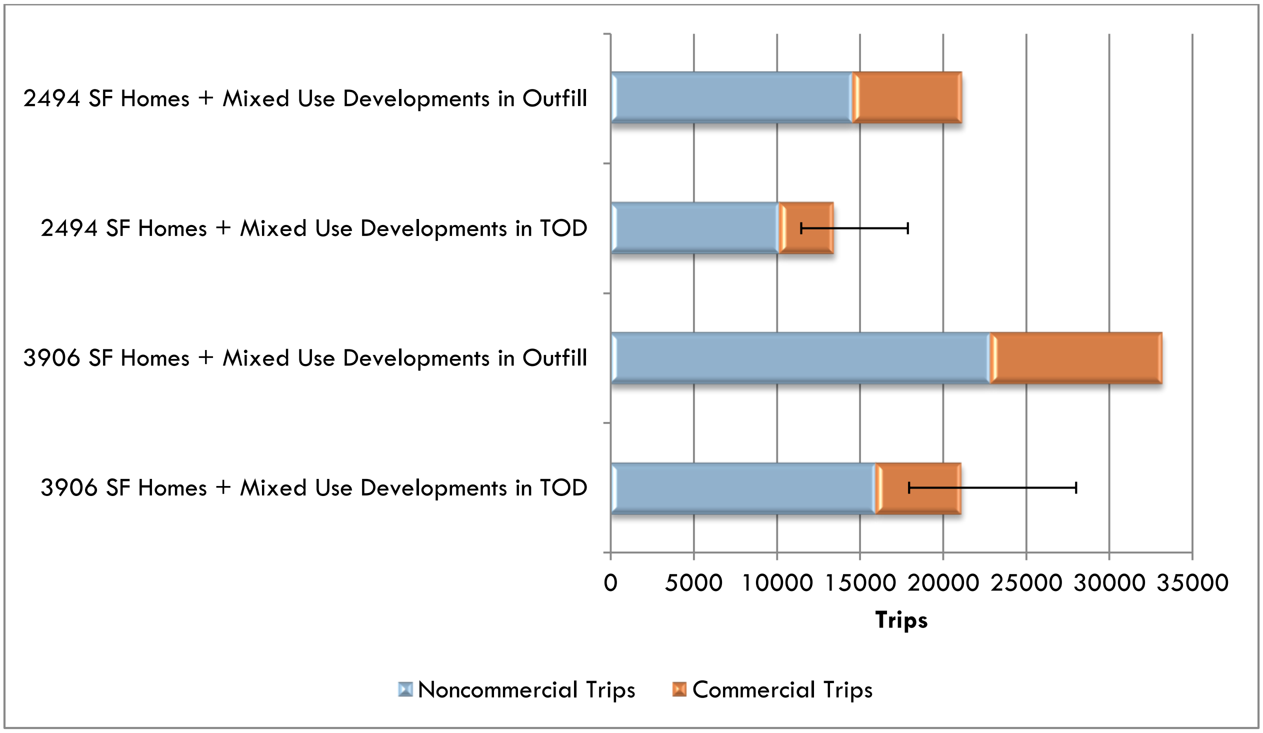

FIGURE 20. COMMERCIAL AND NON-COMMERCIAL AUTOMOBILE TRIP TOTALS FOR SCENARIO 2 (NEW RESIDENTS ONLY)

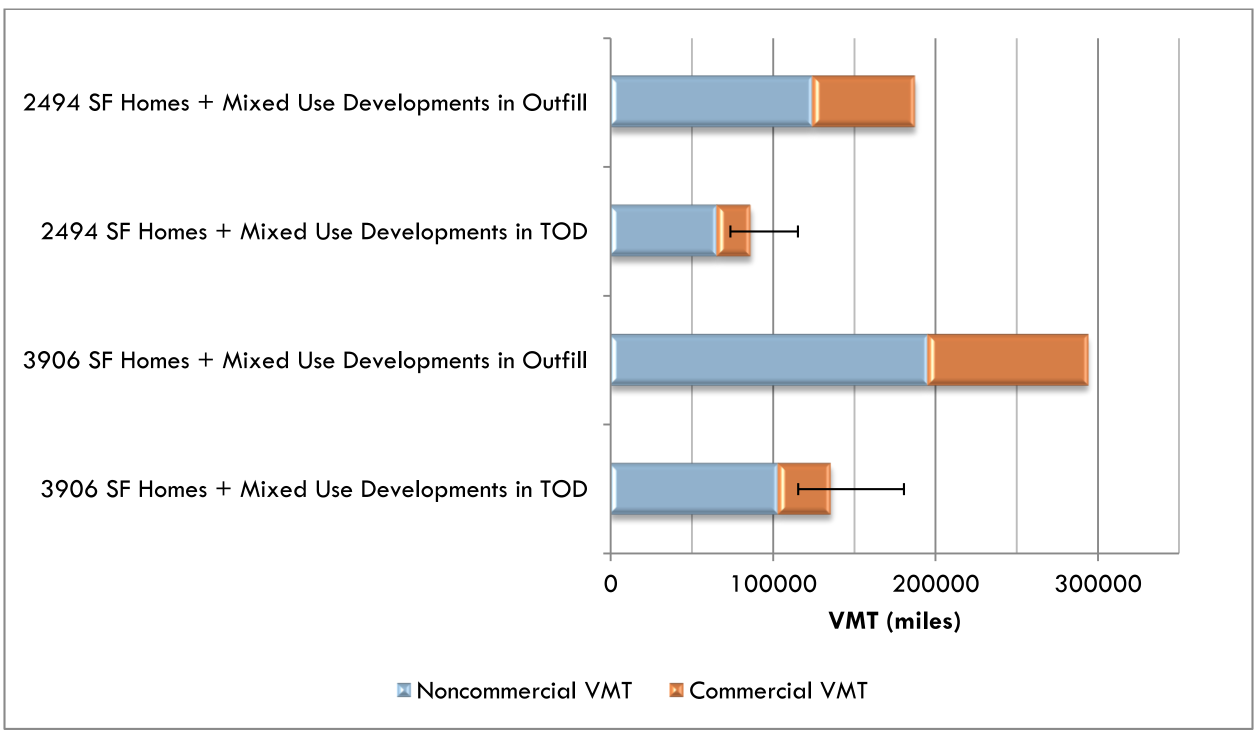

FIGURE 21. COMMERCIAL AND NON-COMMERCIAL AUTOMOBILE VMT TOTALS FOR SCENARIO 2 (NEW RESIDENTS ONLY)

In the conservative base case (with 0% mode-shift) the VMT are reduced by over 7,500 miles a day. This is a considerable saving in motorized travel due only to the relocation of households toward the city. The aggressive land use base case of Scenario 2 reduces almost 5,200 trips and over 110,000 VMT per day. Table 16 lists the VMT savings per TOD household.

TABLE 16. DAILY VMT SAVINGS PER TOD HOUSEHOLD (WHEN COMPARED TO BAU HOUSEHOLD)

Scenario Breakdown	Daily VMT Saved per Household (miles)
Scenario 1-Base-Conservative and Aggressive (single-family home infill, 0% mode-shift)	20.7
Scenario 1-Full Benefit-Conservative and Aggressive (single-family home infill, 44% mode-shift)	44.7
Scenario 2-Base-Conservative and Aggressive (dense mixed-use infill, 0% mode-shift)	29.0
Scenario 2-Full Benefit-Conservative and Aggressive (dense mixed-use infill, 44% mode-shift)	45.7

The VMT savings will not only mean less traffic, and in turn less congestion, but also potential saving in the form of reduced tailpipe emissions and other environmental impacts. These impacts are quantified over a 60 year period in the next section ("Calculating environmental impacts from travel changes"). 60 years is the assumed turnover of the infrastructure for a newly developed TOD, and keeping this temporal scale allows the buildings and the transportation results to be consolidated for the study's final results. The decrease in vehicular travel would also mean less wear and tear on roads and vehicles. This would lead to fewer repairs and an overall longer lifespan. The savings on roadway repairs is an added infrastructure benefit not accounted for here. However, the reduced wear and tear and longer life for vehicles was taken into account when quantifying emissions savings due to vehicle manufacturing. These results are discussed in the environmental impacts section.

Table 17 and Table 18 list daily trip and VMT reductions that include both the travel of TOD residents and the patrons of commercial and office establishments. The number of trips are the same as those in Table 14 because the assumptions are based on travel behavior to and from particular establishments and that is not different for BAU or TOD. The VMT numbers are different because the trip lengths are shorter in TOD than in BAU. Another aspect to pay attention to is the percent reduction from BAU in Scenario 2. These percentages are much lower than in Scenario 1 because it includes all of the people from outside the TOD that are driving to the TOD for shopping and work.

TABLE 17. TRIP REDUCTIONS FOR ALL DAILY TRIPS BY SCENARIO

Scenario Breakdown			Daily Non-Commercial Trip Reduction	Daily Commercial Trip Reduction	Total Daily Trip Reduction	Reduction from BAU
Single-Family Home Infill	Conservative Land Use	0% mode-shift	4	0	4	0.1%
		44% mode-shift	1243	0	1243	44.1%
	Aggressive Land Use	0% mode-shift	6	0	6	0.1%
		44% mode-shift	1935	0	1935	44.1%
Dense Mixed-Use Residential and Commercial Infill	Conservative Land Use	0% mode-shift	19	3297	3316	5.2%
		44% mode-shift	6436	3297	9733	15.1%
	Aggressive Land Use	0% mode-shift	30	5163	5193	4.8%
		44% mode-shift	10080	5163	15243	14.1%

TABLE 18. VMT REDUCTIONS FOR ALL DAILY TRAVEL BY SCENARIO

Scenario Breakdown			Daily Non-Commercial VMT Reduction	Daily Commercial VMT Reduction	Total Daily VMT Reduction	Reduction from BAU
Single-Family Home Infill	Conservative Land Use	0% mode-shift	7552	0	7552	27.5%
		44% mode-shift	16317	0	16317	59.4%
	Aggressive Land Use	0% mode-shift	11752	0	11752	27.5%
		44% mode-shift	25393	0	21052	59.4%
Dense Mixed-Use Residential and Commercial Infill	Conservative Land Use	0% mode-shift	30183	185751	215934	31.3%
		44% mode-shift	71763	185751	257514	37.3%
	Aggressive Land Use	0% mode-shift	47271	313951	361222	31.6%
		44% mode-shift	112392	313951	426343	37.3%

There are uncertainties associated with the limitations of the ITE trip generation manual and the equations used for calculating the number of shopping and work trips generated. Figre graph the trip and VMT savings with the uncertainty from mode-shifts represented as error bars. Commercial trips and VMT dominate the results. As mentioned previously, the trip reductions come only from the new TOD residents and are fewer than the trips savings that include the travel of non-TOD residents visiting commercial establishments in the TOD.

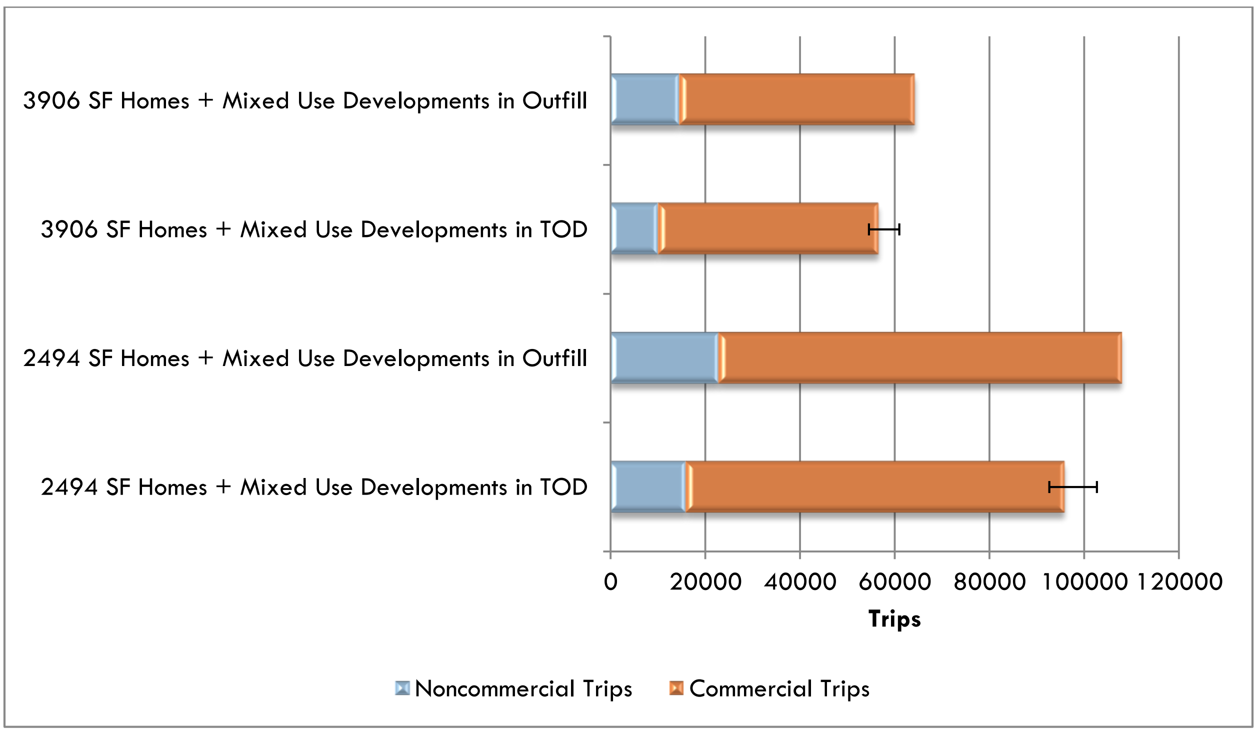

FIGURE 22. COMMERCIAL AND NON-COMMERCIAL TRIP TOTALS FOR SCENARIO 2 (NEW TOD RESIDENTS AND COMMERCIAL PATRONS)

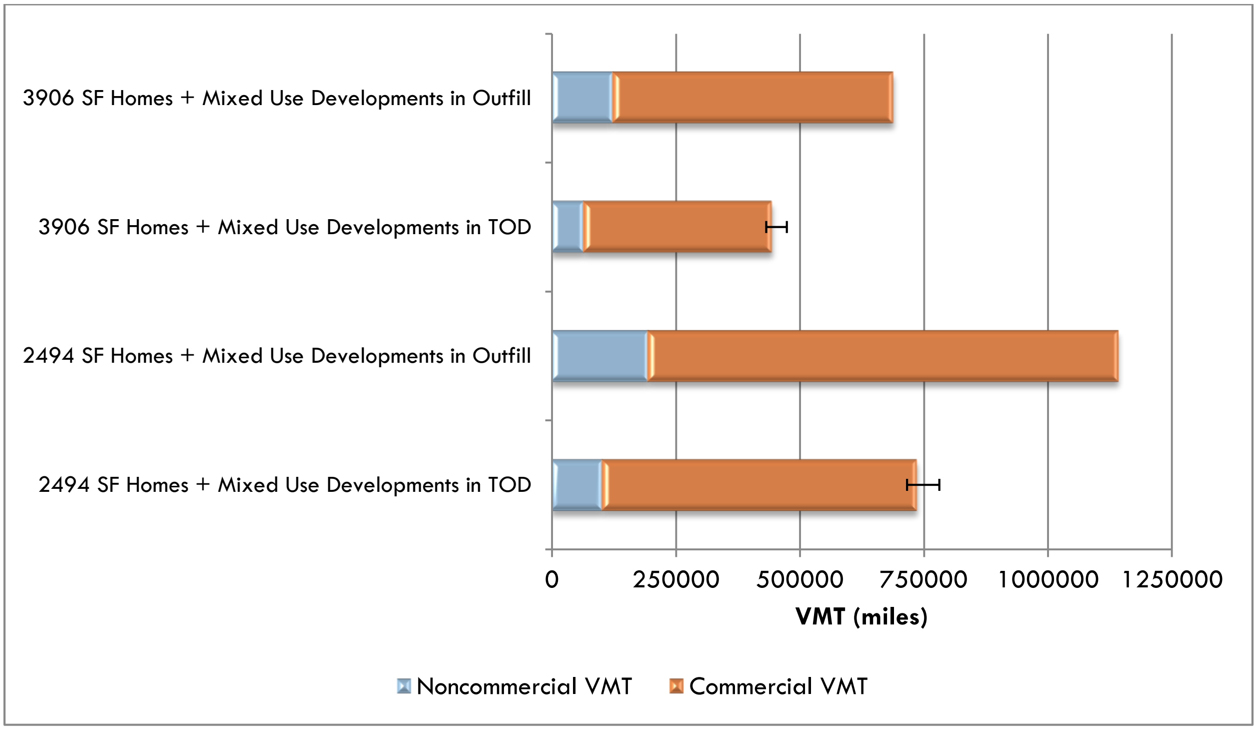

FIGURE 23. COMMERCIAL AND NON-COMMERCIAL AUTOMOBILE VMT TOTALS FOR SCENARIO 2 (NEW RESIDENTS AND COMMERCIAL PATRONS)

Calculating environmental impacts from travel changes

Energy consumption and environmental impacts vary with vehicle type and change with time as manufacturing methods and fuel economies improve. Vehicle types were filtered from the 2009 NHTS data and are listed in Table 19. These values do not sum to 100% because the data set also includes heavy trucks, motorcycles, golf carts, and other vehicle types. It is assumed that standard commuter traffic can be characterized by the use of cars, vans, SUVs, and light-duty trucks. Thus, these percentages are normalized in order to total 100% for the purpose of this study.

TABLE 19. VEHICLE USE BY TYPE FROM 2009 NHTS

Vehicle Type	Raw Value From NHTS	Normalized %
Cars	49.1%	51.4%
Vans	7.8%	8.2%
SUVs	19.0%	19.9%
Pick-Up Trucks	19.6%	20.5%
Totals:	95.5%	100%

To account for the changing impact from vehicle manufacturing and fuel economy changes over time, a time-series for each data set was built for the entire 60-year building life, and is used throughout this analysis. Each time-series listed the impacts and energy use for each of the sixty years, then averaged all the values to one factor which is characteristic of the entire building lifetime. Energy use and environmental impacts were evaluated as a life-cycle component with vehicle manufacturing, fuel production, and vehicle operation all calculated separately.

The energy consumption and air emissions impacts due to vehicle use were the most straight-forward to analyze, as these values varied directly with fuel economy. The impacts of fuel production from "well-to-wheels" were calculated per gallon of fuel production, which varied by vehicle type because of different fuel economies. Because fuel economy improves over time, greater emissions reductions are realized by fewer gallons of gasoline produced and some improvements in the production process with time. This model accounts for a penetration of oil sands into the market, which can initially increase impacts resulting from fuel production feedstock.

Vehicle manufacturing was analyzed over time with the assumption that 100% of the fleet must be manufactured with lightweight materials in order to meet the 2050 fuel economy goals. The California Air Resources Board reported that lightweighted vehicles will have a 20% market penetration by 2025 when compared to 2000 levels (CARB, 2010). By this estimation, the current market penetration is about 10%. As materials change with light-weighting, impacts also change and this analysis is included in the time series.

The United States Environmental Protection Agency (EPA) has set standards to improve fuel economy of new vehicles. For the purpose of this analysis, average vehicles were assumed to reach 35 miles per gallon (mpg) by 2025 and 55 mpg by 2050 for newly manufactured vehicles. The 2009 NHTS data show that about 7 years are needed for the vehicle fleet to turnover and, therefore, reach this standard (US Department of Transportation, 2011). Thus, the 2020 manufacturing goals will be the 2027 fleet average, while the 2050 manufacturing goals will be the 2057 fleet average.

Operational and fuel production energy use and emissions per VMT were obtained from Argonne National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model (US Department of Energy, 2010). The energy consumption and air emissions per VMT were obtained for 2012 and for 2050, when maximum fuel economy will be achieved. These emissions per VMT were then interpolated over the entire 60 years, with a plateau assumed to occur at 2050 as no further incentives to improve fuel economy projected beyond this time.

A total of seven time-series were performed in order to account for three different phases of vehicle use and multiple categories of vehicles. The breakdown is as follows.

- vehicle use-phase of cars
- vehicle use-phase of trucks
- fuel production of cars
- fuel production of trucks
- vehicle manufacturing of cars
- vehicle manufacturing of SUVs
- vehicle manufacturing of pick-up trucks

For use-phase and fuel production, vans and cars were included in one category while SUVs and trucks made up the other category because of similar fuel economies. In vehicle manufacturing, vans were assumed to be most similar to SUVs in materials use. For the purpose of quantifying manufactured vehicles, each vehicle was assumed to be used for an average of 200,000 miles (CARB, 2004).

After total VMT were calculated for each scenario and the energy consumption and air emissions per VMT were obtained, the overall energy use and impacts could be calculated. For the two scenarios in this study (low-density infill and high-density mixed-use infill), a business as usual case (BAU) was defined and compared to a similar TOD case. Each TOD case was analyzed with an average mode-shift away from automobiles of 30%. Uncertainties for the TOD calculations were obtained by assuming a baseline of 0% mode-shift and a full benefit scenario of 44% shift (mode-shift variations are illustrated in Figure 17).

The EPA's Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) was used to convert specific air emissions into normalized units of three impact areas (Bare et al., 2002; Norris, 2002). Global warming potential, human health respiratory potential effects and photochemical smog formation potentials are the main areas of concern for air emissions, in addition to the energy consumption calculations. The TRACI tool provides a numerical multiplier to be used with each criteria pollutant in order to normalize to the three main categories of interest.

Results for transportation energy consumption and environmental effects

Figure 24 displays the most striking benefit that can be realized from this analysis; over 50% of global warming potential (measured in CO_2 equivalents) can be saved in each scenario, when comparing the average TOD situation to BAU. Aggressive Scenario 2 had the greatest number of dwelling units added, nearly 4,000, and shows the greatest potential savings at over 1.3 million metric tons of CO_2 equivalents when infilling TODs instead of BAU growth.

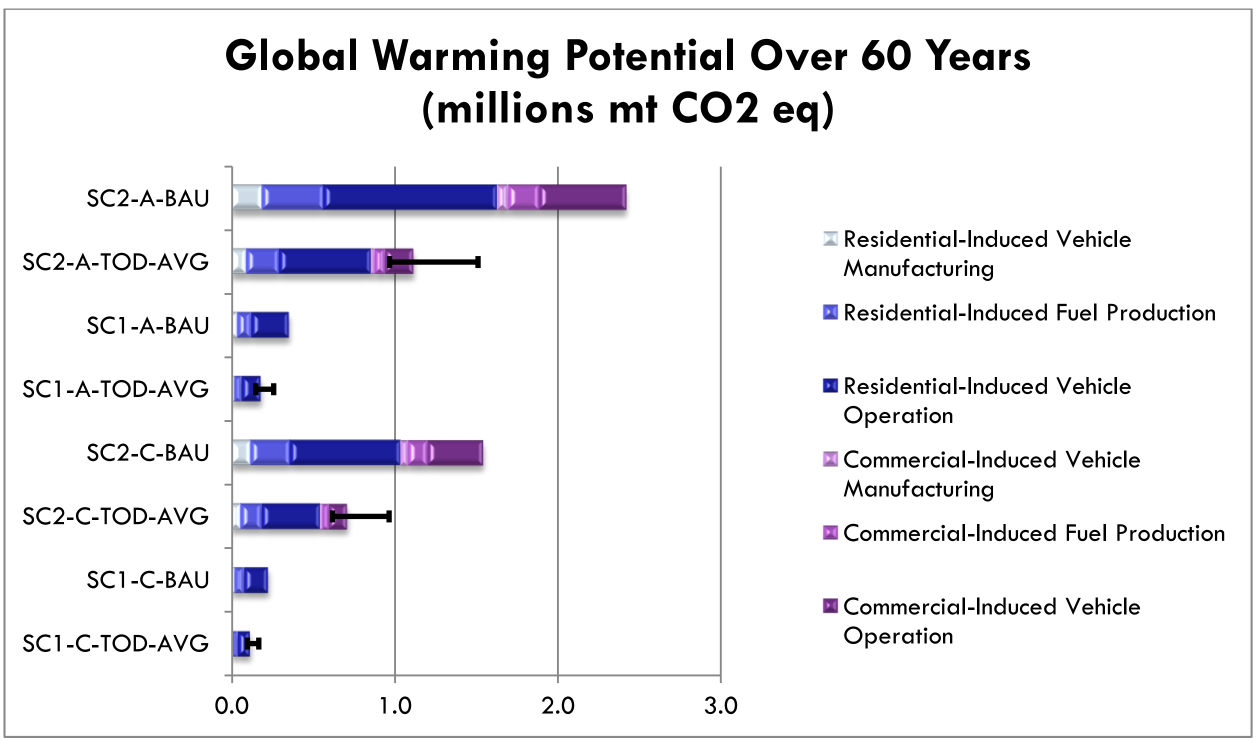

FIGURE 24. ANALYSIS OF GLOBAL WARMING POTENTIAL OVER 60-YEAR TOD LIFE-CYCLE (MEGATONS CO2 EQUIVALENT)

SC2 is Scenario 2 (dense mixed-use infill), SC1 is Scenario 1 (single-family home infill), A is aggressive land use (vacant lots and under-utilized parcels), C is conservative land use (only vacant lots), BAU is business-as-usual (buildings constructed without access to public transit), TOD is transit-oriented development (buildings constructed within walking distance of light rail station)

Each scenario is dependent on the number of dwelling units and amount of commercial development, and if they are placed at the city's fringe or if they are placed as infill. A minimum potential savings of over 35% is realized solely by reduction of travel distance with urban infill. This savings increases to 50% of BAU when a 30% mode-shift from automobile travel is realized, and further increase to 60% savings with a 44% mode shift. While this ratio of savings from the transportation analysis remains almost even across the scenarios, the magnitude depends on the number of dwelling units and commercial real-estate developed in the TOD.

The other benefit to note from Figure 24 is that vehicle operation dominates the totals by over 50%. Greenhouse gas emissions reductions could be accomplished by encouraging light rail or transit ridership and TOD growth is matched will with this strategy.

Scenario 1 proposes only residential housing, while Scenario 2 includes a large portion of residential and commercial real estate. As a result of these typologies, Scenario 1 has a very small vehicle footprint over 60 years when compared with the two cases of Scenario 2. Once again, the ratio of savings from the two TOD cases remains the same in Scenario 1.

More aggressive land use strategies results in a much larger impact, and magnitude of savings, for a greater number of dwelling units and commercial space. This is to be expected from the patterns previously noted, but it is of note that the total impacts from the conservative BAU scenario (2500 homes built on the fringe) has the same impact as the aggressive TOD scenario (3900 dwelling units and commercial spaces built in the TOD) if no mode-shift happens. This directly illustrates that more growth can be accommodated with less impacts simply based on development designs and land use planning.

Figure 25 displays only the second scenario results of commercial and residential development at the TOD locations. In addition to the savings from TOD infill, a full benefit mode-shift to light rail in the aggressive scenario can have almost an equivalent footprint to the bottom line (no mode-shift) analysis of the conservative case. Once again, with nearly 1,500 more dwelling units and additional commercial space, the aggressive case of the Scenario 2 shows the potential for a highly reduced footprint in comparison.

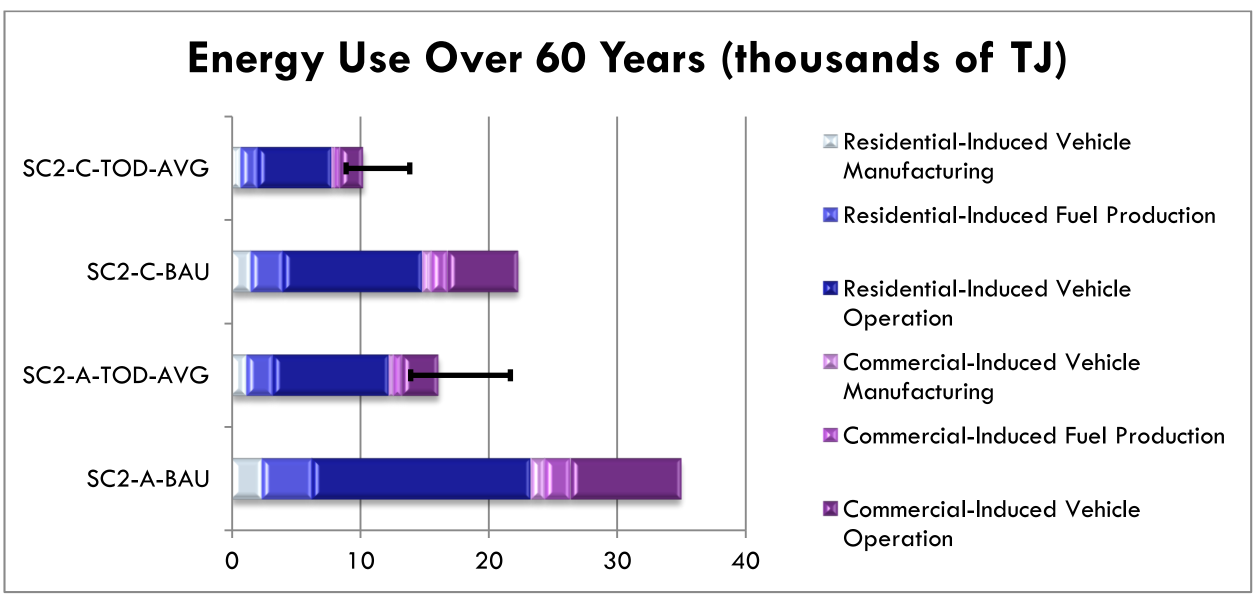

FIGURE 25. ANALYSIS OF ENERGY CONSUMPTION OVER THE 60-YEAR TOD LIFE-CYCLE (ALL THREE SITES)

Similar to the results for global warming potential, energy consumption is largely driven by vehicle operation, which is indicative of the inefficiencies of the internal combustion engine. Despite improved gas mileage over the 60 years, a massive amount of energy must be consumed in the form of gasoline combustion in order to propel the vehicles. Energy feedstock is larger than the vehicle manufacturing component, which likely also stems from the amount of fuel that must be produced for the vehicles over their lifetime.

Alternative fuel vehicles have the potential to greatly reduce this life-cycle energy consumption if the engines manage to be more efficient with the energy of the chosen fuel source. This analysis considered all VMT to be generated by internal combustion engine vehicles, which could be deemed a "worst case" scenario. Any significant penetration of alternative fuel vehicles into the market has the potential to reduce life-cycle energy use and impacts, depending on the methods employed and fuel used.

Figure 26 shows the emissions contributing to potential photochemical smog formation over the 60-year analysis (in Ozone-equivalent units). NO_x is the criteria pollutant which dominates the results for the potential to produce smog in this study. It can be seen in the graph that the majority of potential smog emissions happen in the fuel production stage of analysis. The extraction, transport, and refining processes of fuel production are not localized to the Phoenix area, thus the effects of this are non-local. But a significant portion of the pollutant emissions also result from vehicle operation, which is local to the Phoenix area. Regardless of the location of the processes, many negative environmental effects are experienced some distance away from the location of emission. Therefore, this impact analysis should not be confined to the Phoenix area, despite the focus of the study being land use and transportation at three LRT stations in Maricopa County.

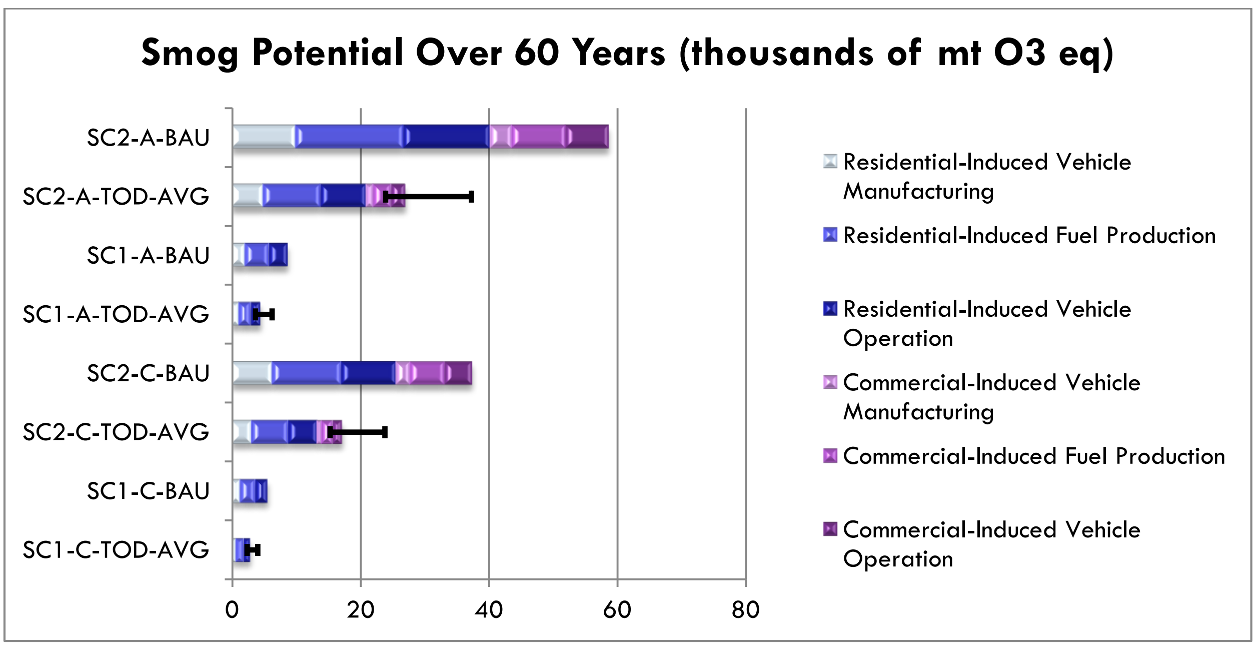

FIGURE 26. ANALYSIS OF SMOG FORMATION POTENTIAL EMISSIONS OVER 60-YEAR TOD LIFE-CYCLE (IN MEGATONS)

With total VMT reductions, there are corresponding reductions in vehicle manufacturing. Once again, assuming a 200,000 mile life of each vehicle, Table 20 shows the potential number of vehicles that would not need to be manufactured, or that would only need to be manufactured at a later date due to the different scenarios and mode shifts.

TABLE 20. AVOIDED VEHICLE MANUFACTURING FROM VMT REDUCTIONS

Scenario	Percent Mode-Shift	Vehicles Saved per Year	Total Vehicles Saved
S1 Conservative (low density residential, vacant lots)	0	14	827
	30	25	1481
	44	30	1787
S1 Aggressive (low density residential, vacant and under-utilized lots)	0	21	1287
	30	38	2305
	44	46	2781
S2 Conservative (high density mixed-use, vacant lots)	0	97	5856
	30	149	8961
	44	174	10409
S2 Aggressive (high density mixed-use, vacant and under-utilized lots)	0	153	9172
	30	234	14034
	44	288	17288

The results consistently show a reduced footprint in the urban infill, transit-oriented development cases. Regardless of resultant mode shift to light rail in these establishments, vehicle travel and environmental impacts are reduced. These presented results also only take into account the travel of the residents in the new TOD dwelling units. When office and retail space are also introduced to the analysis, additional trips would be generated from surrounding residents of Phoenix, but are not considered with the environmental analysis portion of this study. Additional commercial trips originating from outside the TOD and ending within would lead to a greater environmental impact savings because on average these trip lengths are shorter than those made on the urban fringe. Therefore, even though more trips and emissions would result because of these extra vehicular trips, there would still be significant emissions savings compared to having these trips occur on the fringe.

As it stands in this study, each dwelling unit consumes about 150 GJ of energy each year on personal vehicle travel when they live in low density automobile-oriented developments. If this typical dwelling unit were instead located as urban infill without a shift to transit, the yearly energy usage would plummet to 90 GJ and would further drop to 60 GJ with a 44% mode-shift to transit. The amount of energy consumption saved by each dwelling unit each year could have striking effects as it trickles down to reduced energy production.

Using urban infill to reduce the VMT realizes benefits in every area of analysis. Energy consumption, global warming potential, human health respiratory potential effects, and smog formation potential can all be reduced when compared to business-as-usual low-density automobile-oriented growth. Many of these savings are localized results from reduced vehicle operation, while other effects would be widespread around areas where fuel and vehicles are produced. Ultimately the data confirms the supposition that reducing vehicle travel will reduce energy consumption and environmental impacts from a life-cycle perspective.

CONSOLIDATED ENERGY AND ENVIRONMENTAL ANALYSIS RESULTS

The comprehensive energy consumption and air emissions changes that occur from TOD infill instead of BAU sprawl indicate that urban growth can occur in the future with less environmental impacts. The figures below summarize the total impacts for all three site locations over the 60-year life-cycle. The red and orange shaded sections of the bar graphs are buildings life-cycle phases, while the blue and purple shaded sections are transportation life-cycle phases.

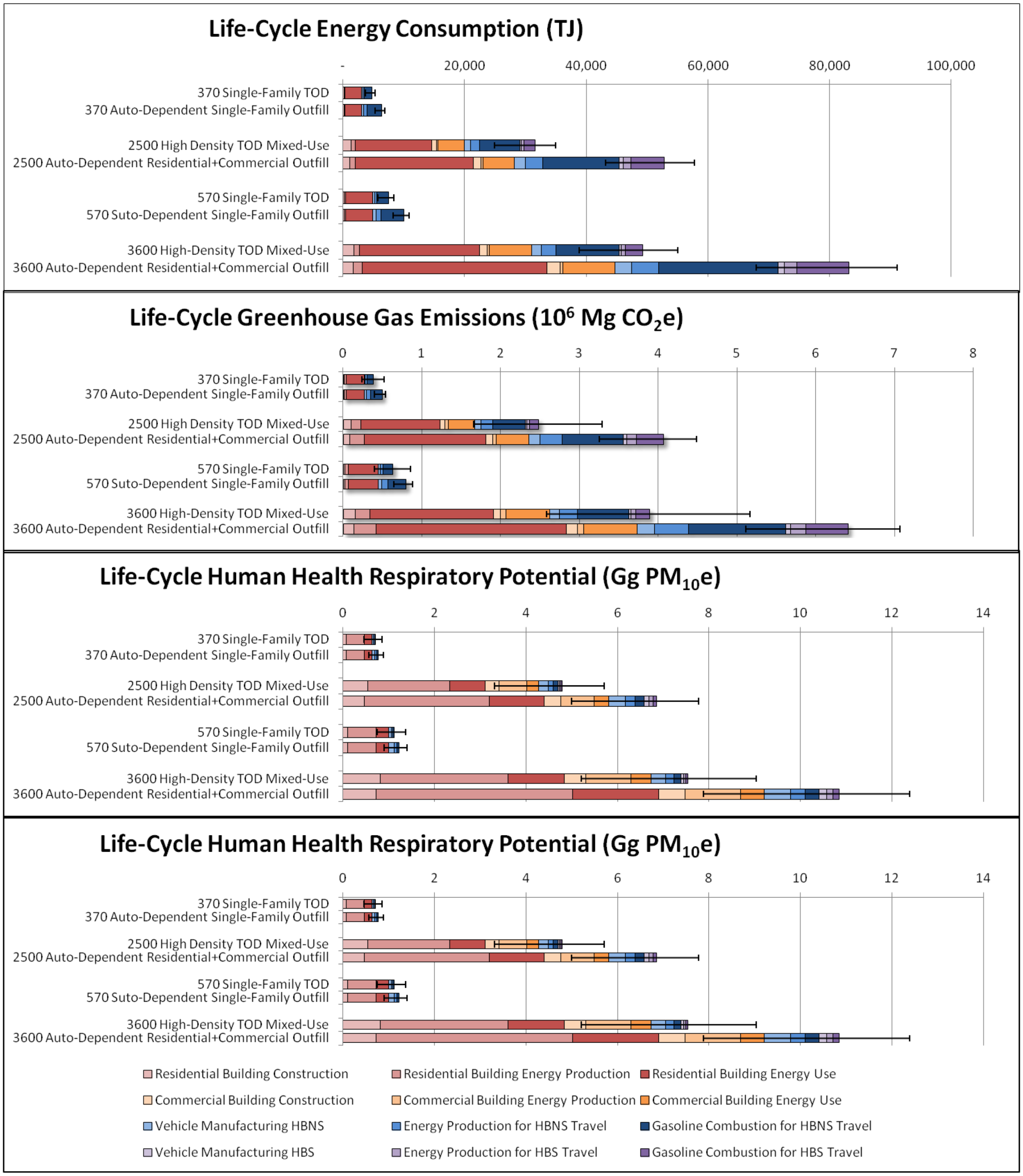

FIGURE 27. LIFE-CYCLE ENERGY AND ENVIRONMENTAL EFFECTS FOR ALL SCENARIOS OVER 60 YEARS (ALL 3 STATIONS)

In transportation phases, HBNS is home-based non-shopping (blue), HBS is home-based shopping (purple). Splitting shopping and non-shopping allows more direct comparison with residential (red) and commercial (orange) in buildings categories.

Figure 27 graphs the energy consumption and environmental effects for all scenarios over the 60 year time period of the study. In the single-family home infill scenarios (referred to as scenario 1, conservative or aggressive), relatively small savings are realized in the transportation phases of the life-cycle due to shorter trip distances. More significant savings are demonstrated in the mixed-use infill scenarios (referred to as scenario 2, conservative or aggressive). Figure 28 shows the same data as Figure 27, but only focuses on the totals for environmental impacts from scenario 2 (mixed-use residential and commercial).

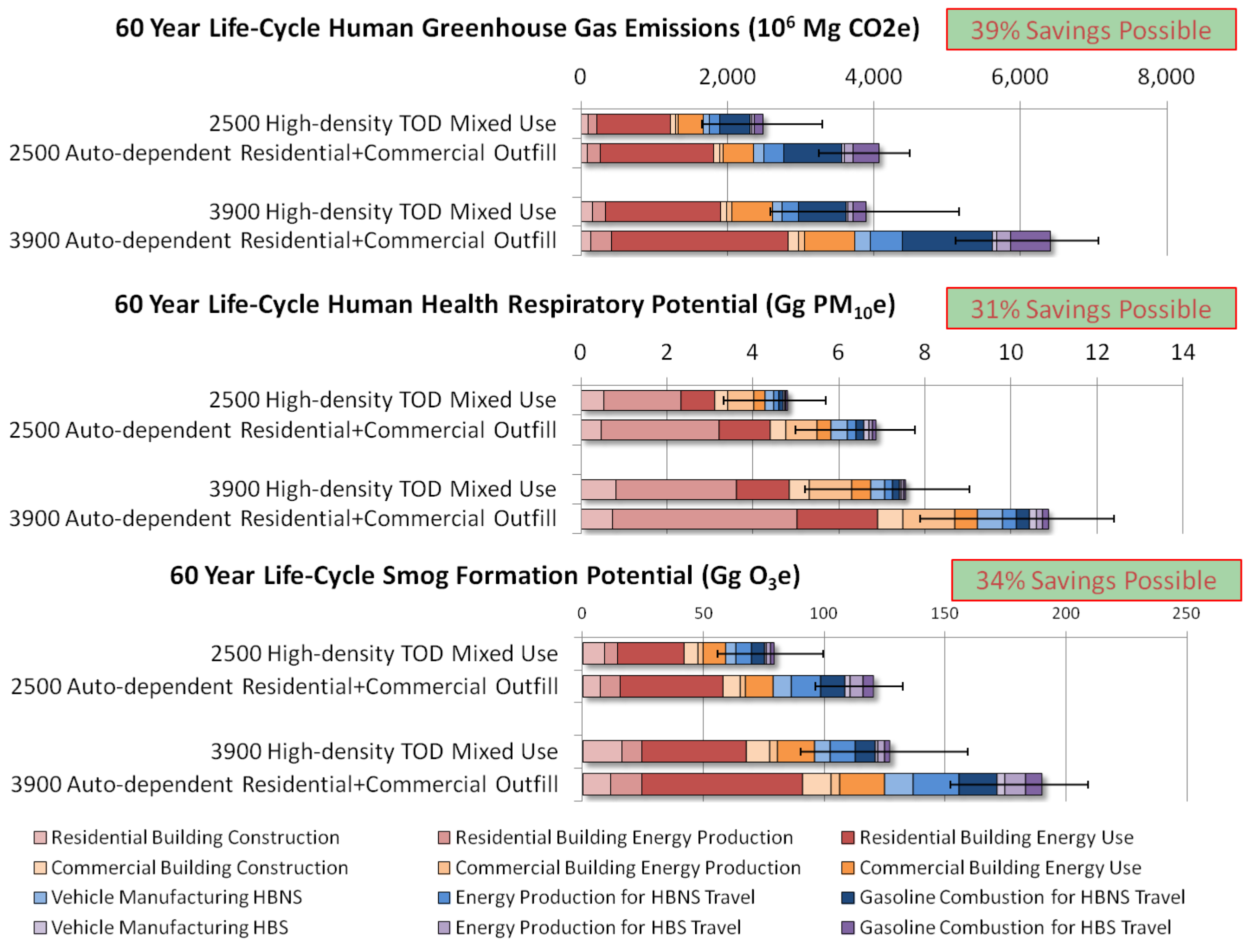

FIGURE 28. CONSOLIDATED LIFE-CYCLE RESULTS FOR TOD INFILL AND BAU OUTFILL SCENARIOS

Both Figure 28 and Figure 28 illustrate very clearly that, in every scenario variation, TOD infill has 31-39% benefits over business-as-usual growth in the form of reduced environmental impacts. Energy consumption can be reduced by as much as 41%. Furthermore, certain life-cycle components can dominate different environmental effects (i.e. a single environmental indicator such as CO_2 vehicle tailpipe emissions does not provide a complete picture of all processes in a system's life-cycle). Notice that the greenhouse gas emissions are dominated by the use phases for both buildings and transportation (that is, the electricity usage and the gasoline combustion), but in human health respiratory potential impacts the fuel and energy production processes dominate for buildings and become nearly equal to the use phases for transportation. Looking at smog formation potential, the building use phases are still the most significant in the buildings categories, but in the transportation categories all three phases are nearly equal. Without life-cycle analysis methods, decision-makers might not get an adequate amount of information upon which to base long-term planning and policy decisions.

TRANSITIONAL STRATEGIES RECOMMENDED AS INTERVENTION POINTS

The comprehensive analyses above outlined the potential barriers to TOD implementation as well as quantified the energy consumption and air emissions savings that could be achieved. The following recommendations will enable proponents of TOD to meet the challenges to increasing density around light rail stations and establishing new patterns of behavior in the Phoenix metropolitan area.

1. Share and standardize best practices:
    a. develop a walk-score for neighborhoods ½ mile from each station.
    b. create a worker/resident target ratio for each TOD neighborhood.
    c. use the walkscore and worker/resident target ratio to develop a business recruitment and long-term development strategy for each neighborhood.

    The three participating municipalities and Valley Metro should participate in developing these tools. The public, too, should be invited to participate. They will have a vested interest in creating a plan, tracking its progress, and helping shape change where they live.

2. Encourage mixed-use, mixed-income neighborhoods with a myriad of inter-modal transportation options.

    The market may be weak for urban infill near the light rail, nonetheless, recent market research shows there is strong demand for affordable housing near light rail stations (BAE Urban Economics, 2012). Those conditions are likely to remain strong or increase over time. In addition, 45% of current Valley Metro ridership are university students (Valley Metro, 2011). Market demand will support tens of thousands of housing units, ranging in price from market rate to student and workforce housing. Smaller neighborhood-based retail, not big-box stores or strip-malls, can add needed services and amenities.

    TOD neighborhoods near the light rail should also be the center of each city's efforts to promote bike use, car sharing, and the like. Bike lanes should be built or re-routed so that they converge at light rail stations. The presence of car sharing will encourage residents living nearby to use their cars less, or perhaps even give up one or all of their household vehicles.

3. Evaluate the light rail system as a whole.

    There is a tendency to measure the success of TOD one station at a time (Niles & Nelson, 1999; Renne, 2008; Schlossberg & Brown, 2004). Greater value may be gained by looking at not just projects developed in a single neighborhood, but at how amenities and services are distributed along the entire system. Having a grocery store or a suite of medical services, for instance, near each station will not be possible. But it is possible to track whether services and amenities are evenly distributed along the entire light rail line. Presently, there is no entity maintaining that perspective on how the light rail system as a whole functions. If Valley Metro were to play that role and conduct a bi-annual survey of services and amenities, such a report could be fed into each city's planning efforts and made available to resident-led committees working to develop neighborhoods.

4. Engage in creative place-making.

   If the three most important aspects of a real estate project to a developer are location, location, and location, then creating a sense of place is the best way for a city to add value to location. The techniques developed by the Project for Public Spaces described above should be used throughout the Valley to help make the neighborhoods around light rail stations distinctive, active, healthy and human-scaled (not car dominated) places.

5. Promote the TOD lifestyle.

   The greatest sustainability benefits are gained not only from increasing density near mass transit stops but also from maximizing mode-shifts in transportation choices. The dominance of urban sprawl and the uniformity of housing types in the Phoenix metropolitan area can be turned from a barrier into a solution. A well-directed marketing campaign that celebrates the benefits of living and working in or near TOD neighborhoods can increase demand for TOD housing projects and help build a market for what is essentially a new product in the Valley. Valley Metro and participating municipalities need developers to build projects. A managed marketing campaign will help create market differentiation for those developers' projects.

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