The Water, Energy, and Infrastructure Co-benefits of Smart Growth Planning in Phoenix, Arizona

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THE WATER, ENERGY, & INFRASTRUCTURE CO-BENEFITS
OF SMART GROWTH PLANNING IN PHOENIX, ARIZONA

3 June 2014

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EXECUTIVE SUMMARY

Phoenix, Arizona is an auto-dependent metropolitan area of close to 5 million people in 28 cities in the subtropical Sonoran desert climate of the Southwest United States. Currently, Valley Metro operates one light-rail line in the region, but additional extensions are under construction and in planning which will create a larger network of high-capacity transit. The local planning organization, Maricopa Association of Governments, has projected a demand for 485,000 households and nearly 130 million ft² of commercial space by 2040 immediately around this network of transit to partially support the projected population growth of the region.

During the Spring 2014 semester at Arizona State University, the multi-disciplinary course “Urban Infrastructure Anatomy and Sustainable Development” brought together students from engineering, sustainability, life sciences and urban planning to estimate the water, energy, and transportation changes of residents who live within walking distance of high-capacity transit in Phoenix and the potential barriers which currently oppose smart growth development. By comparing the results of this assessment to business-as-usual development, we find that the total energy consumption and greenhouse gas emissions from smart growth can be up to 42% lower than an equivalent amount of sprawl development and require nearly 70% less funding for infrastructure construction. Additionally, water consumption can be reduced by 37% and would be a major benefit to the desert region as population continues to grow adding stress on provisions from the Colorado River Basin. While water, energy, and infrastructure co-benefits of smart growth are found to be likely, institutional barriers exist that may prevent development from occurring and these barriers must be overcome to enable this type of development in the future.

A full discussion of the findings is found in the Summary of Compiled Results section on page 86.
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INTRODUCTION

The major metropolitan area of Phoenix, Arizona is located in a desert valley in the Southwest United States and supports an auto-dependent population of close to 5 million people on a land area of over 16,000 square miles. The current 20-mile light rail line, operated by Valley Metro is the first modern high-capacity transit (HCT) system in the city and opened for use in 2009. Extensions on both ends of the line are under construction and a larger plan for high-capacity transit in the region, shown in Figure 1, is in place to increase the mobility of residents as the population swells to over 8 million residents by 2050. The current light rail transit (LRT) system has exceeded initial ridership forecasts and spurred development in the downtown Phoenix, downtown Tempe, and downtown Mesa areas that it connects. Based on the success of the current linear LRT system and the expected influx of new residents, the Maricopa Association of Governments (MAG) is projecting demand for new housing, shopping, recreation, and jobs around current and future HCT, in the form of transit-oriented developments (TOD), in Phoenix by 2040.

Figure 1: Future Transit Supply in the Phoenix Area (MAG, 2013)
A multi-disciplinary course project at Arizona State University assessed the water, energy, greenhouse gas, and infrastructure cost changes of smart growth around HCT, and then explored potential transition strategies to overcome barriers that may prevent smart growth from occurring. This technical report is the findings from the course project which brought together undergraduate and graduate students from engineering, sustainability, life sciences, and urban planning. Additionally, a team of undergraduate civil engineering students designed typical TOD neighborhoods for their senior capstone project and a class of undergraduates in the construction school performed infrastructure cost estimations. In total, this 4-month course project for the class entitled “Urban Infrastructure Anatomy and Sustainable Development” combined the efforts of nearly 60 students from three different courses across Arizona State University. These efforts were graciously supported by a grant from the National Science Foundation. Throughout the project, the students used primary data sources and cutting-edge water, energy, and transportation assessment methods specific to the Phoenix area while interacting with university faculty, city planners, and members of the community to perform a state-of-the-art environmental assessment of TOD behavioral changes.

Publicly funded high-capacity transit in Phoenix opened for service in 2009 with the initial segment of LRT, but plans and funding are in place to increase service throughout the area and public interest for living around transit has steadily grown. Public transportation in the Phoenix area is operated by Valley Metro Public Transportation Authority and serves a population of nearly 4 million people and over 25 municipalities with local bus routes, a regional bus system, vanpools, and light rail (Valley Metro, 2012). After years of failed increases to sales taxes to fund public transit, the LRT system was established after the passing of Proposition 400 in 2004 which raised the sales tax by 0.5 cents. This proposition was also matched by federal funding and increased the share of the sales tax which is meant for public transit: expanding bus routes and funding the light rail system. The initial funds for the light rail were approved with the passing of “Transit 2000” by the City of Phoenix, but Proposition 400 covered the outstanding costs for the initial line and put financing in place for LRT extensions. With HCT transit in the area funded at least through 2025 and rapidly expanding, more residents and businesses will have an opportunity to use the service and are likely to change their behaviors, and consequently, their environmental and water footprints. How do we measure these changes and what will they mean for the urban area as a whole?

METHODOLOGY

The goal of this project was to assess the energy and water consumption changes of residents and businesses which reside in an area with quick access to high-capacity transit, the area we will consider transit-oriented development (TOD). Specifically, this report aims to address transportation characteristics, building energy consumption, and water use of residents and commercial space in TOD, and how the infrastructure needs change as a result of changes to
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consumption. These infrastructure and use effects are estimated over a 60-year period: the first 30 years as development occurs and the second 30 years assessing full-scale operation of TOD. Figure 2 shows the framework which will be used to assess TOD: both the infrastructure and use phases of automobiles, energy consumption, and water use. And the final results and discussion will hinge on the water and energy consumption of each phase (typically described in Joules, J), the resulting greenhouse gas emissions (GHG, characterized as metric tonnes of CO₂ equivalents, mt CO₂e), and cost (presented in 2012 USD, $2012). Students worked in one of four teams: Transportation, Energy, Water, or Transitions. The first three teams focused on the quantitative analysis of TOD consumption habits, as shown in the framework, and the final Transitions group focused on identifying political and socio-economic barriers to TOD in Phoenix and proposing solutions for overcoming institutional barriers.

INPUT: Energy Consumption (TeraJoules: TJ)

INFRASTRUCTURE:
- Mobility Assessment
  - Pavement for Roadways and Parking Lots
- Consumption:
  - Automobile Travel due to Commercial and Residential Space

SYSTEM OUTPUTS:
- Greenhouse Gases (metric tonne CO₂ equivalents: mt CO₂e)

Figure 2: Transit-oriented Development Assessment Framework

To frame the outcome of the TOD analysis, an equivalent amount of development is proposed and assessed in a business-as-usual (BAU) configuration and results are put into context by presenting the potential avoided impacts by building TOD rather than BAU. The energy and water consumption changes of this assessment depends on the initial investment for infrastructure, high-capacity transit, and TOD construction so that people can move to these developments and be able to change their behaviors. As presented in Figure 3, the areas which we will consider TOD are located within the loops of State Routes 101 and 202 (stylized with the red building icons) and the BAU areas would be the current sprawl development patterns which are located outside of these loops (stylized with the blue single-family home icons near Queen Creek, Cave Creek, Buckeye, etc.). The TOD areas align with the plans for increasing HCT service in Phoenix which was shown.
in Figure 1 and the BAU areas represent the current sprawl patterns of development which are occurring, rather than urban infill on available land. The comparison we will be presenting is: how does the energy and water footprint change if you enable people to live near HCT rather than encouraging outward expansion and requiring residents to be dependent upon their automobile?

![Figure 3: Illustration of Substituting BAU (blue) with TOD (red) Development](image)

**Demand for TOD in Phoenix by 2040**

The Maricopa Association of Governments released the Sustainable Transportation and Land Use Integration Study (ST-LUIS) in 2013 which outlined their projections for population growth in the region and how land consumption patterns can change to support more sustainable transportation habits (MAG, 2013). ST-LUIS was a culmination of analysis and planning efforts by many people within and beyond MAG and its goal was to assess the region’s long-term future and changing development patterns to create additional transportation choices. The study reports that there will be a demand for 485,000 total households (about 1.4 million people) and 130 million ft² of commercial space in TOD by 2040. Some of this already exists in the urban cores of Phoenix, Tempe, and Mesa, but we are choosing to assess the total amount of development for this technical paper so that we can comment on how the total footprint of the system has changed due to the introduction of HCT. TOD will likely take advantage of existing vacant parcels in the urban core.
and utilize other land as needed to increase the population density of the area. Currently, the population density is relatively low compared to other urban centers due to the excess of open space in the city and the sprawling suburbs. These demand projections for residential and commercial space form the basis of our assessment of the water, energy, and infrastructure co-benefits of smart growth in Phoenix. What follows are estimations from each of teams (see Figure 2), then the combined results are presented, and finally possible strategies to overcome TOD barriers in Phoenix are discussed.

**TRANSPORTATION OPERATION AND INFRASTRUCTURE ANALYSIS**

Over the last sixty years, Phoenix and its metro area have seen a significant population increase from 100,000 people to roughly 4,300,000 people. Along with this population growth, the land area of Phoenix in this time frame has increased as well from 55 square miles to 1,100 square miles; essentially increasing by twenty-fold. This growth is not expected to stop, either. According to the Maricopa Association of Governments Sustainable Land Use and Transportation Study, the Phoenix-metro area is expected to demand 485,000 households in TOD by the year 2040. Because of this sprawling growth, the overall land space of Phoenix as well as the vehicle miles traveled per year is projected to increase immensely. These yield to negative environmental and social impacts such as cost, greenhouse gas emissions, and energy consumption. With this anticipated growth, should Phoenix continue to grow in the current sprawling effect that it is known for? Or rather, should other types of developments be looked at to mitigate negative environmental impacts caused by new transportation infrastructure and its use?

Roughly 485,000 households have expressed interest in living in denser, more transit-oriented developments. This paper is focused on the infrastructure and use requirements for two scenarios: business-as-usual (BAU), where the roughly half million people move into new single family homes and suburban apartments in greenfield development outside of the current built environment; and transit-oriented development (TOD), where the focus is on dense infill development along current and future-planned transit corridors. The transportation group is tasked with finding what type of transportation infrastructure is needed for each scenario and how households will use this infrastructure. The following report examines methodologies, results, discussions, and conclusions for the commercial and residential infrastructure and use in Phoenix-area BAU and TOD developments.

**BACKGROUND AND LITERATURE REVIEW**
There is further evidence and literature beyond the analysis of infrastructure and use that makes TOD the preferred choice for transportation planning. TOD provides an environment for less driving, increased public transit use and the possibility for more walking and biking. All of these things add up to low transportation costs, healthy opportunities and less pollution. These are some of the reasons people are moving away from the suburbs and back to high density locations. For example, in 2011, U.S. cities grew faster than suburbs for the first time since the 1920s (Frey, 2013). This growth has been linked to baby boomers becoming empty nesters and young people starting families later, as well as keeping them small, resulting in fewer households with children (Leinberger, 2005). Overall, high density cities provide a great environment for these two groups’ wants. Empty nesters have more free time for cultural activities and dining out and often downsize their housing. Young professional often seek convenient urban housing near work and amenities (Katz et al. 2005). If this trend continues these populations will be searching for cities that have these opportunities.

Not only are people moving downtown more, but there has also been an increase in public transit use. According to a new American Public Transportation Association report, more Americans used public transit last year than in any year since 1956. APTA President and CEO Michael Melaniphy said, “There is a fundamental shift going on in the way we move about our communities. People in record numbers are demanding more public transit services” (Hurdle, 2014). This goes hand in hand with the Phoenix light rail ridership numbers. In 2009, the year the light rail opened, average weekday ridership was 35,000. Ridership has seen a large increase over the past few years, rising to an average weekday ridership of 43,000 in 2012 and to 48,000 in 2014 (Valley Metro, 2014).

With these growing trends, high-density housing should be widely available as an alternative choice to the suburbs. It is understood that outlying locations do not support walking and transit alternatives, contributing to more driving and infrastructure needs. Because housing is cheaper on the fringe, BAU creates an environment where households are forced to look further and further away for cheaper housing. There is a need for high density housing that is affordable. This can be done using different strategies, including location efficient mortgages. These mortgages take into account the saving of reduced travel costs. The theoretical background of these mortgages comes from a study done of residential location patterns in California. John Holtzclaw found that household transportation costs are highly correlated with residential density and transit accessibility. Further studies (Crane 2000, Ewing Cervero 2001, and Hotzclaw et al. 2002) came to the same conclusion that high density walkable neighborhoods with access to transit tend to drive less and use transit more. This is because they have alternative options for trips, and as a result are able to save money.

Planning transportation for TODs is not only the less expensive option for the city, but it is the less expensive option for the citizens of Phoenix. Even before the 2008 spike in gas prices, “transportation costs were the second-largest expenditure for the typical American Household, averaging $8,500 per year” (Rauterkus et al, 2010, pg. 118). Usually people do not take the time to add up how much their cars cost them every year. Or they do not look at the full cost of a trip
when determining whether to take their car or an alternative mode. Todd Litman analyzed twenty transportation costs, developing a cost estimate of traveling by different modes and travel conditions. With just internal costs, he found that the average vehicle operating expense was 21 cents per mile. Adding external costs, the total cost ranges from 84 cents per mile to $1.30 during peak urban travel (Litman, 1997).

Moving out into the suburbs not only can have an impact on your wallet, but also on your health. It has been suggested that the rise in obesity, antidepressant prescriptions and asthma is connected to land use and community design (Russ, 2004). Obesity is a growing trend in America and can cause health risks such as heart disease, cancer and diabetes. People who live in the suburbs mostly drive to get places since walking and biking is often impractical and unsafe. Significant health benefits can be achieved by participating in at least 30 minutes of daily moderate exercise (Jakicic and Otto 2006). To achieve 30 minutes of activity, people can walk or bike to work, which can help prevent and treat obesity and the health related problems associated with obesity.

Where you live also has other social and environmental impacts. A recent study done by Smart Growth America and the University of Utah’s Metropolitan Urban Center (2014) found that living in more connected and dense metro areas can help low-income children improve financially as they become adults. They explain that people living in those areas have better access to jobs and public transit. Crime has also pushed its way from the city into the suburbs. The Wall Street Journal reports “suburban homicide rates increased 17 percent between 2001 and 2010, while large cities saw a 17 percent decline over the same period” (McWhirter and Fields, 2012). The explanation for the trend is still being speculated, but one main suspect is law enforcement officials do not have the resources to properly patrol the vast streets of the suburbs. Additionally, a study found that compact development reduces vehicle travel which lowers emissions, which can help improve air quality (Stone et al., 2007). Infill strategies may play a role in reducing energy use and environmental impacts from driving.

Further evidence of support for TOD development is provided in the Kimball et al. 2013 study. They explain the policies currently in place, such as parking fees and restrictions, which encourage TOD growth. Additionally, there is potential financial support for TODs through incentives, grants, public-private partnerships, and planning initiatives. They conclude, emphasizing “there is strong potential for Phoenix to capitalize on the economic, social, and environmental benefits of TOD infill by maximizing the use of this land in a form that minimizes future energy consumption and environmental impacts” (Kimball et al., 2013, pg. 397).
Figure 4: Base maps of TOD and BAU areas

(Left) Base Map of the TOD Area - Above the different cities are shown in green along with the various transportation attributes along the central Light Rail line. This area is home to several downtown areas and dense developments. It is also home to both public and private infrastructure that is nearing the end of its life.

(Right) Base Map of the BAU Area - Above the different cities are shown in green along with the various transportation attributes in a suburban area of Maricopa County. This area has hosted most of the new home growth in the past decade within the Phoenix Metro Area.

Figure 5: Household Density Maps of TOD and BAU Area

(Left) Household Density Map of the TOD Area - Here the household density is shown. The darker the red the more households are within the census blocks. This central city area is far denser than its suburban counterpart.

(Right) Household Density map of the BAU area - Here the household density is shown. The darker the red the more households are within the census blocks. This suburban/newer built area is far less dense than the older center city.
Figure 6: Employment Density Maps of BAU and TOD Areas

(Left) Employment Density Map of the TOD Area - Here the employment density is shown. The relative size of the dots represents the number of employees at each business. This area has a higher job density due to its central location in the region. It is also home to several central business districts including Downtown Phoenix, Uptown Phoenix along Central Avenue, Downtown Scottsdale, Mill Avenue District in Tempe, and Sky Harbor Airport. The light rail is also seen as a major transportation incentive to locate a business in the area.

(Right) Employment Density Map of the BAU Area - Here the employment density is shown. The relative size of the dots represents the number of employees at each business. This area is much more suburban and lacks the centrality as well as business incentives to achieve a high density of employment. Most of the jobs here are service jobs, but the area is dominated by residential land use overall.

**TRANSPORTATION INFRASTRUCTURE**

Assessment Methodology

For the infrastructure aspect of this project, our findings will ultimately propose the land and infrastructure “avoided” by building TOD homes versus the business-as-usual (BAU) building approach. In order to do this, residential BAU developments will first be analyzed. We will focus on a one quarter-mile development used by planners in Maricopa County. Within these development plans, the number of homes per quarter-mile as well as paved street mileage can be determined. This can be obtained through utilizing the standard guidelines for home developments in Maricopa County. Figure 7 displays the standard specification guidelines for typical residential lot sizes. After calculating the amount of land and infrastructure utilized for one typical residential lot, these quantities can be scaled up to the 485,000 household requirement. By assuming that these developments would not be built if the TOD approach was implemented, our findings will include “avoided” paved roads, land space, and furthermore, required energy, greenhouse gas emissions...
(specifically CO2 emissions), and overall costs. Refer to the ‘Results’ section for a more detailed analysis.

![Figure 7: Standard Guidelines of Home Development](image)

Commercial infrastructure was also analyzed. For this, the ‘MAG Sustainable Land Use and Transportation Strategy’ memorandum were utilized. Table 1 below displays the additional commercial demand information given by the MAG study:

<table>
<thead>
<tr>
<th>Commercial Location</th>
<th>Additional Commercial Demand (ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office</td>
<td>76,000,000</td>
</tr>
<tr>
<td>Retail</td>
<td>51,000,000</td>
</tr>
</tbody>
</table>

Current commercial land development rates were used to project future commercial land use, and that will ultimately be compared to the MAG projections for commercial in future TOD development. The MAG study discusses projected commercial land space for 2040, and these values can be assumedly avoided if the TOD approach is utilized.
Transportation Infrastructure Results

Residential Infrastructure

In regard to residential infrastructure, a standard development model was analyzed to determine the surface area of asphalt which could avoid being built if the TOD method is used. Using a 70 foot-by-100 foot area as our standard lot size, and a quarter-mile development size, a total of 800 homes could fit in each development. Therefore, with a 485,000 household requirement, a total of 910 developments would have to be built using the traditional business-as-usual method. According to Figure 7: Standard Guidelines of Home Development, a road with a width of 32 feet lies in front of each home. With another house on the opposite side of the road, it can therefore be assumed that 16 feet of this 32-foot road width is associated with each home. Thus, 610 developments with 800 homes in each result in a total of 540,000,000 ft² of asphalt, or 12,000 acres, being placed. Fully completed calculations are shown in the Appendix I.

The resulting 540 million ft² value associated with avoided asphalt was compared to multiple different environmental indicators. Table 2 below shows various environmental impacts related to the 540 million ft² of paved asphalt:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit/ ft²</th>
<th>Unit Value</th>
<th>Residential Pavement Quantity (ft²)</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>MJ/ft²</td>
<td>12</td>
<td>540,000,000</td>
<td>6,300,000,000 MJ</td>
</tr>
<tr>
<td>CO₂e</td>
<td>kg/ft²</td>
<td>0.89</td>
<td>540,000,000</td>
<td>480,000,000 kg</td>
</tr>
<tr>
<td>SO₂</td>
<td>g/ft²</td>
<td>1.8</td>
<td>540,000,000</td>
<td>1,000,000 kg</td>
</tr>
<tr>
<td>CO</td>
<td>g/ft²</td>
<td>3.4</td>
<td>540,000,000</td>
<td>1,800,000 kg</td>
</tr>
<tr>
<td>NOₓ</td>
<td>g/ft²</td>
<td>14</td>
<td>540,000,000</td>
<td>7,300,000 kg</td>
</tr>
<tr>
<td>VOC</td>
<td>g/ft²</td>
<td>14</td>
<td>540,000,000</td>
<td>7,400,000 kg</td>
</tr>
<tr>
<td>Pb</td>
<td>mg/ft²</td>
<td>1.4</td>
<td>540,000,000</td>
<td>740 kg</td>
</tr>
<tr>
<td>PM₁₀</td>
<td>g/ft²</td>
<td>6.5</td>
<td>540,000,000</td>
<td>3,500,000 kg</td>
</tr>
<tr>
<td>PM₂.₅</td>
<td>g/ft²</td>
<td>0.89</td>
<td>540,000,000</td>
<td>480,000 kg</td>
</tr>
</tbody>
</table>
Commercial Infrastructure

When discussing commercial infrastructure, parking lots were the main focus. The MAG Sustainable Land Use and Transportation Market Study provided the additional commercial ft² demand (ACD) for the year 2040. By utilizing standards for parking spaces per number of commercial ft², along with standard parking lot dimensions, the overall parking lot requirement could be calculated. Figure 9 below shows the standard parking lot requirements:
Taking these into account, along with the ACD statistics from the MAG study, the full square foot commercial parking lot requirement was calculated to be 170 million ft². This value was compared to multiple environmental indicators to see the overall environmental impacts of the forecasted commercial parking lot asphalt. Furthermore, the total cost of the additional parking lot pavement was found by utilizing RS Means software. RS Means software provides the cost per square foot and the depth for the asphalt. The unit cost was multiplied by the depth and area to find the total cost. The environmental impact and cost were displayed in Table 3 and Table 4. The ratio of building area to parking lot area was found and was displayed in Table 5. The ratio was found by dividing calculated parking lot space by the ACD commercial building space.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit/ ft²</th>
<th>Unit Value</th>
<th>Commercial Pavement Quantity (ft²)</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>MJ/ft²</td>
<td>12</td>
<td>170,000,000</td>
<td>2,000,000,000 MJ</td>
</tr>
<tr>
<td>CO₂e</td>
<td>kg/ft²</td>
<td>0.89</td>
<td>170,000,000</td>
<td>150,000,000 kg</td>
</tr>
<tr>
<td>SO₂</td>
<td>g/ft²</td>
<td>1.8</td>
<td>170,000,000</td>
<td>310,000 kg</td>
</tr>
<tr>
<td>CO</td>
<td>g/ft²</td>
<td>3.4</td>
<td>170,000,000</td>
<td>570,000 kg</td>
</tr>
<tr>
<td>NOX</td>
<td>g/ft²</td>
<td>14</td>
<td>170,000,000</td>
<td>2,300,000 kg</td>
</tr>
<tr>
<td>VOC</td>
<td>g/ft²</td>
<td>14</td>
<td>170,000,000</td>
<td>2,300,000 kg</td>
</tr>
<tr>
<td>Pb</td>
<td>mg/ft²</td>
<td>1.4</td>
<td>170,000,000</td>
<td>230 kg</td>
</tr>
<tr>
<td>PM₁₀</td>
<td>g/ft²</td>
<td>6.5</td>
<td>170,000,000</td>
<td>1,100,000 kg</td>
</tr>
<tr>
<td>PM₂.₅</td>
<td>g/ft²</td>
<td>0.89</td>
<td>170,000,000</td>
<td>150,000 kg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 4: Commercial Pavement Quantity and Associated Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit Value ($/yd³)</td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td>17</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 5: Commercial Pavement to Building Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial Building Space (ft²)</td>
</tr>
<tr>
<td>-----------------------------------</td>
</tr>
<tr>
<td>130,000,000</td>
</tr>
</tbody>
</table>
Representative amount of asphalt that will be used if the BAU scenario is constructed - The above map shows the total amount of area that asphalt pavement will cover in commercial developments. The grey area indicates the 170,000,000 ft² of commercial parking lot pavement that will be built if the BAU scenario is built.

**Transportation Infrastructure Discussion**

**Residential Infrastructure**

Using the 485,000 household requirement, a total of 540 million ft² of asphalt will have to be placed. This asphalt is directly related to the estimated 610 developments that would have to be built to accommodate the 485,000 households in 2040, and specifically focuses on the local roads in these developments. This demand for asphalt is significant, and when compared to the TOD approach, it can be assumed that this voluminous asphalt amount could be otherwise avoided.

Although the volume of asphalt itself is vast, other factors can be considered as well to more so promote the TOD approach versus the typical BAU approach. Table 3 lists various parameters associated to the construction of asphalt, including energy use, global warming potential, NOₓ emissions, particulate matter emissions and more. For the 540 million ft² of asphalt, a total of 6.3 PJ of energy would be used, along with 480,000 mt of CO₂e, and 7,300 mt of NOₓ. As shown by these values and the others in Table 3, avoiding construction of the estimated 542 million ft² of asphalt would benefit the climate and air quality in the Phoenix Metro area.

In regard to cost, pavement construction values are extremely high. RS Means estimates that six inch-thick asphalt paving, including bare materials, labor and equipment, costs $24 per square yard, or $2.70 per square foot. Total estimated costs therefore equal $1.5 billion for 540 million ft² of asphalt pavement. These costs are solely initial costs needed to construct the estimated local
road demand by 2040. Avoiding over $1 billion dollars in construction costs could result in significant beneficial savings as well for the Phoenix metro area.

**Commercial Infrastructure**

Commercial infrastructure growth is important because commercial establishments often dominate vehicle demand. Currently, commercial establishments are required to have a certain number of parking spaces to accommodate vehicles. The availability of parking spaces is therefore a personal incentive to drive in lieu of using other forms of transportation. The calculated ratio of parking lot pavement ($ft^2$) to commercial building space ($ft^2$) was found to be 1.4. The projected parking lot space with current code for commercial buildings is larger than the space of the buildings themselves. BAU developments’ dependency on automobiles caused the demand for large parking land usage. Parking lots occupy a great amount of space, which is why their impacts are so significant. The CO$_2$ equivalent greenhouse gas emissions (global warming potential or GWP) in metric tons (mt CO$_2$e) were found to be $150,000,000$ kg for parking lots. The cost to build the parking lot infrastructure was calculated to be $35,000,000$. Furthermore, the energy required was calculated to be $1,700,000,000$ MJ. Currently, there are no specifications for parking lots in Transit-Oriented Development (TOD) areas. One idea behind TOD is the reduction of parking lot space, in order to encourage individuals to use alternative means of transportation instead of driving their own vehicle. For TOD, a 50% reduction of parking lot pavement was used when compared to BAU. The 50% reduction was based on New York specifications, which required 0.6 parking spaces per thousand $ft^2$ of commercial space. Phoenix, on the other hand, requires 5 parking spaces per thousand $ft^2$ of commercial space. Based off Phoenix and New York requirements the assumption for 2.5 parking spaces per thousand square miles of commercial was therefore used for TOD-commercial. The assumption for 2.5 was made because TOD is higher density and could be better represented by New York specifications. A conservative value reduction of 50% from Phoenix specifications however was ultimately used. The consequences of BAU development are that people become auto-dependent. As described above, TOD relies on mass transit, walking, and biking. In essence, TOD is less car dependent so fewer parking spaces would be needed. Based on TOD transportation, mode shift, and higher density requirements of parking spaces, there is potential in the reduction of cost, space, energy, and emissions when TOD is utilized.

**TRANSPORTATION OPERATION**

**Assessment Methodology**

In order to accommodate the projected 485,000 new households in the Phoenix area, some assumptions had to be made. As a class, we determined that for a business as usual (BAU) development, there are around 6 du/acre. In order for transit oriented development (TOD) to exist, there needs to be 10-20 du/acre to facilitate buses and 40 du/acre to facilitate light rail. Therefore,
it was assumed that the density cutoff for BAU and TOD would be between 6 du/acre and 10 du/acre. The average value of 8 du/acre between both values was used.

The density values given in the National Household Travel Survey (NHTS) correspond to the variable HBRESDN. This variable bins the responding households into different categories of housing units per square mile. The following bins are included in HBRESDN: 0-99; 100-499; 500-999; 1,000-1,999; 2,000-3,999; 4,000-9,999; 10,000-24,999; 25,000-999,999. The BAU/TOD cutoff of 8 du/acre roughly translates to around 5120 du/mi². Because this value is found in the bin for 4,000-9,999 housing units per square mile, we assumed the BAU/TOD cutoff is in between bins 2,000-3,999 and 4,000-9,999.

To represent the use in BAU and TOD developments, trips from the NHTS were categorized into one of two categories: residential use and commercial use. Residential use is defined as trips with the trip purposes of going home, social/recreational activities, and personal obligations. Generally, these trips can end at a residential place like a home. Commercial use is defined as the trip purposes of work and retail, which includes shopping and going out to dinner. These trips commonly end at a place other than a home, like a commercial establishment. In this way, all trips in the NHTS are represented with no double-counting occurring.

In true TOD developments, it is important to note that there will be a reduction of trips due to vehicle mode shifts to more sustainable modes of transportation, such as walking, biking, and bus. Because the NHTS was taken in 2008 before the light rail was completed, the NHTS data does not represent true, multi-modal TODs in Phoenix. Therefore, an adjustment factor must be taken into account to include the number of mode shifts away from personal vehicles. A previous life cycle and economic analysis on the Phoenix-metro transportation system done by Chester et al. (2013) refers to an adjustment methodology developed by Nelson-Nygaard (2005) that predicts 20% fewer personal vehicles trips in TODs. This reduction was done in both residential and commercial regards.

For all analysis purposes, SPSS was used to filter and aggregate the data. All trips counted were only those who had VMT from personal vehicle use. In that way no buses, cabs, or other transportation modes were counted. Excel was also employed to do linear tabular calculations that are shown in the tables provided throughout the report.

**Transportation Operation Results**

**Residential Operation**

In SPSS, the variable WHYTRIPS was used with the purpose of “Home”, “Social/Recreational”, “Family personal business/Obligations”, “Transport someone”, “School/Daycare/Religious”, Medical/Dental Services”, and “Other” were selected to differentiate the residential trips from commercial trips. This was done for the low-density BAU cases and the high-density TOD cases separately. Then using VMT_MILE, the average trip lengths for trips ending at home were taken
for both BAU and TOD. Similarly, to find the average number of trips per household per day, the total number of trips for each household in the travel day was aggregated. Then, the average number of trips was taken per household.

The following WHYTRP1S trip purposes were then categorized to the appropriate residential use classifications, as described in the introduction and shown below. The numbers that follow each trip purpose correspond to the code identifiers in the NHTS WHYTRP1S variable.

<table>
<thead>
<tr>
<th>Home</th>
<th>Social/Recreational</th>
<th>Personal Obligations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home (01)</td>
<td>Social/Recreational (50)</td>
<td>School/Daycare/Religious (20)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medical/Dental Services (30)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Family personal business/Obligations (60)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Transport someone (70)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other (97)</td>
</tr>
</tbody>
</table>

Although each household only documented trips on one day of the week in the NHTS, all seven days of the week were included in the responses from different households for the residential portion. It was assumed that residential travel did not significantly differentiate in regards to weekday and weekend travel. In the future however, this could be something to investigate further.

The following table shows the average residential VMT for Phoenix-area BAU and TOD residents obtained by the NHTS.
### Table 7: Residential Trips and VMT per Household

#### Residential: Home (Per Household)

<table>
<thead>
<tr>
<th></th>
<th>BAU</th>
<th>TOD</th>
<th>TOD w/ Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average VMT/Trip</td>
<td>8.1</td>
<td>7.3</td>
<td>7.3</td>
</tr>
<tr>
<td>Average Trips/Day</td>
<td>2.2</td>
<td>2.0</td>
<td>1.6</td>
</tr>
<tr>
<td>Average Daily VMT</td>
<td>18</td>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>Average Weekly VMT</td>
<td>120</td>
<td>100</td>
<td>81</td>
</tr>
<tr>
<td>Average Yearly VMT</td>
<td>6,500</td>
<td>5,300</td>
<td>4,200</td>
</tr>
</tbody>
</table>

#### Residential: Social/Recreational (Per Household)

<table>
<thead>
<tr>
<th></th>
<th>BAU</th>
<th>TOD</th>
<th>TOD w/ Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average VMT/Trip</td>
<td>13</td>
<td>8.8</td>
<td>8.8</td>
</tr>
<tr>
<td>Average Trips/Day</td>
<td>1.3</td>
<td>1.2</td>
<td>0.95</td>
</tr>
<tr>
<td>Average Daily VMT</td>
<td>17</td>
<td>10</td>
<td>8.4</td>
</tr>
<tr>
<td>Average Weekly VMT</td>
<td>120</td>
<td>73</td>
<td>59</td>
</tr>
<tr>
<td>Average Yearly VMT</td>
<td>6,300</td>
<td>3,800</td>
<td>3,100</td>
</tr>
</tbody>
</table>

#### Residential: Personal Obligations (Per Household)

<table>
<thead>
<tr>
<th></th>
<th>BAU</th>
<th>TOD</th>
<th>TOD w/ Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average VMT/Trip</td>
<td>8.0</td>
<td>7.4</td>
<td>7.4</td>
</tr>
<tr>
<td>Average Trips/Day</td>
<td>1.9</td>
<td>1.6</td>
<td>1.3</td>
</tr>
<tr>
<td>Average Daily VMT</td>
<td>15</td>
<td>12</td>
<td>9.3</td>
</tr>
<tr>
<td>Average Weekly VMT</td>
<td>110</td>
<td>82</td>
<td>65</td>
</tr>
<tr>
<td>Average Yearly VMT</td>
<td>5,600</td>
<td>4,300</td>
<td>3,400</td>
</tr>
</tbody>
</table>

#### Residential: Totals

<table>
<thead>
<tr>
<th></th>
<th>BAU</th>
<th>TOD</th>
<th>TOD w/ Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Household VMT</td>
<td>18,000</td>
<td>13,000</td>
<td>11,000</td>
</tr>
<tr>
<td>Annual Residential VMT (Billion)</td>
<td>8.9</td>
<td>6.5</td>
<td>5.2</td>
</tr>
</tbody>
</table>

On Table 7, the Average VMT/Trip and the Average Trips/Day were calculated in SPSS through the methodology described. From there, calculations were carried out consisting of each week containing seven days and a year containing 52 weeks. The reduction for the TOD trips was 20%, as described previously using the Nelson-Nygaard (2005) methodology.

A similar analysis was to find VMT for the “commercial” trip purposes, which results in the total household VMT. A brief summary showing this separate analysis is shown below in Figure 11.
As can be seen in Figure 11, which shows the overall yearly, household VMT with all trips included, the total yearly VMT for 485,000 households includes 8.9 billion VMT for residential BAU and 5.0 billion VMT for commercial BAU. For the TOD scenario, these numbers are much smaller at 5.2 billion for the residential VMT and 2.4 billion VMT for the commercial trips. In total, there is a difference of 6.3 billion overall household VMT between BAU scenario and TOD scenario. This equates to a 45% decrease from the BAU scenario.

Assuming the average vehicle gets 43 mpg, the amount of environmental impacts can then be assessed. For this average, there are 0.63 MJ of energy used and 56 g of CO₂e produced for every VMT. The following table shows the environmental impacts that each scenario would have.
As can be seen by Table 8, the amount of energy consumed, greenhouse gases produced, and cost is in the residential BAU scenario (32 PJ/Year; 2.3 mmt CO2e/Year; $2.5 Billion/Year) is substantially greater than that of the TOD development (19 PJ/Year; 1.3 mmt CO2e/Year; $1.5 Billion/Year). In fact, total energy consumption, gas emissions produced, and cost can be reduced by 42% with the TOD development.

The same environmental impacts analysis can be done when factoring in the number of vehicles necessary for the VMT in the BAU and TOD analyses. The average number of vehicles in BAU and TOD households in the Phoenix area is 2.3 and 1.5 cars, respectively. The following table gives the vehicle manufacturing environmental impacts for 485,000 households.
### Table 9: Vehicle Manufacturing/Maintenance Environmental Impacts

<table>
<thead>
<tr>
<th></th>
<th>Average Number of Vehicles per Household</th>
<th>Average Number of Vehicles Per 485,000 Households</th>
<th>Vehicle Manufacturing Energy (PJ)</th>
<th>Vehicle Manufacturing Greenhouse Gas Emissions (mmt of CO2)</th>
<th>Vehicle Manufacturing/Maintenance Cost ($Billion/Year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAU</td>
<td>2.3</td>
<td>1,100,000</td>
<td>92</td>
<td>6.8</td>
<td>$8.2</td>
</tr>
<tr>
<td>TOD</td>
<td>1.5</td>
<td>730,000</td>
<td>60</td>
<td>4.5</td>
<td>$5.4</td>
</tr>
</tbody>
</table>

As can be seen, even the number of vehicles owned by the different households has negative impacts. In the BAU developments, this is more apparent. For the BAU households, which average 2.3 vehicles per household, 485,000 households translates to 92 PJ of energy, 6.8 mmt of CO$_2$e, and $8.2$ Billion/Year in manufacturing and maintenance. The TOD scenario is much less, with 60 PJ of energy, 4.5 mmt of CO$_2$e, and $5.4$ Billion/Year in manufacturing and maintenance costs. The TOD vehicle ownership scenario has 34% less impacts than the BAU scenario.

### Commercial Operation

As stated, Commercial Use is defined as any trips with the purpose of going to work or retail, such as shopping or going to dinner. In most cases, these trips end at a place other than the home. These types of locations can include shopping malls, restaurants, office buildings, and industrial centers.

The MAG Market Study Memo lists three different types of commercial square footage projections in Figure 50: office, industrial, and retail. These total square footage projections sum up to 9.3 million ft$^2$ of commercial space per year between 2010 and 2040. From Figure 52, however, only 4.2 million ft$^2$ of this space is TOD supportive: 2.5 million ft$^2$ being knowledge-based employment and 1.7 million ft$^2$ for entertainment purposes. According to Figure 49, knowledge-based employment lists professions commonly found in office buildings, while entertainment purposes describe food, retail, and recreation services. Thus, it was assumed that knowledge-based employment would be considered office space and entertainment would be considered retail. A TOD would not be able to support future industrial growth.

In order to measure trips derived from different types of commercial buildings, trip purposes of “Work” (WHYTRP1S=10) was used to analyze office use and “Shopping/Errands” (WHYTRP1S=40) along with “Meals” (WHYTRP1S=80) was used to analyze retail. The following table gives a visual representation of these categories. Again, the numbers that follow the trip purposes correspond to the levels of the variable WHYTRP1S from the NHTS.
Unlike residential use where trips were averaged from the NHTS, for commercial use the trips were generated from the Institute of Transportation Engineers (ITE) Trip Generation Manual. This is because the square footage of the projected TOD commercial need in 2040 was given by the MAG Sustainable Land Use and Transportation Market Study, Figure 50. Using the commercial square foot projections and the ITE Trip Generation manual, the following table was created to show the estimated additional yearly trips in 2040.

Table 10: Commercial Use Trip Purpose (WHYTRP1S) Categories

<table>
<thead>
<tr>
<th>Office</th>
<th>Retail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work (10)</td>
<td>Shopping/Errands (40)</td>
</tr>
<tr>
<td>Meals (80)</td>
<td></td>
</tr>
</tbody>
</table>

It is important to note that the ITE Trip Generation Manual generates both incoming and outgoing trips to establishments. In particular, for the types of establishments used in the manual (Shopping Center and Office) the incoming and going trips had a 50/50 split. This means that exactly half of the trips generated would be incoming trips, which is consistent with the methodology in our report. It was assumed that no work trips would be made on Saturday and Sunday. Secondly, the commercial trip generation accounts for all commercial trips made by the 485,000 plus additional trips made by other people in the Phoenix area.

The following table shows all incoming trips for commercial space as given by the MAG Sustainable Land Use and Transportation Market Study.

Table 11: Commercial Trip Generation

<table>
<thead>
<tr>
<th>Estimated Additional Space in 2040 (Million ft²)</th>
<th>Estimated Additional Daily Trips (Incoming and Outgoing) in 2040 (Thousand)</th>
<th>Estimated Additional Daily Trips (Incoming) in 2040 (Thousand)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office</td>
<td>Weekday</td>
<td>Saturday</td>
</tr>
<tr>
<td>76</td>
<td>120</td>
<td>0</td>
</tr>
<tr>
<td>Retail</td>
<td>51</td>
<td>390</td>
</tr>
</tbody>
</table>
### Table 12: Commercial Trips (Incoming) and VMT

<table>
<thead>
<tr>
<th></th>
<th>BAU</th>
<th>TOD</th>
<th>TOD w/ Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weekday</td>
<td>Saturday</td>
<td>Sunday</td>
</tr>
<tr>
<td><strong>Average VMT/Trip</strong></td>
<td>13</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td><em><em>Additional Daily Trips in 2040</em> (Thousand)</em>*</td>
<td>61</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Average Daily VMT (Thousand)</strong></td>
<td>760</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Average Weekly VMT (Million)</strong></td>
<td>3.8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Average VMT/ Year (Million)</strong></td>
<td>200</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Commercial: Retail**

<table>
<thead>
<tr>
<th></th>
<th>BAU</th>
<th>TOD</th>
<th>TOD w/ Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weekday</td>
<td>Saturday</td>
<td>Sunday</td>
</tr>
<tr>
<td><strong>Average VMT/Trip</strong></td>
<td>5.36</td>
<td>5.66</td>
<td>5.66</td>
</tr>
<tr>
<td><em><em>Additional Daily Trips in 2040</em> (Thousand)</em>*</td>
<td>200</td>
<td>240</td>
<td>400</td>
</tr>
<tr>
<td><strong>Average Daily VMT (Million)</strong></td>
<td>1.1</td>
<td>1.3</td>
<td>2.3</td>
</tr>
<tr>
<td><strong>Average Weekly VMT (Million)</strong></td>
<td>8.9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Average VMT/ Year (Million)</strong></td>
<td>460</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Total Commercial**

<table>
<thead>
<tr>
<th></th>
<th>BAU</th>
<th>TOD</th>
<th>TOD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Incoming Commercial VMT/Year (Million)</strong></td>
<td>660</td>
<td>320</td>
<td>250</td>
</tr>
</tbody>
</table>

In Table 12, the Average VMT/Trip and the Average Trips/Day were calculated in SPSS through the methodology described. From there, calculations were carried out consisting of each week containing five weekdays with one Saturday and Sunday, and a year containing 52 weeks. Like the residential, the reduction for the TOD trips was 20%, as described previously using the Nelson-Nygaard (2005) methodology.

Through making the same assumptions as in the Residential section, the following table shows the environmental impact results for commercial space.
Table 13: Commercial Travel Environmental Impacts

### Annual Commercial Energy Consumption

<table>
<thead>
<tr>
<th></th>
<th>Commercial VMT (Million)</th>
<th>Fuel Production Energy (TJ/Year)</th>
<th>Vehicle Operation Energy (PJ/Year)</th>
<th>Total Energy Used (PJ/Year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAU</td>
<td>660</td>
<td>420</td>
<td>2.0</td>
<td>2.4</td>
</tr>
<tr>
<td>TOD</td>
<td>320</td>
<td>200</td>
<td>0.96</td>
<td>1.1</td>
</tr>
<tr>
<td>Reduced TOD</td>
<td>250</td>
<td>160</td>
<td>0.77</td>
<td>0.93</td>
</tr>
</tbody>
</table>

### Annual Commercial Greenhouse Gas Emissions

<table>
<thead>
<tr>
<th></th>
<th>Commercial VMT (Million)</th>
<th>Fuel GHG Emissions (mt CO2e/Year)</th>
<th>Vehicle Operation GHG Emissions (mt CO2e/Year)</th>
<th>Total GHG Emissions (mt CO2e/Year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAU</td>
<td>660</td>
<td>37,000</td>
<td>130,000</td>
<td>170,000</td>
</tr>
<tr>
<td>TOD</td>
<td>320</td>
<td>18,000</td>
<td>64,000</td>
<td>82,000</td>
</tr>
<tr>
<td>Reduced TOD</td>
<td>250</td>
<td>14,000</td>
<td>52,000</td>
<td>66,000</td>
</tr>
</tbody>
</table>

### Annual Commercial Cost Effects

<table>
<thead>
<tr>
<th></th>
<th>Commercial VMT (Million)</th>
<th>Fuel Production and Vehicle Operation Cost (Million 2012 USD/Year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAU</td>
<td>660</td>
<td>190</td>
</tr>
<tr>
<td>TOD</td>
<td>320</td>
<td>89</td>
</tr>
<tr>
<td>Reduced TOD</td>
<td>250</td>
<td>71</td>
</tr>
</tbody>
</table>

As can be seen by Table 13, the amount of energy consumed, greenhouse gases produced, and cost acquired in the residential BAU scenario (2.4 PJ/Year; 170,000 mt CO₂e/Year; $190 Million/Year) is substantially greater than that of the TOD development (0.93 PJ/Year; 66,000 mt CO₂e/Year; $71 Million/Year). In fact, with the TOD development, 62% of both the total energy used, gas emissions consumed, and cost acquired can be reduced. This is larger than the 42% of energy and greenhouse gas emissions that can be saved in residential trips. What this says is that there is a better chance to reduce energy consumption and emissions through commercial TOD development than BAU development.

**Transportation Operation Discussion**

**Residential Operation**

What can be gathered from Table 7 is that not only are VMT in the TODs shorter, but that the average number of VMT trips per day is generally less in TODs as well. The average daily VMT for trips home in a BAU is 18 VMT. The average daily VMT for trips home in a TOD is 14 VMT.
without reduction and 12 with reduction. This same trend in average daily VMT applies to Social/Recreational trips (BAU: 17, TOD: 10, TOD with Reduction: 8.4) and Personal Obligation (BAU: 15, TOD: 12, TOD with Reduction: 9.3) trips as well.

The total yearly household average for VMT in a BAU, TOD, and TOD with Reduction is 18,000 VMT; 13,000 VMT; and 11,000 VMT, respectively. In a TOD setting with no mode shifts in place, the VMT is already 27% less than that of the BAU. This could be because denser TOD areas are generally developed within a closer distance of amenities, such that people do not need to travel as far to receive the personal services they need. With the trip reduction taken into account, the VMT savings is then increased to 42% of the BAU VMT.

It is also interesting to mention that another reason for the increase in BAU VMT when compared to TOD VMT could be due to the number of vehicles in the household. The average number of household vehicles in a BAU in Phoenix is 2.3 vehicles. The average number of household vehicles in a TOD in Phoenix is 1.5 vehicles. This makes logical sense as the more vehicles a household has, the more VMT they are able to accrue in the course of a year.

Note that this residential analysis is not the total VMT a household has within it a year. It is only a measure of the residential trip VMT within a year. With all household trips taken into account, the total yearly household VMT is 29,000 VMT/year for BAU, 19,000 VMT/year for TOD, and 16,000 VMT/year for TOD with the 20% reduction from mode changing. The next section will look at the commercial side of total household VMT.

**Commercial Operation**

Similar to the residential analysis, the VMT/Trip in commercial trips is less in TOD than it is in BAU. The average daily VMT for weekday work trips in a BAU is 13 VMT. The average daily VMT for weekday work trips in a TOD is 8.3 VMT. This same trend in average daily VMT applies to retail trips (BAU: 5.4, TOD: 2.2) as well.

The total incoming commercial VMT in a BAU, TOD, and TOD with Reduction is 660 million VMT; 320 million VMT; and 250 million VMT, respectively. In a TOD setting with no mode shifts in place, the VMT is already 52% less than that of the BAU. With the trip reduction taken into account, the VMT savings is then increased to 62% of the BAU VMT. This could be due to the fact that people who live in denser, TOD neighborhoods are closer to work and retail amenities. It’s important to note that the differences of 52% and 62% between commercial BAU along with TOD and TOD with reduction are much greater than that of residential trips (27%, 42%). This may be because personal, residential trips that people take in both TOD and BAU are more similar in length and frequency than commercial trips.

The difference in yearly commercial and residential VMT between BAU and TOD with the 20% reduction is 4.0 billion, which is about 43% of the VMT generated by BAU. Overall, about 32
billion VMT per year are generated in Phoenix. By transitioning both commercial and residential housing to TOD, 13% of the total VMT generated in Phoenix per year can be reduced.

**COMBINED TRANSPORTATION DISCUSSION**

Figure 12 displays greenhouse gas emissions, cost, and energy in regard to transportation use (both residential and commercial) and transportation infrastructure (both residential and commercial).

![Figure 12: Overall Transportation Impacts](image)

The combined overall results show a 52% reduction in GHG emissions, 47% reduction in cost, and 52% reduction in energy use utilizing the TOD approach. The biggest differences of GHG emissions came from the elimination of needed residential infrastructure along with decreased commercial and residential travel. The biggest difference of cost came from a major decrease in travel and the difference in energy use was a result of a decrease of all travel and infrastructure. Even though travel is the largest part of the reduction, it should be noted that there is a major reduction that almost eliminates the infrastructure impact.

**CONCLUSION**

Based on the research it has been determined that transit-oriented development is a more efficient and beneficial approach. The research for infrastructure consisted of a cost, energy, and greenhouse gas emissions comparison between TOD and BAU. The results found that BAU required the addition of 540 million ft² of local road pavement. The 540 million ft² of pavement is
pavement that could assumedly be avoided by doing infill development in the urban core. Pavement needed for parking lots was analyzed based on commercial demand for 2040. These results showed that the commercial demand would require an additional 170 million ft^2 of pavement. It was found that TOD would use half of the amount that BAU would use for parking lot pavement. The amount needed by the TOD was found to be 85 million ft^2. By utilizing the TOD approach and avoiding the significant amount of asphalt needed for the BAU approach, energy consumption, CO2 emissions and overall costs will all be decreased.

Research for transportation use showed that overall VMT for TOD was significantly less than that of the BAU approach. In regard to residential transportation use, annual VMT for BAU and TOD was 8.9 billion and 5.2 billion, respectively. This resulted in a 42% decrease in residential VMT using the TOD approach. In regard to commercial transportation use, annual VMT for BAU and TOD was 5.0 billion and 2.4 billion, respectively. This study resulted in a 52% decrease between VMT for BAU and TOD. The overall decrease between TOD and BAU is supported by the mixed-use concept and also by vehicle count per household. Transit-oriented Development provides alternate forms of transportation for people living within it, such as public transportation, light rail, or even walking and biking options. By having these various modes readily available, there is not as great of a demand for personal vehicle travel. Furthermore, the number of vehicles per household varies between BAU and TOD. As mentioned in the study, those living in TOD have 1.5 vehicles per household, while those living in the BAU have 2.3 vehicles per household. Overall, by implementing the TOD approach in Phoenix’s future, a mode shift among Phoenicians, as well as a great decrease in overall VMT could be seen.

As seen throughout this project, this transportation analysis fully supports the implementation of transit-oriented development in Phoenix’s urban core. From increased awareness of the impacts of transportation use and infrastructure, both the city and its residents can be more aware of alternative, more sustainable decisions aside from the usual BAU approach. With a projected TOD demand of 485,000 households by 2040, and proven by the various results found within this report, the TOD approach would not only benefit Phoenix and its residents, but could also motivate and inspire other cities throughout the United States to develop the same approach.

**ENERGY CONSUMPTION AND INFRASTRUCTURE ANALYSIS**

This report, “Energy Infrastructure and Use” is one of four complementing reports – on Transportation, Energy, Water, and Transitions – for the Spring 2014 Urban Infrastructure Anatomy & Sustainable Development project course taught by Dr. Mikhail Chester at Arizona State University.
The objective of this report was to answer the question, what energy infrastructure is required and what are the use phase impacts of 485,000 households in Maricopa, Arizona located in a Transit Oriented Development (TOD) arrangement versus a Business As Usual (BAU) arrangement?

This report is organized into three parts: an executive summary that highlights the most substantive results and methods, five subsections that detail all of the research performed respectively, and a discussion of the overall implications of the study and opportunities for further investigation.

EXECUTIVE SUMMARY

A $400 million marginal investment in TOD infrastructure enables the price of energy to be reduced by the same amount per year for 485,000 residential households in Maricopa County, Arizona. Figure 13 illustrates five major economic insights (all values in nominal dollars):

1. The difference in energy infrastructure capital costs is projected at almost $800 million in the BAU case versus about $100 million in TOD where the cost of electricity wires is most significant.
2. TOD requires investment in transit infrastructure, which is estimated at $1 billion for the Valley Metro Light Rail system, and results in total TOD infrastructure costs of about $1.1 billion.
3. Energy use costs for ratepayers is about twice as much in BAU than TOD, $760 million and $360 million per year respectively.
4. Insufficient data was available to estimate differences in energy use for the commercial sector.
5. The energy use of the light rail is negligible.

![Figure 13: Infrastructure Costs and Use Phase Benefits of BAU and TOD Infrastructure](image-url)
Figure 14 illustrates difference in emissions from infrastructure construction and use phase energy consumption in TOD vs. BAU, as well as the projected electricity production mix that was used to calculate those results. As with energy consumption and costs, the BAU greenhouse gas emissions footprint is expected to be twice as large as the TOD case at 4 and 2 mmt CO$_2$e respectively. Infrastructure emissions were negligible compared to use phase.

![Annual Greenhouse Gas Emissions](image)

**Figure 14: Environmental Impact from Energy**

The BAU and TOD scenarios were defined based on the 2011 Maricopa Association of Governments (MAG) Sustainable Land Use and Transportation Market Study, wherein a demand for 485,000 TOD households and a corresponding 130 million ft$^2$ of commercial space was estimated for the region’s projected 2040 population. BAU was assessed in the context of all new infrastructure development on the edge of the city, anecdotally known as “urban sprawl,” and TOD was assessed in the context of high-density housing and infill development.

Residential and commercial energy use was estimated first, as unlike other commodity industries, in the electricity industry – supply must equal demand. Figure 15 below illustrates the average dwelling unit size, residential energy use, and ratepayer costs for 485,000 households in the BAU and TOD scenarios based on the 2011 American Housing Survey data for Phoenix-Mesa-Scottsdale, and the primary electric power utility (APS’s) average residential tariff rate. At an average of 2,200 ft$^2$ and 880 ft$^2$, BAU dwelling units are 2.4 times larger than TOD dwelling units, and consume an additional 3.3 TWh per year or $400 million per year. No evidence was found to support building energy use changes in commercial space. The total estimated in BAU and TOD cases was 2.6 TWh per year or $260 million per year based on a representative sample of office and retail building floor space from the EIA 2003 Commercial Buildings Energy Consumption Survey (CBECGS) for Climate Zone 5 as shown in Figure 16, which is the hottest climate zone.
As of the time of this study, the Valley Metro Light Rail operates on 20 miles of guideway, with $1 billion in capital assets on record, and is confirmed to expand to 41 miles. BAU was defined to include no additional investment in the light rail system, and TOD as a linear projection based on that 105% increase in operational guideway miles, for all capital assets, as shown in Figure 17. The infrastructure cost was therefore estimated as $0 for BAU, and an additional $1 billion for TOD. The energy use and emissions estimated were not material.
The energy infrastructure costs for residential and commercial sectors were based on two key capacity requirements: land coverage and peak demand from energy use. Every dwelling unit must have a connection, and power must be available for the hottest days in July and August – the days with the highest power demand.

Because the scope of this analysis was to consider the marginal growth of an existing city with existing infrastructure, the scope of assets considered in this report was limited to the electric distribution network – including 69 kV wires, substations, and transformers – and did not consider transmission infrastructure, generation capacity or other grid components. Moreover, the AHS database included both gas and electric energy consumption for households, which were combined into a net kilowatt-hour-equivalent (kWhe) energy consumption value. Gas-specific infrastructure was not considered.

Wires were estimated as the majority of infrastructure costs at $600 million and $50 million in BAU and TOD respectively, versus $150 million and $50 million for substations and transformers. Wire costs were estimated based on land area coverage, for all underground wires, as shown in Figure 18, where the BAU scenario assumed 5 dwelling units per acre, whereas the TOD scenario assumed 40 dwelling units per acre.

![Figure 18: Electric Wire Coverage for Dwelling Unit Configurations](image)

To meet infrastructure capacity requirements, additional substations and transformers required were estimated based on the assumption of 1 substation per additional 120 MW of capacity in BAU and 1 transformer per additional 30 MW of capacity in TOD. Peak demand was estimated at 1.8 and 2.28 times the average energy demand for commercial and residential energy consumption respectively based on data from the US Energy Information Agency at a total of 540 MW for commercial demand, 1.8 GW residential BAU, and 1GW residential TOD.
The conclusion of this study is that over 60 years BAU costs roughly twice TOD primarily due to the 12-times greater length of wires needed to connect households to the grid, and 2-times greater energy demands of larger sprawling homes in BAU.

**RESIDENTIAL ENERGY CONSUMPTION**

Residential energy consumption includes the electricity and gas energy used to power the households of the greater Phoenix area. The hypotheses set forth at the beginning of this research project were that historical data would (1) show differences in energy consumption patterns for BAU and TOD households, and (2) that these patterns could be applied to estimate the total capacity for 485,000 households, and therefore the infrastructure necessary as considered in the Infrastructure section. This remainder of this section details the results and methods used to test those hypothesis, including positive correlations housing types, energy demand, capacity, ratepayer costs, and greenhouse gas emissions.

The major assumptions for carrying out the analyses were as follows

1. The multi-unit housing was used for TOD and single unit for BAU from the AHS census (U.S. Department of Housing & Urban Development Office of Policy Development & Research, 2013).
2. Retail price of electricity (APS) was averaged for the year.
3. All residents pay as per standard retail rate of electricity of (APS).
4. Peak residential power demand is 2.3 times larger than average demand.
5. No units are vacant.

**Summary of Results**

The average consumption of energy per unit in TOD areas was found to be 10 kWh/ft²/yr, and BAU was 9.9 kWh/ft²/yr for the year 2011. Extrapolating these values till 2040, wherein the number of households increases to 485,000; the average consumption per unit for TOD was assessed to be 7.3 kWh/ft²/yr. If these households went to the BAU development then the average demand by the households would be 6.2 kWh/ft²/yr. This translates to $0.36 billion for TOD and $0.76 billion for BAU worth of total energy (including gas and electricity both) usage in 2040 annually. The results are tabulated in the Table 14.

If electricity consumption alone is to be considered, the numbers for consumption per square foot per year increase slightly, 8.5 kWh/ft²/yr. for TOD & 6.5 kWh/ft²/yr. for BAU in year 2040, but when considered per unit household the overall consumption, of both energy and electricity, for TOD is much lesser than BAU. This is due to the larger size of the average BAU household as compared to the TOD household.
Table 14: Summary of results for Energy.

<table>
<thead>
<tr>
<th>Year</th>
<th>2011</th>
<th>2040</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average Demand</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOD kWh/ft²/yr.</td>
<td>10</td>
<td>7.3</td>
</tr>
<tr>
<td>BAU kWh/ft²/yr.</td>
<td>9.9</td>
<td>6.2</td>
</tr>
<tr>
<td><strong>Additional Energy Demand</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOD Billion kWh/yr.</td>
<td>-</td>
<td>3.1</td>
</tr>
<tr>
<td>BAU Billion kWh/yr.</td>
<td>-</td>
<td>6.5</td>
</tr>
<tr>
<td><strong>Peak Energy Demand</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOD GW</td>
<td>-</td>
<td>0.81</td>
</tr>
<tr>
<td>BAU GW</td>
<td>-</td>
<td>1.7</td>
</tr>
</tbody>
</table>

*Including gas consumption in terms of kWh/month and all units of a multi-unit building being occupied

**Methodology**

The results found were based on estimations detailed in this section in five parts:

A. Average Consumption of Energy
B. Additional Energy Demand
C. Peak Demand
D. Greenhouse Gas emissions
E. Total Consumption

**Average Consumption of Energy**

The AHS data directly provides the consumption of electricity in terms of the dollar value for the units covered in their census, averaged on a monthly basis (AMTE). Also provided is the floor area (in square feet) of each of the units surveyed (UNITSF). To convert the values from kWh to MJ, the multiplication factor of 3.6 was used.

Therefore,

\[
 Consumption of electricity = \frac{AMTE}{UNITSF} \text{ (Units - $/ft^2$/month)}
\]

To convert the above obtained value into kWh/ ft²

\[
 Average\ retail\ price\ of\ electricity = $0.12\ per\ unit\ (APS)
\]
Thus the consumption of electricity \( (E) = 12*{\text{AMTE/UNITSF}}/0.12 \text{ KWh/ft}^2/\text{yr}. \)

All the values so obtained were plotted with respect to the year the particular household was built and a trend line was generated (Figure 19). On the basis of this trend line the average demand for BAU and TOD were determined for the year 2011 and 2040.

![Figure 19: Electricity Consumption for BAU and TOD](image)

Another variable to be considered here is the usage of gas as a source of energy in both single and multi-unit homes. The AHS census data provides the necessary data for the consumption of gas in terms of the average monthly bill (AMTG) for the unit/residence in question. Using similar procedure as above and normalizing the obtained value of energy from gas in to kWh.

Therefore,

\[
\text{Consumption of gas} = \text{AMTG} / \text{UNITSF} \text{ (Units - $/ft}^2\text{/month)}
\]

To convert the above obtained value into / ft\(^2\)

\[
\text{Average retail price of gas} = $9.7+ (1.2 \text{ per therm)} \text{ (Southwest Gas)}
\]

\[
\text{Each therm of gas} = 29 \text{ kWh}
\]

\[
\text{Thus consumption of gas} (G) = 12*29*(\text{AMTG-9.7})/\text{UNITSF} \text{ KWh/ft}^2/\text{yr}.
\]
And overall consumption = \((E) + (G)\)

All the values so obtained were plotted with respect to the year the particular household was built and a trend line was generated (Figure 20). On the basis of this trend line the average demand for TOD and BAU were determined for the year 2011 and 2040.

![Figure 20: Energy Consumption for BAU and TOD](image)

The values obtained are given in Table 15.

<table>
<thead>
<tr>
<th></th>
<th>w/o Gas</th>
<th>w Gas</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOD</td>
<td>8.5</td>
<td>7.3</td>
<td>kWh/ft²</td>
</tr>
<tr>
<td>BAU</td>
<td>6.5</td>
<td>6.2</td>
<td>kWh/ft²</td>
</tr>
</tbody>
</table>

**Additional Electricity or Energy Demand**

The additional energy demand is obtained from the product of the values from the previous tables multiplied with the number of households (Number of households = 485,000).

Therefore,

**Additional Energy/electricity = Number of houses \((E \text{ or } E+G)\) [Billion kWh/yr]**
**Peak Energy Demand**

Based on the Average electricity demand the Peak demand is determined by multiplying with a factor of 2.3 (Based on the operational data available from US Energy Information Administration). The main assumption for assessing this value being that the peak for residential consumption would be same as overall peak consumption for APS.

Therefore,

\[
\text{Peak Energy Demand} = (E \text{ or } E+G) \times 2.3 / 365 / 24
\]

\[\text{Unit} = \text{GW}\]

**Greenhouse Gas Emissions**

\[
\text{Greenhouse gas emissions} = (E \text{ or } E+G) \times 0.12 \times 10^{-3} \times (\text{Average area in ft}^2 \text{ of household in TOD or BAU}) \times (\text{No. of households expected in year 2040})
\]

Where,

\[E \text{ or } E+G = \text{Average electricity/energy consumption}\]

\[0.1245 \times 10^{-3} = \text{CO}_2e \text{ of greenhouse gas emission}\]

*(Chester, Nahlik, Fraser, Kimball, & Garikapati, 2013)*

\[\text{Avg. area of household in TOD or BAU} = 880 \text{ or } 2,200 \text{ ft}^2.\]

\[\text{Number of households expected in year 2040} = 485,000\]

**Total Consumption**

When considering the total energy consumption by the residential sector, the energy from gas cannot be ignored and thus the analyses was carried out and the values obtained were normalized in terms of kWh. The purpose of considering the overall energy consumption (electricity + gas) other than just electricity is that gas is just an important form of energy for the houses on the fringe (BAU) that use it for the purpose of heating and cooking primarily in order to keep the consumption of energy low. In the case of TOD development usage of gas has primarily decreased, as the newly constructed apartments utilizing gas form a small minority and thus any data extrapolated would not give the correct result. In short the energy consumption would eventually hit zero in the near future (such a scenario is not possible). Thus to assess the 2040 usage of energy
in a TOD household, the trend line used was not the one as determined from the graph rather a new trend line was generated having the following equation:

\[ Y = y_{E+G} + m_E(X - X_{E+G}) \]

\[ Y = 10 - 0.096(2040-2011) \]

Where,

\[ Y = \text{Average consumption of energy for TOD household in year 2040} \]

\[ y_{E+G} = \text{Average consumption of energy for TOD household in 2011} \]

\[ m_E = \text{slope of trendline determined from electricity only usage for a TOD household} \]

\[ X, X_{E+G} = \text{Year in question (2011 & 2040)} \]

The above generated trend line takes into account the fact that energy is being consumed at the same rate as electricity and helps determine the future consumption based on the 2011 value already obtained from the previous energy trend line. This gives a more accurate representation for the energy consumption for a TOD household (Refer Table 16).

<table>
<thead>
<tr>
<th>Table 16: Overall Values for Electricity and Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Year</strong></td>
</tr>
<tr>
<td><strong>Area</strong></td>
</tr>
<tr>
<td>Tod</td>
</tr>
<tr>
<td>BAU</td>
</tr>
<tr>
<td><strong>Electricity costs</strong></td>
</tr>
<tr>
<td>Tod</td>
</tr>
<tr>
<td>BAU</td>
</tr>
<tr>
<td><strong>Additional</strong></td>
</tr>
<tr>
<td>Tod</td>
</tr>
<tr>
<td>BAU</td>
</tr>
<tr>
<td><strong>Additional</strong></td>
</tr>
<tr>
<td>Tod</td>
</tr>
<tr>
<td>BAU</td>
</tr>
<tr>
<td><strong>Peak Electricity Demand</strong></td>
</tr>
<tr>
<td>Tod</td>
</tr>
<tr>
<td>BAU</td>
</tr>
<tr>
<td><strong>Peak Energy Demand</strong></td>
</tr>
<tr>
<td>Tod</td>
</tr>
<tr>
<td>BAU</td>
</tr>
</tbody>
</table>
### Table 17: Greenhouse gas emissions and monetary value of increased energy costs

<table>
<thead>
<tr>
<th>For Year 2040</th>
<th>TOD mmt of CO$_2$e/yr</th>
<th>With Gas</th>
<th>Without Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHG emissions</td>
<td>TOD mmt of CO$_2$e/yr</td>
<td>1.4</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>BAU mmt of CO$_2$e/yr</td>
<td>2.9</td>
<td>3.0</td>
</tr>
<tr>
<td>Monetary Value of the increased energy costs</td>
<td>TOD Billion $</td>
<td>0.37</td>
<td>0.43</td>
</tr>
<tr>
<td></td>
<td>BAU Billion $</td>
<td>0.76</td>
<td>0.80</td>
</tr>
</tbody>
</table>

One is led to believe that the TOD would have a lower consumption of electricity or for that fact the total energy as compared to a BAU development but such is not the case when compared on a per square ft. basis (Table 17). This may be explained by the fact that BAU homes built on the fringe are given special incentives such as Time of Use (TOU) plans Energy Efficient Upgrades etc. which may not necessarily be available for the multi-unit residential buildings in the TOD area due to various reasons. The important point to note here is that all comparisons are being done on a per square ft. basis. As soon as the data is compared on a per unit basis the average consumption and peak demand for BAU household are much greater than that of TOD (by a factor of 2.4). Thus when compared on a per household basis TOD turns out to be a more energy efficient option for housing as compared to the BAU.

**Discussion of Residential Energy Consumption**

**Key Results**

The key results may be summed up as follows:

- The average demand per square ft. for TOD is greater than BAU by almost 17%
- Average demand per household BAU is greater than TOD by 52%
- Total Peak for BAU is greater than TOD by 52%
- GHG emissions for BAU are almost 2 times of those for TOD (1.39 mmt of CO$_2$e)

**Scope of Analysis**

The present scope of analysis covers households meeting the following criteria as per the AHS census data survey:

A. Household should be a part of the Phoenix Metropolitan area.
B. Household should have a non-zero average monthly electricity bill. The average monthly gas bill may be zero.
C. Household is not a mobile home

Since all households come under the Phoenix Metropolitan area and no further information was available on their location (TOD or BAU, Downtown or suburban) therefore assumptions had to be made regarding the TOD and BAU household differentiation.
Sensitivities

The results are sensitive to two key factors:

A. Building types included for TOD and BAU households & corresponding energy usage & ft² factors.
B. Retail price of electricity.

Implications

The average size of the housing in both BAU and TOD is the main factor for the difference between the values obtained in the analysis. Therefore it is very important to assess the TOD and BAU household composition properly. Any change in the average size of the household will have a direct impact on the values obtained in the analyses conducted.

Opportunities for Further Research

Given the number of data points covered in the census conducted in the American Housing Survey data, it may seem hard that the data is still is not enough and it is too generalized. The data could be further refined through more specific information being available on the Households. This could range from the location of the house in the specific suburb, or area of the city to the resident being a customer of the APS or SRP electricity providers. Information like this could help further fine tune the analyses in terms of giving more accurate results based on the different tariff structures for the two energy providers. Inclusion of the Time of Use (TOU) plans would be another avenue that should be explored for future research. TOU plans are a very useful method in reducing ones bills down but what this also does is that it portrays as the particular household having low energy consumption as compared to a similar sized house not implementing a TOU plan. Assuming the fact that none of the houses are implementing TOU plans only serves to unnecessarily lower the numbers determined in the assessment. Thus information on TOU plans will go a long way in carrying out a more accurate analysis.

Quantifying the households properly in terms of TOD and BAU, instead of broadly categorizing them on the basis of assumptions. Based on the specific information on the location of the household i.e. if it’s close to the TOD and its supporting feeder services or built on the fringe would help calculate the consumption data more accurately.

Commercial Energy Consumption

Similar to the previous section, commercial energy consumption includes the electricity used to power the commercial buildings of the greater Phoenix area. The hypotheses set forth at the beginning of this research project were that historical data would (1) show differences in energy consumption patterns for BAU and TOD commercial buildings, and (2) that these patterns could
be applied to estimate the total capacity for 485,000 households, and therefore the infrastructure necessary as considered in Section 4. Infrastructure. No direct data was obtained for the state of Arizona, and insufficient data was found to make a distinction between energy usage in BAU and TOD scenarios. The remainder of this section details the results, and data and methods used to estimate an overall consumption value, including commercial floor space types, energy demand, capacity, ratepayer costs, and greenhouse gas emissions.

The major assumptions for carrying out the analyses were as follows

1. Energy consumption in EPA Climate Zone 5 is representative of Phoenix
2. Median survey data for building consumption per square foot is representative of the total average.
3. BAU and TOD development will result in the same quantity and type of commercial development on a per square footage basis.
4. Peak commercial power demand is 1.8 times larger than average demand.
5. Retail price of electricity (APS) was averaged for the year.
6. All residents pay as per standard retail rate of electricity of (APS).
7. No units are vacant.

Summary of Results

This estimation was based on data obtained from the 2003 Commercial Buildings Energy Consumption Survey (CBECS) and MAG Sustainable Land Use and Transportation Market Study. The median was a better measure of central tendency, because there was large variance with extreme values for electricity consumption and square footage of very large buildings. Using job projections and estimations demand of commercial space per employee to calculate additional commercial electricity usage does not display any difference between BAU and TOD. This is because the estimation assumes the same square footage per employee for commercial demand in BAU and TOD, (Office - 250 ft² per employee, Retail - 500 ft² per employee). The following are the normalized sector electricity consumption and expenditure rates, projected commercial electricity use, and greenhouse gas emissions.

<table>
<thead>
<tr>
<th>Office</th>
<th>17</th>
<th>$1.60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retail</td>
<td>27</td>
<td>$2.70</td>
</tr>
<tr>
<td>Average</td>
<td>21</td>
<td>$2.10</td>
</tr>
</tbody>
</table>
Table 19: 2040 BAU and TOD Commercial Electricity Use

<table>
<thead>
<tr>
<th></th>
<th>Additional Commercial Demand 2010-2040 (Million ft²)</th>
<th>Energy Intensity (kWh/ft²/year)</th>
<th>Additional Electricity Usage 2040 (TWh/year)</th>
<th>Median Capacity (MW)</th>
<th>Peak Capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office</td>
<td>76</td>
<td>17</td>
<td>1.3</td>
<td>140</td>
<td>260</td>
</tr>
<tr>
<td>Retail</td>
<td>51</td>
<td>27</td>
<td>1.4</td>
<td>160</td>
<td>280</td>
</tr>
<tr>
<td>Total/avg.</td>
<td>130</td>
<td>21</td>
<td>2.6</td>
<td>300</td>
<td>540</td>
</tr>
</tbody>
</table>

Table 20: Additional GHG Emissions from 2040 Commercial Electricity Use

<table>
<thead>
<tr>
<th></th>
<th>Additional Electricity Usage 2040 (TWh/year)</th>
<th>Energy (PJ/year)</th>
<th>GHG Emissions (mmt CO₂e/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office</td>
<td>1.3</td>
<td>4.5</td>
<td>0.56</td>
</tr>
<tr>
<td>Retail</td>
<td>1.4</td>
<td>4.9</td>
<td>0.61</td>
</tr>
<tr>
<td>Total</td>
<td>2.6</td>
<td>9.4</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Methodology

Information on business and commercial electricity usage will come primarily from the 2003 Commercial Buildings Energy Consumption Survey (CBECS). This is available from the Energy Information Administration. CBECS data is a survey of US commercial electricity use and it is not specific to the Phoenix area. The data used was from *File 15: Consumption and Expenditures for Sum of Major Fuels and Electricity*, with the following variables used for sorting and calculations.

- **SQFT8** - Square footage
- **PBA8** - Principal building activity
- **HDD658** - Heating degree days (base 65)
- **CDD658** - Cooling degree days (base 65)
- **ELCNS8** - Annual electricity consumption (kWh)
- **ELEXP8** - Annual electricity expenditures ($)

The data can be sorted into U.S. census regions and divisions or climate zones. The CBECS climate zones are based on the National Oceanic and Atmospheric Administration (NOAA) climate divisions. These use 30-year averages for cooling degree-days (CDD) and heating degree-days (HDD). Therefore, survey data grouped by average daily temperatures or heating and cooling days.
will give a better estimation of the commercial electricity consumption in Phoenix. Maricopa County is in climate zone 5, which has the fewest HDD and the highest number of CDD.

\[
\text{Zone 5} = \text{CDD} \geq 2000 \quad \text{Zone 5} = \text{HDD} < 4000
\]

Therefore, any data with Cooling degree days values less than 2000 or Heating degree days values greater than or equal to 4000 were excluded. This should include areas with buildings that use a comparable amount of energy for heating and air conditioning.

In addition to the current energy consumption trends, there also needs to be a forecast for commercial electricity demands. The MAG Sustainable Land Use and Transportation Market Study gives commercial growth projections by job sector and the additional square footage needed. For instance, Transit Oriented Development would primarily include office, retail, and food service space. This is based on estimated demands for job growth and can combine existing vacant commercial space with new development. By combining the MAG study with the CBECs data, TOD commercial electricity usage can be estimated by building activity and increased square footage associated with new employment.

The next step was to sort and group the zone 5 by Principal building activity. The reference to “Knowledge-Based” jobs assumed employment in an office building with comparable electricity usage. The sectors for “Entertainment”, retail, and food sales/service were grouped together for both commercial demand projections and the CBECs building type data. In addition, enclosed malls were excluded in the calculations for the entertainment or retail building category. This was due a lower probability of TOD development and a different sampling technique. Although the industrial sector is part of the commercial projections for Maricopa County, it was excluded in the final product. The TOD Employment and Commercial Projections by Sector was used to calculate both TOD and BAU electricity demand. The assumption was that TOD projected commercial demand could all develop near transit or none would be near transit in the BAU scenario.

Some basic statistics, including arithmetic mean, standard deviation, and median, were calculated for Square footage, Annual electricity consumption, and Annual electricity expenditures. In addition, both the electric consumption and electric expenditure were divided by the Square footage for each building with mean, standard deviation, and median calculated giving (kWh/ft\(^2\)) and ($/ft\(^2\)). Since the survey data was collected in 2003, a conversion factor of 0.79 was used to convert 2003 dollars to 2013 dollars to maintain consistency with other data in the report.

Additional calculations included finding the median capacity by multiplying the Additional Electricity Usage in 2040 (kWh/year) by the number of hours in a year and dividing by 1000 to give in MW. Next, to approximate peak capacity a peak-to-average electricity demand ratio of 1.8 was used. The EIA tracks this ratio and 1.8 is a recent estimation from similar climate areas, such as the Southeast, Texas, and Southern California. The peak demand was calculated by multiplying this ratio by the median capacity. Finally, for the greenhouse gas emissions were calculated by converting kWh to MJ then multiplying by 0.12 to get kg of CO\(_2\)e.
Discussion of Commercial Energy Consumption

Quantitatively BAU and TOD commercial space have the same amount of projected electricity use, this was mainly because of the data available. The length of a lease, buildings that have both retail and office space, and businesses that have seasonal employment demands are a few examples of factors that increase variability and complexity when comparing or combining commercial data with residential data. Also, the number of people using or building activity can fluctuate throughout a building over time. Differences in rent, city and county taxes, or utilities are all incentives to lease or build commercial space in one area over another.

Some TOD businesses and jobs may need and use less space per employee. For instance, a company decides to lease a floor of office space in TOD rather than a building in BAU. It will serve the same number of employees with 5-15% less square footage. There was extra space in the BAU building, but the rent was cheaper per square foot. In addition, the retail or “Entertainment” category may pay higher rent for less space in TOD, but get more business located in a higher-density area. This could lead to many TOD office type jobs requiring less than 250 ft² per employee and some retail requiring slightly less than 500 ft² per employee. Furthermore, this could also change the total projected commercial demand for TOD and all of Maricopa County. These types of trends could result in lower TOD commercial electricity use.

Finally, the Maricopa County commercial projections do not include the additional floor area demand for other sectors, including: service, health care, education, and government. There will be some job growth that will not require new commercial space, but development will occur with basic services to support the outward growth. Therefore, the calculated value for BAU electricity usage may be lower because it does not include any new commercial space needed in other sectors of the employment projections. Furthermore, certain types of commercial space may require a minimum population, density, or demand before any new construction, (i.e. enclosed shopping malls, hospitals, or major medical centers). Fewer households in BAU may reduce demand for a few new commercial spaces, such as specific service or school. Thus reducing overall electricity needs. Especially if many existing hospitals, schools, etc. in TOD have adequate capacity.

Light Rail Energy Consumption

The Light Rail system – and other forms of public transportation – is the “T” in “TOD.” Without a transportation system, TOD is not possible. This section assesses the infrastructure and use phase costs, energy factors, and emissions for the BAU and TOD scenarios.

Key assumptions used in this analysis:

1. Infrastructure costs and energy use are proportional to track length
2. 2013 depreciated values of capital assets are scalable for future costs
Summary of Results

For the Valley Metro Light Rail, BAU means no additional infrastructure costs, and ongoing electricity usage costs of approximately $1 million per year. The TOD expansion scenario requires $1 billion in capital investment, 1.2 mmt CO₂e emissions from construction, and an increase in annual energy use of 18 GWh per year at $1 million per year with 8,000 mt CO₂e per year additional emissions as well for the current Arizona electric fuel production mix.

The BAU scenario was defined as no increase in the 20 operational track miles as of the time of this study, and the TOD scenario was based on implementation of Valley Metro’s confirmed 21 miles of light rail expansions through 2026, assuming proportional increase in capital assets and usage to track length of 105%.

Results are summarized in Table 21. The projected increase in peak demand in the TOD scenario is 3.3 MW, equivalent to 2,000 TOD households – less than 1% of this study’s overall consideration for 485,000 households.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>BAU</th>
<th>TOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Track Length [miles]</td>
<td>20</td>
<td>41</td>
</tr>
<tr>
<td>Peak Demand [MW]</td>
<td>3.1</td>
<td>6.4</td>
</tr>
<tr>
<td>Annual demand [GWh/year]</td>
<td>18</td>
<td>36</td>
</tr>
<tr>
<td>Electricity use costs [$ Million/year]</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Infrastructure Capital Assets [$ Billion total]</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>GHG Emissions - use [mt CO₂e/year]</td>
<td>8,000</td>
<td>16,000</td>
</tr>
<tr>
<td>GHG Emissions - infrastructure [mmt CO₂e]</td>
<td>0</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Methodology

The results described in the previous section were based on estimations detailed in this section in four parts:

1. BAU Electricity Usage Costs
2. TOD Electricity Usage Costs
3. Infrastructure Costs
4. Greenhouse Gas Emissions
**BAU Electricity Usage Costs**

The annual electricity usage costs were estimated in terms of dollars per year [$/year] as a function of the electric service provider, APS’s Large General Service Tariff Rate (terms A, B, and C), and Valley Metro Light Rail infrastructure and usage data (terms x, y, and z) at current rates, where:

\[
\text{Annual electricity usage costs} = A \times x + B \times y + C \times z
\]

Where,

- **Daily service charge** – [$/day]
  
  23 [$/day] [per substation], for “service at Transmission Voltage”

Valley Metro Fast facts: “Traction power substations convert the higher-voltage power provided by the utility company distribution lines into lower-voltage direct current needed to operate light rail vehicles. A typical substation building is 20 feet wide by 40 feet long by 12 feet high. There are 15 substations evenly spread along the line that support the system.”

- **Demand charge** – for peak power load [$/kW]
  
  14 [$/kW] + 9.1 [$/kW], for the first 100 kW and additional respectively.

- **Energy charge** – for hourly consumption [$/kWh]
  
  0.047 [$/kWh], represents a the average of the bundled charges for summer and winter periods

And,

\[
x = \text{(days/year)} \times \text{ (# of Substations 2012)}
\]

\[
y = \text{Peak load of light rail system}
\]

\[
z = \text{total electric energy consumption}
\]

Values were estimated for each of the three terms as follows:

A. Service charge (A*x)

\[
$/yr = A \times x
\]
= 23 \[\$/day\] [per station] * 365[days/year] * 15 [\# of Substations_{2012}] \\
= $39,000

B. Demand charge (B*y)

\[
\$/yr \quad = B*y
\]

= 14 \[\$/kW\] *100 \[kW\] + 9.1 \[\$/kW over 100 kW\] * (Peak load of light rail - 100 kW)

= 14 \[\$/kW\] * 100 \[kW\] + 9.1 \[\$/kW\] * 3,000 \[kW\]

= $29,000

Where,

Peak load of light rail system - was estimated based on the total electricity consumption for the year of 18 GWh (The National Transit Database provides 2012 annual data in the “RY 2012 database” labeled as “Kwh_propulsion”), distributed over the service periods described in the Fast Facts Sheet, as 3.1 [MW] as shown in Table 22 below.

### Table 22: Light Rail Schedule and Electricity Allocations

<table>
<thead>
<tr>
<th>Service frequency (stops per hour)</th>
<th>Start</th>
<th>Stop</th>
<th>Day</th>
<th>Days</th>
<th>hrs / day</th>
<th>hrs / week</th>
<th>Load Allocation</th>
<th>Electricity Usage (kWh/year)</th>
<th>Power Demand (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Period --&gt;</td>
<td>4:40 AM</td>
<td>7:30 AM M-F</td>
<td>5</td>
<td>2.8333</td>
<td>14.17</td>
<td>42.5</td>
<td>8%</td>
<td>1,381,951</td>
<td>1,871</td>
</tr>
<tr>
<td></td>
<td>7:30 AM</td>
<td>6:30 PM M-F</td>
<td>5</td>
<td>11.0000</td>
<td>55.00</td>
<td>275</td>
<td>50%</td>
<td>8,942,033</td>
<td>3,118</td>
</tr>
<tr>
<td></td>
<td>6:30 PM</td>
<td>12:00 AM M-Th</td>
<td>4</td>
<td>5.5000</td>
<td>22.00</td>
<td>66</td>
<td>12%</td>
<td>2,146,088</td>
<td>1,871</td>
</tr>
<tr>
<td></td>
<td>6:30 PM</td>
<td>3:00 AM F</td>
<td>1</td>
<td>8.5000</td>
<td>8.50</td>
<td>25.5</td>
<td>5%</td>
<td>829,170</td>
<td>1,871</td>
</tr>
<tr>
<td></td>
<td>5:00 AM</td>
<td>7:00 PM Sat</td>
<td>1</td>
<td>14.0000</td>
<td>14.00</td>
<td>56</td>
<td>10%</td>
<td>1,820,923</td>
<td>2,494</td>
</tr>
<tr>
<td></td>
<td>7:00 PM</td>
<td>3:00 AM Sat</td>
<td>1</td>
<td>8.0000</td>
<td>8.00</td>
<td>24</td>
<td>4%</td>
<td>780,396</td>
<td>1,871</td>
</tr>
<tr>
<td></td>
<td>5:00 AM</td>
<td>12:00 AM Sun</td>
<td>1</td>
<td>19.0000</td>
<td>19.00</td>
<td>57</td>
<td>10%</td>
<td>1,853,440</td>
<td>1,871</td>
</tr>
<tr>
<td></td>
<td>12:00 AM</td>
<td>4:40 AM M-F</td>
<td>5</td>
<td>4.6667</td>
<td>23.33</td>
<td>-</td>
<td>0%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>3:00 AM</td>
<td>5:00 AM Sat-Sun</td>
<td>2</td>
<td>2.0000</td>
<td>4.00</td>
<td>-</td>
<td>0%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>168</td>
<td>546</td>
<td>100%</td>
<td>17,754,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

C. Energy charge (C*z)

\[
\$/yr \quad = B*y
\]

= 0.047 \[\$/kWh\] * 18,000,000 \[kWh\]

= $830,000
D. Total

Is therefore estimated as:

\[ = \$39,000 + \$29,000 + \$830,000 \]
\[ = \$980,000 \]

**TOD Electricity Usage Costs**

The TOD electricity usage costs were estimated in terms of dollars per year \([$/\text{year}]\) proportional to the projected increase in track length at about \$2M per year. Valley Metro projected an additional 21 miles of Light Rail track coverage to be implemented by 2026 in addition to the existing 20 miles, or an increase of 105%. We assumed that the system would maintain the same level of flow capacity and frequency of stops. If the light rail did increase flow capacity, by 56% for example, to match the MAG projected increase in TOD population, then it could potentially meet this flow by increasing stop frequency 56%. This would increase the value of our results by a factor of 1.6. However, we do not think it would be reasonable to reduce peak stop frequency from once every 12 minutes to less than once every 6 minutes, and so we did not consider this option in our analysis, and recommend any future estimates, that consider flow capacity, to account for scheduling constraints of the system as well.

\[
ElectricityCosts_{2026} = ElectricityCosts_{2012} \times (1 + \%_{\text{Increase LR Track Length}}) \\
= \$980,000 \times (2.1) \\
= \$2,000,000
\]

**Infrastructure Costs**

Valley Metro currently has \$1 billion in infrastructure assets, and we project that doubling, by the same method as energy use, to \$2 billion in the TOD case as shown in Table 23. Infrastructure assets include line items for: Guideway, Bridges, Passenger Stations and Facilities, Park and Ride Facilities, Electric Power Substations, Signal and Communication Systems, Revenue Vehicles, and Equipment. The guideway and vehicles account for the majority of the infrastructure costs at 53% and 18% respectively, and electric power substations are only 9%.
The Water, Energy, & Infrastructure Co-Benefits of Smart Growth in Phoenix

Table 23: Valley Metro, Inc. 2013 Capital Assets

<table>
<thead>
<tr>
<th>Capital Asset</th>
<th>BAU Value ($ Millions)</th>
<th>TOD Value ($ Millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guideway</td>
<td>520</td>
<td>1,100</td>
</tr>
<tr>
<td>Bridges</td>
<td>52</td>
<td>110</td>
</tr>
<tr>
<td>Passenger Stations and Facilities</td>
<td>87</td>
<td>180</td>
</tr>
<tr>
<td>Park and Ride Facilities</td>
<td>29</td>
<td>59</td>
</tr>
<tr>
<td>Electric Power Substations</td>
<td>73</td>
<td>150</td>
</tr>
<tr>
<td>Signal and Communication Systems</td>
<td>38</td>
<td>78</td>
</tr>
<tr>
<td>Revenue Vehicles</td>
<td>180</td>
<td>370</td>
</tr>
<tr>
<td>Equipment</td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td><strong>Total Infrastructure Assets</strong></td>
<td><strong>980</strong></td>
<td><strong>2,000</strong></td>
</tr>
</tbody>
</table>

**Greenhouse Gas Emissions**

Greenhouse Gas Emissions were estimated in two parts for energy use and infrastructure in terms of metric tonnes (mt) Carbon-dioxide equivalents of global warming potential.

The energy use component is 8,000 and 16,000 mt CO₂e/year for BAU and TOD respectively, based on local factors for the Arizona electric production mix used in previous studies as 0.12 [kg CO₂e/MJ], and the annual electricity consumption of 18 and 36 GWh.

The infrastructure component is 0 for the BAU case and 1.2 mmt CO₂e for the TOD case. The TOD value was estimated using the CMU GDI EIO-LCA Producer Model for “Rail transportation sector” considering $1 billion in economic activity.

**Discussion of Light Rail Energy Consumption**

The infrastructure costs dominate the economics of the Light Rail with a difference of $1 billion from BAU to TOD versus only $1 million for use – a three order of magnitude difference. Valley Metro notes in its Financial Report that the values for capital assets are Net of Depreciation, and also includes useful life in years of all of the assets as well. Further research could account for the ongoing costs of replacement, maintenance, and discount depreciation into real dollars.

Use phase factors, including energy consumption, peak demand, and emissions are equivalent to less than 2,000 residential households, and therefore for the scope of this report not material.
INFRASTRUCTURE

Energy infrastructure is the network of power generation, transmission, and distribution – from production facilities to our buildings – that allows us to have low cost reliable power in our homes and offices. Because the research question we are investigating is the location of 485,000 additional households to an existing city and infrastructure, we defined the scope of this section as the electric utility distribution components. Specifically, the substations, transformers, and wires necessary to step-down high-voltage energy from the large transmission lines and the smaller power lines that run underground throughout our cities.

Summary of Results

In the BAU scenario, 397.5 ACSR wire cost $910 per dwelling unit, while in TOD the cost per dwelling unit is $73. This savings amounts to $840 per dwelling unit of overhead wire. Different wire types have a greater savings for developers due to the greater density of dwelling units as shown in Table 27. An average BAU and TOD wire length needed per dwelling unit was assumed and then using an approximate number of dwelling units per acre, we can determine the approximate cost per dwelling unit for each wire type. These estimations for cost per mile for each wire include engineering, construction, administration, and overhead expenses. These values were taken from an Electric System Transmission and Distribution Planning Study for New Smyrna Beach, Florida in 2006. They were used to show the potential cost difference in BAU and TOD scenarios.

For every square mile of BAU development an accompanying $3.5 million will have to be invested in substation and transformer infrastructure. With the substation and transformer infrastructure currently in place throughout the valley infrastructure upgrades will only need to take place if demand exceeds 30 MW per square mile. Greenhouse gas emissions will also be affected when implementing new infrastructure. For every substation built it will cost 150 mt CO₂e, with each transformer costing 23 mt CO₂e. This is a total of 61 mt CO₂e per square mile (Carnegie Mellon University Green Design Institute). When dealing with BAU development this environmental cost cannot be averted due to its unequipped landscape. TOD will be able to mitigate greenhouse gas emission because a new substation and 4 transformers will not always have to be built to service growth only when demand exceeds 30 MW.

BAU and TOD Distribution Costs

In Table 24, average costs per mile are broken down for multiple overhead and underground wire types and further broken down into new and reconductor costs. Since we can determine approximate low voltage wire needed for the BAU and TOD scenario, we can then use the average costs per mile data and determine the costs for each scenario and ultimately the savings of the TOD scenario.
Table 24: Line cost per mile for overhead and underground for typical line types

<table>
<thead>
<tr>
<th></th>
<th>Three Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$/mile</td>
</tr>
<tr>
<td>Overhead</td>
<td></td>
</tr>
<tr>
<td>#2 AAAC</td>
<td>$ 69,000</td>
</tr>
<tr>
<td>397.5 ACSR</td>
<td>$ 74,000</td>
</tr>
<tr>
<td>652 AAAC</td>
<td>$ 79,000</td>
</tr>
<tr>
<td>795 AAAC (115 kV)</td>
<td>$ 350,000</td>
</tr>
<tr>
<td>Underground</td>
<td></td>
</tr>
<tr>
<td>#1/0</td>
<td>$ 90,000</td>
</tr>
<tr>
<td>#4/0</td>
<td>$100,000</td>
</tr>
<tr>
<td>500 MCM CU</td>
<td>$150,000</td>
</tr>
</tbody>
</table>

Electric System Transmission and Distribution Study, City of New Smyrna, Florida. Costs include material, labor, engineering, and overhead.

Table 25: BAU cost Scenario

<table>
<thead>
<tr>
<th></th>
<th>$/mi²</th>
<th>$/ dwelling unit/mi²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>New</td>
<td>Reconductor</td>
</tr>
<tr>
<td></td>
<td>New</td>
<td>Reconductor</td>
</tr>
<tr>
<td>Overhead</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#2 AAAC</td>
<td>$ 2,700,000</td>
<td>$ 3,200,000</td>
</tr>
<tr>
<td>397.5 ACSR</td>
<td>$ 2,900,000</td>
<td>$ 3,500,000</td>
</tr>
<tr>
<td>652 AAAC</td>
<td>$ 3,100,000</td>
<td>$ 3,700,000</td>
</tr>
<tr>
<td>795 AAAC (115 kV)</td>
<td>$14,000,000</td>
<td></td>
</tr>
<tr>
<td>Underground</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#1/0</td>
<td>$ 3,500,000</td>
<td>$ 4,200,000</td>
</tr>
<tr>
<td>#4/0</td>
<td>$ 4,000,000</td>
<td>$ 4,800,000</td>
</tr>
<tr>
<td>500 MCM CU</td>
<td>$ 5,900,000</td>
<td>$ 7,100,000</td>
</tr>
</tbody>
</table>
### Table 26: TOD Cost Scenario

<table>
<thead>
<tr>
<th></th>
<th>$/mi²</th>
<th>$/dwelling unit/mi²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>New</td>
<td>Reconductor</td>
</tr>
<tr>
<td><strong>Overhead</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#2 AAAC</td>
<td>$1,700,000</td>
<td>$2,100,000</td>
</tr>
<tr>
<td>397.5 ACSR</td>
<td>$1,900,000</td>
<td>$2,300,000</td>
</tr>
<tr>
<td>652 AAAC</td>
<td>$2,000,000</td>
<td>$2,400,000</td>
</tr>
<tr>
<td>795 AAAC (115 kV)</td>
<td>$8,900,000</td>
<td>$</td>
</tr>
<tr>
<td><strong>Underground</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#1/0</td>
<td>$2,300,000</td>
<td>$2,700,000</td>
</tr>
<tr>
<td>#4/0</td>
<td>$2,500,000</td>
<td>$3,100,000</td>
</tr>
<tr>
<td>500 MCM CU</td>
<td>$3,800,000</td>
<td>$4,600,000</td>
</tr>
</tbody>
</table>

### Table 27: TOD Scenario Savings

<table>
<thead>
<tr>
<th></th>
<th>$/mi²</th>
<th>$/dwelling unit/mi²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>New</td>
<td>Reconductor</td>
</tr>
<tr>
<td><strong>Overhead</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#2 AAAC</td>
<td>$970,000</td>
<td>$1,200,000</td>
</tr>
<tr>
<td>397.5 ACSR</td>
<td>$1,000,000</td>
<td>$1,300,000</td>
</tr>
<tr>
<td>652 AAAC</td>
<td>$1,100,000</td>
<td>$1,300,000</td>
</tr>
<tr>
<td>795 AAAC (115 kV)</td>
<td>$4,900,000</td>
<td>$</td>
</tr>
<tr>
<td><strong>Underground</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#1/0</td>
<td>$1,300,000</td>
<td>$1,500,000</td>
</tr>
<tr>
<td>#4/0</td>
<td>$1,400,000</td>
<td>$1,700,000</td>
</tr>
<tr>
<td>500 MCM CU</td>
<td>$2,100,000</td>
<td>$2,500,000</td>
</tr>
</tbody>
</table>

### Table 28: Area and linear miles of wire for 485,000 homes

<table>
<thead>
<tr>
<th></th>
<th>Square miles needed for 485,000 homes</th>
<th>=</th>
<th>mi²</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOD</td>
<td></td>
<td>19</td>
<td>mi²</td>
</tr>
<tr>
<td>BAU</td>
<td></td>
<td>150</td>
<td>mi²</td>
</tr>
<tr>
<td>TOD</td>
<td>Linear miles per 485,000 homes</td>
<td>=</td>
<td>mi</td>
</tr>
<tr>
<td>BAU</td>
<td>Linear miles for 485,000 homes</td>
<td>=</td>
<td>mi</td>
</tr>
</tbody>
</table>
Table 29: Potential Savings for 485,000 TOD homes

<table>
<thead>
<tr>
<th></th>
<th>Overhead Wire</th>
<th>Underground Wire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost for total square miles TOD homes =</td>
<td>$35,000,000</td>
<td>$48,000,000</td>
</tr>
<tr>
<td>Cost for total square miles BAU homes =</td>
<td>$440,000,000</td>
<td>$600,000,000</td>
</tr>
<tr>
<td>Potential Savings</td>
<td>$410,000,000</td>
<td>$550,000,000</td>
</tr>
</tbody>
</table>

In the TOD, there would be significant savings per dwelling unit in the low voltage infrastructure costs due to the amount of wire used per house. TOD units average about 40 units per acre, while BAU only averages about 5. TOD developments are also more compact, meaning they have shared walls, multiple stories, and typically no significant outdoor space. This means developers in TOD scenario will need less wire to connect each unit to the grid, whether it is conduit underground or overhead.

For all potential 485,000 homes the potential savings for overhead 397.5 ACSR wire in the TOD scenario is $410 million. Since TOD homes are significantly denser, all of the household can fit on 19 mi². In BAU 151 mi² are needed for the same 485,000 homes. Using the same calculation for linear miles of wire infrastructure needed per square mile, TOD houses need 480 miles of wire infrastructure while BAU needs just under 6,000 miles. This potential costs savings for one overhead and one underground wire are shown in Table 29.

Table 30: Energy and Emissions BAU and TOD

<table>
<thead>
<tr>
<th></th>
<th>Energy (TJ/mi²)</th>
<th>Greenhouse Gas Emissions (mt CO₂e/mi²)</th>
<th>Total Energy (TJ) 485,000 houses</th>
<th>Greenhouse Gas Emissions (mt CO₂e) 485,000 houses</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOD</td>
<td>.55</td>
<td>14</td>
<td>10</td>
<td>270</td>
</tr>
<tr>
<td>BAU</td>
<td>.86</td>
<td>22</td>
<td>16</td>
<td>3,300</td>
</tr>
</tbody>
</table>

Table 31: Substation and Transformer Cost

<table>
<thead>
<tr>
<th>Substation cost</th>
<th>=</th>
<th>$6.2 million</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transformer cost</td>
<td>=</td>
<td>$1.9 million</td>
</tr>
</tbody>
</table>
| Substation at full capacity cost [4 transformers] | = | $14 million (4 mi²)
| 6.2 million x ((4) 1.9 million) = 14 million per 4 mi² |
| Substation at full capacity cost [4 transformers] | = | $3.5 million (1 mi²)
| 14 million / 4 = 3.5 million per 1 mi² |

The Water, Energy, & Infrastructure Co-Benefits of Smart Growth in Phoenix
Table 32: Substation and Transformer GHG emissions

<table>
<thead>
<tr>
<th>Description</th>
<th>Emission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substation greenhouse gas emission per unit</td>
<td>150 mt CO₂e</td>
</tr>
<tr>
<td>Transformer greenhouse gas emission per unit</td>
<td>23 mt CO₂e</td>
</tr>
<tr>
<td>Substation greenhouse gas emission at full capacity [4 transformers]</td>
<td>240 mt CO₂e (4 mi²)</td>
</tr>
<tr>
<td>Substation greenhouse gas emission at full capacity [4 transformers]</td>
<td>61 mt CO₂e (1 mi²)</td>
</tr>
</tbody>
</table>

Methodology

In the BAU scenario, we can assume 1 house has an average plot of land, 100 feet by 70 feet, with 6 feet of sidewalk and 12 feet of road in front. Each house faces one another and shares the 24 foot road. Other than the road, each house shares a common fence on the three other sides of the property. With these assumptions, the number of houses per acre and per square mile can be determined. This is the densest scenario with rows and rows of houses. There are no commercial buildings, through streets, or other miscellaneous plots of land. For this study, it is also assumed that the conduit for the distribution lines is underground directly between the two houses. Therefore each house needs about 65 feet of wire in BAU, which is 330 feet of wire per acre. In the TOD scenario, each acre needs 210 feet of wire, 64% of the amount needed in BAU.

Currently the SRP has installed an interconnected grid of 69 kV power lines and distribution substations. The substations are located every four square miles (srpnet.com). The current substation capacity for the established substation around the valley is 120 MW. Each substation contains four transformers, which have a 30 MW rating; with four transformers at every substation the total capacity over four square miles is 120 MW (Beaty, 2014). The estimated cost for a new substation is about $6.2 million. The estimated cost for a transformer is about $1.9 million (Midwest ISO, 2011). In total, to construct a new substation at full capacity, 120 MW, it will be about $3.5 million dollar per square mile. $3.5 million cost consist of 1 substation and 4 transformers to service 1 square mile of development.

Substation and Transformer Cost

- Substation cost - $6.2 million
- Transformer cost - $1.9 million
- Substation at full capacity cost [4 transformers] - $14 million (4 mi²)
  - 6.2 million x (4 * 1.9 million) = 14 million per 4 mi²
- Substation at full capacity cost [4 transformers] - $3.5 million (1 mi²)
  - 14 million / 4 = 3.5 million per 1 mi²
Table 33: BAU Scenario

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Acre</td>
<td>=</td>
<td>43560 ft²</td>
</tr>
<tr>
<td>1 sq. mile</td>
<td>=</td>
<td>27878400 ft²</td>
</tr>
<tr>
<td>1 average house</td>
<td>=</td>
<td>8260 ft²</td>
</tr>
<tr>
<td>1 house</td>
<td>=</td>
<td>100 ft</td>
</tr>
<tr>
<td></td>
<td></td>
<td>70 ft</td>
</tr>
<tr>
<td>Road + sidewalk</td>
<td>=</td>
<td>18 ft</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dwelling units/acre</td>
<td>=</td>
<td>5.0</td>
</tr>
<tr>
<td>Dwelling units/sq. mile</td>
<td>=</td>
<td>3,200</td>
</tr>
<tr>
<td>Low voltage wire/acre</td>
<td>=</td>
<td>325 ft</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.06 mile</td>
</tr>
<tr>
<td>Low voltage wire/sq. mile</td>
<td>=</td>
<td>208,000 ft</td>
</tr>
<tr>
<td></td>
<td></td>
<td>39 mile</td>
</tr>
<tr>
<td>Low voltage wire/house</td>
<td>=</td>
<td>65 ft</td>
</tr>
</tbody>
</table>

Table 34: BAU Housing Assumptions

<p>| |</p>
<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No alley</td>
</tr>
<tr>
<td>24 ft road</td>
</tr>
<tr>
<td>Every house has equal amount of road in front of house</td>
</tr>
<tr>
<td>Conduit underneath road</td>
</tr>
<tr>
<td>Additional 30 ft to connect house</td>
</tr>
<tr>
<td>Underground conduit</td>
</tr>
<tr>
<td>No commercial</td>
</tr>
<tr>
<td>No apartments</td>
</tr>
<tr>
<td>6 ft sidewalk</td>
</tr>
</tbody>
</table>

The TOD scenario has significantly more dwelling units per acre in comparison to the BAU scenario. We assume TOD has 40 dwelling units/acre, while BAU shown above has 5 dwelling units/acre. This means that the TOD scenario will need significantly less low voltage wire per acre, as more dwelling units occupy the same amount of space.

In Table 35, it is assumed the low voltage wire runs the length of the property and connects to a main meter on the property, which then gets distributed to each dwelling unit. This is a worst case
scenario. The developer will most likely have the main meter as close as possible to the utility side of the wire. These results do not take into account the wire needed to go to each dwelling unit, only the wire that connects the property to the nearest distribution line.

Table 35: TOD Scenario

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dwelling units/acre</td>
<td>=</td>
<td>40</td>
</tr>
<tr>
<td>Low voltage wire/acre</td>
<td>=</td>
<td>210 ft</td>
</tr>
<tr>
<td>Low voltage wire/sq. mile</td>
<td>=</td>
<td>130,000 ft</td>
</tr>
<tr>
<td>Acres available for infill</td>
<td>=</td>
<td>730 acres</td>
</tr>
<tr>
<td>Dwelling unit demand</td>
<td>=</td>
<td>170,000 du</td>
</tr>
<tr>
<td>Acre of Development</td>
<td>=</td>
<td>4,300 acre</td>
</tr>
<tr>
<td>Infrastructure in place</td>
<td>=</td>
<td>3,600 acres</td>
</tr>
<tr>
<td>Infrastructure needed</td>
<td>=</td>
<td>730 acres</td>
</tr>
<tr>
<td>Low voltage wire demand</td>
<td>=</td>
<td>150,000 ft</td>
</tr>
<tr>
<td></td>
<td>=</td>
<td>29 mile</td>
</tr>
</tbody>
</table>

The BAU assumptions try to compact the most houses in a square mile. These assumptions do not include land needed for arterial streets, commercial, schools, churches, or other possible land uses. The TOD scenario is also very basic as it assumes one interconnection point need from the utility to the property.

**Substation and Transformer GHG Emissions**

The following variables were used to determine the GHG emission cost:

- Substation greenhouse gas emission per unit – 150 mt CO$_2$e
- Transformer greenhouse gas emission per unit – 23 mt CO$_2$e
- Substation greenhouse gas emission at full capacity [4 transformers] – 240 mt CO$_2$e (4 mi$^2$)
  - 150 * (4) 23 = 240 (4 mi$^2$)
- Substation greenhouse gas emission at full capacity [4 transformers] – 61 mt CO$_2$e (1 mi$^2$)
  - 240 / 4 = 61 per 1 mi$^2$

**Discussion of Energy Infrastructure**

The infrastructure analysis focused on the primary and secondary distribution wire and substation infrastructure for residential households and commercial floor space. For BAU and TOD we
assumed both scenarios used the same type of wire, but just used different lengths because BAU has a density of 5 houses per acre while TOD has 40 houses per acre. We then used an approximate cost for different wire types and whether the lines were overhead or underground and compared the results. We also assumed that the GHG emission and the energy needed for the infrastructure was the same throughout the different wire types.

With a TOD oriented expansion, GHG emission will increase at a lower rate than BAU development scenario. A lower TOD GHG emission rate is produced due to the decrease in infrastructure upgrades associated with TOD development. In a BAU situation, more land will need to be allocated to support substation and transformer infrastructure. Due to the presence of an established infrastructure network in TOD, fewer resources will be needed to service the increase in population.

The cause for the differing infrastructure costs was mainly due to overall land required for both scenarios. Since BAU required 6,000 miles of wire infrastructure for all 485,000 homes and TOD required 500 miles of wire infrastructure, TOD will have significantly less greenhouse gas emissions, reduced cost, and less energy required for the wire infrastructure. This is due to the assumption that TOD has 40 houses per acre and requires about 5.5 feet of wire per house while BAU has 5 houses per acre and requires about 65 feet of wire per house.

When analyzing wire infrastructure vs. transformer and substation infrastructure it is apparent that the cost of new wire far outweighs transformer and substation cost. This is important to note because in a BAU scenario wire instillation will be needed to serve the new development. In a TOD scenario expansive wire infrastructure development might not be needed due to existing established infrastructure. If infrastructure retrofitting is necessary it will be contingent upon specific site development such as a hospital needing a higher peak capacity requirement.

The initial cost, emissions, and energy needed to install wire infrastructure was used to represent the entire process needed to install the wire including engineering, labor, material, overhead, etc. Future studies could break down the different parts of the infrastructure and evaluate alternatives in terms of the specific infrastructure supporting overhead and underground wires, including wood versus steel utility poles, wire type, and labor. Adding in commercial infrastructure requirements and the load would add value to the results. With additional data sets, varying transformer and substation cost could be calculated to estimate varying types of infrastructure upgrades typically associated with different land use types. A comparison between Maricopa’s two major utilities, APS and SRP, detailing their specific costs and typical infrastructure used would yield a more accurate cost and emissions estimate. With this information developers and utilities would be able to assess more accurately their options for their infrastructure to lower their emissions and reduce costs.

A confined focus was place upon infrastructure contain within the city and did not assess potential electricity transmission cost. Calculations were based upon 69 kV transmission infrastructure
located within the existing city. Therefore, the variations between TOD vs. BAU development associated with varying transmission expenses are not accounted for in the existing analysis of infrastructure cost. An evaluation of the distance between the area of consumption and an established location of an electricity generating power plant will provide a more accurate representation of the cost difference between BAU and TOD expansion. The costs and emissions focused on the infrastructure needed for commercial and residential because we needed to find the impact that 485,000 houses will have in both BAU and TOD Scenarios. By expanding the scope of work to include high voltage transmission lines (69 kV and above) we can further assess the impacts of the 485,000 houses in Maricopa County by including the wire, substations, transformers and possibly the generation sources that might need to be built to accommodate the growth.

Also, due to limited data, estimated infrastructure cost values derived from varying cities throughout the nation. More accurate results can be produced by obtaining infrastructure costs that are directly linked with the Phoenix metro area.

**Overall Comparison of BAU and TOD**

This section aggregates and compares the results of the previous analyses in the context of the 2011 MAG study with consideration for the 2040 growth projections for BAU and TOD. The results reported here encompass the residential, commercial and light rail electricity data in one comprehensive analysis. Final data for consumption are reported in Table 36. Included are annual energy use, emissions, cost of electricity and peak power demand. Some are given on a per square foot basis for context and for this reason residential and commercial data are kept segregated. The single column for commercial data indicates similar results for both BAU and TOD scenarios. More detail concerning this matter can be found in the Commercial Energy Consumption section.

**Table 36: 2040 Consumption Final Results**

<table>
<thead>
<tr>
<th></th>
<th>Commercial</th>
<th>Residential</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BAU/TOD</td>
<td>BAU</td>
</tr>
<tr>
<td>Annual Consumption (kWh/ft²)</td>
<td>21</td>
<td>6.2</td>
</tr>
<tr>
<td>Peak Demand (kW/ft²)</td>
<td>0.0042</td>
<td>0.0016</td>
</tr>
<tr>
<td>Annual Emissions (mt CO₂e)</td>
<td>1,200,000</td>
<td>2,900,000</td>
</tr>
<tr>
<td>Annual Cost of Electricity ($/ft²)</td>
<td>$2.20</td>
<td>$0.73</td>
</tr>
<tr>
<td>Annual Cost of Electricity</td>
<td>$280,000,000</td>
<td>$760,000,000</td>
</tr>
</tbody>
</table>

Average annual consumption of energy was adjusted by multiplying hours in a year and the total area of space required for residential and commercial space separately. Now in terms of power
The Water, Energy, & Infrastructure Co-Benefits of Smart Growth in Phoenix

(MW) the residential and commercial sectors were combined with respect to each scenario and inflated by 25% to account for peak demand. This was done in order to predict the total power required to meet peak demand in 2040. Presented in the first row of Table 37, the total power required was used to estimate the scale of infrastructure i.e. transformers and substations necessary to support peak demand. As per data reported in the Infrastructure section: a new transformer is needed for every increase in 30 MW demand and each substation can support four transformers. The second and third rows of Table 37 therefore depict the amount of either transformers or substations required to support the additional space in each configuration. Note these numbers do not include what is in place today; therefore they reflect a total required capacity rather than an additional need. Emissions due to the increase in light rail use and the construction of required infrastructure as well as the costs associated with capital and construction of infrastructure are also included.

<table>
<thead>
<tr>
<th>Table 37: 2040 Infrastructure Distribution Final Results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BAU</strong></td>
</tr>
<tr>
<td><strong>Total Power Required to meet Peak Demand (MW)</strong></td>
</tr>
<tr>
<td>Transformers at full capacity (30 MW capacity)</td>
</tr>
<tr>
<td>Substations at full capacity (4 transformers)</td>
</tr>
<tr>
<td>Emissions - Transformer Construction (mt CO₂e)</td>
</tr>
<tr>
<td>Emissions - Substation Construction (mt CO₂e)</td>
</tr>
<tr>
<td>Annual Emissions - Light Rail Use (mt CO₂e)</td>
</tr>
<tr>
<td>Emissions due to Light Rail Construction (mt CO₂e)</td>
</tr>
<tr>
<td>Cost (wires + transformers + light rail-TOD)</td>
</tr>
<tr>
<td>Cost (wires + substations + light rail-TOD)</td>
</tr>
</tbody>
</table>

Table 38 reflects the cost of energy for users, the cost of necessary infrastructure and annual emissions that would be required to support 485,000 households and 130 million ft² of commercial space in either BAU or TOD scenarios. These numbers are inclusive of the residential, commercial and light rail sectors. The infrastructure costs reflect wires and transformers or wires and substations and light rail for only the TOD scenario. The BAU scenario did not incur costs associated with additional light rail infrastructure. Since TOD areas are, for the most part, in developed areas, it is assumed that the construction of substations would not be necessary and that current substations will be retrofitted to support additional transformers. On the other hand, since the required transformers for the BAU scenario are quiet excessive and development may be primarily sprawled on the fringe; it is assumed that only substations at full capacity would be implemented. Annual emissions are the cumulative emissions due to residential, commercial and
light rail energy use and construction of energy and light rail infrastructure normalized over a 30-year period (2010-2040).

<table>
<thead>
<tr>
<th>Table 38: Final Results for 2040 Population Projections</th>
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<tbody>
<tr>
<td>BAU</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td><strong>Total Annual Cost of Electricity</strong></td>
</tr>
<tr>
<td><strong>Infrastructure Cost (wires + transformers + light rail)</strong></td>
</tr>
<tr>
<td><strong>Infrastructure Cost (wires + substations)</strong></td>
</tr>
<tr>
<td><strong>Annual Emissions (mt CO2e/year)</strong></td>
</tr>
</tbody>
</table>

To visualize these results more concretely, Figure 13 - Figure 15, show compartmentalized case scenarios for use costs, energy infrastructure costs and greenhouse gas emissions respectively.

**COMBINED ENERGY DISCUSSION**

The research presented throughout this report tells a consistent story: that investment in high-capacity high-efficiency transportation infrastructure enables housing developments to be located closer to each other and built much more efficiently in terms of capital and operations. The results are consistent in terms of economics, energy, and environmental impact.

It’s interesting to note that despite the significant decrease in average total household size and energy consumption, the use per square foot slightly increases in the TOD case. Our hypothesis is that peoples’ needs and comfort levels do decrease as a result of a smaller dwelling unit. More likely, is that they stay the same, and are simply able to meet those needs in a more efficient and energy intensive way with the same number of appliances and major electronic devices, and with less empty space to heat in the winter and cool in the summer. Further research could investigate the differences in the residential demographics of BAU vs TOD inhabitants and seek to understand energy use behavioral differences therein and what if any fraction of the population will live in only one location or the other.

It is also reasonable to believe that the commercial sector might follow a similar trend. Information was not found to support that commercial space in TOD is smaller than in BAU, however it is intuitive to think in the case of urban infill, scarce space will become more valuable and therefore condensed. Further research into any difference between TOD and BAU commercial space use and demand could investigate commercial land use trends in Phoenix. Since the MAG study used 250 ft² per employee for office commercial building space for TOD and all of Maricopa County commercial space demand projections, any data that would show a difference in the square-feet-
per-employee in TOD and BAU could be insightful. Also, a simple survey could be done focusing on one commercial sector or building type as a baseline.

Expanding light rail also expands area available for TOD. Whether or not this land is located in an urban core, the presence of light rail creates new potential for a community that uses land efficiently. Future studies could investigate the energy trade-offs of other forms of transportation, such as busses and taxis, that when combined with light-rail enable a lifestyle without ownership of a personal vehicle that is not viable in BAU.

In terms of the electricity infrastructure, for the BAU scenario, it is assumed that the development will take place on undeveloped land on the outskirts of the Phoenix metro area. The infrastructure would all have to be developed and put in place for the new residential and commercial space. In TOD the infrastructure in place will most likely already be developed and infrastructure upgrades will be site dependent. The TOD costs, emissions, and energy needs estimated in this report however, assumed new infrastructure there as well, and did not consider retrofitting or congestion. Our hypothesis is that in most cases of TOD, the infrastructure upgrades or modifications necessary would actually be less than what we have estimated. This hypothesis could be tested with research that uncovers the specific energy consumption and capacity in place in the Maricopa area, as well as the detailed grid components necessary beyond wires, substations, and transformers. Furthermore, Arizona specific values for peak demand as a ratio of average power consumption, as well as maximum line ratings and local reliability requirements would support a more robust assessment of the infrastructure requirements.

Finally, gas infrastructure was not considered by itself. The trend in the EIA data was that TOD buildings were all electric, and gas energy was only considered in BAU. The tradeoffs between the efficiency in using gas for heating applications versus the infrastructure cost of piping an additional fuel source to each dwelling unit could also be investigated.

**WATER CONSUMPTION AND INFRASTRUCTURE ANALYSIS**

**INTRODUCTION**

Water is a necessity, especially in the semi-arid Phoenix metropolitan area. In recent decades, water resource sustainability has been a focus of study for academics, professional engineers, and state and local government agencies. The state of knowledge and research on water, spanning from availability and future forecasting of water resources to infrastructure and end-use, is expansive for the state of Arizona and the Phoenix Metropolitan area. The knowledge base is continually increasing at a steady rate as various groups within the state and region develop a heightened
knowledge of the problems that persist with the sustainability of water in the semi-arid desert and how it affects the long-term potential of the city.

The aim of our work was to analyze infrastructure requirements and end-user water demand in the Phoenix metropolitan area for an additional 485,000 households projected to be added by 2040. Our study investigated two development scenarios: business-as-usual (BAU) and transit-oriented development (TOD). The BAU scenario was characterized by urban sprawl and continued residential and commercial development on the suburban fringe of the greater Phoenix area. The TOD scenario was characterized by reallocating residential and commercial development to more concentrated areas of Phoenix. Specifically, areas within a half-mile radius of the Phoenix Light Rail system were designated as TOD development zones.

Within the two scenarios, two aspects of water were assessed: water-related infrastructure and consumptive use. The current infrastructure was engineered decades ago with excess capacity to account for the expected growth of the region. We reviewed the state of the systems to determine whether there is still excess capacity, particularly in the regions of interest. If there was insufficient capacity in the current system for the TOD plan, additional treatment plants and pumping facilities were added. Similarly, the BAU scenario required additional infrastructure on the urban extremities, including pipelines for water distribution and wastewater collection, pumping to meet pressure and volumetric demands, drainage networks for stormwater collection, and treatment facilities for both drinking water and wastewater. Infrastructure improvements included additional water supply, as determined by the demand created by the two scenarios. This included additional canals to distribute existing water supplies, groundwater pumps distributed around the urban periphery, and installation of water reuse systems. We also examined the water required for construction of the new developments and the associated infrastructure (i.e. the water embedded in roads, buildings, and other public facilities).

With regards to consumption, we investigated how water use rates differ in the TOD and BAU scenarios. Differences in development density resulted in different water requirements for residential landscapes, which were divided between high water-use mesic landscaping (turf grass, shade trees, and sprinkler systems) and low water-use xeric landscaping (desert plant species, gravel ground cover, drip irrigation systems). We also examined current water use patterns within high- and low-density dwellings based on historical data, in order to include differences in consumption rates for the developments in the two scenarios. This included the effects of public education and increasing knowledge of water sustainability goals. Our analysis also accounted for water demand from other uses, such as industry, commercial areas, public facilities (hospitals, schools, etc.), and recreation (parks, golf courses, etc.). This also included the possibility of implementing water reuse and reclamation practices to meet additional demand.

Ultimately our comparative metrics included initial and recurring costs of the additional infrastructure, as well as total water demand, in both scenarios. We also included some indication
of the sensitivity of our results to climate, in order to comment on the robustness of our analysis in the face of climate change and urban heat island effects.

**Primary Data Sources**

- Peer reviewed journal articles
- Government affiliated studies and/or documents
- City General Plans/Zoning codes
- Websites for existing Phoenix-area water treatment plants
- City of Phoenix Water Services Department
- City of Tempe Water Services Department
- City of Mesa Water Services Department
- Published Historical Data from Phoenix Active Management Area and surrounding AMAs

**Team Structure**

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<thead>
<tr>
<th>Name</th>
<th>Task(s)</th>
<th>Affiliation</th>
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<tr>
<td>Stephanie</td>
<td>Impacts on surroundings (TOD vs. BAU); miscellaneous support</td>
<td>Urban and Environmental Planning, Geographical Sciences and Urban Planning</td>
</tr>
<tr>
<td>Tate</td>
<td>Household water use and change (TOD vs. BAU)</td>
<td>Civil Engineering, Transportation, School of Sustainable Engineering and the Built Environment</td>
</tr>
<tr>
<td>Mathew</td>
<td>Treatment capacity; treatment facility planning</td>
<td>Civil Engineering, Environmental, School of Sustainable Engineering and the Built Environment</td>
</tr>
<tr>
<td>Tom</td>
<td>Residential and recreational outdoor water use</td>
<td>Civil Engineering, Hydrosystems, School of Sustainable Engineering and the Built Environment</td>
</tr>
<tr>
<td>Babu</td>
<td>Planning and construction</td>
<td>Construction Engineering, Del E. Webb School of Construction</td>
</tr>
<tr>
<td>Scott</td>
<td>Commercial and roadway water use</td>
<td>Civil, Environmental, and Sustainable Engineering, School of Sustainable Engineering and the Built Environment</td>
</tr>
<tr>
<td>Nick</td>
<td>Water/Wastewater treatment infrastructure, distribution systems</td>
<td>Civil Engineering, Hydrosystems, School of Sustainable Engineering and the Built Environment</td>
</tr>
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</table>
**Methodology**

We conducted a side-by-side analysis of water use and infrastructure requirements for approximately 485,000 new households in the Phoenix area, comparing business-as-usual (BAU) suburban fringe development to transit-oriented-design (TOD) urban infill. Specifically, the analysis investigated five aspects of water systems that together encompass the potential differences between these two development strategies:

1. Residential indoor and outdoor water use.
2. Industrial and commercial water use.
3. Water and wastewater treatment facilities.
5. Embedded water of additional energy production.

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**Figure 21: System Boundary**
Residential Indoor and Outdoor Water Use

The “Design Standards Manual for Water and Wastewater Systems” published by the City of Phoenix Water Services Department provided water supply design standards for single- and multi-family residences. These accounted for indoor use for both dwelling types, as well as outdoor use for single-family homes. There were also design standards for landscape irrigation (per acre) that were used to account for outdoor use at multi-family residences. Using the housing densities decided upon by the entire class, these design standards were used to estimate the additional residential water use for both the BAU and TOD scenarios. However, the design standards were adjusted to reflect reductions in per capita water use. The 2011 City of Phoenix Water Resource Plan provided data of these recent trends. Absent finding alternative projections of per capita water use in the Phoenix area, these trends were extrapolated to 30 years in the future as an estimate of the average requirement over a typical 60-year building time horizon.

Industrial and Commercial Water Use

Industrial water demand in the planning area included mining, paper production, dairies and feedlots and golf course irrigation served by a facility water system. Industrial demand, particularly for power generation was a large cultural demand component in the studied area. Turf related facilities and golf courses were significant water users, where turf related facilities and golf courses accounted for 39% of the commercial demand. There were 81 large-scale dairy operations and 8 large-scale feedlots in Phoenix which accounted for 7% of the industrial demand. Sand and gravel operations were fairly stable demand with approximately 6% of the total industrial demand. Another 9% of industrial demand were used by small-scale dairies, industrial facilities and high water use landscape areas less than ten acres in size.

Water and Wastewater Treatment Facilities

When planning for growth, not only water supply infrastructure but also water treatment facilities were designed. Even though this was a portion of the infrastructure, it was highly dependent on the projected use of the water and production of the wastewater by the future residents of the city. There were fundamental differences in treatment facility planning between the BAU and TOD scenario. The main difference was that the TOD scenario was centered on the cities of Phoenix, Tempe, and Mesa while the BAU scenario included cities along the outer fringe of the metropolitan area including Buckeye, Cave Creek, and Queen Creek. Design guides for each city indicated how much water was expected to be used for different types of land use. Table 3.3 in the City of Phoenix Design Standards Manual for Water and Wastewater Systems listed the design standard flows for
land uses from single family residential to multi-family to commercial use. The infrastructure surrounding these land uses was designed expecting these design flows including peak demands as defined by 1.7 times the normal demand. The current treatment facilities were designed with these flows in mind while accounting for some future growth. For the TOD scenario, the current capacities of the treatment facilities within the cities of Phoenix, Tempe, Mesa, and other surrounding “core” areas designated as being within the TOD sector were considered and compared to an additional 485,000 households of different specific land use. A mix of single family and multifamily dwellings were also considered. An analysis of the increase in design flows and how they will impact the currently designed treatment facilities were performed. The ability of these facilities to absorb these increased flows was assessed and if the facilities were unable to absorb them, the excess flow was accounted and described as a result. This is saying that the city experienced a shortage of treated water or an excess flow of wastewater that needed to be treated through the construction of additional treatment facilities or modification of existing facilities. The same approach was performed for the BAU scenario but only considered the outer limit cities of Buckeye, Cave Creek, and Queen Creek. The BAU scenario resulted in the need for newly constructed treatment facilities as the land use was converted from undeveloped desert to new residential or commercial. These fringe cities do not currently have the capacity to handle these new incoming 485,000. The result for the BAU was the calculated excess flow or shortage that these cities treated and assuming constructed new treatment facilities to perform this function.

**Water Distribution Networks**

Additional construction and/or retrofitting of networks was based on two variables: the first being network modifications required to support new water and wastewater treatment facilities; and, the second being new roadways and housing that would require additional distribution and wastewater collection systems. Network construction and retrofitting was based on the 2013 Design Standards Manual for Water and Wastewater systems, provided by the City of Phoenix Water Services Department. Water distribution and transmission systems were the focus of network modifications required to support the new water and wastewater treatment facilities. Data on existing infrastructure was in accordance with the Design Standards Manual for piping and distribution systems. Constructed or retrofitted distribution and transmission systems included (but were not limited to): water mains, corollary piping extending from mains, wells, and pumps. Additionally, constructed or retrofitted wastewater collection systems included (but were not limited to): manholes, piping, and sewers. Construction of network systems corresponded with the construction of new water/wastewater treatment facilities and/or roadways that will serve the geographical area of interest. The construction of network systems also captured all metrics that were relevant to the three indicator variables (i.e., dollars, GHG, energy). Dollars to construct the networks were calculated either directly through materials/labor costs, or by using previous, similar projects to reasonably estimate current construction costs (noting that both of these methodologies included future maintenance costs). Energy and GHG emissions associated with
networks were estimated based on the products and processes involved with network construction, as well as maintenance throughout the network’s life cycle.

Embedded Water of Additional Energy Production

Energy and water are closely interconnected and commonly referred to as the “water-energy nexus”. The water group took into account one part of this nexus: the water used to produce electricity as there is a significant amount of water used throughout the process of creating electricity at power plants. The annual generation of electricity in Arizona is comprised of coal at 39%, nuclear at 28%, natural gas at 27% and hydroelectric at 5%. Of the annual generation, 30-35% of the energy is exported out of Arizona and will have to be taken into account when applying functions to water used by power plants. (Bartos & Chester, 2013). There is also a small amount of renewable energy such as solar being used in Arizona but the water use to produce this energy is negligible. The amount of water used to produce one megawatt-hour of electricity differs according to which type of power plant is subject as certain types of power plants consume more water than others. The focus was only on the types of power plants being used in the Phoenix metropolitan area according to the main electricity providers APS and SRP. The addition of 485,000 new households demanded more electricity and in turn more water to produce the electricity; water use at the current state needed to be projected for the next 30 years for the power plants. The water use for energy was collected from research done by the World Bank, as well as more specific research about the United States and primarily Arizona. An example of this is the analysis done for “The Conservation Nexus: Valuing Interdependent Water and Energy Savings in Arizona.” Findings from these sources divulged the gallons of water needed to produce one megawatt-hour of electricity from multiple power plants.

RESULTS

Residential Indoor and Outdoor Water Use

We began with the most direct effects of the 485,000 households on the water system in both scenarios: residential water use. Because the TOD scenario was designed to have higher density (more households per unit area), a greater percentage of people would be expected to be residing in multi-family units, whereas the BAU scenario would be inclined towards a higher percentage of single-family homes. As multi-family homes share common outdoor space, water used to maintain residential landscaping and swimming pools is distributed among more households, reducing per household water usage rates. This difference is reflected in design standard manuals for several Phoenix-area cities. For example, the City of Mesa Engineering & Design Standards calls for 490 gpd (gallons per day) for each unit with density less than 2 units per acre. This decreases with increasing density, with only 230 gpd required for each unit with 9-22 units per
The design values for Phoenix were in good agreement with actual usage rates determined from available data, after conversion from per capita rates to per household (without need for an assumption of number of people per household, which was likely to be different for the two scenarios). According to the 2011 Water Resource Plan for the City of Phoenix, the population of 1.5 million people averaged 110 gpcd (gallons per capita per day) in 2010. Approximately half of this total demand (81 MGD; million gallons per day) is for single-family homes, and one sixth (27 MGD) for multi-family homes. Given the ratio of single-family homes to multi-family homes from the American Housing Survey (~65:35) and the total number of water accounts (~360,000; from the 2011 Phoenix Water Resource Plan), this resulted in approximately 340 gpd for single-family residences and 220 gpd for multi-family. Given the necessity of accounting for system losses, the slightly higher design standard values for Phoenix were used.

Assuming that BAU was comprised mostly of single-family residences, and that TOD would consist mostly of multi-family residences, the difference of 120 gpd per household was used to determine the additional residential water usage for the BAU scenario: 58 MGD for 485,000 households. However, per capita usage rates in Phoenix have decreased by approximately 25% since peaking at 150 gpd in 1997. This is due to many factors, including water conservation programs, increased water awareness, changes in landscape design, and technological improvements. A continued decrease is expected, though not necessarily at the same rate. If per capita usage rates decrease at approximately half that rate, or another 25% over the next 30 years, the water savings of the TOD scenario is reduced to 44 MGD. Figure 22 compares the BAU vs. TOD scenarios by illustrating a summary of use (in MG/yr) for various sectors, including: residential, commercial, industrial, and energy.
Industrial and Commercial Water Use

Projected commercial and industrial water use in BAU and TOD development areas was based on data provided by the 2011 Water Resource Plan published by the City of Phoenix of Water Services Department. The 2011 Water Resource Plan shows that non-residential water use (i.e., industrial, commercial, agricultural, municipal) accounts for 33% of total water use in Maricopa County. The 2011 Water Resource Plan also shows that the commercial water use accounts for 41% of total non-residential water use in BAU and TOD development areas; and, industrial water use accounts for 8% of non-residential water use in BAU and TOD development areas. Based on these values and industrial water use data provided by the ADWR, we were able to project commercial and industrial water use by taking the product of the industrial water use values with the proportion of commercial water use to industrial water use (i.e., 41/8 = 5.1).

We did not expect significant, if any, variations of water use in TOD versus BAU development scenarios with regards to commercial and industrial water use in Maricopa County. For example, a commercial or industrial water user in Maricopa County will require nearly equal quantities of water regardless of their location in a TOD or BAU development area. Therefore, we assumed that commercial and industrial water use for the TOD and BAU scenarios were equivalent.

Water and Wastewater Treatment Facilities

An analysis of the current (2010) and planned (2040) wastewater treatment capacities from the MAG publication on regional growth concerning wastewater treatment yielded interesting results for a countywide surplus of treatment capacity. A TOD scenario utilized surplus capacity, thereby limiting the associated costs, greenhouse gas emissions, and energy usage related to the construction and maintenance of the existing and future wastewater treatment plants (WWTPs).

After looking at the county’s treatment capacity and treatment plants as a system, and using growth projections and current wastewater generation, a balancing or optimization of the system brings about savings if the expected population growth in certain “fringe” municipalities in the Business-As-Usual (BAU) scenario was reallocated to greater population increase in areas served by public transportation. Based on the MAG regional growth projections for all associated areas in Maricopa County, the 2040 expected surplus of wastewater treatment capacity was approximately 155 million gallons per day (MGD). This came directly from the MAG report, with an expected 2040 population of 7.4 million in Maricopa County with an expected wastewater generation of 780 MGD and a capacity of 940 MGD. This was used as the baseline BAU scenario for wastewater treatment capacities in Maricopa County to compare our Transit-Oriented Development (TOD) scenario analysis and results.

The growth projections in the report showed a few key areas with large deficits in terms of future treatment capacities when compared to population growth by 2040, while other areas showed large surpluses. A few municipalities that stood out were Buckeye (48 MGD deficit), Chandler (55 MGD surplus), Mesa (26 MGD surplus), Maricopa County unassociated areas (37 MGD deficit),
Phoenix (100 MGD surplus), and Surprise (28 MGD deficit). A balancing among these areas and others with relatively smaller surpluses or deficits was found through optimization of the system, and with this optimization the savings in the aforementioned categories ($, GHG, energy) was quite large and bring about a more sustainable Maricopa County in terms of water use. This was done within the parameters of a TOD scenario, redistributing populations from fringe areas into the cities served by public transit.

Based on mapping of the current and proposed public transportation infrastructure, cities and municipalities that were determined to be within the TOD sectors include: Chandler, Gilbert, Glendale, Goodyear, Mesa, Paradise Valley, Peoria, Phoenix, Salt River, Scottsdale, and Tempe. All other areas listed in the MAG report were deemed outside of the TOD areas. From this, as well as the future WWTP capacities, linearly decreasing the expected growth of populations in fringe cities based on the number of households and population being redistributed would mean the system could reduce the planned surplus capacity by 7 MGD (see Table 40 below, dropping the surplus treatment capacity from 160 MGD to 150 MGD). The tables presented below show the calculations performed in order to get to this savings. While this is a relatively modest savings in terms of necessary treatment capacity for wastewater, there is still potential for incremental savings and reductions in dollars, GHG emissions, and energy based on more extensive optimization and community planning. It is also worth noting that this is not a full optimization of the system as there was a linear rate applied to the “available populations” (difference between 2010 and 2040 population projections for fringe cities) rather than a linear programming application to optimize the population redistribution to limit the relative deficits and surpluses in fringe cities. At this point, the optimization has only been applied to the increase in populations in TOD sectors; the model attempts to limit the surplus capacities by causing a positive population flux for TOD cities and municipalities showing a surplus in treatment capacity while still keeping within the constraints of the population increase limits of 485,000 households (or 1.3 million individuals based on government census data extrapolating 2.7 individuals per household).

Optimizing the redistribution showed that existing and future treatment plant capacities in two specific TOD sectors were still not limiting the projected surplus to its full extent. Chandler and Phoenix still show surplus capacities of 42 MGD and 66 MGD, respectively, based on the previously listed constraint of 1.3 million people being redistributed. Two separate scenarios would allow a greater optimization of the treatment systems in Maricopa County: a greater population flux from fringe areas to TOD sectors, or removing or revising future planned expansions or construction of new WWTPs. Obviously, more factors play into the future planning of treatment plants within Maricopa County, and a significant amount of uncertainty in the population growths exist, so the results presented can only represent the optimization of an “ideal” system in terms of savings on costs, emissions, and energy.

Taking a different approach to assessing potential benefits of the TOD scenario would be to consider the current and future planned capacities as fixed to see where relative deficits and surpluses already exist within the system. When assessing this, Table 40 below shows just over a
130 MGD deficit in wastewater treatment capacity in the outlying BAU regions by 2040. With that, assuming that the existing and currently planned expansions to wastewater treatment facilities by 2040 encompass the BAU scenario, it becomes evident that a greater increase in system capacities will be required for BAU. Alternatively, the TOD sectors show a net surplus of over 240 MGD, meaning that the surplus capacity of the existing and currently planned expansions to wastewater treatment would be sufficient to treat any excess wastewater generated by the shifted population for a TOD scenario. Planned expansions could potentially be reduced, but that level of analysis would require far more granular forecasting of population growth outside of the assumptions from the MAG report.

Unfortunately, the most granular data available for water treatment infrastructure was the wastewater treatment capacity. Water treatment capacity given by data in certain cities throughout the Maricopa County Metropolitan Area was insufficient to determine the difference in TOD and BAU development scenarios. It is an over-generalization that all water treatment plants treating water to a potable state will eventually run into the wastewater treatment system. One particular case study is for the Scottsdale community, which sees an abundance of water treatment capacity as well as wastewater treatment capacity exist in several treatment facilities in the Scottsdale vicinity. The Infrastructure Improvement Plan for Water and Wastewater Impact Fees 2013 identifies the current treatment infrastructure capacity as about 160 MGD, and a distribution capacity of 150 MGD, while still leaving a net surplus capacity for unused daily water at around 53 MGD. Alternatively, the wastewater treatment capacity listed in this same report was at about 42 MGD currently (well in line with the MAG estimated wastewater treatment capacity for 2015 in Scottsdale of 46 MGD). This should serve as evidence that the evaluation of water treatment facilities is far more in depth than the sweeping assumption of “all treated water will eventually go to wastewater treatment facilities”. Similarly, applying a broad factor or percentage of treated water that will eventually find its way to wastewater treatment infrastructure cannot be deemed a fitting estimate for this study. Water use on the residential, commercial, and industrial sectors have been discussed previously, and these discussions as well as the estimated cost, GHG emissions, energy requirements for this infrastructure was considered captured in the use phases rather than in an evaluation of existing and planned facilities and how these plans may see a shift for BAU versus TOD scenarios in the Phoenix Metropolitan area.
Table 40: Business-as-Usual Scenario for Maricopa County Wastewater Treatment

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<th>Business as Usual</th>
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<td>Tempe</td>
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<td>187,200</td>
<td>23.17</td>
</tr>
<tr>
<td>Tolleson</td>
<td>6,200</td>
<td>6,400</td>
<td>1.32</td>
</tr>
<tr>
<td>Wickenburg</td>
<td>7,700</td>
<td>33,200</td>
<td>0.45</td>
</tr>
<tr>
<td>Youngtown</td>
<td>5,600</td>
<td>7,300</td>
<td>0.50</td>
</tr>
<tr>
<td>Totals:</td>
<td>4,181,400</td>
<td>7,361,400</td>
<td>444</td>
</tr>
</tbody>
</table>
Table 41: Transit-oriented Development Scenario for Maricopa County Wastewater Treatment

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Avondale</td>
<td>114,800</td>
<td>11.48</td>
<td>43,700 31,124 83,676 8.37 13.85</td>
<td></td>
</tr>
<tr>
<td>Buckeye</td>
<td>586,800</td>
<td>58.68</td>
<td>510,200 363,370 223,430 22.94 (11.99)</td>
<td></td>
</tr>
<tr>
<td>Carefree</td>
<td>5,000</td>
<td>0.45</td>
<td>900 641 4,359 0.39 0.77</td>
<td></td>
</tr>
<tr>
<td>Cave Creek</td>
<td>13,500</td>
<td>1.33</td>
<td>8,100 5,769 7,531 0.75 (0.52)</td>
<td></td>
</tr>
<tr>
<td>Chandler</td>
<td>289,900</td>
<td>27.83</td>
<td>- - 418,910 40.21 42.39</td>
<td></td>
</tr>
<tr>
<td>El Mirage</td>
<td>51,400</td>
<td>4.52</td>
<td>16,700 11,894 39,506 3.47 0.13</td>
<td></td>
</tr>
<tr>
<td>Fountain Hills</td>
<td>31,500</td>
<td>1.83</td>
<td>6,700 4,772 26,728 1.55 1.65</td>
<td></td>
</tr>
<tr>
<td>Gila Bend</td>
<td>65,200</td>
<td>5.87</td>
<td>62,800 44,371 20,829 1.88 (1.18)</td>
<td></td>
</tr>
<tr>
<td>Gila River</td>
<td>9,500</td>
<td>10.10</td>
<td>6,300 4,487 5,013 5.33 6.97</td>
<td></td>
</tr>
<tr>
<td>Gilbert</td>
<td>287,800</td>
<td>23.02</td>
<td>- - 375,065 30.00 0.00</td>
<td></td>
</tr>
<tr>
<td>Glendale</td>
<td>313,400</td>
<td>30.40</td>
<td>- - 347,936 33.75 0.00</td>
<td></td>
</tr>
<tr>
<td>Goodyear</td>
<td>366,200</td>
<td>36.62</td>
<td>- - 531,000 53.10 0.00</td>
<td></td>
</tr>
<tr>
<td>Guadalupe</td>
<td>5,300</td>
<td>0.53</td>
<td>100 71 5,229 0.52 0.18</td>
<td></td>
</tr>
<tr>
<td>Litchfield Park</td>
<td>14,800</td>
<td>1.48</td>
<td>6,000 4,273 10,527 1.05 15.35</td>
<td></td>
</tr>
<tr>
<td>Mesa</td>
<td>649,000</td>
<td>73.01</td>
<td>- - 681,986 99.22 0.00</td>
<td></td>
</tr>
<tr>
<td>Maricopa County</td>
<td>615,500</td>
<td>61.61</td>
<td>513,800 373,056 242,444 24.27 0.14</td>
<td></td>
</tr>
<tr>
<td>Paradise Valley</td>
<td>16,200</td>
<td>2.04</td>
<td>- - 16,200 2.04 (0.24)</td>
<td></td>
</tr>
<tr>
<td>Peoria</td>
<td>383,500</td>
<td>38.35</td>
<td>- - 551,590 56.16 0.00</td>
<td></td>
</tr>
<tr>
<td>Phoenix</td>
<td>2,261,100</td>
<td>238.55</td>
<td>- - 2,626,319 277.08 65.92</td>
<td></td>
</tr>
<tr>
<td>Queen Creek</td>
<td>93,600</td>
<td>9.36</td>
<td>74,200 52,846 40,754 4.08 (0.08)</td>
<td></td>
</tr>
<tr>
<td>Salt River</td>
<td>7,500</td>
<td>4.32</td>
<td>- - 11,285 6.50 0.00</td>
<td></td>
</tr>
<tr>
<td>Scottsdale</td>
<td>301,600</td>
<td>36.26</td>
<td>- - 382,199 45.95 0.00</td>
<td></td>
</tr>
<tr>
<td>Surprise</td>
<td>644,400</td>
<td>64.44</td>
<td>515,000 373,911 270,489 27.05 8.95</td>
<td></td>
</tr>
<tr>
<td>Tempe</td>
<td>187,200</td>
<td>34.44</td>
<td>- - 231,010 42.50 0.00</td>
<td></td>
</tr>
<tr>
<td>Tolleson</td>
<td>6,400</td>
<td>3.86</td>
<td>200 142 6,238 3.77 0.43</td>
<td></td>
</tr>
<tr>
<td>Wickenburg</td>
<td>33,200</td>
<td>2.19</td>
<td>15,500 18,161 15,039 0.99 0.21</td>
<td></td>
</tr>
<tr>
<td>Youngtown</td>
<td>7,300</td>
<td>0.66</td>
<td>1,700 1,211 6,089 0.55 (0.25)</td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td>7,361,400</td>
<td>783</td>
<td>1,811,400 1,290,099 7,361,401 790 148</td>
<td></td>
</tr>
</tbody>
</table>
Table 42: Optimized Redistribution of Population Limiting Capacity Surplus in TOD Sectors

<table>
<thead>
<tr>
<th>TOD Sector</th>
<th>% of Population</th>
<th>Redistributed Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chandler</td>
<td>10.0%</td>
<td>125,010</td>
</tr>
<tr>
<td>Gilbert</td>
<td>6.8%</td>
<td>87,265</td>
</tr>
<tr>
<td>Glendale</td>
<td>2.7%</td>
<td>34,536</td>
</tr>
<tr>
<td>Goodyear</td>
<td>12.8%</td>
<td>164,800</td>
</tr>
<tr>
<td>Mesa</td>
<td>18.1%</td>
<td>232,986</td>
</tr>
<tr>
<td>Paradise Valley</td>
<td>0.0%</td>
<td>-</td>
</tr>
<tr>
<td>Peoria</td>
<td>11.5%</td>
<td>148,090</td>
</tr>
<tr>
<td>Phoenix</td>
<td>28.3%</td>
<td>365,219</td>
</tr>
<tr>
<td>Salt River</td>
<td>0.3%</td>
<td>3,785</td>
</tr>
<tr>
<td>Scottsdale</td>
<td>6.2%</td>
<td>80,599</td>
</tr>
<tr>
<td>Tempe</td>
<td>3.4%</td>
<td>43,810</td>
</tr>
<tr>
<td>Total</td>
<td>100.0%</td>
<td>1,290,100</td>
</tr>
</tbody>
</table>

Water Distribution Networks

Rather than placing an emphasis on existing water treatment capacities and infrastructure, an estimate for increased distribution and piping networks for both water delivery and wastewater/sewage transportation was considered. To do this, similar metrics and assumptions were made for the electricity study of increased infrastructure requirements for the delivery of electricity in the BAU scenario. This involved establishing a “typical” community development on the fringe sector and evaluating what kind of water distribution and wastewater transportation might be necessary for BAU development. Our “model” neighborhood community included 5 households per acre, based on assumptions and calculations made for the electrical infrastructure, and a single roadway spanning the length of one square acre (approximately 210 ft). The general assumption was that for every mile of roadway, there exists two miles of piping: one mile of potable water distribution and one mile of wastewater transportation. The respective pipe sizes for water distribution and wastewater transportation were 12 inches in diameter. For every square mile of community, it was also assumed that a larger main exists for distribution and wastewater transportation. The length of this larger main was assumed to be 5,300 ft for every square mile of BAU development. The respective pipe sizes for this assumption were 30 inch pipes for both distribution and wastewater transportation. The results of the rather basic calculations for determining the required piping network infrastructure within fringe development in the BAU scenario are contained in the tables below.
Embedded Water of Additional Energy Production

Water used in energy production (‘‘embedded water’’) for the types of power plants and sources of renewable energy in Arizona were sought from APS and SRP, the primary electricity suppliers for the Phoenix metropolitan area. The majority of power plants are fueled by coal or natural gas with one nuclear power generating station. Other sources of energy come from biomass, solar, wind, geothermal, landfill gas, and hydroelectric power. Some of these are negligible as they do not provide a significant amount of electricity compared to other energy sources. From the study “Water and Energy Sustainability with Rapid Growth and Climate Change in the Arizona-Sonora Border Region” it was found that it takes 790 gallons of water to produce one megawatt hour of energy at the Palo Verde Nuclear Power Plant, the only nuclear power plant in the state. For a power plant that uses natural gas it takes around 420 gallons of water and coal based power plants use 510 gallons per megawatt hour of energy. There are 10 natural gas power plants and 9 coal power plants that supply electricity for the Phoenix metropolitan area shown in the table below.
Table 44: Power Plant Capacities

<table>
<thead>
<tr>
<th>Power Plants</th>
<th>% used in AZ</th>
<th>Type</th>
<th>Capacity</th>
<th>Location</th>
<th>G/MWhr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aqua Fria Generating Station</td>
<td>Wholly owned by SRP</td>
<td>Natural Gas or Oil, Also Solar Generation</td>
<td>626 MW Solar, 200 MW Solar</td>
<td>Peoria</td>
<td>415</td>
</tr>
<tr>
<td>Coolidge Generating Station</td>
<td>Wholly owned by SRP</td>
<td>Natural Gas</td>
<td>575 MW</td>
<td>Coolidge, AZ</td>
<td>415</td>
</tr>
<tr>
<td>Coronado Generating Station</td>
<td>SRP 100% owner</td>
<td>Coal</td>
<td>773 MW</td>
<td>St. Johns</td>
<td>510</td>
</tr>
<tr>
<td>Craig</td>
<td>29% owned by SRP</td>
<td>Coal</td>
<td>1283 MW</td>
<td>Craig, CO</td>
<td>510</td>
</tr>
<tr>
<td>Desert Basin Generating Station</td>
<td>100% owned by SRP</td>
<td>Natural Gas</td>
<td>577 MW</td>
<td>Casa Grande</td>
<td>415</td>
</tr>
<tr>
<td>Four Corners Power Plant</td>
<td>10% owned by SRP</td>
<td>Coal</td>
<td>2040 MW</td>
<td>Farmington, NM</td>
<td>510</td>
</tr>
<tr>
<td>Hayden</td>
<td>50% of 1 of 2 units</td>
<td>Coal</td>
<td>131 MW</td>
<td>Hayden, CO</td>
<td>510</td>
</tr>
<tr>
<td>Kayenta</td>
<td>100% owned by SRP</td>
<td>Natural Gas or Oil</td>
<td>521 MW</td>
<td>Tempe</td>
<td>415</td>
</tr>
<tr>
<td>Mesquite</td>
<td>50% owned by SRP</td>
<td>Natural Gas</td>
<td>625 MW</td>
<td>Arlington, AZ</td>
<td>415</td>
</tr>
<tr>
<td>Navajo</td>
<td>21.7% owned by SRP Coal</td>
<td>Coal</td>
<td>48 MW</td>
<td>Navajo Reservation Page, AZ</td>
<td>510</td>
</tr>
<tr>
<td>Palo Verde Nuclear Power</td>
<td>17.49% Owned by SF Nuclear</td>
<td>Natural Gas</td>
<td>654 MW</td>
<td>Tonopah, AZ</td>
<td>785</td>
</tr>
<tr>
<td>Santan</td>
<td>100% owned by SRP</td>
<td>Natural Gas</td>
<td>1193 MW</td>
<td>Gilbert, AZ</td>
<td>415</td>
</tr>
<tr>
<td>Springerville</td>
<td>25% owned by SRP</td>
<td>Coal</td>
<td>400 MW</td>
<td>Springerville, AZ</td>
<td>510</td>
</tr>
<tr>
<td><strong>APS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Four Corners Power Plant</td>
<td>38% owned by APS</td>
<td>Coal</td>
<td>782 MW</td>
<td>Farmington, NM</td>
<td>510</td>
</tr>
<tr>
<td>Cholla</td>
<td>62% owned by APS</td>
<td>Coal</td>
<td>615 MW</td>
<td>Holbrook, AZ</td>
<td>510</td>
</tr>
<tr>
<td>Navajo</td>
<td>14% owned by APS</td>
<td>Coal</td>
<td>315 MW</td>
<td>Navajo Reservation Page, AZ</td>
<td>510</td>
</tr>
<tr>
<td>Redhawk</td>
<td>100% owned by APS</td>
<td>Natural Gas</td>
<td>1060 MW</td>
<td>Tonopah, AZ</td>
<td>415</td>
</tr>
<tr>
<td>West Phoenix</td>
<td>100% owned by APS</td>
<td>Natural Gas</td>
<td>1000 MW</td>
<td>Southwest Phoenix</td>
<td>415</td>
</tr>
<tr>
<td>Ocotillo</td>
<td>100% owned by APS</td>
<td>Natural Gas</td>
<td>340 MW</td>
<td>Tempe</td>
<td>415</td>
</tr>
<tr>
<td>Sundance</td>
<td>100% owned by APS</td>
<td>Natural Gas</td>
<td>450 MW</td>
<td>Coolidge</td>
<td>415</td>
</tr>
<tr>
<td>Palo Verde Nuclear Power</td>
<td>29.1% of the plant</td>
<td>Nuclear</td>
<td>1160 MW</td>
<td>Tonopah, AZ</td>
<td>785</td>
</tr>
</tbody>
</table>

1 MWhr = electricity for 1,000 homes for 1 hour

One megawatt of energy can power 1,000 homes for one hour; the exchange rate per day is 24 MWh to power 1,000 homes for 24 hours. In turn, it required 19,000 gallons of water at the nuclear power plant to produce power to 1,000 homes for one day. Natural gas power plants use 10,000 gallons and coal power plants will use 12,000 gallons. Not all of this water is consumed; however, much is recycled and reused within the power plant depending on types of turbines used and the type of power plant.

Over the next 30 years, electricity will be in greater demand with the addition of 485,000 homes resulting in an increase of gallons of water used to supply electricity. Annual residential consumption for the 485,000 households will be 3.1 million MWh under the TOD scenario and 6.5 million MWh for BAU, a difference of approximately 3.4 million MWh more under the BAU scenario. Commercial and industrial consumption will be comparable under the two scenarios, which will require an additional 2.6 million MWh in either case in 2040. The location of the homes determines which power plants were used to supply electricity but still requires approximately the same amount of water to produce energy because electricity will still be needed regardless of whether the home is in BAU or TOD. The factors for amount of embedded water in energy are...
dependent on the technological advances of power plants to conserve water and the increase in renewable resources that use less water to generate electricity, but if an average value of 470 gal/MWh is used, this equates to 4.3 MGD of water production necessary to meet the additional electricity demands in the BAU scenario.

**Greenhouse-Gas Emissions and Required Energy**

Water use and the water infrastructure for all sectors require energy for their installation, operation, and eventual end-of-life scenario. Because energy use is associated with the emission of greenhouse-gas (GHG) emissions, water use and water infrastructure are associated with the emission of GHG. Several factors were used to account for energy (in MJ) and GHG emissions (in kg CO$_{2}$e) for water use processes, where factors were obtained from *The Conservation Nexus: Valuing Interdependent Water and Energy Savings in Arizona* (Bartos and Chester, 2014). Additionally, factors were used to account for energy (in MJ) and GHG emissions (in kg CO$_{2}$e) for water infrastructure processes, obtained from the Water Energy Sustainability Tool (WEST Web) (Horvath and Stokes, 2014). These factors are shown in Table 45 and Table 46.

<table>
<thead>
<tr>
<th>Process</th>
<th>Quantity</th>
<th>Energy (MJ)</th>
<th>GHG Emissions (kg CO$_{2}$e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Treatment</td>
<td>per 1000 gallons</td>
<td>0.19</td>
<td>24</td>
</tr>
<tr>
<td>Wastewater Treatment</td>
<td>per 1000 gallons</td>
<td>4.9</td>
<td>600</td>
</tr>
<tr>
<td>Water Distribution</td>
<td>per 1000 gallons</td>
<td>4.4</td>
<td>540</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Product</th>
<th>Quantity</th>
<th>Energy (GJ)</th>
<th>GHG Emissions (kg CO$_{2}$e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete Pipe - 12in</td>
<td>per 1000ft of pipe placed</td>
<td>2.4</td>
<td>260</td>
</tr>
<tr>
<td>Metal Pipe - 12in</td>
<td>per 1000ft of pipe placed</td>
<td>4.5</td>
<td>360</td>
</tr>
<tr>
<td>Plastic Pipe - 12in</td>
<td>per 1000ft of pipe placed</td>
<td>5.0</td>
<td>300</td>
</tr>
<tr>
<td>Concrete Pipe - 30in</td>
<td>per 1000ft of pipe placed</td>
<td>13</td>
<td>1,300</td>
</tr>
<tr>
<td>Metal Pipe - 30in</td>
<td>per 1000ft of pipe placed</td>
<td>14,000</td>
<td>1,100</td>
</tr>
<tr>
<td>Plastic Pipe - 30in</td>
<td>per 1000ft of pipe placed</td>
<td>36,000</td>
<td>2,200</td>
</tr>
</tbody>
</table>
Using these factors, the energy required and associated GHG emissions were calculated for the following sectors in terms of their overall water distribution: residential, commercial, and industrial. Additionally, the required energy and GHG emissions were calculated for wastewater treatment plants and water treatments plants. The associated GHG emissions and required energy with regards to water distribution for the three aforementioned sectors (i.e., residential, commercial, and industrial) are shown in Figure 23 and Figure 24. Figure 23 shows that the residential sector was the most significant user of water in Phoenix.

Figure 23: Energy Associated with Residential, Industrial, and Commercial Water Distribution

Figure 24: GHG Emissions Associated with Residential, Industrial, Commercial, and Energy Water Distribution
Energy and GHG emissions with regards to water infrastructure (e.g., piping) are shown in Figure 27 and Figure 28. Because additional piping is not necessary for the TOD scenario these values were only associated with the BAU scenario.
Figure 27: Energy Associated with Water Infrastructure

Figure 28: GHG Emissions Associated with Water Infrastructure

An overall summary of the energy requirements and greenhouse gas emissions for both scenarios can be seen in Figure 29 and Figure 30.
Costs

The construction costs and operation and maintenance costs of wastewater treatment plants were estimated based on treatment capacity for each city in both scenarios. The construction of a new plant costs about $170,000 per MGD of treatment for wastewater treatment facilities (MAG, 2003). For operation and maintenance costs, the city of Phoenix pays about $0.75 per 1000 gallons to treat wastewater at the 91st Avenue WWTP. This figure was used as the operation and maintenance costs for all wastewater treatment plants in this analysis. For piping, it was assumed that each mile of pipe, whether it was for water or wastewater had costs associated with piping, valves, manholes, and fire hydrants. The cost breakdown for each component is shown in Table 47. Assuming that the existing distribution network was already mostly in place to meet the needs of the TOD scenario, additional infrastructure costs for the BAU scenario are shown in Figure 31.
When we expanded these cost figures to both scenarios, we obtained an overall cost comparison. The responsibility of these costs is a more complicated issue. The treatment costs are generally the responsibility of each municipality whereas the piping installation costs will be a shared responsibility between private developers and the municipalities. The system could incur a 7 MGD savings in future planned capacity (see Table 40, dropping the surplus treatment capacity from 160 MGD to 150 MGD). With the 7 MGD savings in future planned capacity, existing and planned wastewater treatment plants would still be required to meet the capacity. From Table 3, we obtained the amount of wastewater generated for BAU and TOD, where these values were used to determine the cost per day. Table 48 refers to the total capital needed to construct new wastewater treatment plants. There was a deficit of capacity for the BAU scenario which means more plants would need to be constructed to meet that excess demand whereas a surplus of capacity existed in the TOD scenario meaning the wastewater treatment capacity was sufficient to meet the extra demand of the infill development.
Table 48: Construction Costs of WWTPs for BAU and TOD

<table>
<thead>
<tr>
<th>Additional Wastewater Capacity Required (MGD)</th>
<th>Capital Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAU 160</td>
<td>$26,000,000</td>
</tr>
<tr>
<td>TOD 0</td>
<td>$0</td>
</tr>
</tbody>
</table>

Table 49: Operation and Maintenance Costs of WWTPs for BAU and TOD

<table>
<thead>
<tr>
<th>Wastewater Generated (MGD)</th>
<th>Cost per Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAU 780</td>
<td>$590,000</td>
</tr>
<tr>
<td>TOD 800</td>
<td>$600,000</td>
</tr>
</tbody>
</table>

The additional piping for the fringe areas were calculated and are summarized in Table 43. These costs include pipe, valve, manhole, and fire hydrant material and installation, Table 50 summarizes the cost the distribution network associated with a length of pipe for BAU and TOD development. For BAU development, the factors taken into account will be additional piping, manholes, valves, and fire hydrants. For TOD development, additional capacity needed would be a case by case basis. Infill construction will occur only in areas where capacity exists because increasing capacity will be cost prohibitive to a development project. As a result, there is no additional infrastructure required for TOD development.

Table 50: Cost of Water and Sewage Utility Lines for BAU and TOD

<table>
<thead>
<tr>
<th>Length of Pipe (ft)</th>
<th>Length of Pipe (mi)</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAU 42,000,000</td>
<td>8,000</td>
<td>$5,600,000,000</td>
</tr>
<tr>
<td>TOD 0</td>
<td>0</td>
<td>$0</td>
</tr>
</tbody>
</table>

The total cost comparison between the two scenarios is shown in Figure 32. Figure 32 is the annualized cost over the analysis time frame, where the currency is represented in 2012 USD. Figure 32 also includes the estimated costs to treat the water for use.
COMBINED WATER DISCUSSION

Water Usage

We analyzed three different sectors for differences in water usage rates between TOD and BAU scenarios: residential, commercial/industrial, and the embedded water in energy production. For residential usage, we have determined that a 44 MGD less water would be required under the TOD scenario. This saving is a result of shared outdoor spaces with multi-family homes in the TOD scenario, whereas the BAU scenario would feature more detached, single-family households with a greater total number of swimming pools and landscaped areas. This is only a fraction of the total usage, and less than the total usage we determined for commercial and industrial purposes. However, we estimate that the differences in these latter usages between TOD and BAU would be small, since we assume that businesses are unlikely to substantially alter their water usage patterns based on location, and that the same number of businesses would be demanded by the potentially displaced 485,000 households in either scenario.

Energy Analysis

The findings for water used to produce electricity at power plants reveal that a significant amount of water is used for energy. This is related to the water-energy nexus, a linkage that cannot be ignored because energy production needs water, and water production needs electricity. The MWh projections for BAU and TOD reveal that BAU households by 2040 will consume 3.1 million MWh more than TOD households per year. This difference will increase the demand of water needed to generate electricity demonstrating that locating the 485,000 households in TOD will conserve more water than locating houses in BAU. For commercial usage, an additional 2.6 million MWh will be consumed in 2040 by the addition of 485,000 households. This usage is the same in both scenarios as the same amount of people will be accessing businesses and is further
explained in the energy usage section of this report. Based on current data of the water requirements of energy production, the TOD scenario will require 4.3 MGD of water less than the BAU scenario, bringing the total water savings of the TOD scenario (when added to residential usage) to 48 MGD.

Of the three power plants analyzed in this study, the nuclear power plant used the largest amount of water to generate one MWh at 790 gallons while natural gas used the least amount at 420 gallons of water. Naturally natural gas would seem like the ideal power plant to use but there are factors of cost and GHG emissions to observe with all types of power plants. With regards to water conservation, an important topic in Arizona, power plants can become more efficient in terms of water consumed, recycled, and cooled through enhanced technology. Improving the energy efficiency in thermoelectric power plants can have indirect water savings and reduce cooling water demand (Bartos & Chester, 2013). While enhancing current and new power plants so that they are using water more efficiently, the best way to conserve water and cut down on GHG emissions is to advocate for more renewable energy such as solar and wind power to generate electricity for homes. Renewable energy uses less water by far compared to thermoelectric energy, and while wind energy is hard to obtain in Arizona and geothermal is of low grade and only suitable for direct use there is an ample amount of solar energy that could be implemented into the sunshine state. Transferring energy production to renewable energy instead of thermoelectric will cut down on the amount of water used to generate electricity in the future.

**Water Treatment**

The end result of the wastewater treatment analysis shows that redistributing the population would cause a decrease in net surpluses based on the current plan for Wastewater Treatment facility construction and ongoing operations. The net surpluses would only be decreased by 7 MGD out of the total 940 MGD, which is a modest decrease. However, the expected generation was 780 MGD for 2040 based on the MAG assessment and actually increased to 790 MGD based on the population redistribution and the metrics for wastewater generation in certain communities. Ultimately, more thoughtful and holistic planning could result in a decrease to planned construction, but knowing that those construction and operational plans are already in place just solidifies the case for a better balance of surplus and deficit scenarios across the entire county if the TOD scenario were to take place.

Independent of the population redistribution analysis, the 2040 planned capacities for all sectors show a net surplus in wastewater treatment capacity. However, the BAU regions show a net deficit of 130 MGD while the TOD sectors show a net surplus of 240 MGD. This should speak volumes towards the implications of smart growth within Maricopa County and especially near the core sectors of the Phoenix metropolitan area. In a smart growth scenario, the County could mitigate risks and potential expenditures on increasing wastewater treatment capacities in fringe regions while lowering the net surplus in core sectors and still maintaining an abundance of treatment capacity.
Water Distribution Network

An analysis of the water distribution infrastructure and our estimated requirements for a BAU development scenario indicated that there were a great deal of cost savings, GHG emission reductions, and energy reductions to be realized with Transit-Oriented Development. The assumption of not requiring retrofitting or enhanced capacity in the current infrastructure is a large generalization of the existing system that likely would not hold true, but the goal was to show the inherent costs and other expenditures necessary to continue down the path of fringe development and sprawl. These costs and expenditures are significant, and certainly make the case in favor of TOD with regards to water distribution and wastewater transmission infrastructure.

Conclusions

The potential economic and environmental savings associated with the TOD scenario designate it as the clear favorable solution when compared to BAU activities. The economic and environmental savings are correlated with the utilization of existing wastewater treatment plants to meet future water use needs; and, the limited deployment of new, fringe water distribution networks in favor of existing water distribution networks. With regards to the policy and decision-making significance of our findings, the utilization of existing wastewater treatment plants and the limited deployment of new water distribution networks is associated with several policy and decision-making barriers. However, we feel these barriers can be addressed through several strategies and implementable policies.

One barrier is gaining a consensus for a TOD scenario among the 27 cities in the studied area. Gaining a consensus would be achieved through two strategies. The first strategy is to build public support for the TOD scenario by marketing campaigns focused on enticing people to move to TOD cities (e.g., Phoenix, Tempe, and Glendale). The second strategy is to build a strong relationship with the Maricopa Association of Governments, as the Maricopa Association of Governments represents the best opportunity to ascertain any concerns that the 27 cities may have with the TOD scenario and discuss these concerns with all 27 city representatives present.

Another barrier is the reduced real-estate costs associated with developing land in BAU areas. While in many instances there are smaller infrastructure and water distribution network costs associated with TOD development, the significantly reduced real-estate costs associated with BAU development causes BAU to be more favorable for developers. To increase the favorability of TOD development for developers, either: subsidies could be provided for TOD development, which would be a marginal value in terms of the overall savings from BAU development; or, increased taxes or fees could be placed on BAU-focused development.
SUMMARY OF COMPiled RESULTS

The transportation, building energy consumption, and water use have been combined to assess the total energy, greenhouse gas emissions, and costs associated with the transit-oriented development system over a 60-year period. Many of the previous results have been presented annually, but all are combined here multiplied over 60-years and include maintenance and replacement for some infrastructure systems as well as changing technologies over time. Roadway infrastructure requires rehabilitation over time and water distribution and collection networks require repairs or replacement through the analysis period. Future vehicle fuel economy improvements and changes to Arizona’s electricity generation mix are included in the assessment and alter the impact profiles of the both systems. Figure 33 shows the combined results and compares the TOD assessment to an equivalent amount of BAU development to show the potential for reducing impacts over 60 years. The results are simplified by combining the infrastructure components with the water use-phase, because together they comprise at most 4% of the total impact. Transportation and building energy use are shown individually and are further separated to show the relative share of residential and commercial use.

Figure 33: Combined 60-year Impact Results
A TOD configuration can enable reductions for energy consumption, water consumptions, greenhouse gas emissions, and costs over 60 years as large as 45% over an equivalent amount of BAU development. This is mainly due to avoided transportation and reduced energy consumption in households. Nearly 1.6 million TJ of energy will be saved, a 42% reduction, due to 50% reductions from both transportation and residential building energy consumption. When spread over all 485,000 for 60 years, that energy equates to about 420 gallons of gasoline per household per year in energy savings, which could total nearly $1,500 per year. Greenhouse gas emissions show a similar result with a 41% reduction, which is 140 mmt of CO\textsubscript{2}e over the analysis period. Again, the reductions are driven by transportation and residential energy consumption and would be equivalent to each household reducing their GHG footprint by 5 metric tonnes each year for 60 years. Up to $100 billion could be saved over 60 years, a 45% reduction, and is helped by a 60% reduction from the combined infrastructure and water use component. To pass those savings on to each TOD household would amount to $3,500 annually over the analysis timeframe. With water consumption dwarfed by the use-phases of transportation and building energy, results are small. Therefore, Figure 34 provides the breakdown of water consumption by sector.

![Figure 34: Total Water Consumption over 60 Years](image)

Reducing water consumption is a priority for Phoenix, Arizona because it is a sprawling desert city in the Southwest United States, which is facing a water shortage as a handful of major cities compete for limited resources. Residential water use makes up 74% of the total for a BAU development configuration and provides the greatest opportunity for savings. By moving 485,000 households to TOD, a 37% reduction to residential water use can be realized. As energy consumption is reduced and the production of electricity becomes more efficient, water use for energy production can be reduced by up to 38%. Together, these two water conservation efforts cause an overall 30% reduction to water use when including all 130 million ft\textsuperscript{2} of commercial space as well as the water needed for energy production and residential households. The residential savings would be equivalent to each household saving 25,000 gallons of water per year over the 60-year analysis, which would be the same as each household taking 500 fewer showers per year for 60 years. As the Phoenix area is expected to grow and MAG projects many residents to demand a TOD lifestyle, the ability to share swimming pools and landscape irrigation loads can reduce per capita water consumption and potentially reduce overall consumption despite the addition of new...
residents. Current consumption habits provide such stress on the Colorado River basin that Phoenix is not projected to be able to sustain the population growth estimates. This is despite already using water more conservatively than much of the United States (Bartos and Chester, 2014). Any chance to reduce consumption while increasing the population can be a useful opportunity for the Phoenix area, and TOD has the potential to provide that water security. By constructing in a more compact configuration and enabling reduced consumption habits, TOD will also require less infrastructure than BAU and enable municipalities to avoid spending money on unnecessary infrastructure, as shown in Figure 35.

Public infrastructure costs, for both initial construction and rehabilitation over 60 years, can be reduced by $4.7 billion, or 70%, mainly due to utilizing existing infrastructure rather than constructing new facilities and networks. Building and maintaining fewer roads, less electricity distribution network, and fewer miles of pipe for water use has the potential to save municipalities nearly $80 million per year for 60 years. These funds could then be used for other activities or passed on to residents through avoided tax increases. The only case where public infrastructure costs are higher is for energy because that is where the additional light rail costs have been included. Light rail is included with the energy assessment because it runs on electricity, rather than being included in the transportation analysis because it will run on a pre-determined schedule and use a predictable amount of energy without being governed by the transportation demands of the TOD residents. The cost of the water distribution network for the BAU development scenario comprises 83% of the total infrastructure costs in that case. The relative costs of the water distribution network are very high compared to the energy consumption and GHG emission profiles from water because the expensive infrastructure supports a relatively low impact consumable, water. While roadways facilitate millions of VMT and the associated emissions, and while electric wires facilitate consumption that causes electricity generation from fossil fuels, water use does not require as large a relative share of energy to distribute and consume and therefore, emits less GHG emissions. The major assumption that drives the infrastructure cost savings for transportation, energy, and water is that existing roads and distribution networks will be more extensively utilized before any new construction is considered. By our assessment, nearly
all additional demand from the TOD in the urban core can be supported by infrastructure which is currently in place.

The Maricopa Association of Government’s Sustainable Transportation and Land Use Integration Study has projected an influx of residents and demand for commercial space to the Phoenix area and specifically to developments around transit, and the combined results of this technical report show that these residents are likely to have a smaller water and environmental footprint and cost less money to support with public services. Though this report has focused on energy consumption, water consumption, GHG emissions, and costs, the air quality footprint of TOD residents will likely also be improved as discussed by Chester et. al. (2013) and Kimball et. al. (2013). The Phoenix area is routinely out of attainment for concentrations of particulate matter and innovative strategies for improving air quality are needed. Fewer particulates will be emitted from vehicle tailpipe emissions by prioritizing smart growth configurations and enabling residents to change their behaviors. The same effect can be found by enabling residents to reduce building energy consumption and, thereby, reduce the particulate emissions from fossil fuel-powered electricity generation plants. The MAG report has projected the demand for TOD by 2040 and the findings show that this configuration can save municipalities and residents money, and yet, we still have not seen new developments occur on a large scale to support this demand. Some developments around current light rail stations have been successful since the line’s opening and the rail network is also expanding. Institutional factors need to change in the next 25 years to spur these developments. The following section provides a qualitative discussion of how we may be able to move toward a smart growth future.

**TRANSITIONING: BARRIERS TO CHANGE**

The Transitions project group analyzed political and socio-economic barriers hindering the adoption of transit-oriented development (TOD) in the Phoenix metropolitan area and its pursuant potential success. We discuss the hurdles of political inertia, inadequate funding, and current light rail development as key political barriers. We then identify the Phoenix metropolitan area’s dependence on the construction industry and the lack of affordable housing in TOD zones as key socio-economic barriers. For each barrier discussed, we synthesize solution recommendations to facilitate moving towards transit-oriented development.

We additionally considered barriers of particular importance to the Phoenix metropolitan area that will need to be addressed to ensure successful urban infill development, specifically a lack of green spaces and the prevalence of food deserts. For these barriers we performed case studies of cities which have overcome these issues in order to make recommendations for Phoenix. One example of green space implementation discussed is already a Phoenix community – we simply recommend replicating this type of project on a larger scale. We then describe a set of indicators that might be
useful for municipalities to use to assess their progress throughout the process of overcoming these barriers to transit-oriented development.

**POLITICAL/INSTITUTIONAL BARRIERS TO MASS TRANSIT IN PHOENIX**

**Barrier: Political inertia works against the adoption of transit oriented development**

Traditionally, the cities that make up the greater Phoenix metropolitan area embrace the concept of “home rule,” wherein any powers not specifically given to state and federal government are reserved by each of the cities unto themselves. This concept is an outgrowth of suspicion toward the authority of centralized governments, and is a common characteristic in many American metropolises, particularly in the Midwest and west. In Maricopa County, home rule is prominently on display in the operation of the Maricopa Association of Governments (MAG), the regional planning agency charged with oversight of transportation projects. MAG has to frequently balance the needs and desires of each of the more than twenty cities party to its jurisdiction, and allay the fears of any one city in getting “run over” or dictated to by a larger or more influential city. Because of home rule, many times MAG is stymied in its effort toward building higher quality transit options. For instance, Phoenix, Tempe, and Mesa have each more or less embraced the potential of rail oriented transit, and have made efforts toward expanding the (surprisingly successful) system on a regional basis. Ring suburb cities, notably Scottsdale, but also others such as Buckeye and Surprise, have resisted these expansions due to cost considerations, but also because their citizens have yet to see the need for any kind of mass transit beyond limited busing, and also a general fear of the kind of social changes expansion of transit options serving primarily poor and minority citizens might bring. These cities rely on their powers under home rule to prevent being forced to acquiesce to regional transit.

Economically, the citizens in these suburbs are still fairly comfortable with the system they have already invested in, namely automobile based transit with its attendant streets and highways. Since they already own their vehicles and are pleased with the freedom and access those vehicles provide, they see little reason to increase taxation rates to invest in other forms of transit they will find little reason to use. As the current state of Arizona’s roads and highways is still very good, the status quo remains in place.

In terms of politics, representatives in government feel little incentive to buck this status quo, as the constituents who invest the time and effort to involve themselves in the political process are “automobile centric”. The people who vote tend to be older, less ethnically diverse, and more affluent than the population as a whole, and are precisely those who would tend to find the least value in a public transit scheme.
Solution: Overcome inertia by atomizing and individualizing transit by city

Still, many cities without more robust transit options have begun to look upon the success of the existing light rail corridor with envy, and have begun to see the potential advantages that diversifying their transit can offer. Realizing that there is no “one size fits all” approach to transit, and that a more landlocked city would fall back upon home rule to stand against solutions developed for a city with more flexible borders, we propose that MAG begin the process of developing a tailored transit package for each city within the county that has the potential for high levels of baseline ridership as identified by the ST-LUIS study. Since it is politically and economically impossible to treat the greater Phoenix community as a single city, we say, “Don’t do it!”

By focusing mass transit efforts on a “by city” basis, the citizens and governments of those cities can adopt the transit that they specifically need and are willing to pay for. In the short run, this will mean that there are many separate transit schemes instead of one larger one. This will, of course, be less efficient. But it will serve the most important first purpose of breaking down the mental barriers the members of these communities have regarding their transit options. Once they build and have begun to rely upon those transit options, only then will integration into the larger metropolitan transit scheme become possible, and perhaps even desirable.

Barrier: Difficulty in Procuring Funds for Transit Projects

In order to continue having access to public transportation it is obvious that there will need to be funding provided to the state of Arizona for deployment of such services. Among several methods to get this funding, one that has proven to have success in Maricopa County is the usage of sales and gas taxes. Most notable is Proposition 400 which was passed in November of 2004 and is currently active until December of 2025. Proposition 400 enacted a half-cent sales tax to construct new freeways, improve arterial systems, as well as to fund public transit such as light rail and various bus services as stated by Valley Metro (2014). What makes taxes such as these important is that they give transit-oriented development a boost in financial support thus increasing its rate of implementation. On the downside, opposition from the public to approve of such taxes can be difficult to overcome and it is important to continuously understand how likely the public is to vote for such propositions. This section of the report is directed toward discussing public views in order to gauge how well tax programs will benefit future TOD improvements and expansions. The two primary sources of information being used for this case study are the meeting minutes from the Maricopa Association of Government (MAG) presented on January 29, 2014 and the PowerPoint presentations discussed at this meeting.

Measuring public opinion as well as attitude is a difficult task since standpoints vary from person to person. However, one common tool that has had success is surveys which in particular can translate responses into observable data. One such survey that pertains to revenue for TOD was implemented in December 2013 to evaluate the public residing under the MAG, which includes
Maricopa County and parts of Pinal County. This Regional Transportation Survey (RTS) specifically targeted 602 “high efficacy voters, not general voters, to discover their receptiveness on taxes or fees for transportation” (Maricopa Association of Governments [MAG], 2014). Of these 602 voters 82% were of Caucasian race, a total of 68% were of age 55 or older, and 76% frequently drive alone to work (MAG, 2014). Looking at these demographics depicts who these frequent voters are which Eileen Yazzie, a staff member of MAG, stated tended to be “older, White, and Republican” (MAG, 2014). What this data shows is there are both a lack of ethnicity as well as an age gap within the high efficacy voters. With the majority of votes coming from one prominent group it becomes evident that their combined voting power has the most potential to decide the outcomes of TOD. Thus, we look at their survey responses in further detail to determine how they may choose to vote for the taxes that support TOD.

To start the analysis of the survey responses, the second question that was asked was “What do you think is the ONE most important transportation-related issue or problem in the greater Phoenix area today” (MAG Regional Transportation Survey, 2014). As this was an open ended question 18% said lack of bus service/ rapid transit and 11% said lack of light rail and access to light rail. These two responses were in the top three most popular being preceded by traffic congestion on freeways taking 18% of the response. These numbers are striking because they show that public transit is still considered a big problem by the frequent voters. From this nearly half of the voters said that by improving the public transportation issues it would most improve the overall transportation problems in their area. The key takeaway from these numbers is that frequent voters perceive that there is a need for improvements to public transportation. Even though these individuals acknowledge the problem of public transportation, the way in which they approach solving these issues sheds light on if taxes are the best way to fund TOD. The last important statistic that came for the MAG RTS is that the high efficiency voters had opposition to helping improve the public transportation problem through their own contributions. As Kathy DeBoer from WestGroup Research stated “support drops when is seems that the tax or fee will increase their own costs” (Meeting Minutes, 2014). With this lack of support, an extension of the half-cent tax to help fund transportation is not likely to win the popular vote. Putting these prime findings from the survey together indicates that voters are evidently aware that there is a problem with the current state of public transportation. It is also clear that they understand that this is an important problem that needs to be fixed to improve the transportation within their area. Despite their understanding, they still are unlikely to pay for these problems to be solved. Reflecting on this case study has shown that there is room for improvements.

**Solution: Marketing and public education campaigns must be put into place**

Looking at the demographics of the surveyed participants holds the key for addressing the problem of getting funding through tax programs. Again these participants are the high efficacy voters who are generally older, White, Republican, and drive alone 76% of the time. It is evident that there exists an age gap as well as a dominant race at each election. Therefore, the other ethnicities, age groups, political groups, and voters who do not regularly travel alone need to be engaged in the
voting process. Thus, diversifying the demographics of future high efficacy voters is the task at hand. This can be done through stronger campaigning and educational programs sponsored by the cities of Maricopa County. Both the benefits and drawbacks of implementing TOD need to be thoroughly discussed among these potential voters while emphasizing the benefits. When choosing which benefits to discuss there needs to be a strategy to make sales taxes look appealing to the public. Martin Wachs analyzed the sales tax that the state of California passed to benefit transportation and found important characteristics that should be discussed with the public. Of these characteristics the two that can be emphasized in Maricopa County are labeled “taxes have finite lives” and “local control over revenues” (Wachs, 2006). By explaining to the public that the taxes they vote have a finite life span, usually from fifteen to twenty years, allows the public to have a sense of control over their money according to Wachs. In addition this also gives some flexibility for change in the system, meaning if the transportation projects do not please the public then they have the chance to vote for a different option in future elections. Wachs’ concept of “local control over revenues” requires explaining to potential voters that the revenue generated from the sales tax will be used only for the approved projects. Doing so informs the public that their investments will be used for only the projects they voted on. This will give the public reassurance as to why such taxes, like Proposition 400, need to continue. If allowed, these improvements create potential to attract new voters of different demographics. It should also be emphasized that the existing infrastructure still has significant costs. Although Maricopa County’s roadways are currently in good shape, maintaining them over time is a cost ADOT has estimated to be tens of billions of dollars, and has upwards of a dozen new taxation schemes to raise this money. Compared to this, TOD is a small investment with large potential rewards.

With increased awareness and knowledge of why taxes are needed for TOD funding, it also creates the potential for building coalitions that are in favor of adopting TOD. These coalitions are for the purpose of voting on sales taxes for public transportation projects, showing strong approval of implementing TOD. Having these pro-sales-tax coalitions allows the public to group together, working toward achieving a mutual goal. Therefore it will result in a melting pot of demographics since such a coalition does not focus solely on agendas of race, wealth, age, or politics. An example of where a pro-transportation coalition formed was in the case of Denver, Colorado during the FasTracks light rail project. During its construction a “coalition of area mayors, the RTD [Regional Transit District] board, elite and minority businesses, and organized labor” overcame opposition and secured the vote for a sales tax to build the light rail project (Lowe, Pendall, Gainsborough, & Nguyen, 2014). In addition to the members included in the Denver coalition, Maricopa County will have to strongly involve the public. From here the under-represented voters will be targeted and taxes can be voted on to give the much needed funding for TOD projects.

**Barrier: Current Light Rail Development**

The light rail is currently located in three cities in the Phoenix metro area: Mesa, Tempe, and Phoenix. Since the installation of the light rail and subsequent success, these cities are making
progress towards transit-oriented development through new development and re-development of their downtown areas specifically.

The first 20 miles of the light rail was opened in December 2008, funded by a combination of the federal government, the cities of Phoenix, Tempe, and Mesa, and money from the Proposition 400 half-cent tax (passed in 2004). Funds from Prop 400 will also be used to cover some costs of future extensions to this light rail system. These extensions would add track in all directions, including a streetcar in downtown Tempe. The 3.1-mile extension farther east into Mesa is currently being constructed, and is set to open in 2016. The 3.2-mile extension in the northwest valley is also being constructed, and will also open in 2016. The other extensions will be opening over the next few decades until 2032, resulting in about 57 miles of light rail in the Phoenix metro area.

**Development in Phoenix**

In 2004, on the heels of Proposition 400 passing, the Phoenix City Council approved a development plan for downtown Phoenix, which focused on development along the then-future light rail line. This plan included information on converting the area to be more pedestrian-friendly, which in turn would make it more light rail-friendly, decreasing the amount of parking available to discourage vehicle use, increase housing densities, and creating mixed-use areas. All these ideas ultimately lead to this plan to be focused on transit-oriented development. A progress update for this development plan was published in 2007 in order to show what was done since passing the original development plan in 2004. There were definitely improvements shown with entire projects in housing, retail, and business being completed, and future projects were proposed and in planning stages. The partnership with ASU has really helped downtown Phoenix grow, especially with the light rail connecting two campuses. In 2013, the Phoenix City Council adopted a study, “Adams Street Activation Study” to focus on developing key areas of downtown Phoenix. This study basically helped solidify the Phoenix City Council’s vision for the downtown area in the future.

The City of Phoenix is currently pushing for more businesses to move into the downtown area through certain incentives and programs including assisting Phoenix businesses with getting loans and bonds that go towards specific development projects. The Phoenix City Council is also focusing on targeting specific industry sectors to come to Phoenix and working with current businesses in Phoenix to continue to grow within the city. In order to accomplish this, they want to really focus on the downtown area and surrounding areas by encouraging and supporting adaptive reuse projects, streamlining regulatory processes, launching another Biomedical Research and Education campus through collaboration with Mayo Hospital and ASU, and focusing on development along the light rail corridor.

**Development in Tempe**

In 2003, the City of Tempe adopted a general plan for Tempe by the year 2030, which was then ratified in 2004, and amended in 2007. In this plan, it is evident that the City of Tempe had decided
to focus on development of the downtown area, especially around the light rail. In 2005, the City of Tempe adopted the Transportation Overlay District to encourage development and redevelopment of regions that would become part of a multi-modal transportation system. This District regulates land uses and also has a set of development standards that support transit, bicycle, and pedestrian traffic, and prevent development that would disrupt those modes of transportation. Also within this General Plan 2030, the City of Tempe outlines objectives and strategies for developing the city like community development, revitalization, encouraging mixed-use and mixed-income areas, promoting walkable communities, encouraging alternative modes of transportation, redevelopment of existing infrastructure, and eliminating non-essential traffic. The City of Tempe also partnered closely with ASU, much like the City of Phoenix, in order to address development issues and figure out ways to overcome those problems together since ASU is a major developer in both cities.

While there are no extensions of the light rail planned in Tempe, there is a proposed streetcar plan that would be located in downtown Tempe near the ASU campus. Tempe has continued to develop the downtown area through their partnership with ASU, especially since the light rail was opened. However, the City of Tempe did make zoning changes before the light rail was opened in order to prematurely promote TOD. Other Overlay Districts were created in 2005 and 2006 throughout Tempe in order to follow development mentioned in the General Plan 2030. The City of Tempe has created a General Plan 2040, but it will not be ratified until elections later this year. Tempe currently has many projects in the works for the downtown/ASU area with new businesses and housing being planned, constructed, and completed in the next few years. The downtown area is truly bustling with development.

**Development in Mesa**

The City of Mesa recently adopted the Central Main Plan in 2012, which will focus on development along the light rail corridor. The plan is for mixed-use, transit-oriented development to occur along that corridor in order to create a more active and safe downtown area. This plan is actually an add-on to the General Plan passed in 2002 in order to address new issues within the city in terms of development. Much like the City of Tempe, this Central Main Plan addresses changes to zoning regulations that would regulate development to only include new development projects and redevelopment projects that focused on mixed-use areas and transit-oriented development. This development plan also makes broad recommendations for change in order to make Mesa a more sustainable city by increasing density, and using other urban areas like Denver, Portland, Salt Lake City, and San Diego as examples for why Mesa needs to make changes. Compared to the General Plan 2025, the Central Main Plan really makes detailed recommendations and plans for the future, while the General Plan was very much Business-As-Usual without much detail as to how Mesa will be in the future or what changes will occur.

The City of Mesa is focusing on drawing in potential businesses through the success of the light rail, future light rail extensions into Mesa, and the new approach of transit-oriented development.
in the city. There is a push towards finding businesses development areas in the downtown Mesa area since that is the potential most-profitable area from the light rail and other transit options. Some incentives that the city offers are grant programs, a loan fund, tax credit programs, and working directly with businesses to create a customized development schedule. The city also includes small businesses in this focus by providing assistance with starting and establishing a business and the downtown area, also making those same incentive programs available.

**Promoting Development in All Three Cities**

Valley Metro has partnered specifically with the cities of Tempe, Phoenix, and Mesa to promote transit-oriented development, including future light rail extensions. One program that draws attention to future light rail extensions is the METRO Max Rewards that seeks to draw consumers to businesses along future light rail extensions by offering discounts, special deals, promotions, and giveaways at participating businesses.

LISC, or the Local Initiatives Support Corporation, is a non-profit organization with a focus on community development in certain cities like Phoenix, Mesa, and Tempe due to the light rail corridor going through those three cities. In 2011, LISC made a lending commitment of $10 million to Phoenix, Mesa, and Tempe in order to promote transit-oriented development along the light rail corridor, with emphasis placed on housing, retail, and health development. Basically LISC offers grants and loans to organizations for projects focused on community development by mobilizing corporate, government, and philanthropic support of these types of projects. LISC also has two tax credit programs in place for projects in low-income areas.

**What Can We Learn from Portland’s TOD Program?**

One city that has already employed effective transit-oriented development is Portland, Oregon. Portland’s transit-oriented development efforts began in 1998 with the creation of their official TOD Program. Their focus was to educate investors and incentivize TOD through TOD capital improvements, land acquisition, urban living infrastructure improvements, green improvements, and planning activities and studies. In 2011, the TOD Strategic Plan was created by Portland Metro in order to guide all future investments in TOD projects. Between completed or under construction projects, and approved projects, the TOD Program added 2,100 housing units, 110,000 ft² of retail space, 140,000 of office space, and induced 540,000 additional transit riders per year. Like Tempe and Mesa, Portland also has overlay districts that regulate which development can occur around transit. The Metro TOD Program mainly utilizes the purchasing of transit-oriented development easements from developers in order to cut costs for private investors, however to be eligible for the program, the project must meet certain development requirements important to TOD like mixed-use or high density development. In Metro’s 2040 plan, they expect even more TOD and don’t want to extend the city outwards – just upwards – by focusing on development along a specific light rail line. Obviously TOD took some time in Portland as well, and they are employing similar incentive programs to Phoenix, Mesa, and Tempe, but the difference is that they started
very early on (they were the first TOD program in America), and have had time to develop their plans for TOD across Portland.

**Solution: Transit-oriented development plans in place upon construction**

What stands out the most from the information on development in all three cities is that Phoenix and Tempe were way ahead of Mesa. Once those cities heard that a light rail line would happen in the upcoming few years, they made sure development plans were in place that would promote the light rail and any surrounding retail, commercial, or housing spaces. Something really important that these cities did was ensure that only certain development projects could occur surrounding the light rail – basically, all the projects had to support transit-oriented development in order to be constructed or reconstructed along the light rail. Phoenix and Tempe foresaw the economic benefit of the light rail, and used it as an opportunity to improve their cities. Mesa on the other hand, continued on the same path. This could be due to the fact that they didn’t want to risk putting money into development when they didn’t know how well the light rail would do economically, paired with the fact that only a small portion of the light rail would be in the city. However, once the light rail was a success, Mesa created a new development plan to incorporate transit-oriented development. In fact, all previous development plans were very simple, with very little detail on what exactly the city was going to do in the future. The language used made it seem like the city of Mesa just wanted to continue on that same path. The new development plan was quite the change – a longer document that was very well organized and made much more specific promises on new development or redevelopment. The light rail’s success essentially convinced the city of Mesa to make major changes in how the city was run, and how they would truly become more urban than suburban.

So far, Phoenix and Tempe have done well with development and redevelopment, but Mesa is behind. What has really driven Phoenix and Tempe is their partnership with Arizona State University since the university has many students moving between the Tempe and Downtown campuses. Phoenix and Tempe need to further their partnership with ASU in order to continue making strides with development and redevelopment. Through that partnership, they gain ASU’s support, as well as any other groups, organizations, or companies that ASU itself is partnered with.

Since Mesa does not have the option to partner with ASU to build up their downtown area, they must instead look to Phoenix and Tempe as inspiration, and potentially work together to further development. By developing Mesa, especially around the new extension currently being constructed, Phoenix and Tempe would also benefit since there is a large population in Mesa that could use the light rail to visit Tempe or Phoenix. By building the new Cubs spring training stadium and upgrading the surrounding Riverview area, Mesa is convincing more people to visit the city. This could lead to developers wanting to build up the city more, but Mesa really needs to convince interested developers that they are ready and willing to work with them in order to meet both of their needs.
From the study of the city of Portland and their focus on transit-oriented development, Valley Metro could also make changes in order to further TOD in the Phoenix area, especially around existing light rail in Phoenix, Tempe, and Mesa. In Portland, Portland Metro has essentially become a third-party organization that deals with all cities within the Portland metro area in order to further TOD. Valley Metro could use their partnership with Phoenix, Tempe, and Mesa to create some sort of TOD program, much like Portland Metro’s TOD program that was started in 1998. By having these large cities in the Phoenix Metro area back a TOD program created by Valley Metro, Valley Metro would have a much easier time of gaining new developers and redevelopers to go to the cities, as well as look at other cities in the Phoenix metro area that may have future extensions of the light rail. The key to take away from the Portland Metro TOD program is that they really focused on educating investors about TOD, and what they could gain from TOD in the Portland area. Valley Metro could employ that same idea of educating investors interested in development in the Phoenix area, and how they can benefit from TOD.

Socio-economic barriers to mass transit in Phoenix

 Barrier: Maricopa County’s dependence on the construction industry

An important economic barrier to the further establishment of mass transit in the Phoenix metropolitan area is the lack of economic diversity related to an over-reliance on the construction industry in the region. In order to limit the continual expansion of sprawl in the Phoenix metropolitan area, economic transition and diversification with complimentary policy incentives are required. As of 2007, Construction is third largest NAICS industry in Arizona in terms of employer value, behind Wholesale Trade and Retail Trade, and is 8th largest in terms of employment as of 2011 (U.S. Census Bureau, 2007; County Business Patterns, 2011). This reliance on construction for economic growth combined with policy incentives and cheap peripheral lands will be a significant barrier to infill development and TOD. Without the construction industry, Arizona’s economy will be severely affected. Hence, it will be important to adopt policy incentives that perhaps could shift the economy into other sectors and improve profit margins for infill developments and TOD. By shifting economic reliance, sprawl growth could possibly be slowed. This was evident in the economic crisis of 2008, when the construction industry and housing market collapse in Arizona led to a large number of foreclosures on the urban fringes. Shifting economic reliance away from construction and the housing market could help prevent such a crisis from occurring in the future. Another economic issue is the fact that the housing market does not provide adequate alternatives to single-family homes. The argument is made that this is because of consumer choice, however, the market has restricted choices from the start (Levine, 1999). This means that the consumers cannot and have not properly expressed their preferences. If alternatives could be provided, perhaps the market would shift and reflect consumer choices more accurately, alleviating some of the sprawl and low density development issues.
Barrier: A Lack of Affordable Housing

Social equity is an important issue regarding sprawl, as sprawl limits access by the elderly, the young, and the poor to jobs, recreation, and food (Ewing, 1997). There are also important issues regarding environmental deprivation and a loss of a sense of community (Ewing, 1997). Furthermore, with sprawl, there is a great necessity for automobile ownership in order to achieve accessibility, which segregates the elderly, the young, and the poor from the rest of the community and greater urban region. By building at a higher density, which infill development and TOD can help achieve, it can reduce some of the social equity issues. However, TOD and infill tend to increase property prices and desirability of neighborhoods, leading to gentrification. Several barriers will need to be overcome in order to prevent gentrification of TOD neighborhoods.

The ASU Stardust Center for Affordable Homes and the Family prepared a report in 2008 that reviewed four reports relating to affordable housing in the Phoenix area, and identified the regional barriers to affordable housing. Many are corroborated by a report by HUD detailing the regulatory barriers to affordable housing found throughout the country (HUD, 2005). The Stardust report is too comprehensive to completely review for the purposes of this deliverable, so only prominent social and developer barriers will be discussed. It is worth noting that this report was released in 2008, pre-recessionary impacts, so some of the barriers mentioned, especially social, have worsened since the creation of the report.

Social barriers: Wage gaps, lack of employment opportunities, a lack of awareness of affordable housing units, a growth in cost-burdened households, high property taxes, and “Not in my backyard” mentality (NIMBYism)

A number of social barriers must be overcome to successfully transition to a TOD-friendly metropolitan area (ASU Stardust Center, 2008). Ensuring that employment opportunities are created in tandem with housing along transit corridors not only for job creation, but also for job proximity, would help low-income individuals secure financial stability, and hopefully help reduce wage gaps. Local and regional economic development departments could be asked to make an effort to attract businesses to the transit corridor that would guarantee long-term jobs with livable wages for future employees. The City of Phoenix’s Housing Department, Maricopa County’s Housing Authority, and other such agencies could be encouraged to better market the availability of affordable housing units, or the availability of assistance in finding and securing affordable housing units, to low-income residents. Mitigating the first two barriers would help lower the cost burden on lower-income residents, and hopefully help reduce the number of cost-burdened households in the region.

High property taxes caused by gentrification could be mitigated by implementing infill property tax credits for new owners of infill housing, and perhaps even waiving rental taxes for renters in TOD or infill overlay zones, would help attract new residents to the area. Property tax relief or
property tax caps could be instituted to help allow current owners to remain in the area should their
property values and taxes skyrocket in response to new infill development.

The most difficult barrier to overcome is so pervasive that it is worthy of discussion. NIMBYism
can lead to exclusionary zoning and other regulatory barriers that keep out unwanted uses (such as
affordable housing) and drive up land prices. Fostering a greater community spirit, holding public
meetings to discuss the benefits of mixed-income communities and transit corridors, and making
an effort to listen to and allay the community’s fears regarding potential changes to the area might
be first steps that could be taken in helping to eliminate some NIMBY mentality.

**Developer barriers: Process clarity, financial considerations, and zoning**

Most of the barriers listed by developers were complaints regarding the unpredictability they face,
specifically for review procedures and fee schedules (ASU Stardust Center, 2008). These could
easily be mitigated by encouraging municipalities to settle on review procedures and fee schedules
which would remain in place for a set period of time. If changes are to be made, notice should be
given well in advance to allow developers to plan for impending changes for their development
schedules and budgets. Impact and development fees are also listed as a barrier; while developers
often pass along these costs to the owners, they must bear the upfront costs (ASU Stardust Center,
2008). These fees could be reviewed to ensure they are fair to multi-family developments, or
perhaps even lessened for both single-family and multi-family development in infill or TOD
overlay districts. Lastly, developers complained of a return to inclusionary zoning, such as
requiring a specific percentage of units built to be set aside for affordable housing (ASU Stardust
Center, 2008). These complaints could be mitigated by allowing developers to build more units
than the zoning currently for, so long as they set aside a specific percentage of units for affordable
housing.

**CASE STUDIES**

**Successful Green Space Implementation**

One case of the successful implementation of green space – in the form of trees for shade – can be
found right here in Phoenix. A mix of students and professors from the Arizona State University
School of Sustainability were able to successfully plant trees in the Sky Harbor Neighborhood in
Phoenix (Bernstein, Wiek, Brundiers, Pearson, Minowitz, Kay & Golub, 2013). The intervention
study aimed to engage with the community in participatory research while taking the form of a
transformative rather than descriptive-analytical type of research. This study provides a great
example of how to actually achieve change in the implementation of mitigation strategies for urban
challenges, and is replicable and adaptable – especially when used in the TOD application our
team is studying (Bernstein, Wiek, Brundiers, Pearson, Minowitz, Kay & Golub, 2013). The Sky
Harbor Neighborhood falls in the zone for potential TOD implementation, making this case study even more important and applicable.

Bernstein et al. followed almost the exact same procedural framework that our group is undertaking: problem analysis, visioning, intervention design, and intervention test through extended peer review (Bernstein, Wiek, Brundiers, Pearson, Minowitz, Kay & Golub, 2013). The first three steps from Bernstein’s study are parallel to our own work, but our group will not be testing the intervention strategy laid out in the third step. This is primarily due to the limited scope of our work, as this is only a semester long class and the chances of intervention testing is unlikely to occur before the end of the semester. The implementation of the intervention strategy (the planting of the trees) was laid out in three distinct steps: plan, plant, and care (Bernstein, Wiek, Brundiers, Pearson, Minowitz, Kay & Golub, 2013). A similar plan would need to be developed in our project in order to ensure longevity of created green space.

It cannot be stressed enough that the success of Bernstein et al.’s project revolved around stakeholder engagement throughout the entirety of the project. Engagement of the community began from the very outset of the project, building trust between the authors of the study and the members of the community. Appropriate solutions were crafted not by the project authors, but by a combination of both scientific and local residential communities (Bernstein, Wiek, Brundiers, Pearson, Minowitz, Kay & Golub, 2013). Again, the scope and time constraint of our project will not allow for this step, so our solutions will be normative and would need serious refinement before implementation.

Recommendations for Phoenix:

- Expand on Bernstein et. Al.’s shade intervention project to target larger green spaces (plan, plant, care)
- Involve community stakeholder engagement from the outset to create a vision for green space (particularly around TOD)
- Include input from potential homeowners and other relevant actors in the vision
- Assess the vision for sustainability
- From the created vision, craft a strategy to reach the desired future state
- Create a community committee to ensure continued welfare and use of new green space (landscaping, maintenance, events, etc.)

Successful Food Desert Elimination

One study that analyzes various cases of food insecurity in urban areas around the nation provided three examples of cities that succeeded in eliminating food deserts (Pothukuchi, 2005). These three cities were Dallas, Rochester, and Chicago. Dallas and Rochester were aiming specifically at solving the issue of lack of supermarkets, while Chicago was able to achieve food desert
elimination through an umbrella program - Retail Chicago - that sought to bring retail in general to underserved areas (Pothukuchi, 2005).

In the case of Dallas, a study was first done on the current state of grocery store distribution in south Dallas. After the identification and clarification of the problem (lack of grocery stores), financial incentives were given to the only grocery store chain that responded to the call for development in south Dallas – Fiesta Mart (Pothukuchi, 2005). Fiesta Mart built three new stores which achieved great success both through customer support and the financial incentives from the Dallas City Council (Pothukuchi, 2005). The success of Fiesta Mart attracted more chains of grocery stores hoping to achieve financial success in the same manner, thus reducing food deserts in south Dallas even further.

In the case of Rochester, the chain of events leading up to grocery store developments was slightly different. The initial push came from a “community-based food advocacy organization”, Partners Through Food, before efforts were made by the mayor to act (Pothukuchi, 2005). Tops Markets Inc. showed interest in development, strictly as a business move. Wegman’s had developed in Tops Markets Inc.’s home town of Buffalo, so Tops Markets Inc. wanted to counter the infiltration by developing on Wegman’s turf in Rochester, taking some of their competitors market share (Pothukuchi, 2005). Tops opened five new stores in Rochester, including one in the specific zone proposed by Partners Through Food.

Chicago’s success differed in that it was part of a larger movement that incentivized and promoted retail development in the city (Pothukuchi, 2005). Supermarket development in Chicago’s most underserved areas came at a cost – literally. The main reason supermarkets developed in the food deserts of Chicago was for the financial incentives. These incentives came in the forms of “…property tax abatements, low-interest loans, tax-increment financing, and bond financing in [empowerment zones] and state enterprise zones” (Pothukuchi, 2005).

While these three cities provide examples of cities which were able to successfully decrease or eliminate food deserts, some important observations can be made that may help to adopt a similar strategy for the case of food deserts in Phoenix. Simply put, attention must first be brought to the issue of food deserts/lack of grocery stores in a particular locality. This step has already been accomplished for the case of Phoenix, as 55 food deserts have been identified in Maricopa County (Lasch, 2012). The cases above all have support of local government, so the next step for the case of Phoenix would be to try to win support of authorities in a position of power. Another common thread in the successful cities above is that the main driver for success (arguably) is distribution of financial incentives to grocery stores who will move into predefined zones. In summary, what Phoenix needs in order to eliminate food deserts – particularly surrounding potential TOD zones – is political support and financial backing. Once those two major milestones are achieved, grocery stores will have no problem moving into any of the 55 food deserts of Maricopa County. The elimination or reduction in the number of food deserts will in turn help to support successful TOD, and ultimately take away from BAU development.
Recommendations for Phoenix

- Bring widespread attention to the issue of specific food deserts in localities
- Win support of authorities in positions of power (government)
- Identify local/regional grocery store chains to target for recruitment
- Offer distribution of financial incentives to grocery stores who move into determined food deserts
- Create community wide education program that teaches nutrition and other healthy habits

INDICATORS

In order to monitor and encourage the removal of political, economic, and social barriers, and the concurrent progression of TOD acceptance and development within Maricopa County, we propose a set of indices or indicators. Each of these metrics can provide a way for cities to measure trends, and evaluate and compare their standing with other cities. These metrics could be used as a marketing tool for cities excelling in TOD development, for those lagging behind, the metrics could serve as an incentive for taking action.

- **Investment in development by development type** - This will provide a look at what type of development projects are being planned and constructed, showing the growth or decline of mixed-use buildings versus single-use buildings.
- **Number of housing development projects and housing units by type** - This indicator will provide a look at the changes in the housing stock and types of housing being constructed.
- **Amount of vacant land developed** - This will provide a measure of infill development achieved.
- **Locations of building permits** - The location of building permits will show trends and movement between infill and fringe development in the metro area.
- **Transit ridership or vehicle miles traveled** - These will provide an absolute measure of the utilization of different transport modes and provide long term data on trends in mode shifts.
- **Employment by industry and location** - This will provide a measure of changes in the economy and employment by different industry sectors and show whether or not the economy is undergoing diversification. It will also show where employment is, so that migration trends and job accessibility can be considered.
Demographic shifts - Changes in demography in the various locations of the metro area can show migrations of different groups of people and their preferences of locations. It can also provide a look at the social equity of different locations and the effects that new development has on social equity when considered in conjunction with housing and employment accessibility.

Public polls/approval ratings for TOD district improvements and projects - This metric can provide a political gauge of the public’s desire for various kinds of development projects and indicate public preferences or lack of preferences. It can also provide insight into educational and knowledge gaps in public information.

Through our investigation of Maricopa County we have diagnosed some of the political, social, and economic challenges here in the Phoenix metropolitan area. Our recommendations provide solutions for diagnosed barriers and possible avenues for promoting change for a better urban environment. The indicators and metrics described provide an accurate gauge for the progression of change.

CONCLUSION

The successful implementation of transit-oriented development in the Phoenix metropolitan area relies on the constituent cities’ ability to collaborate and overcome the political and socio-economic barriers discussed. It is crucial that these barriers be addressed now, as they will require much time and effort to transcend, and future development relies on our ability to set an open pathway today. Just because the Phoenix metropolitan area has a comparatively modern and problem free automobile infrastructure now does not mean that this situation will continue. ADOT projections indicate that tens of billions of dollars will be required over the next twenty-five years to expand and maintain that system in its current state. In short, this means significant taxation is coming, and sooner than many might expect. The transit oriented development advocated in this report is just one solution to part of this problem, but we believe it should be an integral one. In conjunction with the inclusion of green space and the elimination of food deserts, TOD progress will make the region’s mid-21st century transit corridors attractive, thriving communities to be enjoyed by future generations.

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APPENDIX I: TRANSPORTATION CALCULATIONS

RESIDENTIAL DEVELOPMENT ASPHALT CALCULATION

<table>
<thead>
<tr>
<th>Table 51: Variable Definition for Residential Development Calculations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symbol</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>W</td>
</tr>
<tr>
<td>L</td>
</tr>
<tr>
<td>RW</td>
</tr>
<tr>
<td>$A_{du}$</td>
</tr>
<tr>
<td>$d_u$</td>
</tr>
<tr>
<td>$A_D$</td>
</tr>
<tr>
<td>SW</td>
</tr>
<tr>
<td>LS</td>
</tr>
<tr>
<td>LR</td>
</tr>
<tr>
<td>ND</td>
</tr>
<tr>
<td>TP</td>
</tr>
</tbody>
</table>

Area of Dwelling Unit and Associated Roadway Calculation:

$$A_{du} = W \left( L + \frac{RW}{2} \right) = 70ft \left( 100ft + \frac{32ft}{2} \right) = 8750ft^2$$

Area of Quarter-Mile Development Calculation:

$$A_D = \left( \frac{5280 \text{ ft}}{4} \right)^2 = 6,969,600 \text{ ft}^2$$

Total Number of Dwelling Units per Development Calculation:

$$d_u = \frac{A_D}{A_{du}} = \frac{6,969,600 \text{ ft}^2}{8750 \text{ ft}^2} = 796.52 = 796 \text{ dwelling units}$$
Total Number of Developments Calculation:

\[ ND = \frac{485,000 \text{ households}}{du} = \frac{485,000 \text{ households}}{796 \text{ dwelling units}} = 609 \text{ total developments} \]

Total Amount of Pavement Required Calculation:

\[ TP = W \times \left( \frac{SW}{2} \right) \times du \times ND = 70\text{ ft} \times \left( \frac{32\text{ ft}}{2} \right) \times 796 \times 609 = 542,935,680 \text{ ft}^2 \]

\[ 542,935,680 \text{ ft}^2 \times \left( \frac{1 \text{ acre}}{43,560 \text{ ft}^2} \right) = 12,464.09 = 12,464 \text{ acres} \]

**COMMERCIAL DEVELOPMENT PARKING LOT CALCULATIONS**

Total Parking Space Quantity Calculation:

\[ TP = \frac{ACD}{PS} \]

Total Amount of Asphalt for Parking Spaces Calculation:

\[ TAPS = TP \times W_{PS} \times L_{PS} \]

Total Amount of Asphalt for Aisle Space Calculation:

\[ TAA = \frac{ACD \times W_{PS}}{2} \]

Total Amount of Asphalt for Parking Lot Calculation:

\[ T = \sum TAPS + TAA \]
Table 52: Variable Definition for Commercial Development Calculations

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACD</td>
<td>Additional Commercial Demand</td>
<td>MAG</td>
</tr>
<tr>
<td>PS</td>
<td>Number of Parking Spaces/1000 (ft²)</td>
<td>City of Phoenix Code</td>
</tr>
<tr>
<td>TP</td>
<td>Total Number of Parking Spaces</td>
<td>Calculated</td>
</tr>
<tr>
<td>W&lt;sub&gt;PS&lt;/sub&gt;</td>
<td>Width of Parking Space</td>
<td>City of Phoenix Code</td>
</tr>
<tr>
<td>L&lt;sub&gt;PS&lt;/sub&gt;</td>
<td>Length of Parking Space</td>
<td>City of Phoenix Code</td>
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<tr>
<td>WA</td>
<td>Aisle Width</td>
<td>City of Phoenix Code</td>
</tr>
<tr>
<td>T&lt;sub&gt;APS&lt;/sub&gt;</td>
<td>Total Amount of Asphalt for Parking Spaces</td>
<td>Calculated</td>
</tr>
<tr>
<td>T&lt;sub&gt;AA&lt;/sub&gt;</td>
<td>Total Amount of Asphalt for Aisle Space</td>
<td>Calculated</td>
</tr>
<tr>
<td>T</td>
<td>Total Amount of Asphalt for Parking Lot</td>
<td>Calculated</td>
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</table>

Table 53: Commercial Parking Lot Asphalt Requirements

<table>
<thead>
<tr>
<th></th>
<th>ACD (ft&lt;sup&gt;2&lt;/sup&gt;)</th>
<th>P S</th>
<th>TP</th>
<th>WPS (ft)</th>
<th>LPS (ft)</th>
<th>WA (ft)</th>
<th>TAPS (ft&lt;sup&gt;2&lt;/sup&gt;)</th>
<th>TAA (ft&lt;sup&gt;2&lt;/sup&gt;)</th>
<th>T (ft&lt;sup&gt;2&lt;/sup&gt;)</th>
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</thead>
<tbody>
<tr>
<td>Office</td>
<td>126,218,000</td>
<td>5</td>
<td>631,090</td>
<td>8.5</td>
<td>18</td>
<td>24</td>
<td>96,556,770</td>
<td>64,371,180</td>
<td>160,927,950</td>
</tr>
<tr>
<td>Industrial</td>
<td>91,622,400</td>
<td>5</td>
<td>458,112</td>
<td>8.5</td>
<td>18</td>
<td>24</td>
<td>70,091,136</td>
<td>46,727,424</td>
<td>116,818,560</td>
</tr>
<tr>
<td>Retail</td>
<td>62,045,000</td>
<td>5</td>
<td>310,225</td>
<td>8.5</td>
<td>18</td>
<td>24</td>
<td>53,048,475</td>
<td>35,365,650</td>
<td>88,414,125</td>
</tr>
</tbody>
</table>

**COMMERCIAL TRIP GENERATION CALCULATIONS**

Number of Average Daily Trips Generated by Office Space Calculation:

\[
Average \ Daily \ Trips = EXP \left[ (0.844) \left( \ln \left( \frac{Office \ Space \ in \ ft^2}{1000} \right) \right) + 2.231 \right]
\]

Number of Average Daily Trips Generated by Retail Space (Weekday) Calculation:

\[
Average \ Daily \ Trips = EXP \left[ (0.65) \left( \ln \left( \frac{Shopping \ Center \ Space \ in \ ft^2}{1000} \right) \right) + 5.83 \right]
\]
Number of Average Daily Trips Generated by Retail Space (Saturday) Calculation:

\[ \text{Average Daily Trips} = \exp \left( 0.63 \left( \ln \left( \frac{\text{Shopping Center Space in ft}^2}{1000} \right) \right) + 6.23 \right) \]

Number of Average Daily Trips Generated by Retail Space (Sunday) Calculation:

\[ \text{Average Daily Trips} = 15.63 \left( \frac{\text{Shopping Center Space in ft}^2}{1000} \right) + 4214.46 \]