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Future Life-Cycle Footprints of Passenger Transportation in San Francisco

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Executive Summary:

Vehicle trips presently account for approximately 50% of San Francisco's greenhouse gas emissions(San Francisco County Transportation Authority, 2008). City and county officials have developed aggressive strategies for the future of passenger transportation in the metropolitan area, and are determined to move away from a "business as usual" future. This project starts with current-state source data from a life-cycle comparison of urban transportation systems (Chester, Horvath, & Madanat, 2010), and carries the inventoried emissions and energy usage through by way of published future scenarios for San Francisco. From the extrapolated calculations of future emissions/energy, the implied mix of transportation modes can be backed out of the numbers. Five scenarios are evaluated, from "business as usual" through very ambitious "healthy environment" goals. The results show that when planners and policymakers craft specific goals or strategies for a location or government, those targets, even if met, are unlikely to result in the intended physical outcomes. City and state governments would be wise to support broad strategy goals (like 20% GHG reduction) with prioritized specifics that can inform real projects leading to the goals (for instance, add 5 miles of bike path per year through 2020, or remove 5 parking garages and replace them with transit depots). While these results should not be used as predictions or forecasts, they can inform the crafters of future transportation policy as an opportunity for improvement or a cautionary tale.

Background:

Transportation is one of the most problematic and complex sources of unsustainable behavior in urbanized America. Researchers and policymakers from around the world have attempted to solve the problem throughout the last century, yet the problem constantly changes while solutions continue to fail. Citizens of urban cities demand mobility in order to maintain their lifestyle. Americans expect access to transportation options (infrastructure, an active market, and freedom to travel), whether the benefits of mobility fulfill basic necessities (access to food, healthcare, work, education) or leisure activity (entertainment, spiritual/family activity, fitness). Passenger transportation has both real costs and external costs (externalities). In solving the sustainability problem, the key is to maintain the benefits derived from passenger transportation while reducing or nullifying the negative impacts from regularly transporting people to and from locations (Köhler et al., 2009; Maddison et al., 1996).

Transportation mobility is a necessity for survival in modern U.S. society, but is often ignored or dismissed in computing the operating costs or impacts of day to day living. In economic terms, transportation can display characteristics of both a private good and a public good, and transportation infrastructure can also hold characteristics of a commons (Chapman & Shultz, 2009; Ostrom, 2005; Taylor, 2004). Since many benefits of transportation are intangible, while construction and operating costs of transportation modes are real, it is easy to conclude that any mode of transportation is an economic loss for a city. There are both positive and negative externalities that can be calculated for any passenger trip or some amount of transportation infrastructure. One way to move towards a “level playing field” when analyzing transportation mobility is to assess metrics from a life-cycle view. This is precisely the starting point for my project: a life-cycle assessment (LCA) comparison of urban passenger transportation systems (Chester et al., 2010).

Urban planners and city governments recognize that a robust and functional transportation infrastructure is critical to the viability of the city, but are often faced with tough budgetary choices when revenues fall short of costs. One such city is San Francisco, which has very progressive policies and goals towards environmental stewardship, has published both a Climate Action Strategy (2011) and a 30-year Countywide Transportation Plan (2004), and has top-cover from progressive state government policies and goals. San Francisco County authorities point out that automobile usage accounts for approximately 50% of the city’s greenhouse gas emissions (San Francisco County Transportation Authority, 2008). Chester et al. (2010) compared life-cycle and emissions footprints of passenger transportation in urban cities, including San Francisco. These life-cycle footprints were calculated for a timeframe that can be considered current-state (a blend of existing technical standards/metrics and data from travel surveys completed in the last decade). San Francisco has no intention of carrying this current-state into the future, and intends to alter their future transportation footprint through several initiatives over the next 30-40 years (SFCTA, 2011; San Francisco Municipal Transportation Agency, 2011). While the goals are relatively clear in the minds of transportation and government officials, the paths towards those goals are unclear and fraught with uncertainties and barriers (technical, financial, behavioral). If the goals are achieved, will San Francisco be better off than the status quo, and will unintended consequences emerge to dominate the future footprint of passenger transportation?

Research Statement:

The San Francisco metropolitan area has developed several strategies for the future of transportation infrastructure and mobility. Each of the strategies proposes a goal for modal-mix or emissions reduction, yet none of the published documents are specific enough to detail ridership, infrastructure requirements, or technical performance improvements. While efforts are under way to mitigate transportation impacts by 2035, ambiguous and vague targets may result in initiatives that are doomed from the start or have unintended consequences.

System Boundaries:

This inventory evaluates passenger travel only, and does not account for any portions of the transportation sector used by freight and service vehicles (law enforcement trips, service vehicles such as utility maintenance and street cleaning trucks, etc.). For this project, I used the San Francisco-specific data from Chester et al. (2010) as baseline values, and evaluated the effects of adjustments to those values in the future (e.g. proposed changes/improvements to transportation usage if specific targets and goals are met).

The indicators included in this project are *Energy consumption* (Mega Joules, includes propulsion, idling, and on-board auxiliary devices), *particulate matter* (grams PM_{10} including exhaust and brake and tire wear), and *greenhouse gas (GHG) emissions* (CH_4 and N_2O computed in CO_2 equivalent) (Chester et al., 2010). Embedded in these metrics are specific modes of travel, vehicle years (for automobiles), number of passengers in that mode, and time of day of trip (peak and off-peak). The Chester et al. (2010) data were calculated for three different cities (San Francisco, Chicago, and New York City), and combined into representative values, therefore readers should take caution when comparing the results of this project directly to the values in the publication.

While the Chester et al. (2010) data employs a hybrid LCA approach in order to account for direct and indirect effects of transportation processes and sub-processes, there are a few specific effects not accounted for in this inventory. The national security requirements to protect domestic and foreign fuel sources are not included here (e.g. the energy consumption for storing, maintaining, and securing refineries, ports, and reserves tanks; the portion of the highway maintenance budget that is used by fuel distribution trucks; the portion of the U.S. and United Nations military expenses that is used for power projection and deterrent in areas of the world from which petroleum is imported). Another interesting omission is the consolidation of biking and walking. At first thought, one might consider biking and walking to be equivalent for inventorying transportation factors. However, there are real and various costs associated with the manufacture of bicycles and the manufacture of walking shoes. One could argue that most people wear shoes regardless of travel mode, but a person who walks for mobility is likely to go through more shoes due to wear-and-tear, or require multiple pairs of shoes depending on workplace dress-codes. The data used in this project assumes that biking and walking are equivalent, and have no carbon footprint, no GHG emissions, and no energy consumption (therefore emissions and energy use generated by manufacturing/delivering/maintaining bicycles and shoes are not included here).

Other assumptions within this project generally deal with technical performance and parameters as they were consolidated in the Chester et al. (2010) publication. The travel survey data used in the publication gave a detailed breakout of vehicle types and unique performance characteristics (e.g. number of sport-utility vehicles vs. sedans, and amount of bus trips vs. rail trips). I consolidated these data into three major mode choices: bike/walk, transit, and automobile. This consolidation made it easier to apply the scenario goals to that mix (i.e. the Countywide Transportation Plan proposes a 9.6% increase in automobile usage under the "business as usual" scenario, but does not specify if that would be more sedans or more trucks). So, in consolidating the data I am assuming the same future vehicle mix within that mode as we have in the current-state data (same mix of bus/train/rail for transit mode, etc.). Another major assumption is that the travel survey data can be applied directly to the future scenarios (i.e. the miles-per-trip does not change within that mode, and the passengers-per-vehicle does not change within that mode). Finally, the vehicle types included in this study take average values for different types of passenger cars, and do not specifically separate hybrid-electric vehicles, flex fuel vehicles, fuel-cell vehicles, pure electric vehicles, and other alternative energy vehicles. At the time this data was collected, those vehicle types did not account for a fair share of the market, and many were not available for purchase by the average consumer. It is important to note this last assumption for any future research in the region, since Californians are very motivated to purchase and use alternative-fuel vehicles (plug-in, compressed natural gas, etc.).

Methodology:

Average values for passenger miles travelled (PMT) and vehicle miles travelled (VMT), and the associated environmental impacts, were used as a baseline. These baseline values include both operating effects (while the mode of travel is in use by the passenger) and life cycle effects (those that are inputs or outputs in manufacturing/building or maintaining the mode of travel). To keep the project manageable, I took the Chester et al. (2010) data for one metropolitan area, the San Francisco Bay Area, and then altered the values to simulate new combinations of travel in the future (or adjusted emissions values to reveal the optimal VMT or PMT for different modes of travel in order to meet specific emissions targets).

The mix of travel modes were adjusted in several different increments to reveal the benefits (positive or negative) of those changes in terms of the three environmental indicators (PM_{10}, GHG CO_2e, and energy consumption). In order to select the incremental adjustments, used the published goals and targets of regional travel planners (San Francisco County Transportation Authority, 2004; San Francisco Municipal Transportation Agency, 2011) and extrapolated model scenarios with travel-mode-mixes that meet, fail, and exceed those goals. For example, the San Francisco Climate Action Strategy (CAS) specifies that by the year 2030, the use by mode of transportation in San Francisco would ideally be 30% auto, 30% transit, and 40% bike/walk (San Francisco Municipal Transportation Agency, 2011). For this scenario I took the baseline values for environmental indicators, then adjusted the percentages of transportation modes to the 2030 goals, and evaluated the results for whether they are better or worse, and if they might exceed some of the threshold values specified in other CEQA documents (Letunic & Ferrell, 2007; San Francisco County Transportation Authority, 2008). In order to bracket the data set, I used scenarios that adjusted the mode-mixes to 1) meet very ambitious goals, 2) meet several different moderate goals, and 3) maintain "business as usual."

Scenarios:

As described above, these scenarios use the Chester et al. (2010) data values as a baseline for the San Francisco Bay Area. Linear increases or decreases to those baseline values are computed within five different goal-based scenarios, plus one future "business as usual" scenario. The scenarios are outlined in more detail within Table 1, and are titled as follows.

1) BAU 2035. Projected "business as usual" accounting for population growth and development through the year 2035 (San Francisco County Transportation Authority, 2004),

2) SFMTA CAS. Meeting the goals of the SFMTA Climate Action Strategy (San Francisco Municipal Transportation Agency, 2011),

3) SFCTA 2035 Econ. Meeting the least ambitious goals of the Countywide Transportation Plan, which are focused on "economic productivity (San Francisco County Transportation Authority, 2004),

4) SFCTA 2035 Livability. Meeting the moderately ambitious goals of the 2035 transportation plan, which are focused on "livability" within the county (San Francisco County Transportation Authority, 2011), and

5) SFCTA 2035 Environment. Meeting the most ambitious goals of the 2035 transportation plan, which are focused on a "healthy environment" for San Francisco (San Francisco County Transportation Authority, 2011).

Table 1: Source Documents for Adjustments to Apply to Chester et al. (2010) Average Data

Categories	Source Document		
	2011, SF MTA Climate Action Strategy	**2004, Countywide Transpo Plan**	**2011, SFCTA Transpo Plan 2035**
Transit and Fleet	Zero GHG for transit (pg. 11), "improve bus emissions" (pg. 12)		"Livability" scenario calls for 21% of trips to be transit by 2035
	107,500 metric tons CO_2 by 2035		
Private Vehicles	905,000 metric tons CO_2 by 2035		"Livability" scenario calls for 33% of trips to be drive alone, and 20% of trips to be carpool by 2035
Bike/Walk			"Livability" scenario calls for 26% of trips to be bike/walk by 2035
Whole Sector	1,012,500 metric tons CO_2 by 2035 (pg 13)		Range of scenarios call for 18-50% reduction in metric tons of GHG by 2035
	15% per capita GHG below 2005 levels (pg 13)		"Healthy Environment" scenario calls for 30-85% reduced GHG compared to 2035 trend, but sets the timeframe to meet that goal at the year 2050
	Scenarios for reduction by 2035 - low (<5% reduction in GHG), medium (5-15% reduction in GHG), and High (>15% reduction in GHG)		
Business as Usual Baseline	2035 trend is for ~29% increase in CO_2	TRANSIT - 986,000 trips (26.9% increase) through 2025 (pg. 50)	DRIVE ALONE - 37% of trips by 2035
		AUTO - 3,078,000 trips (9.6% increase) through 2025 (pg. 50)	TRANSIT - 19% by 2035
		WALK - 948,000 trips (6.3% increase) through 2025 (pg. 50)	WALK/BIKE - 22% by 2035
		BIKE - 44,000 trips (10% increase) through 2025 (pg. 50)	CARPOOL - 22% by 2035
		TOTAL - 5,056,000 trips (11.9% increase) through 2025 (pg. 50)	GHG increases by +62% out to 2035
Scenarios for this project	2) Meet goals of SF MTA CAS	1) Meet Countywide Plan: Business as Usual (will be used for comparison)	3) Meet "Economic Productivity" scenario (least ambitious)
			4) Meet "Livability" scenario (somewhat ambitious)
			5) Meet "Healthy Environment" scenario (most ambitious)

Results:

As one would expect, applying linear adjustments to existing data sets does not change relative values. This is true for individual modes of transportation. For example, in any of my future scenarios, a conventional urban bus still produces more GHG emissions than an electric urban bus. This project assumes that technology remains constant, and this assumption is likely a major source of uncertainty in my results. However, if I dismiss this uncertainty (with the implicit assumption that advances in technology would make the negative impacts less negative in the future), then these results may reveal characteristics and relative values of goals that target behavior change. In other words, leaving technology out of the scenarios, successful mode-choice changes within these scenarios should allow policymakers to understand more about which behaviors to target. Then, if technology advances along with these mode-choice changes, the improvements towards sustainable mobility may far exceed planning goals (a win-win situation for metropolitan areas).

Scenario	Trips	VMT	PMT	Operational Energy (MJ)	Operational GHG (g)	Operational PM (g)	Life-cycle Energy (MJ)	Life-cycle GHG (g)	Life-cycle PM (g)
1) BAU 2035	24530656.37	131060775.06	236506664.84	867708320.40	62230045131.90	16878887.65	1250007906.32	95552390830.89	54784392.32
2) SFMTA CAS	21701100.14	114874289.46	204503295.77	737552072.34	52895538362.12	14347054.50	1062506720.37	81219532206.26	46566733.47
3) SFCTA 2035 Econ	21135188.89	111030872.33	197496501.95	711520822.73	51028637008.16	13840687.87	1025006483.18	78352960481.33	44923201.70
4) SFCTA 2035 Livability	19814729.31	102062899.03	181147316.36	650781240.30	46672533848.93	12659165.73	937505929.74	71664293123.17	41088294.24
5) SFCTA 2035 Environment	15476076.42	72596701.02	127428563.71	451208326.61	32359623468.59	8777021.58	650004111.28	49687243232.06	28487884.00

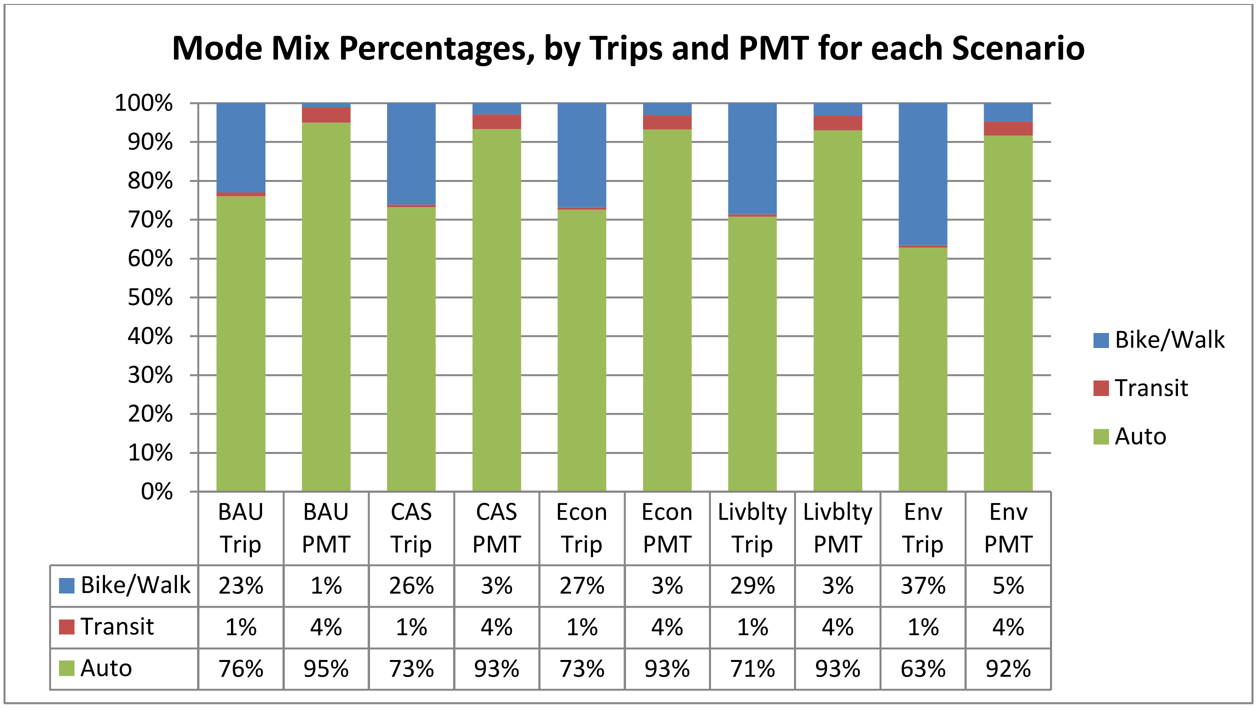
Table 2. Consolidated Inventory Results. Scenario numbers and titles are outlined above.

Table 2 summarizes the numeric results for each scenario. The three indicators I inventoried are energy, GHG emissions, and PM_{10} emissions. While the "business as usual" scenario specified precise trip increases (which allowed for extrapolation to energy and PM_{10} values), the published San Francisco scenarios only addressed future percentages of GHG emissions. Therefore, I extrapolated the same percentage improvements for energy and PM_{10} emissions that were proposed for GHG emissions. Because the scenarios are directly derived from adjustments to emissions levels, I made a very broad assumption that the total numbers of trips, miles, and passengers would adjust in response to those changes. In other words the amount of mobility (trips, VMT, PMT) would change from the projected 2035 levels, with each successive scenario showing fewer overall trips and miles traveled. Since both biking and walking have zero emissions and energy within the model, I could not "backtrack" those values to get an equivalent mode-amount corresponding to the future goal. For simplicity, I assumed that the 2035 projected mode increases could still be used in all future scenarios (that is, biking increases by 10% and walking increases by 6.3%) (San Francisco County Transportation Authority, 2011).

Special Note. In Appendix B I include backup tables and graphics that would have resulted if I assumed the total number of trips would need to stay the same. In other words, any reduction in trips or miles traveled from transit or automobile would, by default, shift to biking and walking. Within these data, the percentages of biking/walking increase considerably with each more aggressive scenario. The most aggressive of the scenarios, "Healthy Environment," would result in 48% of all trips by biking/walking mode. Since this seems like an unrealistic scenario, I decided to re-evaluate the data and assume that other initiatives would be paired with the emissions goals in order to reduce the overall number of trips and miles travelled. By other initiatives, I would assume efforts such as incentivizing telecommuting and improved land-use that would reduce the need to travel for basic needs and work/leisure.

Figure 1 graphs the consolidated results from this project by percentage of mode-mix necessary to meet the different scenario goals. While the results are fairly predictable, there are some minor differences that may provide insight for transportation planners and policymakers, and I will discuss these in the next section. Figure 2 shows the numbers that provide the percentages in Figure 1.

Appendix A contains supporting information in graphs and tables. Specifically, the inventory of indicators (energy, GHG, PM_{10}) for each scenario is graphed for visual comparison. I did not include this data in the main report because the focus of my project has less to do with the emissions and energy usage resulting from future transportation, and more to do with hypothetical future goals and the corresponding mode-mixes San Francisco is committing to if those goals are achieved.



	BAU Trip	BAU PMT	CAS Trip	CAS PMT	Econ Trip	Econ PMT	Livblty Trip	Livblty PMT	Env Trip	Env PMT
Bike/Walk	23%	1%	26%	3%	27%	3%	29%	3%	37%	5%
Transit	1%	4%	1%	4%	1%	4%	1%	4%	1%	4%
Auto	76%	95%	73%	93%	73%	93%	71%	93%	63%	92%

Figure 1. Mode mix percentages (trips and PMT) for each scenario. Biking and walking are combined for simplicity, since both have zero emissions and use no energy according to the source data.

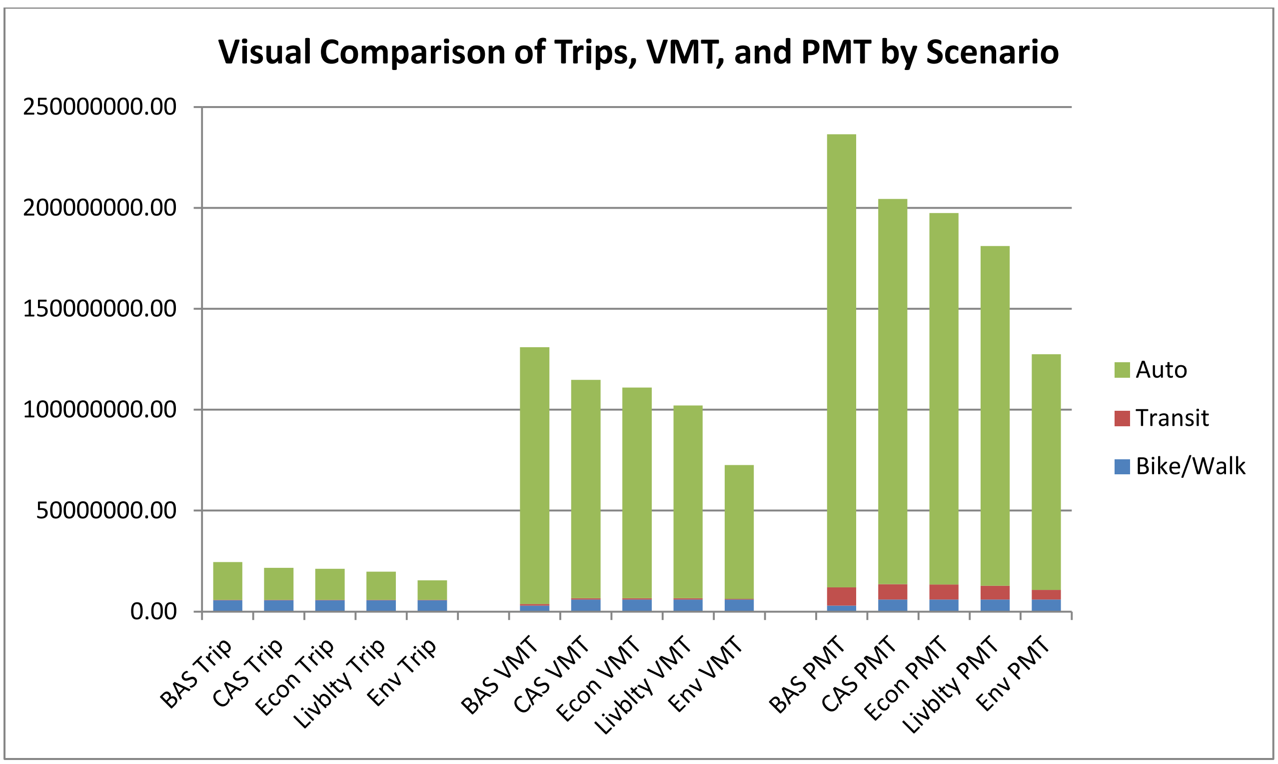


Figure 2. This graph compares the mode-split for trips, vehicle-miles-traveled (VMT), and passenger-miles-traveled (PMT) for each scenario. One interesting note on this graph is that the number of trips increases for bike/walk mode, while the VMT and PMT do not change as dramatically as the other modes. This may indicate that the bike/walk trips would account for a larger proportion of short passenger trips, while automobiles continue to dominate the mode choice for longer-distance trips.

Analysis of Results:

This project is a relatively imprecise exercise in applying future policy goals to current-state life-cycle analysis data. The results should not be taken as a prediction or a forecast, and are not likely to reflect actual emissions, energy usage, or transportation mode-mixes in the future. However, these "back of the envelope" calculations reveal much more about the impacts of policy goals than the technical effects or environmental impacts of future actions. When planners and policymakers craft specific goals or strategies for a location or government, those targets, even if met, are unlikely to result in the intended physical outcomes. In other words, a city aiming to reduce GHG emissions by 10% may fund initiatives intended to result in less emissions in the future, but those specific initiatives will not directly result in 10% reduction of emissions. In the case of San Francisco, the published goals for the future of transportation seem definitive on the surface, yet the uncertainties under the surface are too great to overcome. As an example, the "livability" scenario proposes a reduction of GHG emissions by 25%, and actually further specifies that 26% of all trips would be by bike/walk, 53% by car, and 21% by transit. My results show that in order to reduce GHG emissions by 25%, 29% of all trips would be bike/walk, only 1% transit, and a whopping 71% automobile. As a reminder, I made some very broad assumptions that are likely skewing my data, however there is no direct line that planners can draw between one reduced gram of emissions and an equivalent reduced road-mile or increased walking-mile.

There is also a very basic conflict between dictating emissions targets and implying mode mixes for transportation. As I discussed in the "special note" about whether to shift reduced vehicle trips towards increased bike/walk trips, planners and policymakers must be specific about where transportation usage should shift in the future. I assume that no policymaker or planner intends to specify who cannot use transport systems in the future – as I discussed in the background section transportation infrastructure and "mobility" in general is largely considered a "public good." Therefore, if biking/walking continues to be calculated as zero emissions, zero energy, then a natural accounting fix for future scenarios is to shift all reductions in other modes onto bike/walk trips. Appendix B details how a scenario that shifts emissions reductions onto bike/walk modes could require as much as 48% of all trips to be bike/walk. This is highly improbable, and there is no consideration in these hypothetical scenarios for age or health restrictions. Do older and unhealthy passengers get an exemption for bike/walk modes, and therefore use automobiles? Or, would the exemption encourage transit over automobiles, thereby making transit more congested for young/healthy passengers? There are countless equity and environmental justice issues within these tough choices.

If the goal is to reduce the amount of overall transportation, then priorities must be set to inform many other sectors of society. Additionally, any priorities must account for inherent equity issues. For instance, if San Francisco wishes to increase transit by 10% in the future, there are several ways this may be achieved: 1) increase the number of passengers per transit vehicle, thus minimizing the budgetary expenditures of operations/maintenance/construction costs; 2) increase the number of miles per trip in the county, thus attracting new riders from further distances and reducing the number of auto trips, but increasing the budget for construction and operation/maintenance of the transit system; and 3) increase the number of trips on transit, which may require more rail cars or routes on the existing infrastructure and also may lead to increased operations/maintenance costs due to increased wear-and-tear. Depending on which of these options a planner wants to encourage, there are likely to be major uncertainties in passenger choice/behavior, and also equity issues. If a passenger must spend more on a transit ticket than on gasoline for an existing car, then encouraging the mode shift may not work. Alternately, if new riders are attracted from further distances, then congestion during peak-ride times may encourage passengers who live closer to choose a “dirtier” transport mode instead of transit. All three of these hypothetical initiatives would increase transit usage, but exemplify very different ways to get there.

An interesting detail in the results is the preference towards automobile and bike/walk, and away from transit. I did not perform any statistical analysis of my results, but this discrepancy likely relates to the broad assumptions I made at the onset regarding maintained intra-mode mixes, and maintained performance parameters. Shifting emissions and energy usage towards the most efficient mode (bike/walk) and the least efficient mode (automobile) is one way to maximize a mathematical computation. In doing this, you can shift a large proportion of trips to bike/walk, and then theoretically get more passengers transported on longer trips by automobile. It is likely that if transit ridership factors were increased (number of passengers per trip), along with vehicle-miles-traveled, then the scenario results would come out very differently. Finally, the consolidated data in Figure 1 indicates a marked difference between trip mode-mixes for bike/walk and PMT mode-mixes. For example, the “livability” scenario proposes that 29% of all trips would be bike/walk, but only 3% of the PMT would be bike/walk. This large difference in mode-mix is seen in all five scenarios. There are two likely explanations for this. First is that the performance parameters from the source data are simply propagating through the scenario data (low miles traveled for each bike/walk trip). Second might be that there can be large emissions/energy savings when bike/walk is substituted for short trips, and there may be potential for convincing more passengers to capitalize on biking and walking for those short trips. More than likely, my model is simply propagating an assumption, yet the mode-mix data does support the assumption that there can be benefits to the environment when biking/walking is chosen on short trips.

A quick look at the inventory of emissions and energy usage reveals rather predictable results (see Appendix A, Figures A.1-A.3). Each successive scenario produces a little less emissions and uses a little less energy than the previous scenario. The “healthy environment” scenario performs the best overall on all three indicators. But, a second look shows that the difference between operational indicators and life-cycle indicators gets progressively smaller with each scenario. The results are not definitive, and no statistical analysis supports the validity of the numbers, but it seems that as the transportation mode-mix gets more efficient, the portion of life-cycle negative impacts gets smaller. The externalities associated with life-cycle inventories can therefore be minimized as modal-mix efficiency improves. For San Francisco, this may be an added benefit to the scenarios, and may provided a way to minimize unforeseen expenses into the future.

Finally, when comparing the results of this study with established thresholds, there are some rather interesting implications. A 2007 report on “establishing thresholds of significance under [the

California Environmental Quality Act]" (Letunic & Ferrell, 2007) points out that San Francisco has a dominant "transit first" policy when it comes to evaluating new projects. For example, any transportation system projects evaluated for Level of Service (LOS) methodologies would normally consider a lack of adequate parking infrastructure as a negative for the project. Yet, San Francisco chooses not to follow the parking LOS methodology, because their planners feel that lack of parking will motivate more people to use transit instead of driving (Letunic & Ferrell, 2007). Whether or not this motivating factor is real is immaterial. What is interesting about the LOS methodologies is that projects other than those of pure transportation service/infrastructure can and will likely have an impact on ridership mixes in San Francisco (San Francisco County Transportation Authority, 2008). This ties in nicely with the quandary of whether to shift reduced automobile miles directly to bike/walk miles. For example, a new apartment complex built on the peninsula might be able to fit more apartments into the building by choosing only to build handicap and service parking spaces and no "regular" resident parking spaces. This would discourage vehicle ownership, increase real-estate and tax revenue to the city (more residents in smaller space), and reap the theorized benefits of densified urban housing.

Conclusion:

This project is not meaningful as a rigorous analysis of projected transportation data. It is meant to be a cursory examination of published goals and strategies for the future contrasted against life-cycle data from current-state analysis. Several simplifying assumptions dominate my results, such as maintaining ridership statistics and mode-type-mixes in future scenarios. With that considered, the percentage mixes for transit ridership were lower than expected in all five scenarios, which may indicate that either the ridership values or the trip-length has a significant impact on the modeled results. Furthermore, there was a distinct difference in mode-mix percentages for bike/walk trips compared to bike/walk passenger-miles. This may be an indicator that there are large benefits to be made for reducing environmental impacts when bike/walk trips can cover longer distances. Finally, when planners and policymakers craft specific goals or strategies for a location or government, those targets, even if met, are unlikely to result in the intended physical outcomes. City and state governments would be wise to support broad strategy goals (like 20% GHG reduction) with prioritized specifics that can inform real projects leading to the goals (for instance, add 5 miles of bike path, or remove 5 parking garages and replace them with transit depots). While these results should not be used as predictions or forecasts, they can inform the crafters of future transportation policy as improvement opportunities or a cautionary tale.

Citations:

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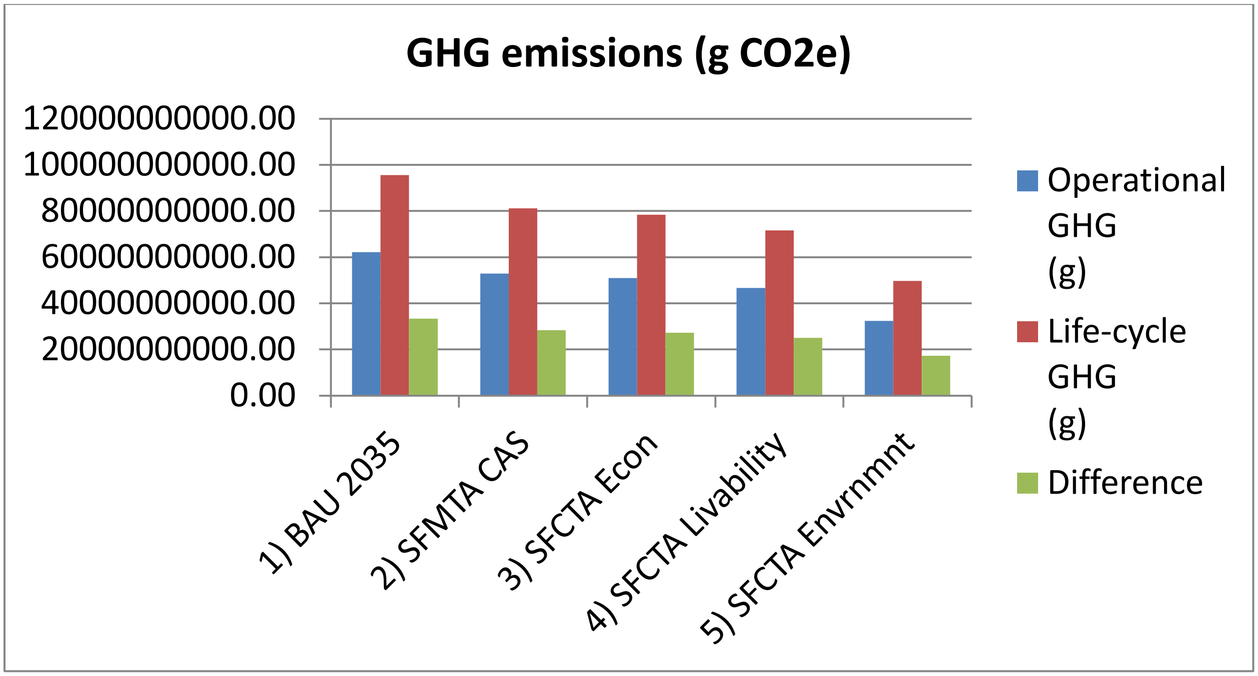
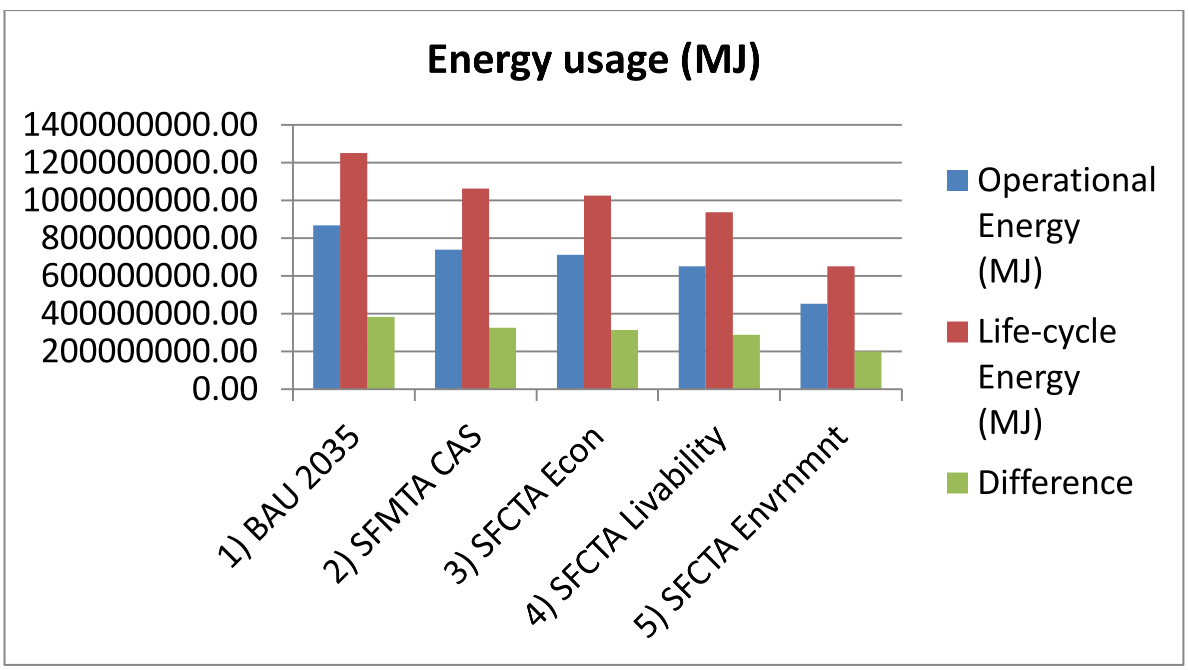
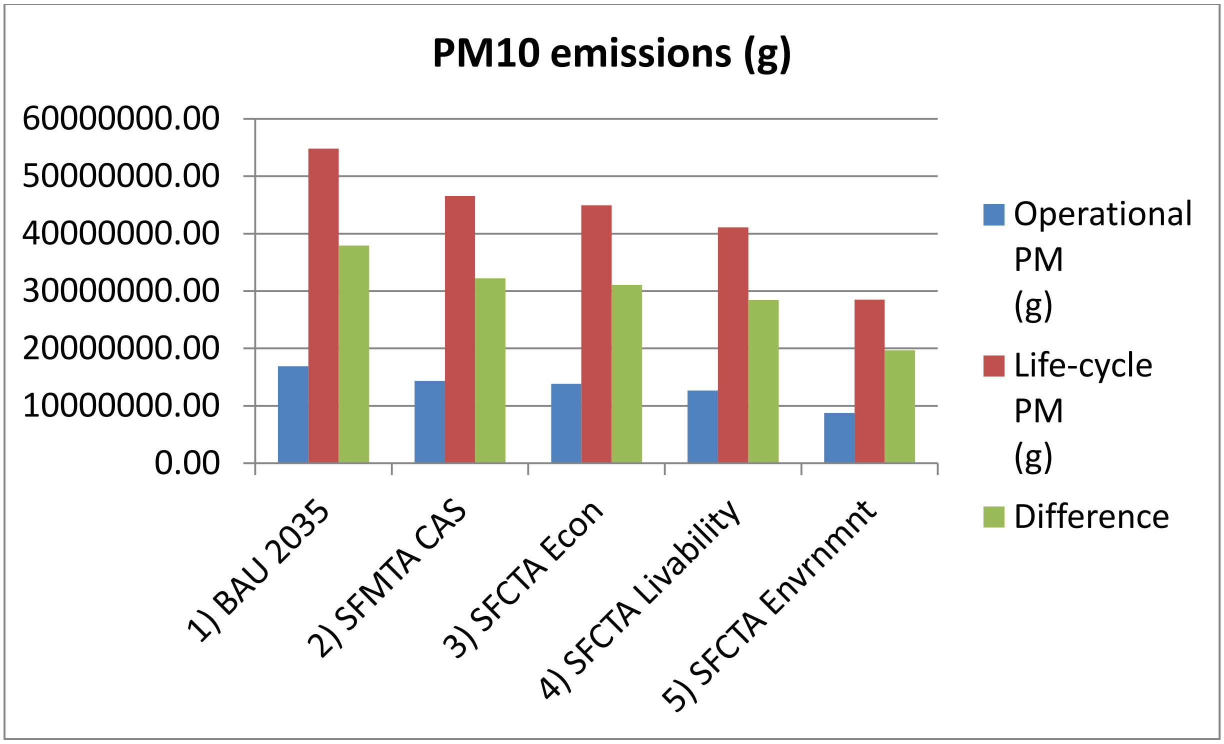
Appendix A: Supporting Information



A.1. Greenhouse gas emissions for each of the five scenarios, with the difference between operational and life-cycle emissions computed in green.



A.2. Energy usage for each of the five scenarios, with the difference between operational and life-cycle usage computed in green.

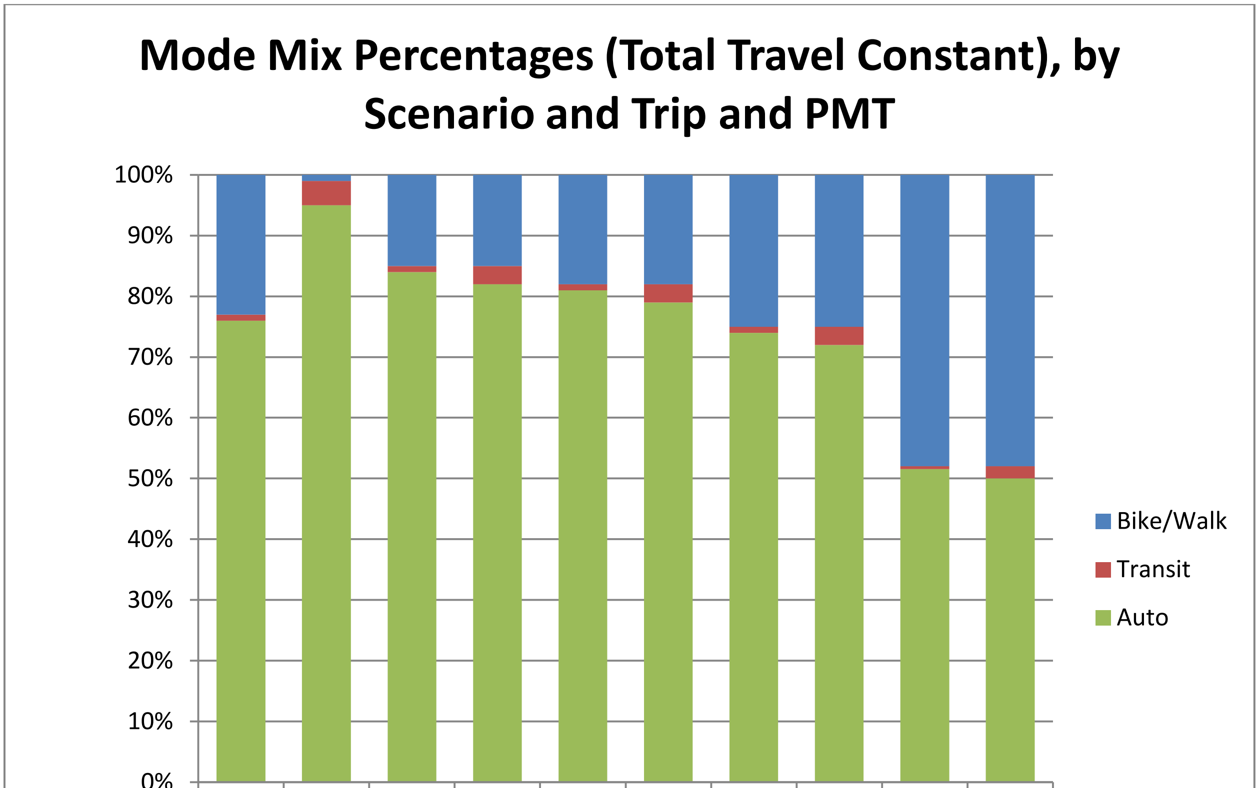


A.3. Particulate matter (PM10) emissions for each of the five scenarios, with the difference between operational and life-cycle emissions computed in green.

A.4. Table of source numbers corresponding to Figure 2 in the project.

	Bike/Walk	Transit	Auto
BAS Trip	5666948.13	169177.57	18694530.67
CAS Trip	5666948.13	143800.94	15890351.07
Econ Trip	5666948.13	138725.61	15329515.15
Livblty Trip	5666948.13	126883.18	14020898.00
Env Trip	5666948.13	87972.34	9721155.95
BAS VMT	2946870.70	736759.81	127377144.56
CAS VMT	5977470.75	626245.83	108270572.87
Econ VMT	5977470.75	604143.04	104449258.54
Livblty VMT	5977470.75	552569.85	95532858.42
Env VMT	5977470.75	383115.10	66236115.17
BAS PMT	2946870.70	8993930.22	224565863.92
CAS PMT	5977470.75	7644840.69	190880984.33
Econ PMT	5977470.75	7375022.78	184144008.41
Livblty PMT	5977470.75	6745447.67	168424397.94
Env PMT	5977470.75	4676843.71	116774249.24

Appendix B:
Mode-Mix Percentages when Shifting Reduced Transit and Auto Trips to Bike/Walk



	BAU Trip	BAU PMT	CAS Trip	CAS PMT	Econ Trip	Econ PMT	Livblty Trip	Livblty PMT	Env Trip	Env PMT
Bike/Walk	23%	1%	15%	15%	18%	18%	25%	25%	48%	48%
Transit	1%	4%	1%	3%	1%	3%	1%	3%	0%	2%
Auto	76%	95%	84%	82%	81%	79%	74%	72%	52%	50%

B.1. Graph showing mode-mix percentages for each scenario (trip and PMT), calculated by adjusting transit and auto numbers based on future emissions goals, and then shifting the reduced number of miles and trips onto the bike/walk mode. This implies that for any saved auto trip in the future, that same trip with the same distance will be replaced by a zero-emissions, zero-energy bike or walk. One quickly notes how unrealistic this goal might be, for example in the "healthy environment" scenario we would be assuming that 48% of all trips would be bike/walk.