King County Metro Mobility and Fleet Investment Strategies to Reduce GHG Emissions

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Executive Summary

Achieving the 2020 Strategic Climate Action Plan goals to reduce greenhouse gas (GHG) emissions from car travel and vehicle emissions will require King County and Metro Transit to sustain and grow public transit service and ridership and transition to a zero-emission bus fleet. While given current financial conditions, Metro will likely need new revenue sources to fund service growth and fleet transition costs, planning for these needed investments have surfaced several questions:

- What are the various options available to Metro to reduce GHG emissions?
- What is the most cost-effective investment strategy Metro Transit can make to reduce GHGs?
- What other considerations, such as equity, are important when comparing strategies?
- How can Metro prioritize investments to develop a balanced portfolio to achieve goals?

To develop a better understanding of the answers to these questions, Metro analyzed mobility and fleet investment strategies to reduce GHG emissions, including:

- **Transit-oriented development (TOD):** Planning of developments surrounding Metro owned properties.
- **Transit demand management**: Targeted campaigns to encourage transit and vanpool ridership
- **Alternative fuels:** Purchase biodiesel blends or renewable diesel for diesel-hybrid bus fleets.
- **Zero emission fleet:** Transition to zero-emission bus fleet.
- **New BRT/RapidRide corridors with land use change:** Speed and reliability and service improvements for BRT type service and associated increase in land use and population density.
- **Frequent service expansion with land use change**: Frequent service (i.e. reduced all-day headways) and associated increase in land use and population density.
- **Frequent service expansion**: Frequent service (i.e. reduced all-day headways) during peak or off-peak periods for select routes
- **Speed & reliability:** Investment in corridors to improve peak and off-peak speeds on non-BRT/RapidRide routes
- **Access to transit:** Non-motorized improvements near high-frequency Metro stops
- **First/last mile connections:** Improving access to high-capacity transit (e.g., VIA to transit).

Strategies were evaluated based on the following quantitative and qualitative considerations:

- **Cost effectiveness:** What monetary investment would Metro Transit need to make to reduce 1 ton of GHGs?
- **Annual maximum GHG emission reductions:** What are the maximum emission reductions that could be achieved in a future year (e.g., 2040) if the strategy is fully implemented?
- **Community Benefit:** Is there a community benefit beyond GHG reduction?
- **Pro-equity opportunity:** Can benefit be implemented to prioritize where needs are greatest?
- **Sphere of Influence:** Does Metro directly or indirectly influence GHG reduction?
- **Transformational Impact:** Does investment reduce future demand for fossil fuel? Is it permanent?
- **Time scale:** How quickly can emission reductions be achieved: near- (<1 yr.), medium- (3-7 yrs.), or long-term (8-15 yrs.)?
- **Implementation Feasibility:** Can Metro independently implement strategy?

Preliminary results of this analysis do not point to one simple strategy, but instead underscore the importance of a portfolio approach to reducing GHG emissions.

- **The strategies Metro can likely implement for the least cost,** including TOD, TDM, and alternative fuels, **are not the same strategies that offer the largest potential opportunity to reduce emissions, which include RapidRide and frequent service with transit-supportive land-use and fleet electrification**.
- **Metro Transit can have the greatest certainty in emission reductions achieved through fleet**, but the opportunity to reduce emissions is fixed at the size of Metro's fleet. **The most transformative investments in low-carbon infrastructure will likely take the longest to fully realize**. Investments in these strategies now – including RapidRide and frequent service with transit-supportive land-use and fleet electrification – will help position King County to achieve long-term goals.
- **Fleet electrification appears to offer emission reduction at a cost comparable to high productivity service investments** in RapidRide and frequent service.
- High productivity service investments appear to offer Metro Transit the opportunity to reduce emissions for lower cost than low productivity service.
- Alternative use of biofuels or renewable diesel could be an interim strategy to reduce fleet GHG emissions.

These preliminary conclusions are drawn from the comparison of the cost effectiveness (cost per ton of carbon reduced) and annual maximum GHG emission reduction potential in 2040 (tons reduced per year) shown in Figure 1.[1] In Figure 1, the width of the bars represent the potential range of cost effectiveness, with narrow bars representing more known costs and wide bars representing costs with various levels of risk or dependencies. The farther left the bar is, the more cost effective it is. The height of the bar reflects the potential emission reduction, with taller bars representing greater potential for emission reductions. The height of the bar varies when the emission reductions are dependent on how the investment is made. For example, investment in high productivity new RapidRide corridors could achieve a maximum of 300,000 tons or as few as 250,000 tons depending on if it is invested in higher or lower productivity corridors. An ideal strategy would be to the far left, indicating the investment is cost-effective, and tall, indicating the emission reduction potential is large.

Several key findings emerge based on this preliminary quantitative analysis of strategies:

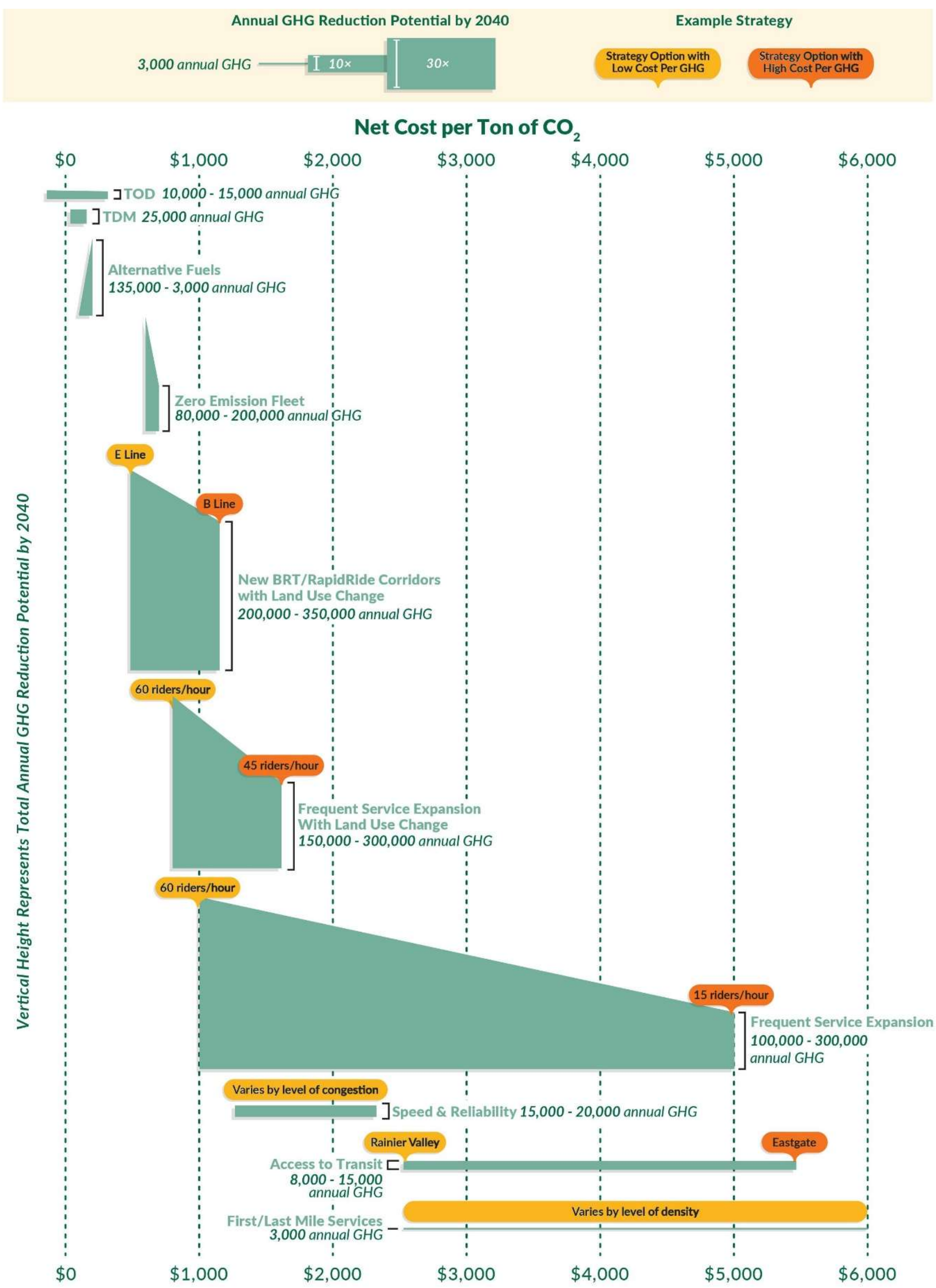
- The most cost-effective investments appear to include TOD, TDM and alternative fuels, all having a cost of between $0 and $300 per ton. When implemented in the most effective way possible, RapidRide or service with land use changes are also likely relatively efficient at

[1] Service investment and costs are modeled based on Metro Connects (2017) and fleet investments are based on the Zero-Emission Battery Bus Preliminary Implementation Plan (2020) (i.e., fleet plan associated with reduced service levels contemplated in 2025-2026 per the executive proposed budget).[1] All cost estimates are shown as annual investments in discounted 2019 dollars. Given uncertainty and modeling limitations, analysis excludes near-term COVID-19 related impacts on ridership. Fuel prices are based on current pricing in 2020.

about $500-800 per ton as is fleet electrification at an estimated $750 per ton. The least cost-effective investments appear to be access to transit and first/last mile efforts.

- The options with the greatest likely potential for emission reductions include RapidRide and service with land use changes (between approximately 100,000 and 300,000 tons/yr.), fleet electrification (135,000 tons/yr.), and service improvements (100,000 to 300,000 tons/yr.). Options with the least potential for emission reductions appear to include TOD, TDM, and speed and reliability.
- The options with the most certain/lowest range of costs include fleet electrification, TDM, and fuel conversion.
- Taken together this information does not point to one single strategy but rather points to a portfolio approach.

Figure 1. ***Net cost effectiveness per ton and annual GHG reduction potential by 2040 of mobility and fleet investment strategies to reduce GHG emissions.***



Other qualitative factors are important when comparing trade-offs among investments to reduce GHG emissions, as shown in Table 1. Each strategy was evaluated based on the qualitative criteria, with green representing the most favorable conditions relative to the criteria and red the least. Ideally climate strategies would offer community benefit, provide pro-equity opportunities, result in direct reductions, be transformative, be achievable in the near-term and be independently implementable by Metro. When comparing strategies by each of the qualitative considerations, results indicate:

- **Community Benefits** are greatest for investments in mobility services because they result in improved mobility and quality of service. Zero-emission fleet investments provide the additional benefit of reduced air pollution; this benefit is minimal for alternative fuels.
- **Pro-Equity opportunities** exist for both mobility and fleet Investments by prioritizing deployment where needs are greatest. Investments in King County Metro owned property supporting TOD, new RapidRide, and new frequent service combined with active engagement to achieve transit-supportive land use that serves priority populations, supports thriving neighborhoods, and avoids displacement offers the greatest opportunity to advance both climate and equity goals. Zero-emission fleet deployment can be prioritized to address environmental justice.
- **Direct or indirect impact** varies by strategy. Metro Transit can influence passenger transportation but cannot directly control transportation choices of residents. In contrast, Metro Transit has direct control over its fleet.
- **Transformational investments** support long-term change to low-carbon infrastructure and reduce demand for fossil-fuel. Mobility investments that include long-lasting capital improvements and compact land-use development have a more permanent and transformational impact. Fleet investments that transition infrastructure to zero-emission fleet transform Metro's fleet reducing future demand for diesel fuel and are more transformative than the use of alternative fuels.

- **Time to achieve** reductions is longest for the most transformational strategies with the most emission reduction potential. Land use change and transition to zero-emissions fleet strategies have a long-lead time. Investments in TDM, alternative fuels, and frequent service could be realized in the near-term. Over half of the emissions from Metro's bus fleet could be eliminated almost immediately through the purchase of renewable diesel.
- **Implementation** of new RapidRide and frequent service with land use change, TOD, and speed and reliability improvements all require significant coordination and support from partners and other organizations.

The portfolio approach recommended here is supported by the near- and long-term investments in the Metro Transit 2021-2022 budget, specifically:

- **Transit Oriented Communities Program Planning:** With the upcoming adoption of Metro's Equitable Transit oriented communities policy, the proposed budget funds the development of a strategic plan and other foundational work needed to identify opportunities to reposition properties from single purpose parking lots or transit facilities to achieve community development goals. In addition, this program will support efforts to integrate land use considerations into how Metro plans for and deploys new high frequency service.
- **New BRT/RapidRide Corridors**: While Metro will not be able to deliver on the entire long-range vision as outlined in Metro Connects without additional funding, the 2021-2022 Proposed Budget supports the implementation of several long-planned RapidRide lines – including Delridge (2021), Madison (2023), and Renton/Kent/Auburn (2023) – and Sound Transit Link light rail integrations.
- **Zero-Emissions Revenue Fleet:** The Executive's proposed budget advances the transition to a zero-emissions fleet. During 2021-2022, Metro will purchase 40 battery electric buses and related charging infrastructure and will plan and design charging infrastructure to support an additional 260 battery electric buses by 2028.
- **Frequent Service Network**: The 2021-2022 proposed budget supports system restructures to align fixed route bus and other Metro services with Link frequent service expansions, including Northgate link in 2021; Eastlink in 2023; and Federal Way, Lynnwood, and Redmond Link in 2024-2025
- **Speed and Reliability Improvements:** The proposed budget includes the following speed and reliability improvements that are in addition to improvements for the proposed RapidRide corridors: South King County Corridor Improvements, spot improvements as part of service restructures (RKAAMP, North Link and East Link), and multimodal corridor improvements on Route 48, Route 40, Route 44.

As identified in the Executive's proposed 2020 SCAP[2], to reduce transportation emissions in King County Metro Transit must take the lead in sustaining and increasing public transit, supporting compact transit-supportive land-use, and reducing emissions from Metro fleets. Achievement of the County's ambitious long-term goals will require investment in all these strategies.

[2] The 2020 SCAP requires approval by the King County Council in 2021.

Table 1: Comparison of mobility and fleet investment strategies to reduce GHG emissions.

Metro Investments	Cost effectiveness ($/ton)	Annual GHG Reduction Potential in 2040 (ton/yr.)	Community benefit?	Pro-equity opportunity?	Direct or indirect?	Transformational investment?	Time to achieve reductions?	Can Metro independently implement?
Transit Oriented Development (TOD)	<$0 - $300	10,000 – 15,000	Yes - Housing	Yes	Indirect	Yes	Medium	No
Transit Demand Management (TDM)	$50-$100	25,000	Maybe – Transit Access	Yes	Indirect	Maybe	Near	Yes
Alternative Fuel	$100 - $300: Biodiesel $200: Renewable diesel	3,000 – 135,000	Minimal	Minimal – Contracting	Direct	Maybe	Near	Yes
Zero-emission fleet	$640 - $740	127,000	Yes – Air pollution and noise	Yes – Air pollution and noise	Direct	Yes	Near, Medium + Long	Yes
New BRT/RapidRide Corridors + Land Use	$500 - $1,500	200,000 – 350,000	Yes – Service	Yes	Indirect	Yes	Medium + Long	No
Frequent Service Expansion with Land Use	$750 - $1,000	150,000 – 300,000	Yes- Service	Yes	Indirect	Yes	Near + Long	No
Frequent Service Expansion	$750 - $3,000	100,000 – 300,000	Yes - Service	Yes	Indirect	Maybe	Near	Yes
Speed & Reliability (Non-RapidRide)	$1,250 - $2,250	15,000 – 20,000	Yes – Service	Yes	Indirect	Yes	Medium	No
Access to Transit	$2,500 - $7,000	8,000 – 15,000	Yes – Accessibility	Yes	Indirect	Yes	Medium	No
First/ Last Mile Connections	$2,500 - $5,500	3,000	Yes - Service	Yes	Indirect	Maybe	Near	Yes

Introduction

King County and Metro Transit have committed to reduce GHG emissions through sustaining and growing public transit and transitioning to an all zero-emission bus fleet. Further investments and policy action by partners and King County residents will be required to achieve the ambitious and urgent goals of the 2020 SCAP to reduce car trips and reduce emissions from vehicles across King County. For the investments in public transit and fleet that Metro Transit controls, several questions have emerged as Metro moves forward to advance the 2020 SCAP goals:

- What are the various options available to Metro to reduce GHG emissions?
- What is the most cost-effective investment strategy Metro Transit can make to reduce GHGs?
- What other considerations, such as equity, are important when comparing strategies?
- How can Metro prioritize investments to develop a balanced portfolio to achieve goals?

To get at these questions the analysis compares the relative cost effectiveness, in terms of dollars invested by Metro Transit per ton of GHGs reduced (i.e., cost to reduce 1 ton of GHGs), and the annual maximum potential GHG emission reductions of different mobility and fleet investment purchasing strategies. Cost effectiveness is a useful metric for comparing across strategies and has been used by LA Metro[3] in a similar analysis. As part of this analysis, strategies from other large transit agencies were reviewed. Many have developed estimates of the impact of carbon reduction from internally focused efforts, but few have evaluated, as this study does, the impacts on overall societal emissions. Strategies vary in the magnitude of GHG emission reductions that can be achieved. Emissions from passenger transportation in King County is much larger than emissions from Metro Transit fleets, as such the opportunity to reduce emissions from passenger vehicle trips is much larger.

Investment strategies were identified and defined based on input from lead staff and aim to align with Metro Connects updates. To develop a better understanding of the answers to these questions, Metro analyzed mobility and fleet investment strategies to reduce GHG emissions, including:

- **Transit-oriented development (TOD):** Planning of developments surrounding Metro owned properties.
- **Transit demand management**: Targeted campaigns to encourage transit and vanpool ridership
- **Alternative fuels:** Purchase biodiesel blends or renewable diesel for diesel-hybrid bus fleets.
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- **Frequent service expansion with land use change**: Frequent service (i.e. reduced all-day headways) and associated increase in land use and population density.

[3] Los Angeles County Metropolitan Transportation Authority, 2010. Greenhouse Gas Emissions Cost Effectiveness Study. Available at: http://media.metro.net/projects_studies/sustainability/images/GHGCE_2010_0818.pdf and Los Angeles County Metropolitan Transportation Authority, 2019. Metro Climate Action and Adaptation Plan 2019. Available at: http://media.metro.net/projects_studies/sustainability/images/Climate_Action_Plan.pdf

- **Frequent service expansion**: Frequent service (i.e. reduced all-day headways) during peak or off-peak periods for select routes
- **Speed & reliability:** Investment in corridors to improve peak and off-peak speeds on non-BRT/RapidRide routes
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- **First/last mile connections:** Improving access to high-capacity transit (e.g., VIA to transit).

This study carried out new modeling work of mobility service investments and pulls from updated fleet electrification implementation cost estimates prepared by Metro Transit for the King County Council in 2020. The study focuses on investments made by Metro Transit and strategies that can be implemented directly by Metro Transit. The scale of mobility investments considered to determine potential for emission reductions are aligned, where applicable, with Metro Connects.[4] Given uncertainty and modeling limitations analysis, excludes near-term COVID-19 related impacts on ridership. Results shown are for maximum annual emission reductions that could be achieved in 2040 if strategies are fully implemented and benefits fully realized by that time.

Cost and emission reduction potential are only a few of the factors considered. The full set of quantitative and qualitative criteria evaluated include:

- **Cost effectiveness:** What monetary investment would Metro Transit need to make to reduce 1 ton of GHGs?
- **Annual maximum GHG emission reductions:** What are the maximum emission reductions that could be achieved in a future year (e.g., 2040) if the strategy is fully implemented?
- **Community Benefit:** Is there a community benefit beyond GHG reduction?
- **Pro-equity opportunity:** Can benefit be implemented to prioritize where needs are greatest?
- **Sphere of Influence:** Does Metro directly or indirectly influence GHG reduction?
- **Transformational Impact:** Does investment reduce future demand for fossil fuel? Is it permanent?
- **Time scale:** How quickly can emission reductions be achieved: near- (<1 yr.), medium- (3-7 yrs.), or long-term (8-15 yrs.)?

The purpose of this analysis is to provide quantitative and qualitative guidance comparing various investments across a set of performance criteria. This analysis is not intended to be project specific, but instead provides a comparison of analysis of relative GHG emission reduction opportunity and costs of different strategies Metro Transit can implement. With limited resources to commit to address climate change, the purpose of this analysis is to assess which investment type will have the most emission reduction benefit. The most desirable strategies to reduce GHG emissions are those that are cost effective, offer a large potential to reduce emissions, offer a community benefit, provide pro-equity opportunities, result in direct reductions, are transformative, are achievable in the near-term and can be independently implementable by Metro. All potential benefits and costs must be considered to support decision making of any specific strategy; this analysis is intended to inform how to explicitly consider the climate and other

[4] Analysis is based on Metro Connects as adopted in 2017.

benefits of investment strategies. All final investment priorities will need to be made considering a range of factors including service needs, operations, safety and equity.

Background: Goals and Priorities from Mobility Framework, 2020 SCAP and King County Ordinance 19502

Transportation generates more than one-third of greenhouse gases (GHGs) in King County. Reducing transportation emissions will require a combination of reducing car trips and vehicle emissions. As a public transit provider, Metro Transit has a key role in reducing emissions from passenger vehicles and directly controls emissions from Metro transit fleets. In 2017, passenger vehicles made up 25.5% of King County emissions, and Metro bus fleets made up 0.5%. Metro fixed route bus fleets result in approximately 100,000 tons[5] of emissions annually to provide transit service. Mode shift to transit, bike or walk from private car trips reduces emissions. On an average weekday before the pandemic, Metro carried over 400,000 riders. Since using Metro Transit uses less fuel on a per trip basis than driving a personal car and Metro's services promote compact land use that reduces trips and trip distances, Metro estimates that at current service levels it reduces regional emissions by over 600,000 tons annually.

Addressing climate change is a core priority for King County and Metro Transit. The Metro Transit Mobility Framework established a guiding principle to "Address the climate crisis and environmental justice" and includes recommendation to meet King County's climate goals by reducing car use, developing clean infrastructure, promoting climate justice, and by prioritizing ways to make transit convenient and accessible. The 2020 Strategic Climate Action Plan (SCAP) proposed by the Executive in August 2020 was updated based on the Mobility Framework and includes goals, strategies and actions to reduce car trips by 20% by 2030 (Figure 2) and county-owned fleet emissions by 45 percent by 2025 and 70 percent by 2030 (Figure 3), compared to 2017.

[5] Emissions from Metro's fixed route bus fleets are much larger than other fleets. In 2019, emissions from other fleets range from 13,000 tons for ACCESS, 7,600 tons for Vanpool, 4,000 tons for non-revenue vehicles and 2,400 tons for marine/water taxi.

Figure 2. 2020 SCAP goals for reducing GHG emissions from car trips in King County.

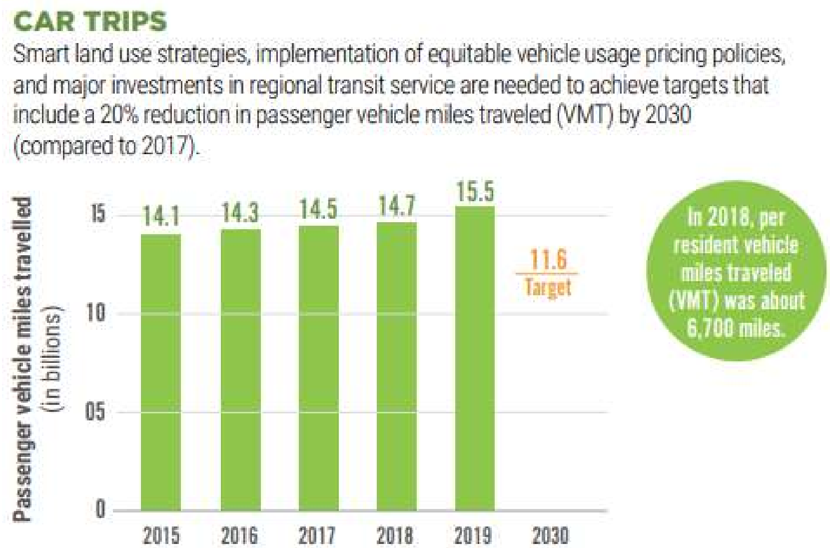
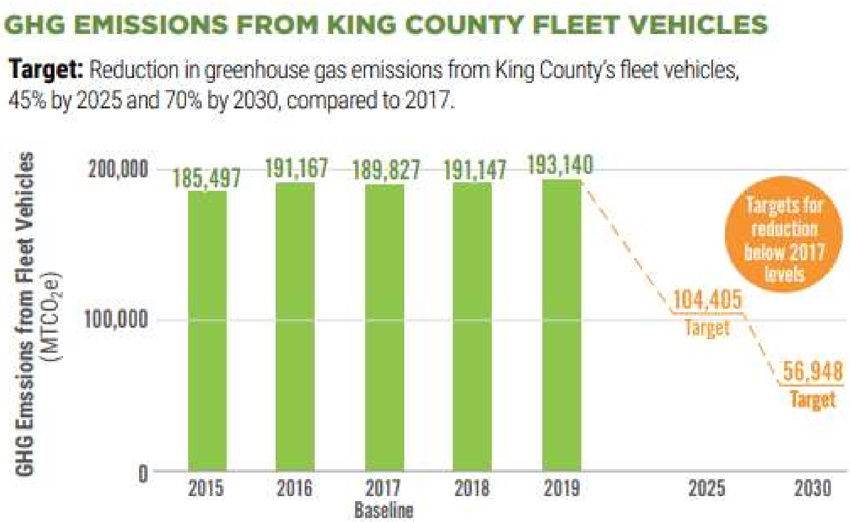


Figure 3. 2020 SCAP goal to reduce GHG emissions from King County Fleet Vehicles



To inform establishing long-term goals for the SCAP and identify specific priority actions for the next five years, King County modeled what levels of transit service, land use density and vehicle usage pricing would be required to reduce car trips by 20% by 2030 and 28% by 2050, in alignment with WA RCW 47.01.440.[6] Results are shown in Table 2, indicating that increased transit service, land use density and vehicle usage pricing equitably implemented are all critical components, and a combined scenario is the best approach for achieving the target. Increasing land use density and affordable housing near transit is a key component of Vision 2050 and is critical to achieving long-term goals. Transit service levels above

[6] King County Climate Action Team (eds.). 2020. King County 2020 Strategic Climate Action Plan. King County, Washington. Available at: https://your.kingcounty.gov/dnrp/climate/documents/2020-SCAP-Full-Plan.pdf

and beyond what is planned in Sound Transit 3 and Metro Connects will be required. Pricing vehicle travel either via congestion pricing, tolling, road usage charge, parking pricing, or similar tools are necessary components to realistically achieve targets. Equitably implementing any pricing strategy presents a real challenge and is critical to ensure it aligns with the ESJ commitments and does not result in an inequitable economic burden.

Three priority actions were advanced in the 2020 SCAP to reduce car trips based on this analysis:

- Advocate and engage in regional conversation to evaluate options for vehicle usage pricing that is equitable.
- Advocate and engage in regional conversation on transit service growth and service funding to achieve County climate goals.
- Update Metro's policies, including Service Guidelines and METRO CONNECTS, to reflect service priorities in routes that will reduce GHG emissions, balancing ridership and climate priorities with other identified investment needs, including equity. Ensuring adherence to climate goals will require service priorities that focus on higher ridership services.

Table 2. Increased Transit Service, Land Use Density, and Vehicle Usage Pricing all critical components to achieve reductions in car trips. Scenarios that achieve the 2020 SCAP target for VMT reduction are indicated by a check mark and those that do not by an "x".

SCENARIOS TESTED TO MEET CAR TRIP REDUCTION TARGETS

— Same as Vision 2050 ↑ Greater than Vision 2050	INPUTS/ASSUMPTIONS			OUTCOMES	
	Transit Service Levels	**Percent of Growth Allocated to Urban + Transit-oriented Suburban Areas**	**Vehicle Usage Pricing Level**	**Percentage of Trips Walk, Bike, Transit, Roll** (% Non-Single Occupancy Vehicle Trips)	**Achieves SCAP target for Reduction in Car Trips** (% reduction in VMT from 2017)
Vision 2050	Sound Transit 3 & Metro Connects	85%	$0.13/mile	57%	✗
Transit Investment Focused	↑	—	—	↑	✓
Land Use Focused	—	↑	—	—	✗
Vehicle Pricing Focused	—	—	↑	↑	✓
Combined Scenario	↑	—	↑	↑	✓

At the government operations scale, King County is committed to reducing vehicle emissions in its own operations. In 2020, the King County Council adopted Ordinance 19052 to accelerate the adoption of electric vehicles. In response to Ordinance 19502, Metro Transit has completed development of a Zero-Emission Battery Electric Bus Implementation Plan. This plan includes updated life-cycle cost assessment of implementation of a zero-emission bus fleet. The 2020 SCAP includes updated goals, strategies, and priority actions to reduce emissions from county fleet vehicles (Figure 3) by increasing the efficiency of County vehicle fleets and minimize their GHG emissions.

Greenhouse gas impacts from transit investments relate not only to transit fleet and facility emissions, but also involve mode shift, congestion relief, and land-use change from mobility investments. Many riders are “choice riders” meaning they chose to ride Metro over other transportation modes. Congestion relief emissions from public transportation reflect improved fuel efficiency of vehicles from reduced road congestion. Land use change to support compact land-use reduces emissions by resulting in shorter trips, fewer trips, more walk/bike trips, trip chaining and lower/no car ownership. Land use impacts represent by far the largest impacts, but also take the most time to realize.

Research supports the shift toward more dense land use following BRT development. A local study analyzed ridership of new King County Metro RapidRide routes between 2010 and 2014, and found within a ¼ mile of stations, there was a 7% increase in the number of residential units.[7] In Lahore, Pakistan, the land use around 10 new BRT stations was analyzed over a 7-year period, and determined that population increased by 12%, mostly due to conversion of single family to multi-family units.

Methodology

Each mobility and fleet investment strategy were modeled and evaluated individually. Mobility investments were modeled based on sample projects and scaled to investment levels as defined in Metro Connects, as adopted in 2017. Fleet strategies are modeled assuming implementation across the full fleet in 2040. Fleet electrification cost estimates are based on an updated cost benefit analysis by Metro in 2020.[8] Annual cost estimates are based on annual operating costs (e.g., service hours or fuel) in 2040 plus annualized capital infrastructure costs for the year 2040 adjusted for discount and inflation rates. Annual cost estimates facilitate comparison across strategies, in practice strategies will be implemented over many years. Annual maximum emission reduction potential is based on the emission reductions that could be achieved when strategies are fully implemented or the benefit is fully realized (e.g., land use change), for the purposes of this analysis, 2040 is used for comparison. Cost effectiveness is then quantified based on annual cost estimates divided by annual maximum emissions reduction potential. This analysis did not consider scenario alternatives of different combination of investment strategies together. While each strategy modeled is distinct, there would be overlap in emissions reductions and the total opportunity to reduce emissions through Metro Connects or fleet investments cannot be determined based on adding together analysis of individual strategies here.

[7] Stewart, O.T. et al. 2017. The Causal Effect of Bus Rapid Transit on Changes in Transit Ridership. J Public Trans. 20 (1): 91-103.

[8] King County, 2020. Zero-Emission Battery Bus Preliminary Implementation Plan. Sept. 30, 2020. Available at: https://kingcounty.legistar.com/LegislationDetail.aspx?ID=4659953&GUID=C6DD58EC-C262-433A-9F76-6515F46FEB5F

Mobility Investment Strategies

For analysis of mobility investments, the PSRC 2040 model and the Sound Transit ridership model were used to measure the impact of select strategies, including frequent service investments and speed & reliability infrastructure, on GHG reductions. Other strategies, such as TOD and first/last mile improvements, were analyzed using other analytical tools, such as transit ridership elasticities and trip generation estimates. For the analysis of these strategies, outputs from the PSRC model and the Sound Transit ridership model were used to inform assumptions and inputs in the analysis, such as metric tons of GHG emissions per mile for both transit vehicles and cars, average speeds and trip lengths. All emission impacts were evaluated at the county level, with a single horizon year of 2040.[9] Investment cost data for the service and speed & reliability strategies are based on cost estimates for Metro Connects (2017) annualized to reflect the cost in 2040 and adjusted for discount and inflation rates. [10] TOD, TDM, and first/last mile connections cost estimates are not based on Metro Connects, specifics in Table 3. All cost estimates are shown in 2019 dollars. This snapshot allows for an annualized cost per GHG reduction to be calculated for each strategy to normalize the results for a clear comparison between strategies. Cost and emission reduction estimates will need to be updated to align with Metro Connects updates, expected in 2021. Table 3 discusses the methodology used for each strategy to estimate the investment impact and GHG reduction.

Table 3: Modeling Methodology for Mobility Investments

Mobility Investment Strategy	Modeling Methodology and Considerations
Transit-Oriented Development (TOD)	Investment and support for transit-oriented development can greatly reduce VMT/capita. With more households and jobs located near high frequency transit, there is a large decrease in VMT due to mode shift to transit and walk/bike trips. Multi-family apartment complexes also generate fewer daily trips compared to single family homes, which contributes to the decrease in VMT and GHG emissions. The TOD analysis was performed outside of the PSRC model, focusing on Metro-owned park-and-ride sites where TOD planning could result in a significant shift in the surrounding land use. The analysis assumed a planning cost of $250,000 per site[11] and used trip generation estimates for

[9] In practice, strategies may yield different rates of GHG emissions reduction over time, with some strategies yielding a consistent amount year-to-year and others yielding increasing or decreasing amounts year-over-year. For comparison, a one-year horizon was used while assuming that every strategy would exhibit a similar year-to-year rate of aggregated GHG reductions.

[10] Costs were increased using a 1.5% annual cost inflation factor and investments were annualized with a discount rate of 3% over a 20-year investment horizon.

[11] Planning cost estimated from previous TOD planning efforts by Metro

	single-family homes versus multi-family apartment complexes to estimate a trip rate reduction of 4 trips per household per day.[12] This trip rate reduction was used along with average trip lengths and vehicle emission rates provided by the PSRC model to produce an average cost per metric ton of GHG emission saved. Analysis assumes that costs beyond planning (e.g. construction) are paid by other entities. To measure the total potential annual GHG emissions reduction, the project team reviewed the list of Metro-owned park-and-rides and determined that approximately up to 20 sites could be suitable for TOD. The average GHG reduction per site was applied to the 20 locations to calculate the total GHG reduction potential.[13] Factors that influence the range of costs and emissions reductions include: • There is uncertainty as to the level of planning investment and corresponding GHG reduction. This analysis assumed a planning cost of ~ $1,000 per unit built based on $250,000 total planning costs and 250 units. If the planning cost exceeds this amount, the average cost per metric ton saved would also increase. • The range of density that a TOD project could be built in would substantially shift the trip lengths and number and change the expected GHG reduction.
Transit Demand Management (TDM)	Values are based on a recent PSRC Regional FHWA grant application that assessed the relative impact of targeted TDM measures along five new RapidRide corridors, the Link Light Rail extensions, and the Sound Transit BRT service. [14] TDM strategies included targeted marketing and incentives for employers and community-based organizations along with increased vanpool participation. To measure the total potential annual GHG emissions reduction, the project team used the recently submitted PSRC Mobility Grant submittal from King County Metro that identified the total estimated GHG reduction from a four-year TDM strategy.

[12] ITE Trip Generation Manual, 10th Edition for single-family vs multi-family land use codes

[13] This included an assumed FAR of 2 and an average unit size of 850 square feet, using land currently dedicated to parking

[14] King County Metro Transit, 2020. Improving Access to Regional Centers through Transportation Demand Management. Regional FHWA Funding Application to PSRC. Available at: https://www.psrc.org/sites/default/files/tip2020-fhwa-king-county-metro_improving-access-to-regional-ctrs-through-tdm.pdf

	Strategy not scaled to level of investment in Metro Connects. Factors that influence the range of costs and emissions reductions include: • The assumed participation rates and response to incentives are based on previous TDM strategies and may not be fully applicable to this specific pilot program. Therefore, the results in GHG reductions may differ from the assumed changes provided in the grant application. • The total potential reduction in GHG emissions may be much larger depending on the longer-term strategy to scale up the TDM program developed for the grant submittal.
New BRT/RapidRide corridors with land use change	The RapidRide/BRT investment type incorporated multiple service and capital elements to measure the impact of both the service aspects of BRT and the land use change generated by BRT. Although RapidRide service is not technically classified as BRT, both services rely on similar capital improvements to operate efficiently so this analysis assumes the two services are similar. To estimate the GHG per service hours ratio, six corridors were evaluated in the PSRC model[15] by reducing their headways to ten-minute all-day service and increasing their speeds by 25 percent and 15 percent in the peak and off-peak periods, respectively. Additionally, the population along the corridors in the PSRC model was increased by 12 percent and the employment by five percent to represent the observed impact BRT has on land use patterns.[16] Model outputs were summarized to determine the relative change in GHG emissions compared to the service and capital investment of the BRT lines. To measure the cost effectiveness for the six corridors the investment per mile and per service hour from Metro Connects was divided by the estimated GHG reductions. To measure the total potential annual GHG emissions reduction, the estimated GHG reduction per service hour ratio was applied to the 2017 version of Metro Connects estimated scale of investment in BRT corridors, which is currently under review and revision in 2020/21.[17] The approximate increase in frequent service hours (which include RapidRide and frequent service) is between 1.0 and 1.5 million annual service hours by 2040. This

[15] The same corridors were evaluated in the speed & reliability analysis

[16] Bus Rapid Transit System: A Study of Sustainable Land-Use Transformation, Urban Density and Economic Impacts, 2020 and The Causal Effect of Bus Rapid Transit on Changes in Transit Ridership, 2018

[17] Approximately $1.5B in speed & reliability investment plus estimated service hour increase of up to 20 percent per route

	strategy does not include additional capital infrastructure costs for expanded operational growth capacity. Factors that influence the range of costs and emissions reductions include: • With new BRT corridors, the greatest GHG reduction benefit may come from the subsequent change in land use, but this impact can vary greatly by region. • Achieved travel speeds and congestion along the corridor can influence ridership and resulting GHG reductions as a function of investment. • With more households and jobs located along high frequency routes, there is potential for a larger decrease in GHG due to mode shift from SOV to transit and walk/bike trips. • Because RapidRide investments are not as capital intensive as the BRT lines studied in the land use research previously referenced, actual emission reductions for RapidRide service may be lower as compared to full BRT service.
Frequent service expansion	Multiple model runs were performed by reducing the headways on Metro routes, during both peak and off-peak time periods. Performing multiple model runs with headway changes on different routes, in different time periods, produced a range of ridership increases, which was then used to calculate mode shift away from driving to estimate the GHG reduction. Sensitivity analysis was used to explore the impact of investments in express longer-distance networks versus frequent service to understand the relative change in GHG reductions. This strategy excludes any changes in land use via population and jobs along corridors and focused on the mode shift of increased transit frequency only. Frequent service is distinct from BRT/RapidRide in not having specific branding and payment systems. The ridership and GHG emissions change were measured for the 2040 horizon year from the model and the investment costs for service were calculated based on a 1.5 percent annual inflation factor applied to today's average cost of $163 per service hour. This strategy does not include additional capital infrastructure costs for expanded operational growth capacity. To measure the total potential annual GHG emissions reduction, the observed GHG reduction per service hour ratio was applied to the net change in frequent service hours identified in Metro Connects for the 2040

	network. The approximate increase in frequent service hours is between 1.0 and 1.5 million annual service hours by 2040. Factors that influence the range of costs and emissions reductions include: • The choice of route for improvement: if service hours are invested along a corridor that does not have the demand to support that level of service, the subsequent emissions reduction would be less per service hour invested. • To the degree frequent service expansion is focused on additional express service from suburban areas this may generate greater savings in VMT per capita due to the longer trip distances as compared to frequent service. However, a dense network of frequent service can generate a higher rate of non-commute transit trips compared to express service. • There may be diminishing rates of return if too much service is added where land use patterns do not support that level of density. In that example, emissions from additional transit service may exceed any reduction in emissions from new riders generated. • Service increases without a subsequent investment in speed & reliability as in the BRT strategy may face limited benefits if the travel time-competitiveness of transit is constrained because of ongoing or increasing congestion.
Frequent service expansion with land use change	The PSRC 2040 model runs and methodology from the “frequent service investments” strategy were modified by updating the land use assumptions in the model to reflect an approximate 6 percent increase in population and 3 percent increase in jobs for areas around a set of modeled frequent corridors. Frequent service is distinct from BRT/RapidRide in not having specific branding and payment systems. The ridership and GHG emissions change were measured for the 2040 horizon year from the model and the investment costs for service were calculated based on a 1.5 percent annual inflation factor applied to today’s average cost of $163 per service hour. This strategy does not include additional capital infrastructure costs for expanded operational growth capacity. To measure the total potential annual GHG emissions reduction, the observed GHG reduction per service hour ratio was applied to the net change in frequent service hours identified in Metro Connects for the 2040 network. The approximate increase in frequent service hours is between 1.0 and 1.5 million annual service hours by 2040.

	Factors that influence the range of costs and emissions reductions include: • The observed relationship between land use and service is still being determined based on limited studies and the increase of 6% and 3% in population and jobs respectively is a conservative estimate from the research. The impact of land use change based on increased service levels could be somewhat limited depending on the specific corridor and the local land use context.
Speed & reliability	Six representative routes were chosen for analysis, two in Seattle, two on the Eastside, and two in South King County to provide a broad cross-section of route-types and land use variation. In the PSRC travel demand model, the speeds for the routes were increased by 25 percent during the peak time period and 15 percent during off-peak. The speed improvements were based on an approximate investment of $1.3 million per mile in various speed & reliability projects, including queue jumps, transit signal priority, and bus stop improvements. The cost of $1.3M per mile was the average cost for the Frequent service-type speed & reliability investment assumed in Metro Connects. The VMT reduction from new Metro riders plus the Metro savings from more efficient operations were used to calculate the GHG emission reduction and determine a cost per metric ton saved. To measure the total potential annual GHG emissions reduction, the estimated GHG reduction per service hour ratio from speed & reliability was applied to the estimated investment in speed & reliability in Metro Connects 2040 network. The total estimate is based on approximately $400M in speed & reliability investment for non-RapidRide corridors. Factors that influence the range of costs and emissions reductions include: • Speed and reliability improvements have a wide range of associated costs per mile, depending on the chosen improvement and the local conditions. If improvements are constructed on corridors that carry under-performing routes, or face little recurring congestion, the average cost per metric ton saved could increase significantly. • Metro would also see GHG reductions from their fleet due to improved operational efficiency along these corridors. Some speed and reliability improvements can increase travel times for those in personal vehicles, while standard transit improvements,

	such as bus queue jumps and bus-only lanes, can increase delay for personal vehicles and reduce capacity. • The investment costs do not include any service hour change. The model focuses on change resulting from speed improvement making transit more attractive. Including investment in increased service would yield results closer to the BRT option.
Access to Transit	The Access to Transit analysis was performed outside of the PSRC model, using previous work with Metro that identified elasticities between transit access projects and ridership change. The Nonmotorized Connectivity Study produced by King County Metro presents a wide range of average costs per new rider for new investments. The average investment per new rider from the analysis was between five to fifteen dollars for a typical set of projects.[18] Outputs from the PSRC model provided assumed GHG emissions per new rider based on average trip lengths and average speeds. The mode shift was applied to provide an equivalent metric ton of GHG emissions reduced per dollar invested. To measure the total potential annual GHG emissions reduction, the estimated GHG reduction per dollar invested estimated through the study was applied to the total investment for access-to-transit investments identified in Metro Connects for the 2040 network. Approximately $450M was targeted for access-to-transit investments in Metro Connects. For first/last mile connections and access to transit infrastructure strategies, the relative cost-effectiveness in reducing GHG emissions does not compare to service-oriented or land use strategies. Furthermore, the ability to scale up access-to-transit and first/last mile strategies to a similar level as service or capital is likely not feasible given constraints in how those strategies could be funded and the diminishing returns of larger investment amounts. As an example, building out active transportation infrastructure such as bike lanes and sidewalks in lower density areas will yield less return in the number of new riders. These strategies do serve multiple goals such as expanding coverage and access to the transit system and improve neighborhood connectivity. Factors that influence the range of costs and emissions reductions include: • There is still limited research that directly measures the relative ridership change and therefore GHG effects of non-motorized first/last mile investments, such as access to transit.

[18] Project types included examples such as bike lanes, pedestrian bridges, and signalized crossings

	• Access-to-transit Investments may convert previous car trips to bicycle or pedestrian trips depending on the type of project, and therefore, the overall GHG benefits may be underestimated in this analysis.
First/Last mile connections	The First/Last Mile Services analysis was performed outside of the PSRC model, using information provided through observed data from the Metro's VIA to Transit program. The average cost per new rider for the Rainier Valley program area has ranged from five to fifteen dollars. The analysis assumed sharing of rides and an average 1.5-mile trip to estimate the GHG output from the VIA vehicles and to determine the total metric tons of GHG emissions saved compared to the cost of service. To measure the total potential annual GHG emissions reduction, the project team used an assumed $250M total investment in first/last mile services over twenty years and annualized the investment for a 2040 horizon year. The original Metro Connects did not have a specific investment amount identified for first/last mile services, however discussions during the update of Metro Connects in 2019 and 2020 have suggested an investment amount that may be similar to the access-to-transit investment, or would be a portion of that total investment amount. The assumed cost per GHG reduction ratio was applied to the total investment to generate a total potential annual GHG reduction. First/last mile programs can reduce VMT/capita by providing a reliable alternative to driving to transit and can shift some entire trips away from single occupancy vehicles. This analysis did not consider the degree to which these services can result in lower rates of car ownership, reducing overall car trips. Metro can prioritize the deployment of both strategies to where needs are greatest to address transit access inequities. Factors that influence the range of costs and emissions reductions include: • First/Last mile programs across the country have had varying degrees of success. King County Metro's program has performed well in some areas and poorly in others. VIA to Transit does have a range of estimated operating costs, which adds uncertainty to the true reduction in GHG emissions. • For simplicity, this analysis assumed a range of how new trips were converted. New trips were either from travelers that were previously driving for their entire trip or were converting from previous non-motorized access or park-and-ride access trips.

	• Estimates are based on limited experience with a new pilot program; as a program is scaled up, costs and ridership shifts could vary.

Fleet Investment Strategies

For this analysis, Metro look to strategies to reduce emissions from Metro Transit fleets, purchase of alternative fuels and transition to zero-emission fleet. A description of methodology approaches is provided in Table 4.

Alternative fuels using renewable fuel sources can reduce emissions from fuel using current fleet and fleet infrastructure. Two fuels most appropriate for Metro Transit diesel hybrid fixed route fleets are biodiesel[19] and renewable diesel.[20] Both fuels are widely used within the transit industry. Renewable diesel is considered a drop-in fuel, chemically identical to diesel. Biodiesel has been used by Metro Transit for over a decade. Currently, Metro uses a 5% blend for all our bus fleets, meaning that 5% of our diesel fuel is plant-based. Metro has successfully tested a 10% blend without adverse impact in bus fleets. Metro Marine Division uses a 20% biodiesel blend for all water taxi operations. Biodiesel blends require only minor filter adjustments, higher percentages of biodiesel can have operational impacts, so Metro has not tested these blends. Neither require significant changes to fleet nor fueling infrastructure. Other fuels, such as renewable natural gas (RNG) or propane, require significant investments in new fleet and fueling infrastructure. Some transit agencies, such as LA Metro, have significant fleets fueled with RNG. Both biodiesel and renewable diesel are available in the Seattle area; however, some customers report availability problems with renewable diesel. If a low-carbon or clean fuels standard is adopted regionally or at the state level, as has been proposed, this would increase the availability of low-carbon fuels.

The King County Council adopted Ordinance to accelerate fleet electrification and set goals to transition to an all-electric fixed route fleet by 2035. The Ordinance included a proviso request for Metro Transit to develop an implementation plan and associated updated cost and environmental assessment. This updated analysis is incorporated in this study.

Table 4. Fleet Investment Strategies Methodology

Fleet Investment Strategy	Modeling Methodology

[19] Biodiesel is a form of diesel fuel derived from plants. Biodiesel can be compatible with diesel engines and can be blended with diesel fuel from fossil fuels. It can be used alone but is most often blended with diesel. At low temperatures 100% biodiesel can begin to gel and solidify preventing operation.

[20] Renewable diesel, like biodiesel, is a diesel fuel derived from plants. In contrast to biodiesel, it is produced to be chemically the same a diesel from fossil fuel. As a result, renewable diesel is a fully drop-in fuel and avoids any of the operational issues that exist with biodiesel.

Biodiesel and Renewable Diesel	For this analysis Metro fixed route diesel fuel consumption was used and compared to current prices for biodiesel and renewable diesel fuels. Total emission reductions were estimated for a variety of fleet sizes, ranging from a reduced fleet size of 1,144, as projected in Council adopted 2021-2022 budget, and an expanded Metro Connects fleet size of 2,028 buses in 2040 to facilitate comparison with mobility investment strategies. Factors that influence the range of costs and emissions reductions include: • Biodiesel prices are based on the Washington State Contract as of August 18. 2020 and renewable diesel prices are based on the City of Seattle contract. Estimates in this analysis do not reflect future projections in fuel markets. • The emission reduction achieved depends on the feedstock (i.e., the biomass source) for the fuels. Traditional biofuel crops could reduce fleet emissions by two, four and eight percent for biodiesel blends of B5, B10, B20 respectively. Renewable diesel could reduce emissions by 62%. Careful attention must be given to the renewable fuel source; if recycled waste products were used the carbon reductions can be significantly higher, but supplies are limited. And if sources come as a result of forest and peatland clearing, emissions from renewable diesel could increases compared to diesel. For example, LA Metro is using renewable natural gas from landfills, which has a very low carbon emission score. • Total emission reductions that can be achieved are a function of fleet size. More emission reductions are achieved, compared to diesel hybrid, if the fleet is larger.

Fleet Electrification	This analysis uses the life cycle cost analysis developed by Metro Transit as part of the proviso response requested by the King County Council. Here information from that analysis on the total cost of implementing the transition to an all zero-emission fixed route fleet and the associated CO_2 emissions is included. This analysis compares the cost per ton for fleet electrification as compared to ongoing use of diesel hybrid fleet.[21] Cost estimates are based on the moderate case scenario forecast[22] using baseline market conditions for 2040 Electrification Fleet Plan as compared to diesel hybrid fleet. Total emission reductions range from reduced fleet size of 1,144, as projected in the Council adopted 2021-2022 budget, and expanded Metro Connects 2040 fleet size of 2,028 buses to facilitate comparison with mobility investment strategies. Factors that influence the range of costs and emissions reductions include: • Costs vary based on timing of fleet procurement over time and infrastructure to support new fleet. • Cost projections are uncertain for newly developed technology; costs may end up being more favorable to electric or diesel fleets. • Total emission reductions that can be achieved are a function of fleet size. More emission reductions achieved, compared to diesel hybrid, if the fleet is larger.

Results and Key Findings

A summary comparison of cost, emission reductions, benefits, sphere of influence, transformation impact and implementation feasibility of each mobility and fleet investment strategy analyzed is shown in Table 5 at the end of this report. Costs per ton of GHG reduced and potential GHG reductions are detailed in figure 4 below. In Figure 4, the width of the bars represents the potential range of cost effectiveness, with narrow bars representing more known costs and wide bars representing costs with various levels of risk or dependencies. The farther left the bar is, the more cost effective it is. The height of the bar reflects the potential emission reduction, with taller bars representing greater potential for emission reductions. The height of the bar varies when the emission reductions are dependent on how the investment is made. For example, investment in high productivity new BRT corridors could achieve a maximum of 300,000 tons or as few as 250,000 tons depending on if resources are invested in higher or lower productivity corridors. An ideal strategy would be to the far left, indicating the investment is cost-effective, and tall, indicating

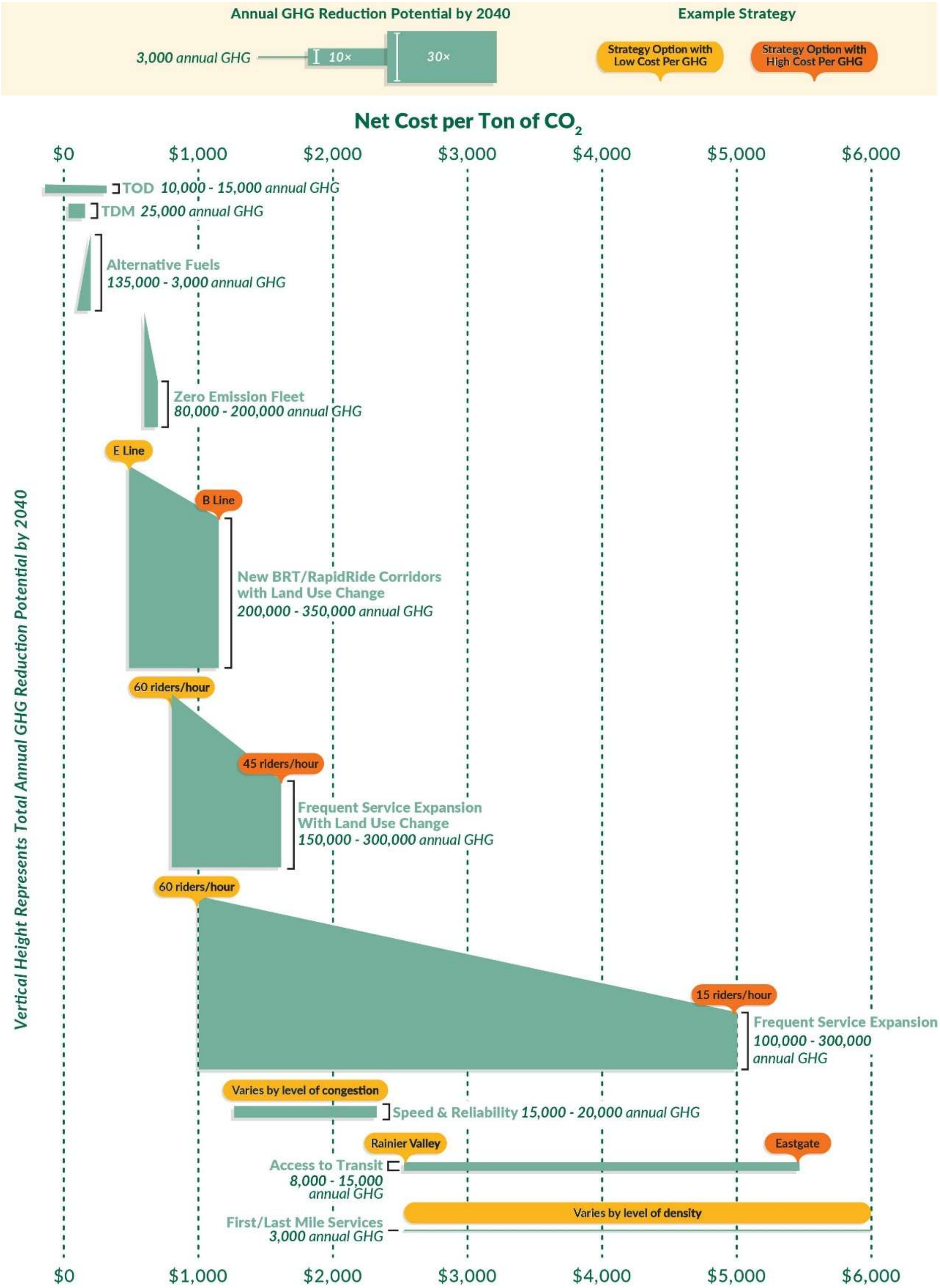
[21] Diesel buses are less expensive to own, operate, and maintain than both hybrids and BEB, so there is a higher cost premium to achieve the same emission reductions as compared to hybrid fleets. Differences between GHG and air pollution emissions from newly purchased diesel hybrid and diesel bus emissions tracks with improvement of fuel efficiency, on the order of 17%.

[22] King County, 2020. Zero-Emission Battery Bus Preliminary Implementation Plan. Sept. 30, 2020. Available at: https://kingcounty.legistar.com/LegislationDetail.aspx?ID=4659953&GUID=C6DD58EC-C262-433A-9F76-6515F46FEB5F

the emission reduction potential is large. Several key findings emerge based on the cost effectiveness and opportunity to reduce emissions strategies:

- The most cost-effective investments appear to include TOD, TDM and alternative fuels, all having a cost of between $0 and $300 per ton. When implemented in the most effective way possible, BRT or frequent service with land use changes are also likely relatively efficient at about $500-$800 per ton, as is fleet electrification at an estimated $750 per ton. The least cost-effective investments appear to be access to transit and first/last mile efforts.
- The options with the greatest likely potential for emission reductions include BRT and frequent service with land use changes (between approximately 150,000 and 300,000 tons/yr.), fleet electrification (80,000 -200,000 tons/yr.), and frequent service expansion (100,000 to 300,000 tons/yr.). Options with the least potential for emission reductions appear to include TOD, TDM, and speed and reliability.
- The options with the most certain/lowest range of costs include fleet electrification, TDM, and fuel conversion. Taken together this information does not point to one simple strategy but rather points to a portfolio approach.

Figure 4. ***Net cost effectiveness per ton and annual GHG reduction potential by 2040 of mobility and fleet investment strategies to reduce GHG emissions.***



A key finding of this analysis is the land use change effect on GHG emissions reduction. Investment in frequent, reliable transit service is key to supporting dense urban development and the reverse is also true: an increase in dense, urban development near high-frequency transit can be a cost-effective means to further reduce GHG emissions. Most research focuses on the land use impact from heavy and light rail, but new empirical evidence shows that BRT has the potential to induce land use development.[23] Additionally, the results from PSRC model runs conducted for this analysis reveal the substantial effects that land use change has on reducing vehicle-miles traveled and subsequent GHG emissions. King County Metro also can directly increase the density surrounding key hubs of transit activity in the region by leveraging the optimal locations of Metro-owned park-and-rides to convert the parking into transit-oriented development such as apartments, retail, and office space. King County Metro has a limited set of locations with which to directly influence TOD planning and therefore the full scale of GHG reduction with the TOD investment strategy is limited. While investments purely in service or capital can be deployed at a broader geographic and financial scale, to achieve a sufficient level of service to shift land use patterns, they need to be focused on a targeted set of corridors. Therefore, the combination of service and land use investments can serve as a cost-effective means to achieve countywide GHG reduction targets.

All investments in frequent service do not deliver the same GHG emission reduction benefit. Investment in more productive service has a greater emission reduction benefit than low productivity service. If service hours are invested along a corridor that does not have the demand to support that level of service, the subsequent emissions reduction would be less per service hour invested. While not specifically modeled for this analysis, express service may generate greater savings in VMT per capita due to the longer trip distances as compared to frequent service. However, a dense network of frequent service can generate a higher rate of non-commute transit trips compared to express service. There can be diminishing rates of return if too much service is added where land use patterns do not support that level of density. In that example, emissions from additional transit service may exceed any reduction in emissions from new riders generated. Additionally if service increases are not accompanied by subsequent investment in speed and reliability as in the BRT/RapidRide strategy, they may have limited benefits if the travel time-competitiveness of transit is constrained because of ongoing or increasing congestion.

In addition to costs and GHG reduction efficacy, other qualitative factors are important when comparing trade-offs among investments to reduce GHG emissions, as shown in Table 5. Each strategy was evaluated based on the qualitative criteria, with green representing the most favorable conditions relative to criteria and red the least. Ideally, climate strategies would offer community benefit, provide pro-equity opportunities, results in direct reductions, be transformative, be achievable in the near-term and be independently implementable by Metro. When comparing strategies by each of the qualitative considerations, results indicate:

- **Community Benefits** are likely greatest for investments in mobility services because they result in improved mobility and quality of service. Zero-emission fleet investments provide the additional benefit of reduced air pollution; this benefit is minimal for alternative fuels.

[23] Basheer, M, L. Boelens, and R. van der Bijl. 2020. Bus Rapid Transit System: A Study of Sustainable Land-Use Transformation, Urban Density and Economic Impacts. Sustainability 12 (8), 3376. Available ahttps://www.mdpi.com/2071-1050/12/8/3376/htm#

- **Pro-Equity opportunities** likely exist for both mobility and fleet Investments by prioritizing deployment where needs are greatest. Investments in King County Metro owned property supporting TOD, new RapidRide, and new frequent service combined with active engagement to achieve transit-supportive land use that serves priority populations, supports thriving neighborhoods, and avoids displacement offers the greatest opportunity to advance both climate and equity goals. Zero-emission fleet deployment can be prioritized to address environmental justice.
- **Direct or indirect impact** varies by strategy. Metro Transit can influence transportation option quantity and quality but cannot directly control transportation choices of residents. In contrast, Metro Transit has direct control over its fleet.
- **Transformational investments** support long-term change to low-carbon infrastructure and reduce demand for fossil-fuel. Mobility investments that include long-lasting capital improvements and compact land-use development have a more permanent and transformational impact. Fleet investments that transition infrastructure to zero-emission fleet transform Metro's fleet, reducing future demand for diesel fuel, and are more transformative than the use of alternative fuels.
- **Time to achieve** reductions is likely longest for the most transformational strategies with the most emission reduction potential. Land use change and transition to a zero-emission fleet strategies have a long-lead time. Investments in TDM, alternative fuels, and express service could be realized in the near-term. Over half of the emissions from our bus fleet could be eliminated almost immediately through the purchase of renewable diesel, though as noted above these reductions would not be permanent or lead to transformational reduction in demand for fossil fuels.
- **Implementation** of new RapidRide and frequent service with land use change, TOD, and speed and reliability improvements all require significant coordination and support from partners and other organizations.

This study does not quantify potential impacts of the combination of strategies, such as land use change, frequent service, and improved access to transit. For example, while bike lanes in places where density is low and therefore car dependency is high might not generate a lot of new riders, adding safe bike lanes and sidewalks in places where the pedestrian trips could be shorter, and therefore possible for a larger share of the population, would likely have a larger benefit for a smaller investment.

Key Conclusions

As identified in the proposed 2020 SCAP, Metro Transit must take the lead to reduce transportation emissions in our region by sustaining and increasing public transit, supporting compact transit-supportive land-use and reducing emissions from Metro fleets. Metro also recognizes that with constrained budgets and staff that these strategies will require new sustained sources of funding and must be implemented over time. Updating these emission reduction and cost-effectiveness estimates to align with the revised Metro Connects service plans and cost estimates in 2021 will be required to compare and align evaluation with updated planning. **Preliminary results of this analysis do not point to one simple strategy to**

reduce GHG emissions, but instead underscore the importance of a portfolio approach to reducing GHG emissions.

- **The strategies Metro can likely implement for the least cost,** including TOD, TDM, and alternative fuels, **are not the same strategies that offer the largest potential opportunity to reduce emissions, which include RapidRide and frequent service with transit-supportive land-use and fleet electrification**.
- **Metro Transit can have the greatest certainty in emission reductions achieved through fleet**, but the opportunity to reduce emissions is fixed at the size of our fleet. Emission reductions will scale with the size of our fleet.
- **The most transformative investments in low-carbon infrastructure will likely take the longest to fully realize**. Investments in these strategies now – including RapidRide and frequent service with transit-supportive land-use and fleet electrification – will help position King County to achieve long-term goals.
- **Fleet electrification appears to offer emission reduction at a cost comparable to high productivity service investments** in RapidRide and frequent service.
- High productivity service investments appear to offer Metro Transit the opportunity to reduce emissions for lower cost than low productivity service.
- Alternative use of biofuels or renewable diesel could be an interim strategy to reduce fleet GHG emissions.

The portfolio approach recommended here is supported by the near- and long-term investments in the Metro Transit 2021-2022 budget proposed by the Executive and recently adopted by council, specifically:

- **Transit Oriented Communities Program Planning:** With the upcoming adoption of Metro's Equitable Transit oriented communities policy, the proposed budget funds the development of a strategic plan and other foundational work needed to to identify opportunities to reposition properties from single purpose parking lots or transit facilities to achieve community development goals. In addition, this program will support efforts to integrate land use considerations into how Metro plans for and deploys new high frequency service.
- **New BRT/RapidRide Corridors**: While Metro will not be able to deliver on the entire long-range vision as outlined in Metro Connects without additional funding, the 2021-2022 Proposed Budget supports the implementation of several long-planned RapidRide lines – including Delridge (2021), Madison (2023), and Renton/Kent/Auburn (2023) – and Sound Transit Link light rail integrations.
- **Zero-Emissions Revenue Fleet:** The Executive's proposed budget advances the transition to a zero-emissions fleet. During 2021-2022, Metro will purchase 40 battery electric buses and related charging infrastructure and will plan and design charging infrastructure to support an additional 260 battery electric buses by 2028.
- **Frequent Service Network**: The 2021-2022 proposed budget supports system restructures to align fixed route bus and other Metro services with Link frequent service expansions, including Northgate link in 2021; Eastlink in 2023; and Federal Way, Lynnwood, and Redmond Link in 2024-2025

- **Speed and Reliability Improvements:** The proposed budget includes the following speed and reliability improvements that are in addition to improvements for the proposed RapidRide corridors: South King County Corridor Improvements, spot improvements as part of service restructures (RKAAMP, North Link and East Link), and multimodal corridor improvements on Route 48, Route 40, Route 44.

Achievement of our ambitious long-term goals will require investment in a variety of these strategies.

Table 5: Summary comparison of mobility and fleet investment strategies to reduce GHG emissions ranked by cost-effectiveness ($/ton).

Metro Investments	Modeling approach and assumptions	Ridership and trip pattern impact	Cost estimate ($)	Cost Effectiveness ($/ton)	Annual GHG Reduction Potential in 2040 (ton/yr)	Community benefit?	Pro-equity opportunity?	Direct or indirect?	Transformational investment?	Time to achieve reductions?	Can Metro independently implement?
Transit Oriented Development (TOD) – Planning of developments surrounding Metro owned properties.	Assumed investments of transit-oriented development within ¼ mile of 20 King County Metro Park & Ride sites.	Up to 4 auto trips reduced daily per new housing unit based on estimates from the ITE Trip Generation Manual.	Assumes cost of $250,000 per TOD investment site (i.e., $1,000 per unit). Cost included for Metro Transit planning only.	<$0 - $300	10,000 – 15,000	Yes - Housing	Yes	Indirect	Yes	Medium	No
Transit Demand Management (TDM) – targeted marketing and incentives to encourage transit and vanpool ridership	Sixteen targeted regional corridors across the county from 2021 to 2024 to increase transit and vanpool ridership.	Greater than 15,000 new daily riders estimated from the PSRC Mobility Grant submittal analysis.	Planning and implementation costs assumed in the PSRC Mobility Grant submittal for TDM strategies.[24] Strategy not scaled to level of investment in Metro Connects.	$50-$100	25,000	Yes – Improved Mobility and Transit Access	Yes	Indirect	Maybe	Near	Yes
Alternative Fuel – Purchase biodiesel blends or renewable diesel for diesel-hybrid bus fleets.	Purchase of Biodiesel (5% - 20% blends) or renewable diesel to fuel 100% of fleet of diesel-hybrid buses. Range of emission reductions based on 2040 reduced fleet size in current budget and expanded Metro Connects fleet size of 2,028 buses. Emission reductions assume traditional feedstocks.	No direct impact	Fuel prices based on 2020 prices and do not reflect future projections or inflation.	$100 for biodiesel $200 for renewable diesel	3,000 - 8,000 for 10% biodiesel; 50,000 – 135,000 for renewable diesel	Minimal	Minimal – Contracting	Direct	Maybe	Near	Yes
Zero-emission fleet – Transition to zero-emission bus fleet by 2040.	Transition to all zero-emission bus fleet by 2040 with trolley buses and battery-electric fleet. Range of emission reductions based on reduced fleet size of 1,144 up to expanded Metro Connects fleet size of 2,028 buses.	No direct impact	Cost estimates based on the moderate case scenario forecast[25] using baseline market conditions as compared to diesel hybrid fleet.	$640	80,000 – 200,000	Yes – Air pollution and noise	Yes – Air pollution and noise	Direct	Yes	Near, Medium + Long	Yes
New BRT/RapidRide Corridors + Land Use – Speed and reliability and service improvements for BRT type service and associated increase in land use and population density.	Within ¼ mile of 6 new BRT/RapidRide routes, population was increased by 12%, and jobs by 5% in the model.	Average productivity of 60 new riders/hour with 10-min all-day headway assumed for future BRT.	Assumed costs from Metro Connects for RapidRide were $5-$10M per mile with a total investment of approximately $1.5B for all future lines and an approximate 20 percent increase in service hours per RapidRide route. Capital costs were annualized over a twenty-year period at a 3% discount rate. Includes average service hour cost of $163 inflated to 2040 dollars with a 1.5% inflation factor. Does not include additional capital infrastructure costs for expanded operational growth capacity.	$500 - $1,500	200,000 – 350,000	Yes – Service	Yes	Indirect	Yes	Medium + Long	No

[24] King County Metro Transit, 2020. Improving Access to Regional Centers through Transportation Demand Management. Regional FHWA Funding Application to PSRC. Available at: https://www.psrc.org/sites/default/files/tip2020-fhwa-king-county-metro_improving-access-to-regional-ctrs-through-tdm.pdf

[25] King County, 2020. Zero-Emission Battery Bus Preliminary Implementation Plan. Sept. 30, 2020. Available at: https://kingcounty.legistar.com/LegislationDetail.aspx?ID=4659953&GUID=C6DD58EC-C262-433A-9F76-6515F46FEB5F

Frequent Service Expansion with Land Use – Frequent service (i.e., reduced all-day headways) and associated increase in land use and population density.	Based on planned increase in annual service hours for Metro Connects, reduced all-day headways and increased land use density, specifically 1.0 to 1.5M additional hours for Frequent Service Type. Service increase plus a 6% increase in population and 3% increase in jobs along the corridors. (Ex. Routes 5, 150)	Average productivity of 45 to 60 new riders/hour	Assumed total costs from Metro Connects of an increase of approximately 1.0 to 1.5M for additional Frequent Service type hours and an average service hour cost of $163 inflated to 2040 dollars with a 1.5% inflation factor. Does not include additional capital infrastructure costs for expanded operational growth capacity.	$750 - $1,000	150,000 – 300,000	Yes- Service	Yes	Indirect	Yes	Near + Long	No
Frequent Service Expansion – Frequent service (i.e., reduced all-day headways) during peak or off-peak periods for select routes	Reduced headways during peak and off-peak for select routes based on planned increase in annual service hours for Metro Connects of 1.0 to 1.5M hours for Frequent Service Type New service with high productivity range (Ex. C Line peak, Routes 7, 49, A Line peak)	Average productivity of 60 new riders/hour	Assumed total annual costs from Metro Connects of an increase of approximately 1.0 to 1.5M additional Frequent Service type hours and an average service hour cost of $163 inflated to 2040 dollars with a 1.5% inflation factor Does not include additional capital infrastructure costs for expanded operational growth capacity.	$750 to $1,000 per metric ton saved	200,000 to 300,000	Yes - Service	Yes	Indirect	Maybe	Near + Medium	Yes
	New service with average productivity range (Ex. C Line off-peak, Routes 36, 372)	Average productivity of 45 new riders/hour		$1,000 to $1,500 per metric ton saved	150,000 to 200,000						
	New service with low productivity range (Ex. Routes 181 and 304)	Average productivity of 15 new riders/hour		$2,000 to $3,000 per metric ton saved	50,000 to 100,000						
Speed & Reliability (Non-RapidRide) – Investment in corridors to improve peak and off-peak speeds on non-BRT/RapidRide routes	Based on non-RapidRide speed & reliability investment allocation in Metro Connects. Examples: Seattle: Routes 5 and 7 South King County: Routes 150 and 181 Eastside: Routes 245 and 226	Estimated ridership elasticity of 0.4% for every 1% increase in speeds based on research provided in TCRP Project A-39 and modeling outputs.	Assumed total costs from Metro Connects of approximately $400M in non-RapidRide speed & reliability investments and a cost of approximately $1.3M per mile. Costs were annualized over a twenty-year period with a 3% discount rate.	$1,250 - $2,250	15,000 – 20,000	Yes – Service	Yes	Indirect	Yes	Medium	No
Access to Transit – Investment into non-motorized improvements near high-frequency Metro stops	No specific locations or projects modeled; instead the analysis used an average cost per new rider.	Estimates of ridership increase generated from the Nonmotorized Connectivity Study completed by King County Metro.	Cost-effectiveness estimates based on approximate cost per rider range of $7.5 to $15. Total potential annual GHG emissions reduction, based on approximately $450M was targeted for access-to-transit investments in Metro Connects.	$2,500 - $7,000	8,000 – 15,000	Yes – Accessibility	Yes	Indirect	Yes	Medium	No
First/ Last Mile Connections – Improving access to high-capacity transit (e.g., VIA to transit).	No specific locations modeled; instead the analysis used an average cost per new rider.	Estimates of ridership increase generated from previous Via to Transit.	Cost effectiveness estimates based on transit pilot programs costs incurred per new rider of between $5 and $15. To measure the total potential annual GHG emissions reduction, the project team used an assumed $250M total investment in first/last mile services over twenty years and annualized the investment for a 2040 horizon year.[26]	$2,500 - $5,500	3,000	Yes - Service	Yes	Indirect	Maybe	Near	Yes

[26] The original Metro Connects did not have a specific investment amount identified for first/last mile services, however discussions during the update of Metro Connects in 2019 and 2020 have suggested an investment amount that may be similar to the access-to-transit investment, or would be a portion of that total investment amount.