Appendix

Final Report

1. Fleet Electrification
2. Miscellaneous Equipment
3. Construction Pricing Context & Constructibility
4. Climate Analysis

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Louisville
Fleet
Decarbonization Analysis and Assumptions

Louisville Fleet Decarbonization

Summary

McKinstry analyzed the costs and emissions savings associated with Louisville converting their fleet to electric models at vehicle replacement, if a suitable vehicle was available. The incremental initial vehicle cost would be $4.3M, but the incremental cost on a lifecycle basis would only be $1M. The amount of CO2 emissions saved would be approximately 9 million lb. These numbers include 2.5% inflation, electric rate inflation of 2.44%, and gas/diesel cost escalation of 2.65%.

	Vehicle replacement cost	Fuel Costs	Maintenance Costs	Total Cost	Total Emissions lb of co2
Status Quo, keep buying ICE	$14,446,954	$3,912,658	$1,596,579	$19,956,191	16,188,795
Phasing in Evs	$18,104,994	$1,710,455	$1,178,767	$20,994,216	6,936,913

Overview

As part of the decarbonization study, McKinstry analyzed Louisville's fleet vehicles for replacement with electric vehicle (EV) equivalents. Based on current technology, transitioning from internal combustion engine (ICE) vehicles to EVs can substantially lower overall carbon emissions. A caveat to consider in assessing the environmental impact of EVs is the variation of electricity generation sources in a given area. The state of Colorado relies mainly on coal and natural gas. However, the share of these fuel sources as a percentage of total generation is decreasing. Alternative energy sources such as wind and solar are increasing rapidly. By using additional onsite renewable energy sources and phasing in vehicle replacement it will be possible for Louisville's fleet to be entirely carbon free.

In the current vehicle market mainly light duty vehicles are being produced. There currently are no manufactures that outfits an EV for police vehicle use. The market is rapidly changing so over the course of the next 5 years new innovation and demand should allow for this use.

EVs typically have a higher initial capital cost to purchase or lease when compared to ICE vehicles, EVs can cost less in the long-term due to lower fuel costs, different maintenance requirements, and longer vehicle lives. Therefore, it is important to consider the entire lifespan of a vehicle when investing in fleet vehicles. There are also limiting factors of EVs to consider, such as range and power needs of certain fleet vehicles, as well as the near-constant changes in the electric vehicle and infrastructure technology.

Battery technology is changing rapidly, resulting in increased charge capacity and lower operating cost per mile. Many manufactures now offer eight year/100,000 mile warranties on their EV batteries (generally covering defects and workmanship), and some offers an ten year/100,000 mile warranty on battery capacity. Auto manufacturer warranties and charge capacity have generally reduced consumer concern about battery life and range. As a result, the analysis of total ownership cost does not account for the cost of EV battery replacement, assuming that municipal vehicles will be retired at the warranty expiration.

Fleet Vehicle Type

Vehicles utilized by the city were divided into five categories.

1. *Light duty vehicles* – Light duty vehicles make up the majority of the vehicles the city owns. They typically encompass any normal passenger vehicle such as sedans, SUVs, light pickup trucks, and minivans. This vehicle is mostly used for transporting people and small amounts of cargo
2. *Light duty high performance vehicles* – This category incorporates mainly police vehicles. These vehicles are similar to the light duty vehicles but have been altered for higher performance due to specific police requirements.
3. *Heavy duty vehicles* – Heavy duty vehicles mostly incorporate large pickup trucks. These vehicles are used for hauling and towing heaving loads.
4. *Large heavy duty vehicles* – This category is for the large snow plows and street sweeper. These vehicles typically are only used seasonally and have a varying work load that is dependent on the weather
5. *Non-road vehicles* – These vehicles are typically construction type vehicles. There usage is usually measured in hours of operation instead of miles.

	Vehicle Category					
	1	2	3	4	5	Total
Building Inspection	3					3
Code Enforcement	2					2
Engineering	4					4
Facilities	3		1			4
Finance	2					2
Parks	10		12			22
Police	7	23				30
Rec Center	1		2			3
Streets			4	5	2	11
Utilities	2		10	2	3	17
WTP	4		1			5
WWTP	3		1			4
open space	4		2	1		7
Grand Total	45	23	33	8	5	114

Fleet Vehicle Emissions

Three key factors contribute to a vehicle's annual CO2 emissions: average miles driven/hours operated, fuel efficiency, and CO2 emissions factor of fuel source. Based on data provided by the City of Louisville, research from the Environmental Protection Agency, and various other public sources estimated Fleet vehicles emissions were calculated. Vehicle specific mile per gallon were used where available. For all heavy-duty vehicles, categories 3 and 4, mile per gallon data is not available and driver reported data from Fuelly.com was used. All category 5 data is based on estimated hours of use and typical gallons of fuel used per hour.

lb of CO2 per year based on average miles driven per year

	Vehicle Category					
	1	2	3	4	5	Total
Building Inspection	8,505					8,505
Code Enforcement	10,692					10,692
Engineering	15,814					15,814
Facilities	13,456		9,263			22,719
Finance	1,640					1,640
Parks	128,631		82,799	1,280		212,709
Police/Admin	35,938	22,821				58,760
Police/Detective	5,350					5,350
Police/Patrol		228,640				228,640
Rec Center	2,472		2,768			5,240
Streets			40,176	86,453	63,994	190,622
Utilities	21,564		72,880	23,043	17,578	135,065
Water/Waste Water	52,836		3,691			56,526
Total	296,898	251,461	211,576	110,775	81,572	952,282

Louisville currently sources all of it electricity from renewable sources. Because of this choice, switching to all EVs would eliminate all source of emissions from its vehicle fleet.

Fleet EV Conversion Costs

EVs typically have lower fuel and maintenance costs than ICE vehicles, but higher capital costs. There is industry consensus that the cost of EVs are trending downward as production volumes increase and battery costs decreases. Capital costs can sometimes be offset by state and local incentives that encourage alternative fleet implementation through funding and technical assistance. However, it is difficult for municipalities to access many of these incentives. To conduct the cost analysis, capital costs were estimated using average cost of ICE and EV by vehicle class. Specifically, replacement costs for ICE vehicles were estimated using public sources such as Kelly Blue Book. For EV public sources, there are not vehicles for every class so an average cost for all EV was used. In addition heavy duty vehicles, large heavy duty vehicles, and construction non-road type vehicles do not have readily available EV comparables so a 50% premium was added to the EV costs. These assumptions can be further refined as additional information becomes available.

Fleet vehicle Class

		Vehicle class									
Department/Type	**Model**	**2**	**7**	**8**	**9**	**11**	**13**	**14**	**15**	**16**	**17**
Building Inspection	Escape		2								
	F150						1				
Code Enforcement	Colorado			1							
	Dakota			1							
Engineering	Colorado			2							
	Expedition								2		
Facilities	Civic	1									
	Colorado			1							
	F150						1				
	Silverado 3/4 4X4									1	
Finance	Bolt							1			
	Impalla				1						
Parks	1500									1	
	2500									2	
	3500									1	
	Colorado			11							
	Dakota			2							
	F250									2	
	F350									4	
	F550									1	
	F750									1	
	Silverado 3/4 4X4									3	
	Tacoma			1							
Police/Admin	Caprice				1						
	Explorer		5								
Police/Detective	Caprice				1						
	Expedition								1		
Police/Patrol	Expedition								1		
	Explorer		21								
Rec Center	2500									1	
	Caravan					1					

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	E350									1	
Street	600BAH										1
	2500									1	
	Silverado 3/4 4X4									1	
	F550									2	
	7400										3
	HV 513 6x4										1
	624K										1
	624I										1
Utilities	2500									4	
	2500									2	
	Colorado			1							
	F150						1				
	F250									1	
	F450									1	
	MV607										1
	Silverado 3/4 4X4									1	
	F550									1	
	410J										1
	410L										1
	7400										1
	7400										1
WTP	Colorado			1							
	F150						3				
	F250									1	
WWTP	Colorado			1							
	Escape		1								
	F150						1				
	F250									1	
Grand Total		1	29	22	3	1	7	1	4	34	12

Even though there are not direct EV replacements for all classes of vehicles in the table above there are enough EV choices in the market that a comparable EV could be purchased. For vehicle classes 16 and 17 there are currently not EV options available. The market is rapidly changing and EV equivalents should be available in the market in the next 10 years. Please note that the EV cost reflects the averaged MSRP of a midsized crossover (Hyundai Kona) and full-sized pickup (Ford F150 Lightning). We have assumed that some portion of Louisville's existing F150s and Expeditions can be replaced by smaller electric fleet vehicles.

Vehicle class costs

Class	Type	Average Cost
1	subcompact car	23,156
2	compact car	25,954
3	small/mid-size pickup truct	28,911
4	subcompact suv/crossover	29,646
5	Mid-size car	31,211
6	Hybrid energy car	33,162

7	compact suv/crossover	33,414
8	Mid-size pickup truck	41,311
9	full-size car	43,112
10	mid-size SUV/crossover	45,487
11	minivan	45,574
12	van	48,018
13	full - size pickup truck	60,022
14	Electric vehicle	47,430*
15	Full size SUV/crossover	72,073
16	Heavy Duty Truck	75,861
17	Construction Equipment	155,670
18	Electric Heavy Duty	113,791.50
19	Electric Construction	233,505.00

For first cost comparison assuming all vehicles could be replaced with an EV equivalent the table below shows the estimated costs by departments for all vehicles in that department. It is expected that these costs will come down as the EV adoption rate increases.

Fleet Maintenance Costs

Due to a more streamlined vehicle system, EVs contain fewer moving components that are vulnerable for repair than in ICE vehicles. With over a dozen moving components, ICE vehicle repairs on the engine, transmission system and gearbox are likely over the vehicle's lifespan. In addition, brake system maintenance costs are about fifty percent less in EVs due to regenerative braking. Regenerative braking is the recovery of kinetic energy during braking. In ICE vehicles, the majority of kinetic energy is converted into heat and emitted unused into the environment during friction braking. EVs can use the electric motor to recover a portion of the kinetic energy for reuse. Regenerative braking provides an extended range while lowering fuel consumption and GHG emissions.

The table below compares maintenance cost of Louisville's vehicles in two different scenarios over the vehicles typical replacement schedule. Scenario one is status quo with all vehicles having internal combustion engines. The second scenario is all vehicles being converted to EV. Both of these scenarios assume the vehicle would be replaced due to age vs mileage, which in general holds true for most city vehicles.

In general the EV maintenance cost are about 75% of the ICE maintenance costs. Louisville currently does a lot of its own maintenance on all of its combustion engine vehicles. If the city starts to switch to EV additional training will be needed and this will likely add some additional cost until EV technicians become more prevalent in the workforce.

Vehicle Maintenance costs

	Vehicle category	Quantity of each Type	Sum of average miles	Maintenance Cost All Combustion over vehicle Life	Maintenance Costs all EV
Building Inspection	1	3	5,812	$5,580	$2,790

Code Enforcement	1	2	7,047	$6,765	$3,383
Engineering	1	4	9,548	$9,166	$4,583
Facilities	1	3	10,332	$9,919	$4,959
	3	1	6,143	$14,669	$12,384
Finance	1	2	2,903	$2,787	$1,393
Parks	1	14	87,463	$83,964	$41,982
	3	14	48,099	$114,860	$96,968
	4	1	241	$719	$607
Police/Admin	1	5	26,541	$25,479	$12,740
	2	1	16,103	$25,894	$18,293
Police/Detective	1	2	3,173	$3,046	$1,523
Police/Patrol	2	22	161,377	$259,494	$183,324
Rec Center	1	1	1,872	$1,797	$899
	3	2	1,567	$3,742	$3,159
Streets	3	4	20,322	$48,529	$40,969
	4	5	16,279	$48,593	$41,023
	5	2	482	$1,918	$1,620
Utilities	1	2	12,704	$12,196	$6,098
	3	10	43,464	$103,792	$87,623
	4	2	1,736	$5,182	$4,375
	5	3	486	$1,934	$1,633
WTP	1	4	24,639	$23,653	$11,827
	3	1	1,300	$3,104	$2,621
WWTP	1	3	12,077	$11,594	$5,797
	3	1	857	$2,047	$1,728
Total		114	522,567	$830,425	$594,300

Type	Replacement Year	Replace after Mileage/hours	Maintenance costs per mile ICE	Maintenance costs per mile EV
1	12	120,000	0.08	0.04
2	8	80,000	0.201	0.142
3	12	120,000	0.199	0.168
4	15	80,000	0.199	0.168
5	20	10,000 hours	0.199	0.168

Fleet Fuel Savings

EVs typically achieve better fuel economy and have lower fuel costs than similar ICE vehicles. A comparison of assumed average fuel efficiencies is shown on below. Fuel efficiencies for ICE vehicles were based on vehicle specification sheets and performance. Fuel efficiencies for EVs were estimated using public sources. There is no published data on electric heavy and light construction vehicles and it was assumed they would be use 3 to 5 times more electricity than light passenger vehicles.

Department/Type	Vehicle category	Average of city mpg or gallons/hr	Average of Highway
Building Inspection	1	24	30
Code Enforcement	1	16	21
Engineering	1	14	18
Facilities	1	18	24
	3	15	19
Finance	1	72	67
Parks	1	16	21
	3	13	15
	4	5	5
Police	1	16	23
	2	17	22
Rec Center	1	17	25
	3	13	13
Streets	3	12	13
	4	5	5
	5*	5	
Utilities	1	14	18
	3	13	13
	4	5	5
	5*	3	5
WTP	1	16	22
	3	14	14
WWTP	1	18	24
	3	14	14
Grand Total		15	19

Vehicle Type	kWh/100 miles
1	35
2	40
3	45
4	150
5	200

Louisville Fleet Decarbonization

On top of fuel efficiency improvements with EVs, the cost per kWh of electricity tends to be lower and more stable than the cost per gallon of gasoline or diesel. The fuel costs used can be seen below. These costs are a snapshot in time and have recently varied greatly. The cost of using electricity to fuel the vehicles is relatively cheap if the charging cycle does not increase the demand charge. For most of the cities buildings if charging at night the buildings peak demand won't be effected. For the City services building due to the large number of fleet vehicles located there it is likely the peak demand charge will increase. This additional cost is taken into account by using the blended electricity rate from the table below for any vehicle that would be stored at that site.

Gasoline Price	**Diesel Price**	**Commercial Electricity Price blended ($/kWh)**	**Commercial Electricity Price ($/kWh)**
$4.01	4.946	$0.11	$0.05

Overall switching all fleet vehicles to EVs has the potential to save up to 90% on fueling costs. This is high dependent on the current gas and diesel fuel costs.

Department/Type	Vehicle category	Quantity of each Type	Sum of average Miles Traveled	Total Gallons Consumed	Cost of Fuel	Total EV kWh Consumed	Cost of kWh
Building Inspection	1	3	5,812	355	$1,423	2,034	$220
Code Enforcement	1	2	7,047	446	$1,789	2,466	$266
Engineering	1	4	9,548	659	$2,645	3,342	$361
Facilities	1	3	10,332	561	$2,251	3,616	$391
	3	1	6,143	392	$1,574	2,457	$265
Finance	1	2	2,903	68	$274	1,016	$46
Parks	1	14	87,463	5,363	$21,518	30,612	$3,306
	3	14	48,099	3,490	$14,080	19,010	$2,053
	4	1	241	48	$238	108	$12
Police	1	1	29,714	1,722	$6,907	10,400	$468
	2	2	177,480	10,485	$42,065	62,118	$2,795
Rec Center	1	4	1,872	103	$414	655	$29
	3	5	1,567	117	$470	627	$28
Streets	3	2	20,322	1,615	$7,129	8,477	$916

	4	2	16,279	3,256	$16,103	24,419	$1,099
	5	10	482	2,410	$11,920	723	$33
Utilities	1	2	12,704	899	$3,607	4,446	$480
	3	3	41,016	3,086	$12,386	16,409	$1,772
	4	4	4,184	837	$4,139	6,276	$514
	5	1	486	693	$3,428	729	$33
WTP	1	3	24,639	1,458	$5,851	8,624	$388
	3	1	1,300	94	$378	520	$23
WWTP	1	7	12,077	745	$2,987	4,227	$408
	3	23	857	62	$249	343	$15
Total		114	522,567	38,964	$163,824	213,655	$15,921

Fleet EV Conversion Plan

Assuming EV vehicle innovation continues the City should be able to replace all vehicles with an EV equivalent over the next 7 to 17 years. The City will need to decide if replacing some lightly used construction type equipment is worth the premium that will most likely be charged, otherwise all other vehicles will have an EV equivalent on the market.

Most city vehicles are assigned to a single person making consolidating difficult. If the City does want to consolidate the parks, utilities, and street departments have the most number of vehicles, most of which are stored at the City Services building. During our visits to this site there were always ~10 trucks parked in the back not in use at the specific time. In addition, there are a number of parking lot snowplow trucks staged at certain locations to plow the parking lots. These could possibly be reduced but would require city personnel to drive from site to site with the plow trucks.

McKinstry would recommend that the City replace vehicles with EV after the current vehicle has meet its replacement criteria. The table below shows the current replacement schedule assuming current usage pattern and shows what type of vehicle will be purchased. Some vehicles will need to be replaced before there is an EV equivalent on the market, in those cases it is assumed that a new ICE vehicle will be purchased and then will be replaced with an EV in the next cycle. In general, it is assumed all type 2 vehicles (mostly police vehicles) will not have an EV equivalent until 2027 and all type 3, 4, and 5 vehicles until 2030.

Department	Replacement Type	2023	2024	2025	2026	2027	2028	2029	2030
Building Inspection	ICE	0	0	0	0	0	0	0	0
	EV	0	0	0	1	0	0	0	0
Code Enforcement	ICE	0	0	0	0	0	0	0	0
	EV	1	0	0	0	1	0	0	0
Engineering	ICE	0	0	0	0	0	0	0	0
	EV	4	0	0	0	0	0	0	0
Facilities	ICE	0	0	0	0	1	0	0	0
	EV	2	0	0	0	0	0	0	0
Finance	ICE	0	0	0	0	0	0	0	0
	EV	1	0	0	0	0	0	0	0
Parks	ICE	5	1	1	0	4	0	0	0
	EV	8	1	1	0	0	2	1	1
Police	ICE	12	2	3	2	0	0	0	0
	EV	0	2	0	0	2	3	2	2
Rec Center	ICE	2	0	0	0	0	0	0	0
	EV	0	0	1	0	0	0	0	0
Streets	ICE	0	0	3	0	0	1	0	0
	EV	0	0	0	0	0	0	0	3
Utilities	ICE	3	0	0	0	1	1	1	2
	EV	1	0	0	1	0	0	0	4
WTP	ICE	1	0	0	0	0	0	0	0
	EV	0	1	0	0	0	0	0	2
WWTP	ICE	0	1	0	0	0	0	0	0
	EV	1	0	0	0	0	0	0	1
Total	ICE	23	4	7	2	6	2	1	2
	EV	18	4	2	2	3	5	3	13

Department	Replacement Type	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Building Inspection	ICE	0	0	0	0	0	0	0	0	0	0
	EV	0	0	2	0	0	0	0	1	0	0
Code Enforcement	ICE	0	0	0	0	0	0	0	0	0	0
	EV	0	0	0	0	1	0	0	0	1	0
Engineering	ICE	0	0	0	0	0	0	0	0	0	0
	EV	0	0	0	0	4	0	0	0	0	0
Facilities	ICE	0	0	0	0	0	0	0	0	0	0
	EV	0	1	0	0	2	0	0	0	1	0
Finance	ICE	0	0	0	0	0	0	0	0	0	0
	EV	0	0	1	0	1	0	0	0	0	0
Parks	ICE	0	0	0	0	0	0	0	0	0	0
	EV	3	0	1	1	12	2	2	0	4	3
Police	ICE	0	0	0	0	0	0	0	0	0	0
	EV	13	4	4	1	3	5	3	1	13	3
Rec Center	ICE	0	0	0	0	0	0	0	0	0	0
	EV	0	0	0	0	2	0	1	0	0	0
Streets	ICE	0	0	0	0	0	0	0	0	0	1
	EV	0	1	0	1	0	0	2	0	0	1
Utilities	ICE	0	0	0	0	0	0	0	0	0	0
	EV	0	0	0	1	5	0	0	1	1	0
WTP	ICE	0	0	0	0	0	0	0	0	0	0
	EV	1	0	0	0	1	1	0	0	0	0
WWTP	ICE	0	0	0	0	0	0	0	0	0	0
	EV	0	1	0	0	1	1	0	0	0	0
Total	ICE	0	0	0	0	0	0	0	0	0	1
	EV	17	7	8	4	32	9	8	3	20	7

Assuming the above replacement schedule an estimated replacement cost is shown below. A yearly inflation rate of 2.5% was used.

Department	Replacment Type	2023	2024	2025	2026	2027	2028
Building Inspection	ICE	$0	$0	$0	$0	$0	$0
	EV	$0	$0	$0	$86,387	$0	$0
Code Enforcement	ICE	$0	$0	$0	$0	$0	$0
	EV	$55,212	$0	$0	$0	$60,944	$0
Engineering	ICE	$0	$0	$0	$0	$0	$0
	EV	$303,075	$0	$0	$0	$0	$0
Facilities	ICE	$0	$0	$0	$0	$83,736	$0
	EV	$89,899	$0	$0	$0	$0	$0
Finance	ICE	$0	$0	$0	$0	$0	$0
	EV	$57,619	$0	$0	$0	$0	$0
Parks	ICE	$379,305	$77,758	$79,701	$0	$334,945	$0

	EV	$487,872	$56,592	$58,007	$0	$0	$124,935
Police	ICE	$478,286	$68,499	$105,317	$71,966	$0	$0
	EV	$0	$118,119	$0	$0	$98,588	$151,578
Rec Center	ICE	$151,722	$0	$0	$0	$0	$0
	EV	$0	$0	$63,993	$0	$0	$0
Streets	ICE	$0	$0	$322,954	$0	$0	$85,830
	EV	$0	$0	$0	$0	$0	$0
Utilities	ICE	$227,583	$0	$0	$0	$83,736	$176,126
	EV	$55,212	$0	$0	$86,387	$0	$0
WTP	ICE	$75,861	$0	$0	$0	$0	$0
	EV	$0	$56,592	$0	$0	$0	$0
WWTP	ICE	$0	$77,758	$0	$0	$0	$0
	EV	$55,212	$0	$0	$0	$0	$0
Total	ICE	$1,312,757	$224,014	$507,972	$71,966	$502,418	$261,956
	EV	$1,104,102	$231,304	$122,000	$172,775	$159,531	$276,513
	All Vehicles	$2,416,859	$455,317	$629,972	$244,741	$661,949	$538,469

Department	Replacement Type	2029	2030	2031	2032	2033	2034
Building Inspection	ICE	$0	$0	$0	$0	$0	$0
	EV	$0	$0	$0	$0	$114,331	$0
Code Enforcement	ICE	$0	$0	$0	$0	$0	$0
	EV	$0	$0	$0	$0	$0	$0
Engineering	ICE	$0	$0	$0	$0	$0	$0
	EV	$0	$0	$0	$0	$0	$0
Facilities	ICE	$0	$0	$0	$0	$0	$0
	EV	$0	$0	$0	$100,183	$0	$0
Finance	ICE	$0	$0	$0	$0	$0	$0
	EV	$0	$0	$0	$0	$81,144	$0
Parks	ICE	$0	$0	$0	$0	$0	$0
	EV	$64,029	$120,518	$258,072	$0	$129,785	$72,443
Police	ICE	$0	$0	$0	$0	$0	$0
	EV	$103,579	$106,168	$770,296	$223,085	$228,663	$58,595
Rec Center	ICE	$0	$0	$0	$0	$0	$0
	EV	$0	$0	$0	$0	$0	$0
Streets	ICE	$0	$0	$0	$0	$0	$0
	EV	$0	$615,137	$0	$259,829	$0	$272,983
Utilities	ICE	$87,976	$370,085	$0	$0	$0	$0
	EV	$0	$482,074	$0	$0	$0	$133,030
WTP	ICE	$0	$0	$0	$0	$0	$0
	EV	$0	$190,711	$97,739	$0	$0	$0
WWTP	ICE	$0	$0	$0	$0	$0	$0
	EV	$0	$95,355	$0	$55,771	$0	$0

Total	ICE	$87,976	$370,085	$0	$0	$0	$0
	EV	$167,608	$1,609,963	$1,126,108	$638,869	$553,923	$537,051
	All Vehicles	$255,583	$1,980,049	$1,126,108	$638,869	$553,923	$537,051

Department	Replacement Type	2035	2036	2037	2038	2039	2040
Building Inspection	ICE	$0	$0	$0	$0	$0	$0
	EV	$0	$0	$0	$116,181	$0	$0
Code Enforcement	ICE	$0	$0	$0	$0	$0	$0
	EV	$74,254	$0	$0	$0	$81,963	$0
Engineering	ICE	$0	$0	$0	$0	$0	$0
	EV	$407,602	$0	$0	$0	$0	$0
Facilities	ICE	$0	$0	$0	$0	$0	$0
	EV	$120,905	$0	$0	$0	$150,511	$0
Finance	ICE	$0	$0	$0	$0	$0	$0
	EV	$77,491	$0	$0	$0	$0	$0
Parks	ICE	$0	$0	$0	$0	$0	$0
	EV	$1,263,658	$215,875	$221,272	$0	$602,044	$252,035
Police	ICE	$0	$0	$0	$0	$0	$0
	EV	$249,666	$343,540	$189,301	$64,678	$938,531	$203,856
Rec Center	ICE	$0	$0	$0	$0	$0	$0
	EV	$272,711	$0	$86,064	$0	$0	$0
Streets	ICE	$0	$0	$0	$0	$0	$236,870
	EV	$0	$0	$286,517	$0	$0	$154,274
Utilities	ICE	$0	$0	$0	$0	$0	$0
	EV	$763,128	$0	$0	$116,181	$150,511	$0
WTP	ICE	$0	$0	$0	$0	$0	$0
	EV	$136,356	$76,110	$0	$0	$0	$0
WWTP	ICE	$0	$0	$0	$0	$0	$0
	EV	$74,254	$139,764	$0	$0	$0	$0
Total	ICE	$0	$0	$0	$0	$0	$236,870
	EV	$3,440,025	$775,290	$783,153	$297,040	$1,923,560	$610,165
	All Vehicles	$3,440,025	$775,290	$783,153	$297,040	$1,923,560	$847,035

Louisville Fleet Decarbonization

Over the next 17 year, if the above replacement schedule was followed, the incremental initial vehicle cost would be $4.3M, but the incremental cost on a lifecycle basis would only be $1M. The amount of CO2 emissions saved would be ~9 million lb. These numbers does not include any financing costs, but do include 2.5% inflation, electric rate inflation of 2.44%, and gas/diesel cost escalation of 2.65%.

	Vehicle replacement cost	Fuel Costs	Maintenance Costs	Total Cost	Total Emissions lb of co2
Status Quo, keep buying ICE	$14,446,954	$3,912,658	$1,596,579	$19,956,191	16,188,795
Phasing in Evs	$18,104,994	$1,710,455	$1,178,767	$20,994,216	6,936,913

At this time McKinstry does not recommend leasing EVs as the biggest benefit to leasing would be on the maintenance costs and possibly being able to receive some of the vehicle tax incentives. Maintenance costs for EV are less than ICE and City already does most of its own maintenance. Some retraining of the city's fleet mechanics may be needed but in general EV's are easier to maintain other than the electronic components, but most electronic issues are likely to happen during the warranty period when the dealer would be responsible for fixing. In addition, as more EV are adopted more qualified EV technicians will become available for the city to hire.

Because the City is a public entity it is hard to qualify for tax credit and incentives. There are some unique purchasing mechanisms available that allow public entities to receive part of these tax incentives but with all the recent changes in these program this will need to be further investigated.

There are no specific fire code for EV vehicles. Because most EV batteries are integral to the vehicle, are not designed to be replaced easily, and are expected to last the lifetime of the City's replacement schedule EV battery storage will not be necessary or recommended.

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Louisville
Miscellaneous Equipment
Decarbonization Analysis and Info

Louisville Summary Supporting Info

1 - Executive Summary

Small Vehicle EV Charging

Relative to automobiles, gas powered lawn and garden equipment produce far fewer total carbon emissions, but they still add significantly to the problem with carbon accumulation and also with deteriorating air quality in urban areas. The US Department of Energy estimates that 1.2 billion gallons of gasoline are consumed annually in the US for lawn care. This translates to nearly 12 Million tons of CO_2 emitted per year.

Small gasoline engines like those in gas powered riding mowers and garden equipment are fast becoming the number one contributor to smog forming air pollution. These small engines emit hundreds of times more pollutants per hour than automobile engines. These pollutants - benzene, butadiene, formaldehyde, oxides of nitrogen, carbon monoxide and small particulates are known carcinogens and known respiratory, cardiovascular, and neurological health risks. The EPA considers gasoline powered lawn and garden equipment "an important source of dangerous air pollution."

New lithium battery powered riding mowers, park equipment, and leaf blowers compete effectively with gasoline powered tools regarding power and performance and have significantly longer operating run times than older electric models. On top of that these new tools are quieter and will not produce the lingering gasoline smells that are an indicator of the fumes and pollution that gasoline powered equipment produces.

Louisville Summary Supporting Info

Current equipment

The city currently has three departments that own the majority of the small engine vehicles and equipment. The is equipment was broken down into smaller subcategories for analysis. The table below show she equipment categories.

	Qty of equipment		
Type	**golf qty**	**parks**	**open space**
aerator	1	0	0
ATV	8	12	0
blower	3	0	0
Cart	3	0	0
chainsaw	2	2	0
chipper	0	1	0
excavator	0	1	0
forklift	0	11	0
generator	0	0	0
loader	1	0	0
mower	17	16	2
roller	0	1	0
saw	0	1	0
skid	0	2	0
sprayer	1	0	0
tractor	1	3	0
trimmer	4	0	0
washer	1	0	0

Louisville Summary Supporting Info

This equipment was then assigned typical yearly runtime hours which could be used calculate the carbon emissions, maintenance costs, and replacement costs. The table below provides the hours of runtime for each equipment category. Runtimes were estimated based on the existing equipment type and confirmed with golf, parks, and open space facilities teams.

	hours of operation per year		
Type	**golf**	**parks**	**open space**
aerator	50	0	0
ATV	30	50	0
blower	100	0	80
Cart	1000	125	0
chainsaw	50	0	0
chipper	50	120	40
excavator	0	50	30
forklift	0	50	30
generator	0	0	40
loader	100	0	50
mower	800	380	300
roller	45	50	60
saw	0	190	0
skid	0	50	80
sprayer	50	0	0
tractor	50	65	30
trimmer	500	0	200
washer	50	0	60

The EPA has published typical emission factors for small engines. These factors scale with engine size. The table below provides these factors for both gasoline and diesel. Most of the Cities equipment is gasoline.

HP	CO2 lbs/yr gas	CO2 lbs/yr diesel
1	1.08366	1.14138

Louisville Summary Supporting Info

Using the same fuel costs as the fleet vehicles and the above emission factors we were able to estimate the total cost of running the small engine equipment and it emissions.

Equipment type	Gallons of Fuel (yearly)	Fuel Cost (yearly)	Lb of CO2 (yearly)
aerator	46	185	623
ATV	756	3,062	10,440
blower	222	889	3,002
Cart	1,680	6,740	22,757
chainsaw	18	71	238
chipper	408	1,637	5,527
forklift	232	931	3,143
loader	126	622	2,511
mower	18,346	77,358	274,348
roller	40	160	542
saw	160	640	2,162
skid	431	2,050	8,039
sprayer	50	201	677
tractor	390	1,929	7,790
trimmer	200	802	2,709
Grand Total	**23,104**	**97,277**	**344,507**

Small Engine Electrification

Most the equipment categories currently have electric equivalents available. The categories that do not or have very limited choices are, tractor, skid, loader, chipper, and roller. Some of these types of equipment are actively being developed. In addition, in the mower category there is some specialty golf mowers that do not have a good electric choice.

Unfortunately, unlike the electric fleet vehicles most of the electric lawn care equipment does not have battery warranty that match the equipment warranty. As this technology matures the warranties will get better.

Another large hurdle for this equipment is the cost of the electrified version. Most electric versions of the non-handheld equipment is about 1.75 times the cost of the gas version. Maintenance costs are lower but not enough to offset the initial up-front cost.

Louisville Summary Supporting Info

The table below shows the electrical cost and cost to purchase new electric versions of the equipment. Cost for most of the equipment is estimated to be about 1.75 time the gas/diesel powered equivalent.

Type	Count of Type	Electric Fuel (kWh)	Electric Fuel Cost ($)	Electric Vehicle Costs ($)
aerator	1	858	39	39,839
ATV	18	14,331	1,336	403,765
blower	3	4,133	186	25,088
Cart	3	31,332	1,410	36,750
chainsaw	2	328	15	2,056
chipper	2	7,609	822	57,579
forklift	1	4,327	467	50,703
generator	11	-	-	775,520
loader	1	3,282	148	9,471
mower	35	372,136	27,701	1,539,193
roller	1	746	81	25,673
saw	1	2,977	321	9,184
skid	5	10,593	1,144	355,859
sprayer	1	933	42	62,272
tractor	4	10,183	947	247,067
trimmer	4	3,730	168	2,450
washer	1	-	-	5,369
Grand Total	**94**	**467,498**	**34,826**	**3,647,837**

McKinstry would recommend replacing existing equipment that is at the end of its life, most large equipment is replaced by the department every 8 years, with the electric equivalent.

Refueling/charging

With the newest battery technology available most of the larger equipment can operate during a typical workday. This equipment isn't designed for battery swap out in the field, so if the battery charge got low the operator would need to plug it in somewhere to charge or switch to a different piece of equipment. Typically, they would need to switch to a different piece of equipment. The charging time for this equipment isn't fast enough to get a full charge in a reasonable amount of time. For smaller handheld equipment spare batteries can carried along to change out and when the charge gets low. This will take some training to get operators use to carrying around extra batteries that are fully charged. When the city switches to the fleet vehicles to EV's, most work style trucks may have the ability to charge auxiliary devices like batteries for small handheld equipment. For most of this equipment it is recommended that everything be charged overnight as it is unlikely that anything would be able to be charged during the day and used that same day.

Charging

Most small motor equipment will require at least a 120v 15amp circuit to charge. It is recommended that there is one dedicated plug for each piece of equipment. Additional electrical infrastructure will be needed to make charging plugs accessible to all equipment where it is stored.

Battery Life

Battery technology is significantly improving year to year. Most batteries are Lithium based and have longer life spans than the equipment. Depending on the manufacture the battery warranty may or may not match the typical equipment life. For small handheld equipment purchasing extra batteries will allow longer use and does not add much cost. For larger equipment the battery can be a significant part of the cost and having a second battery on hand will be cost prohibitive. In addition, the larger equipment isn't always designed for quick battery change outs. Like electric vehicles, batteries for this type of equipment will eventually have warranty life greater than the cities typical use.

Appendix

Final Report

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Construction Pricing Context

The MEP scope narratives described in previous sections and included in the appendices were used by McKinstry's construction division to provide Rough Order of Magnitude (ROM) pricing. This early ROM budgeting process sought to be reasonable but conservative wherever possible. **Typically for ROM-level pricing a range of +/- 20% is applied to the total construction and start up costs.** This range can be reduced, and the pricing further refined, via a deeper understanding of existing building conditions and detailed design. Note this does not account for escalation, which is addressed separately. This pricing represents the total construction and startup cost to Louisville, including:

- General contractor markup
- Design fees
- Engineering energy analysis
- Controls
- Equipment startup, commissioning, testing, and balancing
- Placeholders for miscellaneous trades (e.g. carpentry).
- Allowances specific to each building for construction conditions (e.g. crane time)

All construction costs are in 2023 dollars unless noted otherwise.

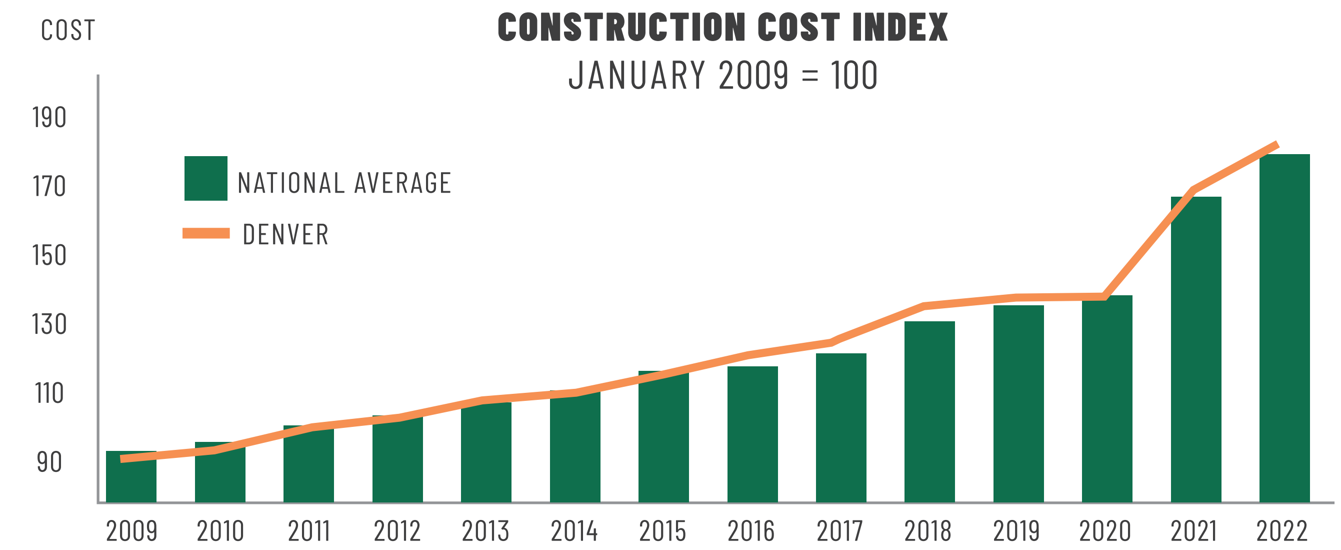
Using These Construction Costs

Throughout this report, differentiation is made between "total construction costs" and "net cost over business-as-usual fossil fuel systems"The distinction between the two is:

- Total costs: these are the total construction costs. This is the total amount of money that will need to be allocated for budgetary purposes.
- The like-for-like project costs were derived from a combination of the City's CIP budget and detailed cost estimating of turnkey like-for-like equipment replacement as the comparison scenario.
- Net Cost: these are the total construction costs minus the like-like replacement costs that would've been spent to replace the existing units. These numbers represent the true cost of this decarbonization effort.

Note the numbers in the 2023 City Budget are budget numbers, and do not represent all costs for replacing the existing units. As such, they should not be used when determining the costs of decarbonization. In addition, the cost estimates in this report assume miscellaneous equipment (e.g. expansion tanks, domestic hot water storage tanks) need to be replaced. This assumption should be validated in detailed design, and could result in the total construction cost being lower if equipment can be reused.

As shown in the graph by the Mortenson, construction costs have been steadily rising since 2009. However, costs rose drastically from 2020 to 2022 (approximately 35%) due to global supply chain issues and unforeseen consequences of the COVID-19 pandemic.



SOURCE: MORTENSON CONSTRUCTION

Constructibility

Recent upheavals in the global supply chain and labor workforce have caused uncertainty in the construction market. Our construction teams are seeing the following trends as of March, 2023:

ELECTRICAL LEAD TIMES:

- Most commodity items, such as conduit, wire, fittings, etc. are readily available.
- Lead times for Switchboards are being quoted 50-80 weeks. Panel-boards can be 20-40 weeks depending on complexity.

MECHANICAL LEAD TIMES:

- 26-30 weeks for larger and more customized equipment (50 ton RTUs)
- Equipment needs to be ordered earlier in detailed design process to accommodate long lead times. Requires additional coordination earlier in design.

In order to combat these lead time challenges, design teams may need to be flexible with their specifications and the products/manufacturers they are selecting.

LABOR MARKET:

While we are seeing a general relaxing of labor shortages in other markets around the country, the contractor and labor shortages continue to persist in the Denver market.

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Decarbonization Strategic Roadmap | Future Weather

Future Weather Sensitivity

Global climate change will affect how mechanical systems designed to provide comfortable environments respond in a future, warmer environment. This document seeks to daylight ranges and uncertainties in future warming scenarios, and understand the design and energy implications of considering future weather.

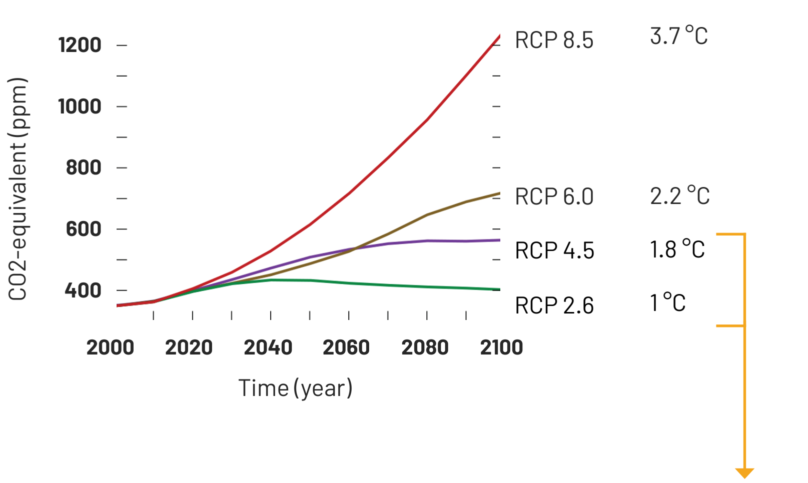
The Intergovernmental Panel on Climate Change (IPCC) has introduced a concept called Representative Concentration Pathway (RCP) to try to quantify possible future climate states based on complex models of greenhouse gas (GHG) concentrations and predicted global emissions.

There are four RCPs, representing a variety of possible outcomes:

- **RCP8.5** - Business as usual, no substantial change to current global emissions rates
- **RCP6.0** - Moderate action to reduce global emissions
- **RCP4.5** - Moderately aggressive action to reduce global emissions
- **RCP2.6** - Aggressive, immediate and coordinated action to reduce global emissions

RCP 4.5 is used for this study.

Emissions of RCPs over Time [2]

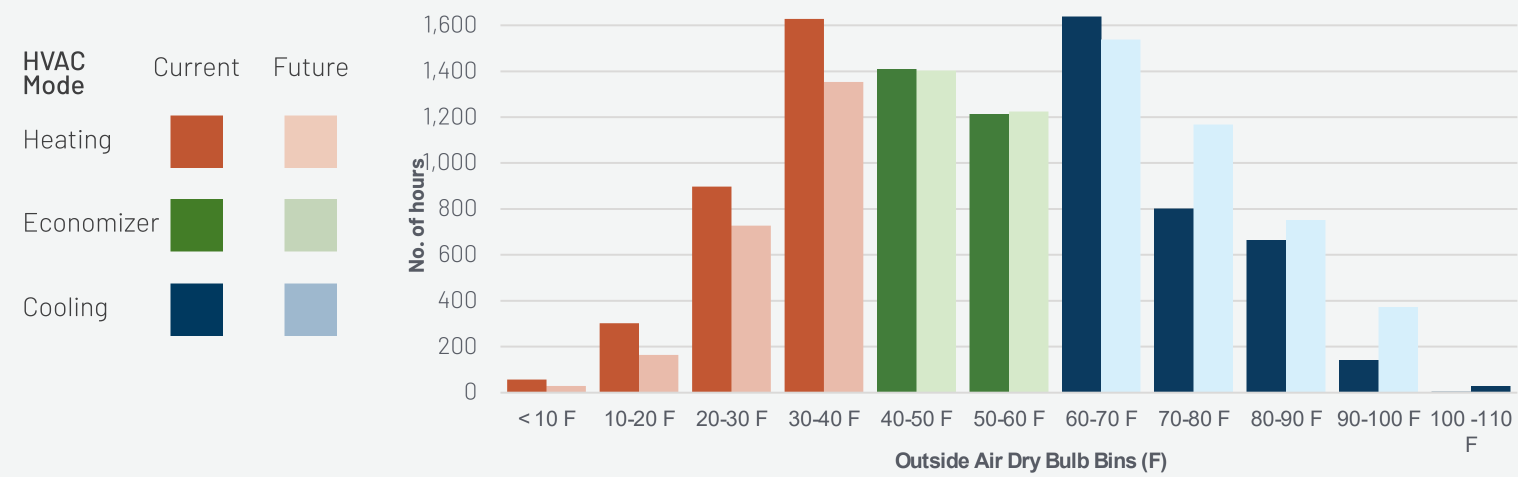


RCP 4.5 and RCP 2.6 will both achieve the Paris Agreement target of limiting global temperature rise to below 2° C.

Temperature Impact

The impact on dry bulb temperature when considering future weather can be show in the figure to the right. **Temperatures shift upward, spending less time in the colder heating temperature bins, and shifting upwards into the warmer cooling driven temperature bins.**

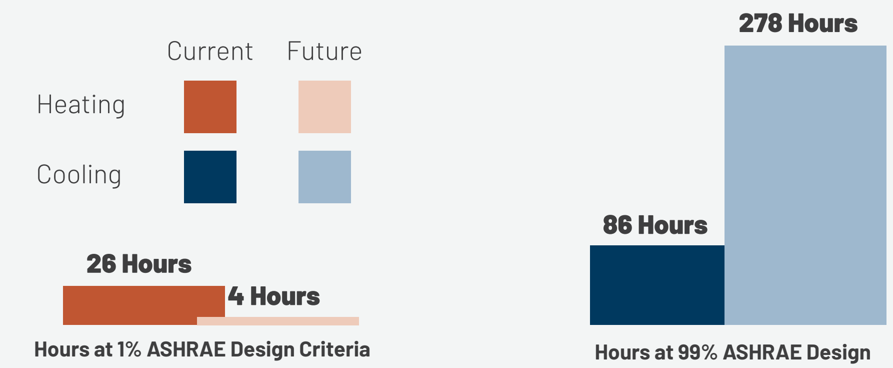
Temperature Bins



Design Impact

This temperature shift could play a hand in decisions about equipment sizing. **There may be opportunity to downsize heating equipment based on these weather bins. Cooling equipment should be selected to prepare the city for weather of the future.**

Design Temperature Hours



Energy & Carbon Impact

Building heating load is directly correlated with dry bulb temperature. **At the Recreation Center, the existing building heating load would decrease by approximately 10% under future weather conditions. There is still significant savings associated with decarbonizing the heating load.**

Recreation & Senior Center
Heating Energy with Future Weather