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How Should I Get to School? A Life Cycle Assessment of DC's Public Transportation

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“You can’t understand a city without using its public transportation system.”

---- Erol Ozan

Introduction (Overview)

Life cycle assessments (LCAs) have been at the forefront of many decisive pieces of environmental legislation; serving municipalities, governments, and companies as a tool for decision making. LCAs form a framework to assess complex interconnective systems through the development of models based on a set of criteria. Students will develop individual LCAs with regards to the District of Columbia’s public transportation system and decide which mode of transportation (i.e., bus, Uber, electric scooter, or metro) will be most energy efficient measured in terms of megajoules per passenger mile and grams of CO_2 equivalence per passenger mile. This three-week unit will integrate the physical principles of energy efficiency (i.e., conservation of energy and entropy) with economics (i.e., cost per kWh for metro, daily ridership cost). The various energies and their subsequent transformations have constraints with regards to their utility with current modern technologies which will be discussed as students delve deeper in the evaluation phase of the unit. The locality of each student will likely affect their overall decision(s) based on availability of resources, distance from school and access to public transportation in their surrounding neighborhoods. The development of the LCA will facilitate a greater depth of knowledge, critical thinking, and engagement as students explore the complexities of one simple question: *how should I get to school*?

Demographics:

I serve as the 11th-grade academy Physics science teacher at Woodrow Wilson High School. This past year, I taught an introductory class titled "Engineering Essentials" to freshmen which introduces the design process in a project-based curriculum. Woodrow Wilson High School is a relatively high-performing school in Washington, DC that consists of approximately 2,000 students. The diverse student body presents challenges for instructional delivery because of persistent achievement gaps within the school. Students have historically tested below grade level in mathematics with only 22% of students meeting academic expectations. The socioeconomic issues associated with urban schools are still present (i.e., in-seat attendance, assignment completion rate, etc.). The student body is often segregated due to the number of advanced placements classes offered coupled with minimal opportunities for remediation throughout the year. The two-feeder schools for Woodrow Wilson High School are Deal Middle School and Hardy Middle School which represent two different socioeconomic populations in DC.

The physics department is currently in the process of redesigning its curriculum to reflect more project-based and analysis of phenomena to cultivate critical-thinking in a collaborative forum. Last year presented novel obstacles for students to access authentic learning since three-months were taught through distance learning because of the COVID-19 pandemic. After five years of teaching in the District of Columbia Public School (DCPS), I have learned that students respond best to a positive, dynamic classroom, with hands-on activities. The development of this unit is intended to be implemented in both in-class or hybrid learning schedules. The more the student understands the content's relevance, the more likely they are to gain a greater depth of knowledge however this can be challenging without consistent in seat instruction. This unit will address the enigmatic principle of energy efficiency through the application of an LCA. The exposure of developing models to assess the complexities of integrated content will cultivate the transportable skills associated with systems thinking within the students.

Objectives:

This three-week unit attempts to enhance students' content mastery and analytical skills by developing LCAs to determine the most energy efficient and cost-effective way for students to get to school. Students will require mastery in multifactor modelling, energetics of technology, conservation of energy, and energy economics. Students will develop individualized mathematical transportation models with parameters that apply to their residence/locality with justifications for each. As a class we will discuss energy transformations and their implications with energy efficient technologies. In addition, we will explore DC transportation data and examine emerging patterns by calculating megajoules per passenger mile and grams of CO_2 equivalence per passenger mile with various transportation modalities (i.e., metro, uber, and electric scooter) within each ward of the District of Columbia. The objectives for this unit seek to have students assess modes of energy transportation by 1) developing a system flow model grounded in energy transformations and resources 2) compare the energy of per passenger mile and greenhouse gas emissions per passenger mile as impact factors using LCA framework. This unit is meant to be a project that elicits individual exploration as well as cultivates a depth of thinking that goes beyond the standards of NGSS. It is my hope that students will gain a deeper understanding of energy efficiency by mastering energy transformations and the governing principle(s) of modelling to develop a decision about how to get to school.

Unit Content:

LCA as a Tool for Objective Evaluation

The development of life cycle assessments (LCAs) began in the 1960s and 1970s as a method for assessing environmental issues associated with energy distribution, solid waste, natural resource management, and product efficiency. [1] In 1969, the Coca-Cola Company conducted an internal analysis that compared the raw materials and fuels used in the manufacturing of beverage containers. [1] Similar studies were carried out in Europe as petroleum shortages forced governments and industries to examine policies to reduce waste as an economic lifeline. During the 1980's solid waste disposal became an emergent issue for municipalities, again LCAs were used to assess existing infrastructure to provide valuable insight to multi-dimension systems. The growth of LCA development drastically evolved due to impropriety accusation(s) from several state attorney generals in 1991 which cited a lack of standardization across industries and companies. [1] As a result many companies were thought to have bias their results in their product analyses. The LCA standards in the International Standards Organization (ISO) was established in 1997 to address inconsistencies within the analyses carried out. [1] LCAs form a framework to assess complex interconnective systems through the development of models based on a set of criteria.

Overview of LCA Framework

The ISO provides a four-stage standard life cycle assessment which consists of the following: goal and scope, inventory analysis, impact assessment, and interpretation as shown in Figure 1. [2] At the inception of an LCA is a precise statement that outlines the goal(s) and scope to which the study is attempting to address. This provides the context of study and its subsequent conclusions. The level of detail will vary based on each study and industry however information such as functional unit (i.e., comparative quantities that comprise the system in question), system boundaries, assumptions, and data quality should be present. [2] The second stage within the framework involves the identification of all raw materials, energy inputs/outputs, and by-products (emission, solid waste) expelled in the surrounding environment through a life cycle inventory analysis (LCI). All data must be relevant to the functional unit defined in the prior stage (i.e., goal and scope) and as such is often subject to modifications and alterations. Once the components have been identified a working flow model is produced that illustrates data and their associated relationship(s) with each system process; all data and systems processes should be confined to within the system boundary identified within the scope of the question. A wealth of system(s) datasets have been curated by ISO and other entities to encourage standardization and ensure the utilization of high-quality data. [2] The impact assessment component of the LCA framework evaluates the magnitude and significance of the each LCI unit by aggregating units within impact categories. A complex issue like climate change may have myriad LCI units that contribute to anthropogenic warming however the impact category specifically examines emissions from a range of sources rather than energy-mass balance of the atmosphere. Again, the goal and scope ground the causal mechanisms and data being used in the analysis which limits the interpretation of the results. The interpretation stage includes the evaluation of all preceding stages to ensure appropriateness of data and analyses with respect to the defined scope. It should be noted that like all models the overall results/conclusions will inherently have uncertainty within them especially if the flow model is highly integrated and complex. An examination of transportation data will often lead to uncertainties in average emissions of cars because of engine efficiency and model of car. There are several uncertainty analyses that can be employed as a best practice for reporting results, however this is still not universally adopted. [2] Overall, the general framework of an LCA, illustrated in Figure 1, should be thought of as a tool to assess complex multi-dimensional problems but should be critically assessed by numerous parties to ensure quality of conclusions prior to any policy and product alterations.

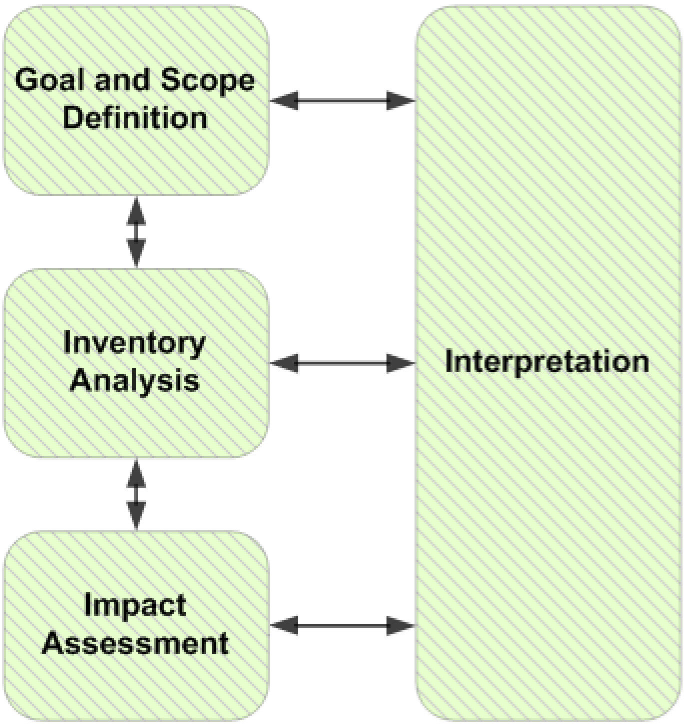

Figure 1. A standard Life Cycle Assessment Framework outlined by the ISO.

Employing LCAs in Passenger Transportation

In recent years, passenger transportation systems have been examined with regards to energy requirements and emissions because of projected climate change scenarios as well as increased global economic volatility. According to Davis and Diegel (2007) passenger transportation is responsible for 20% of US energy consumption. [3] Governments and municipalities have historically only examined emissions of greenhouse gases and energy consumed during the use phase when developing policy as shown in Table 1. [3] The most common form of assessment within the transportation sector is the passenger to energy use ratio. This data can be highly informative to develop greater efficiencies in urban development. The implementation of a more holistic approach using the LCA framework to interrogate use and manufacturing may yield different conclusions and a more comprehensive analysis.

Passenger Travel and Energy Use, 2008

	Number of vehicles (thousands)	Vehicle-miles (millions)	Passenger-miles (millions)	Load factor (persons/ vehicle)	Energy intensities (Btu per vehicle-mile)	Energy intensities (Btu per passenger-mile)	Energy use (trillion Btu)
Cars	**137,080.0**	**1,615,850**	**2,569,202**	**1.59**	**5,465**	**3,437**	**8,831.4**
Personal trucks	**89,079.8**	**926,657**	**1,705,049**	**1.84**	**6,699**	**3,641**	**6,207.6**
Motorcycles	**7,742.9**	**14,484**	**17,091**	**1.18**	**2,212**	**1,875**	**32.0**
Demand response[a]	**65.8**	**1,495**	**1,412**	**0.9**	**16,509**	**17,482**	**24.7**
Buses	b	b	b	b	b	b	**199.9**
Transit	67.1	2,388	21,918	9.2	39,906	4,348	95.3
Intercity[c]	b	b	b	b	b	b	30.3
School[c]	683.7	b	b	b	b	b	74.3
Air	b	b	b	b	b	**b**	**1,975.7**
Certificated route[d]	b	5,871	570,922	**97.2**	**291,246**	2,995	1,710.0
General aviation	228.7	b	b	b	b	b	265.7
Recreational boats	**13,188.5**	b	b	b	b	b	**245.7**
Rail	**20.2**	**1,345**	**36,169**	**26.9**	**68,345**	**2,541**	**91.9**
Intercity (Amtrak)	0.3	272	6,179	22.7	54,514	2,398	14.8
Transit	13.3	763	18,941	24.8	62,601	2,521	47.8
Commuter	6.6	310	11,049	35.6	94,587	2,656	29.3

Source:
See Appendix A for Passenger Travel and Energy Use.

[a] Includes passenger cars, vans, and small buses operating in response to calls from passengers to the transit operator who dispatches the vehicles.
[b] Data are not available.
[c] Energy use is estimated.
[d] Only domestic service and domestic energy use are shown on this table. (Previous editions included half of international energy.) These energy intensities may be inflated because all energy use is attributed to passengers–cargo energy use is not taken into account.

Table 1. A data table of passenger travel and energy used for various modes of transportation from 2008. [3]

Countries have already begun to conduct such examinations on their public transportation infrastructure. A recent study in 2019, investigated urban mobility in Qatar comparing metro train and automobile systems regarding several environmental impacts (i.e., climate change, particulate matter formation, human toxicity, marine eutrophication, terrestrial acidification, and water depletion). Al-Thawadi and Al-Ghamdi projected the potential environmental benefits of reducing 190,000 automobiles within the city of Doha and determined that passenger train transportation could decrease total emissions of CO2 by 19.42 kt, reduce PM_{10} by 3.15 tons and prevent human toxicity exposure of 1,4-dichlorobenzene by 377.17 tons. [4] Similarly, cities in the United States (i.e., Los Angeles, San Francisco, and Boston) are reexamining their public transportation infrastructure and employing LCA analyses to investigate energy use per passenger. Chester and Horvath (2009) performed a comprehensive comparative analysis on modes of passenger transportation (i.e., Diesel Bus, Conventional Gasoline Sedan/SUV, and Light Rail system) in San Francisco. [5] The study incorporated direct and indirect processes (i.e., raw material extraction, manufacturing, construction, operation, maintenance, fuels and infrastructure). Chester and Horvath employed a hybrid LCA model for their analysis with each mode's life cycle. The environmental performance is calculated as passenger-kilometer-traveled also known as PKT. [5] A total of 79 components were evaluated across each transportation modality with respect to energy, greenhouse gas emissions, and air pollutants produced. [5] A similar study was carried out by Chester et al. in 2012 investigating the Los Angeles passenger transportation (Figure 2). In both studies' vehicle operations were found to constitute most of the energy per passenger mile traveled in gasoline sedans/SUVs and diesel buses, ranging from 1 to 4.5 megajoules. [5,6] It should be noted that urban diesel busses differed significantly in vehicle operations between off peak (6.5 MJ) and peak hours (.75 MJ). [5,6] The light rail system in San Francisco was significantly more energy efficient per passenger mile with most energy contributions being split amongst propulsion electricity and infrastructure construction/operations. The LA gold line light rail system had similar energy expenditure profiles when compared to the San Francisco Bay area. It should be noted that the overall energy consumption per passenger mile traveled is influenced by several factors most notably the type of energy generation (natural gas, coal, hydroelectric) and existing infrastructure.

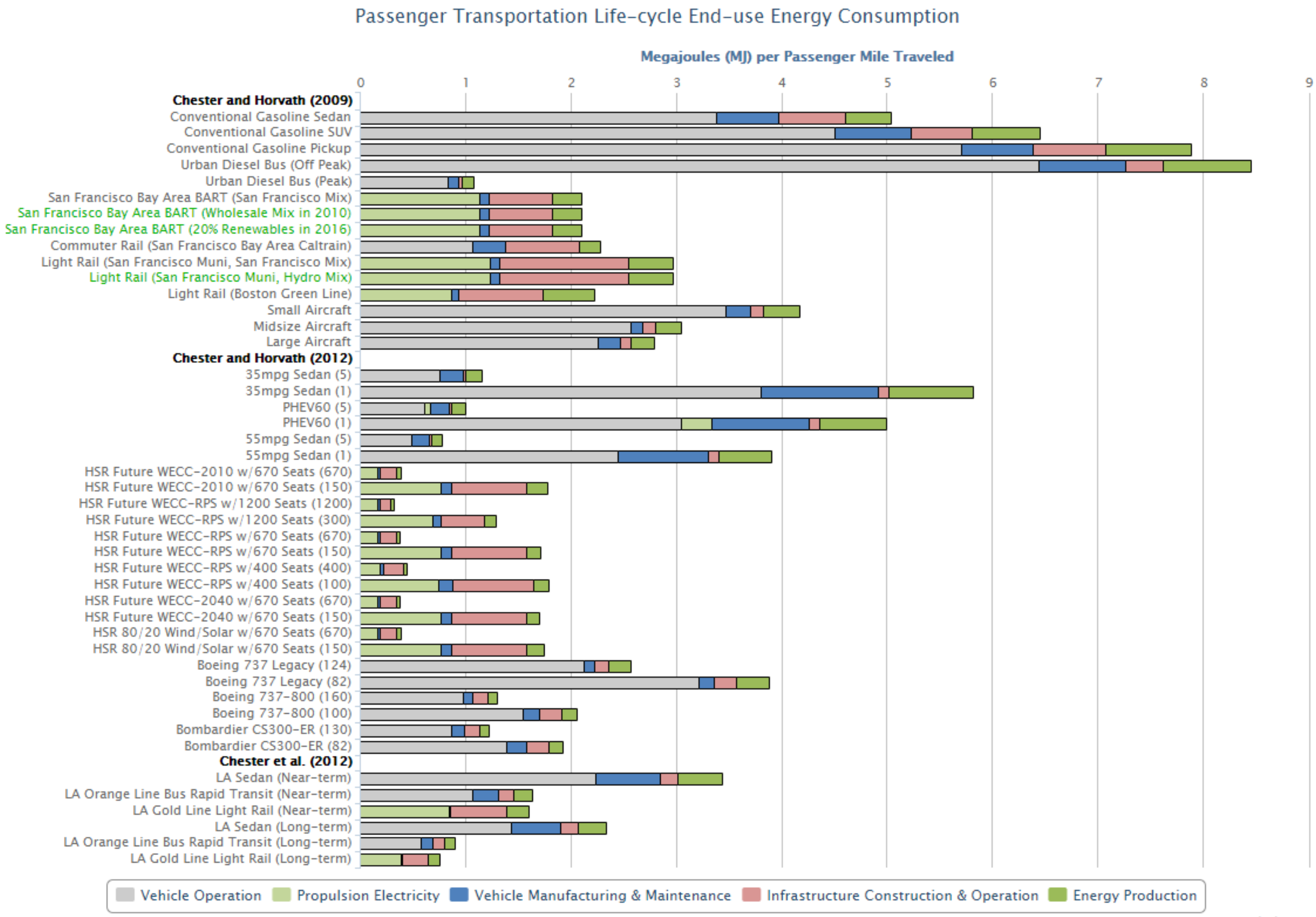

Figure 2. A bar graph illustrating transportation life cycle assessments with respect to energy (MJ) per passenger mile with various modes of transit and urban environments.

The District of Columbia Energy Portfolio

The District of Columbia (DC) is unique for its lack of natural resources and high energy demands. DC is approximately 68 square miles which sits between Virginia and Maryland with 705,749 residents. [7] The district houses a singular natural gas powerplant that exclusively provides electricity to federal buildings. Each year DC consumes a total of 11.3 TW of electrical power and generates 0.1 TW as such the district relies heavily on energy imports from neighboring states. To alleviate the over reliance on energy imports the District of Columbia adopted a renewable portfolio standard to promote localized renewable energy sources. As of April 2019, a total of 4,500 solar energy systems generated 64 megawatts within the city limits. [7] Solar energy accounts for approximately 85% of the total renewable generated electricity. [7] The two large scale solar facilities in the district are located at the Joint Base Anacostia-Bolling military complex and Washington Nationals baseball stadium which have the capacity to generate 7 megawatts combined.

DC Passenger Transportations Modalities

Metro Rail

The Washington Metro rail system opened in 1976 which serviced riders from Farragut North to Rhode Island Avenue-Brentwood. [8,9] The metro system has since expanded to six lines, 91 stations, and 117 miles of route, servicing DC, Maryland, and Virginia. [8,9] In 2018, a total of 295 million trips were taken, ranking the metro as the second busiest in the United States, behind the New York City subway system. [8,9] The system is electrically powered by 750 volts of direct current using the third rail. [8] The Washington Metro rail system has experienced several challenges including securing funding for expansion and infrastructure repair. The metro has historically relied upon ridership/fares to fund maintenance, however in 2018 Maryland, Virginia, and Washington agreed to contribute $500 million annually. [8] This has prompted the expansion plan to proceed and infrastructure repair to resume. The Washington Metro system is often an affordable and efficient mode of passenger travel for students and offers a socialized experienced of travel with peers. A vast majority of students utilize this mode of transportation, as rides are free for students and many of my students are from distal areas within the district. However, depending on residential locality many often must walk and take a metro bus before they have access to the system.

Automobiles (i.e., Uber, Personal Car, Metro Bus)

The Washington Metrobus system consists of more than 1500 buses that provides transportation to an area of 1,500 square miles. [8] A total of 269 routes with over 11,000 bus stops provide wide public transportation access to residents in Washington DC, Maryland, and Virginia. [8] In 2016, the metro bus system provided 123.6 million trips. The bus fleet consists of diverse bus models that utilize several fuels types including, diesel, hybrid electric, and compressed natural gas. [8] Most students who utilize the metro often require several bus transfers prior to riding the metro rail. Students that reside in northeast and northwest DC, where metro rail coverage can be relatively sparse typically ride metro buses to school. It should be noted that the metro bus and metro rail systems are operated by the same entity, Metropolitan Area Transit Authority (WMATA) which allows seamless transfers between each system through a passenger’s SmartTrip card. The school at which I teach, Woodrow Wilson High School, is in the northwest of DC and has access to both a metro station and bus station within a city block which are free services for students. In 2011, approximately 3.8 million vehicles were registered in D.C. along with neighboring counties in Maryland and Virginia also known regionally as the DMV. [9] The transient nature within the DMV has resulted in chronic traffic issues throughout the region. The DC Transit authority estimates that an average commuter will spend an additional 61 hours annually in traffic congestion, with most of the time idling. [9] The most common models of passenger vehicle(s) within the DMV are SUVs and the minivan which are powered by gasoline. The district is incentivizing residents to invest in electric vehicles through a government partnership with local electric provided by the Potomac Electric Power Company (PEPCO). Not many students drive to school with their personal vehicles due to a lack of parking lot space. Students are dropped off by parents in the morning for extracurriculars or utilize a ridesharing service such as Uber or Lyft.

LCAs of Passenger Transportation in the District of Columbia

A comprehensive LCA has yet to be developed for the District of Columbia Washington Metro area, even with the projected growth that is expected to occur within the city. For the context of this unit students will only investigate conventional gasoline sedans, light metro rail system, diesel buses, and electric scooters regarding passenger transportation life-cycle end-use energy consumption. Students will develop a flow model for a randomly assigned modality that they will research in the context of overall energy generation within Washington metro area. An energy impact index will be generated for components within their flow models to assess energy efficiency and greenhouse gas emissions per passenger mile (see scooter example below). The impact index will serve as a proxy during the impact assessment and provide a relative score for students to compare amongst groups. A large part of this unit is to expose students to deep enriched critically thinking through the LCA framework and interpret their results in group discussion(s). The goal for each student is to choose the most energy efficient modality based on the LCA models being presented and determine the appropriateness of this passenger transportation for their residential locality and lifestyle.

The District of Columbia Electric Scooter LCA

To prepare students for the inventory analysis and impact assessment with a standard car, metrobus, and metro rail system, we will look to analyze a case study with dockless electric scooter. The rise of electric scooter and bikes offer yet another mode of transit that some students have access to and this system is relatively simplistic when compared to the metro rail system. Research will be carried out to identify and describe the systems which comprise the life cycle of electric scooters within the DMV. In addition, we will investigate the relative capacity of electric scooters in the district as a means for reliable transportation. As of 2019, the District of Columbia had approximately 10,000 electric dock-less scooters from four different vendors (i.e., Bolt, Bird, Lime, and Razor). An electric scooter is a rather simple device which is made up of various materials including rubber, aluminum alloy, plastics, steel, and electric wiring. These raw materials represent the first stages of an electric scooter life cycle prior to assembly. Manufacturing scooters requires soldering wires, molding plastic components, and welding the aluminum frame. Once manufacturing is complete shipping and delivery from the factory to designated customers can occur. Most models utilize a 91.2 watt hour lithium battery with a range of approximately 15-miles. [10] Other maintenance and use processes include charging, which typically occurs overnight as well as battery replacement. The average electric scooter is ridden five times per day with an average distance of 1.5 miles in DC. The average lifetime of an electric scooter is estimate to by around 0.5 to 2 years depending on use. [10] It should be noted that customer damage varies widely and can affect the overall quality and experience of use. The electric scooter is a relatively new mode of transportation available in urban districts but with the recent LCAs studies of electric scooters outlined by Hollingsworth et al. 2019 we can extrapolate a flow model as illustrated in Figure 3.

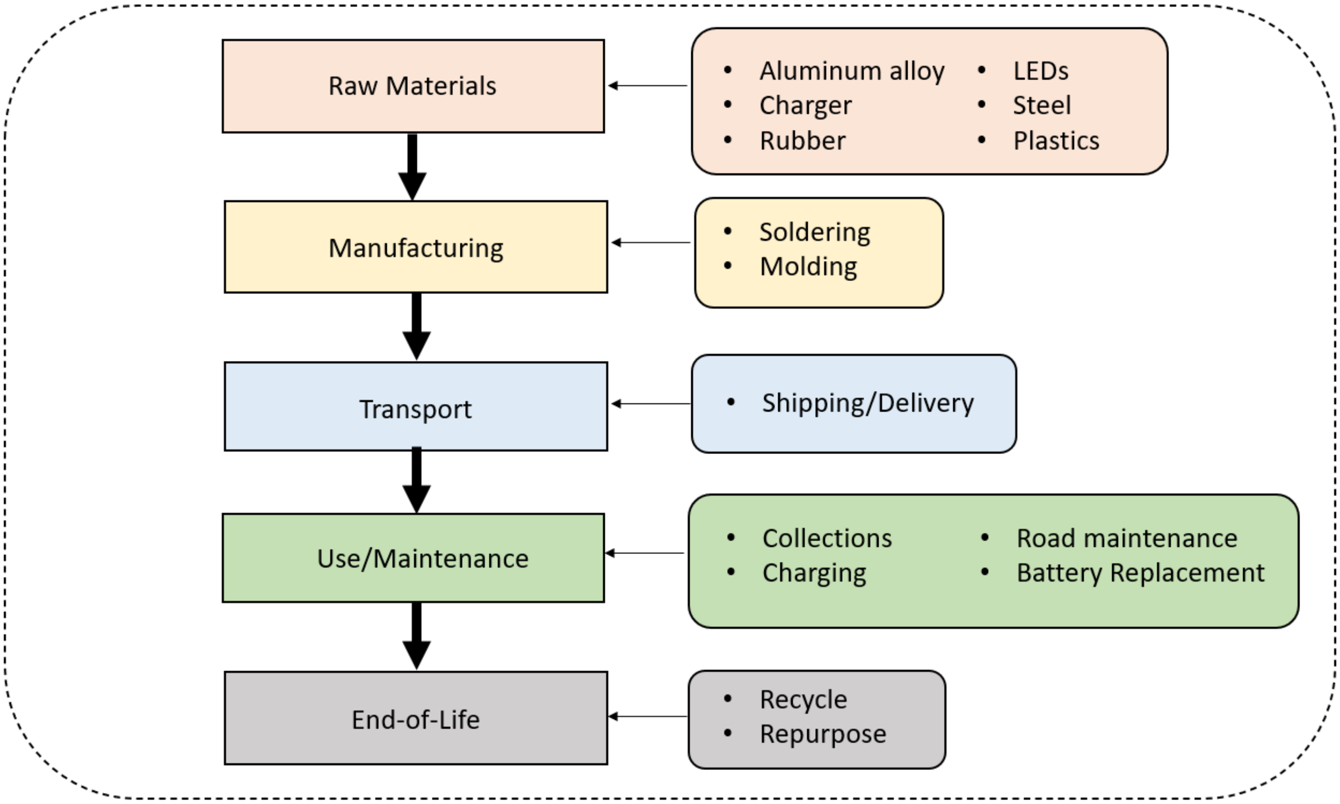

Figure 3. A systems flow model for a life cycle assessment for dockless electric scooters.

Impact Assessment of Cars, DC Metrobus, and DC Metrorail

There are several modifications and assumptions that are necessary to discuss in this unit as there are limitations with grade appropriate mathematics and access to local transportation data which prevents a thorough analysis, not to mention the time constraints in the classroom. Students will develop a workflow model to one of the three common modes of passenger transportation within the district. A similar mapping process will be utilized for students to create flow models and systems boundaries with suggested groupings will include but are not limited to, vehicle manufacturing (raw materials, assembly), operations, infrastructure (construction and maintenance), and fuels (refinement and distribution). These categories were chosen as they typically account for 80% of the life cycle effects. Students will conduct an impact assessment through the analysis of data provided from Table 2. Data was extrapolated and collated between two primary sources: Chester 2009 as well as the Washington Metropolitan Area Transit Authority (WMATA) annual ridership reports to streamline the overall process for the students. [5,8] The two environmental impact factors being examine were megajoules per passenger mile and grams of CO2 equivalence per passenger mile the data was compiled to produce an impact factor that students could easily assess these were EIF and GIF. Both were standardized through unit conversions, where appropriate, and were determined per passenger using the average ridership per vehicle. The average vehicle occupancy was determined through data from WMATA and the U.S. department of transportation. [7,8] For each subset of data in both EIF and GIF values were normalized using the powers of ten to generate a weighted numerical value that could be more readily interpreted by students.

Component	Energy	Energy Impact Factor	EIF per Passenger	GHG (CO_2)	GHG Impact Factor	GIF Per Passenger
Sedan (car)	121 GJ/veh.	1.21	0.761006289	10 MT/veh	0.1	0.062893082
DC Metrobus	114 GJ/veh.	1.14	0.056185313	129 MT/veh	1.2	0.059142435
DC Metro	3,750 GJ/train	37.5	0.517598344	230 MT/train	2.3	0.031746032
Sedan (car) [1.59 pgns]	4.8 MJ/VMT	0.48	0.301886792	367 g/VMT	3.67	2.308176101
DC Metrobus [20.29 pgns]	32 MJ/VMT	3.2	0.157713159	2,373 g/VMT	23.73	1.169541646
DC Metro [72.45 pgns]	100 MJ/VMT	10	0.138026225	10000 g/VMT	100	1.38026225
Construction (car)	76 MJ/ft^2	7.6	4.779874214	6 kg/ft^2	0.6	0.377358491
Maintenance (car)	7.3 MJ/ft^2	0.73	0.459119497	614 kg/ft^2	61.4	38.6163522
Construction (bus)	76 MJ/ft^2	7.6	0.374568753	6 kg/ft^2	0.6	0.029571217
Maintenance (bus)	7.3 MJ/ft^2	0.73	0.035978314	614 kg/ft^2	61.4	3.026121242
Station Construction	11.6 MJ/yd3	1.16	0.016011042	36 kg/yd^3	3.6	0.049689441
Station Maintenance	104 MJ/day/stn	10.4	0.143547274	351 g/kWh	35.1	0.48447205
Refining & Distribution	19 MJ/gal	0.19	0.119496855	1700 g/gal	17	10.6918239
Refining & Distribution	18 MJ/gal	0.18	0.008871365	1600 g/gal	16	0.788565796
Refining & Distribution				9756 g/gal	97.56	1.346583851

Table 2. An extrapolated dataset from WMATA and (Chester 2009) that calculates the relative impact factor with regards to total energy and greenhouse gas emissions per passenger.

Teaching Strategies

Heterogenous Groups with Gallery Walk (Hybrid Model)

Given the uncertainty of next year, this unit is particularly conscious of developing strategies for a hybrid model in preparation for potential scheduling adjustments throughout the year. In a traditional school year, students typically are placed in heterogenous groups to conduct scientific investigations and inquiry learning. This provides the platform for students to build social-emotional capacity through collaboration and explore diverse perspective with respect to problems solving. At the end of every learning cycle students are asked to present results, hypotheses, conclusions, and theories within their assigned groups. One of the most effective pedagogical strategies to effectively communicate between groups has been the implementation a gallery walks. This instructional strategy allows students multiple opportunities to refine conceptual understanding through peer feedback. Groups are asked to assess each other thinking and provide critical feedback to improve content understanding and/or communication. During remote instruction heterogenous groups are assigned randomly through Zoom breakout rooms. Students are asked to observe a phenomenon and collaborate in groups of three to develop a working model of the governing principles driving the phenomenon. Each group is assigned a Jamboard slide to illustrate their thinking. Jamboard is an online tool which serves as a digital whiteboard for students to freely collaborate, any student with a Google account have access to this tool. It is the expectation of class that every student participates, as a result I assign each member in the group a specific font or color that illustrates member contribution. At specific times in the learning cycle students share their Jamboards in a virtual gallery walk with similar feedback protocol to in class instruction.

Extended Constructed Response (ECR)

Extended constructed response questions provide an opportunity for students to demonstrate the extent of mastery within a given content area while building capacity for sustained critical thinking. Students will be provided an essential question (i.e., How do the laws of thermodynamics limit the efficiency of a combustion engine? Use data to support your claims.), every two weeks, that complements an observable phenomenon or data-driven inquiry lab. It is the expectation that students simply write in class for a set duration of time. This serves as a great independent exercise for meaningful exit tickets to determine what misconceptions or questions students are still grappling with. The ECR is an iterative exercise where students frequently update their responses to improve precision and content mastery through multiple opportunities during the learning cycle. The Next Generation Science Standards (NGSS) heavily emphasize students' ability to rationalize phenomena. Last year, students dramatically improved literacy skills and produced higher quality responses. To encourage a growth mindset, multiple drafts are required prior to final submission. This process serves as the foundation for a growth mind-set and provide numerous opportunities for students to refine their rationale and improve their mechanics.

Phenomenon Deconstruction

As a science, physics offers opportunities for students to apply a multitude of mathematical concepts and arithmetic skills when describing physical phenomena. This unit will seek to strengthen students' content mastery of energy transformation while simultaneously refining systems thinking through integrated analysis of LCAs. From my experience teaching at Woodrow Wilson High School, activities that are grounded in meaningful real-world scenarios often lead to the most individual growth. This unit will utilize inquiry as an access point for student ingenuity and provide the context for students to revise their ideas about the concepts being introduced. A typical learning cycle ask students to evaluate a phenomenon through prior knowledge. The key to this pedagogical strategy is presenting a compelling phenomenon that is multi-dimensional and relevant to students. Prior to explaining what is occurring, students are asked to describe what they see to ensure all details are observed. Students are then asked to develop a model that may provide a explain what they are observing. Supplemental activities or questions throughout the learning cycle support student understanding in explaining the phenomenon. Throughout all stages, I do not provide an answer but rather probing questions to guide of determine depth of knowledge. This practice has transformed student engagement and excitement as many want to understand why?

Activities

Energy Transformation Demonstrations – Modeling Stirling Engine and Flashlights

Like last year, we will begin the energy unit by deconstructing a flashlight and Stirling engine to refine our knowledge of energy types and their subsequent transformations. Students will observe a series of phenomena to better understand the intricacies associated with energy transformations. A heavy emphasis will be placed on comparing various models of Stirling engines with regards to their energy pathways. Students will individually identify and record in their science notebooks all forms of energy observed in the initial demonstration. After three to five minutes students will collaborate in small groups to determine the energy pathway for the whole group demonstration. Students will be given ten minutes to illustrate the energy pathway starting with the chemical potential energy. Each group will present on their initial observations to prepare for the independent work. In groups of four, students will identify the types of energy present within each system (i.e., model of Stirling engine). Each group will construct an energy pathway diagram and identify forms of energy and locations of energy transformation. Individually students will be asked to explain why Stirling engines will never achieve perfect efficiency using supportive evidence from their observations as well as content from their science notebooks. This activity is designed to familiarize students with multi-step energy transformations in preparation for the culminating project at the end of the unit. This activity can be scaffolded to accommodate middle and elementary students by simplifying the observed energy transformations.

Systems Thinking of Transportation Assessment utilizing LCA Data

The summative project will ask students to examine the energy efficiency (per passenger) of public transportation in the District of Columbia. This will occur in two phases, through the introduction of lifetime cycle analysis. As a whole group or in teams, students will research a standard dockless electric scooter to determine distribution, raw materials, maintenance, and end of life processes involved. A flow model will be constructed using systems thinking through the application of concept mapping. Each group may have variation on their systems boundaries and process that are included but the overall product should be comprehensive within our time constraints. Systematically thinking about a relatively simple product will build the necessary capacity for complex modes of public transportation. The second phase of the project ask students to compare three modes of public transportation with regards to energy and greenhouse gas emission per passenger. Student will utilize the impact factor table in Figure 5 generated from LCAs and local public transit dataset to conduct their assessments of a standard car, metrobus, and metro rail. Lastly, students will determine which mode of transportation would be most efficient for them based on their home residence. This project will provide an opportunity for students to gain a deeper understanding and appreciation for the complexities associated with public transportation as well as the importance of energy systems. It is my hope that a simple question of how you should get to school will illuminate students into thinking deeply about other aspects of everyday life as well.

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[10] Hollingsworth, Joseph, Brenna Copeland, and Jeremiah X. Johnson. 2019. “Are E-Scooters Polluters? The Environmental Impacts of Shared Dockless Electric Scooters.” *Environmental Research Letters* 14 (8). https://doi.org/10.1088/1748-9326/ab2da8.

Teacher and Student Resources

Teacher Resources

For supplemental information that will be utilized at varying degrees throughout the unit please review the following. A deactivated link is provided along with a summary of the resource. In addition, several referenced materials are recommended for review that further supplement the content in this unit.

Khan Academy

Khan Academy is a non-profit educational organization that provides free lectures in the form of YouTube videos as well as practice exercises along with a personalized dashboard if students register on the website. This resource is helpful for students that require supplemental learning or need to make up work due to absences. Alternatively, this serves as a good resource for asynchronous learning if in person teaching is not option due to the COVID-19 pandemic. (https://www.khanacademy.org)

Physics classroom

Physics classroom is a free online resource for beginning students and teachers. There are several animations, problem sets, and tutorials that supplement classroom content. The website provides guidance to targeted misunderstandings and strengthens students’ critical thinking skills with multi-tiered word problems. Students who require additional support should be guided to this website. (http://www.physicsclassroom.com)

Unit Reference Material

Chester, Mikhail. “Passenger Transportation LCA Database.” Transportation LCA. Accessed July 15, 2020. http://www.transportationlca.org/index.php.

Dr. Mikhail Chester from Arizona State University (ASU) has published an online portal that is dedicated to transportation LCAs specifically within urban districts such as Los Angeles and San Francisco. The database is publicly available of use and serves as a resource for students and teacher who looking to conduct their own life cycle assessments within their area.

Appendix on Implementing District Standards

NGSS Standard Integration

The unit will incorporate standards from the Next Generation Science Standards (NGSS) in Unit III. The focus will be primarily on the nature of energy and the associated thermodynamic principles however the LCA with serve as the method for assessment of a real-world energy efficiency scenario.

Disciplinary Core Ideas

Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. (HS-PS3-1)

Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. (HS-PS3-1) (HS-PS3-2)

When two objects interacting through a field relative position, the energy stored in the field is changed. (HS-PS3-5)

Crosscutting Concepts

When investigating or describing a system, the boundaries and initial conditions of the system need to be defined, their inputs and outputs analyzed and described using models. (HS-PS3-4)

Science & Engineering Practices

Use mathematical representation of phenomena to describe explanations. (HS-PS2-2)
