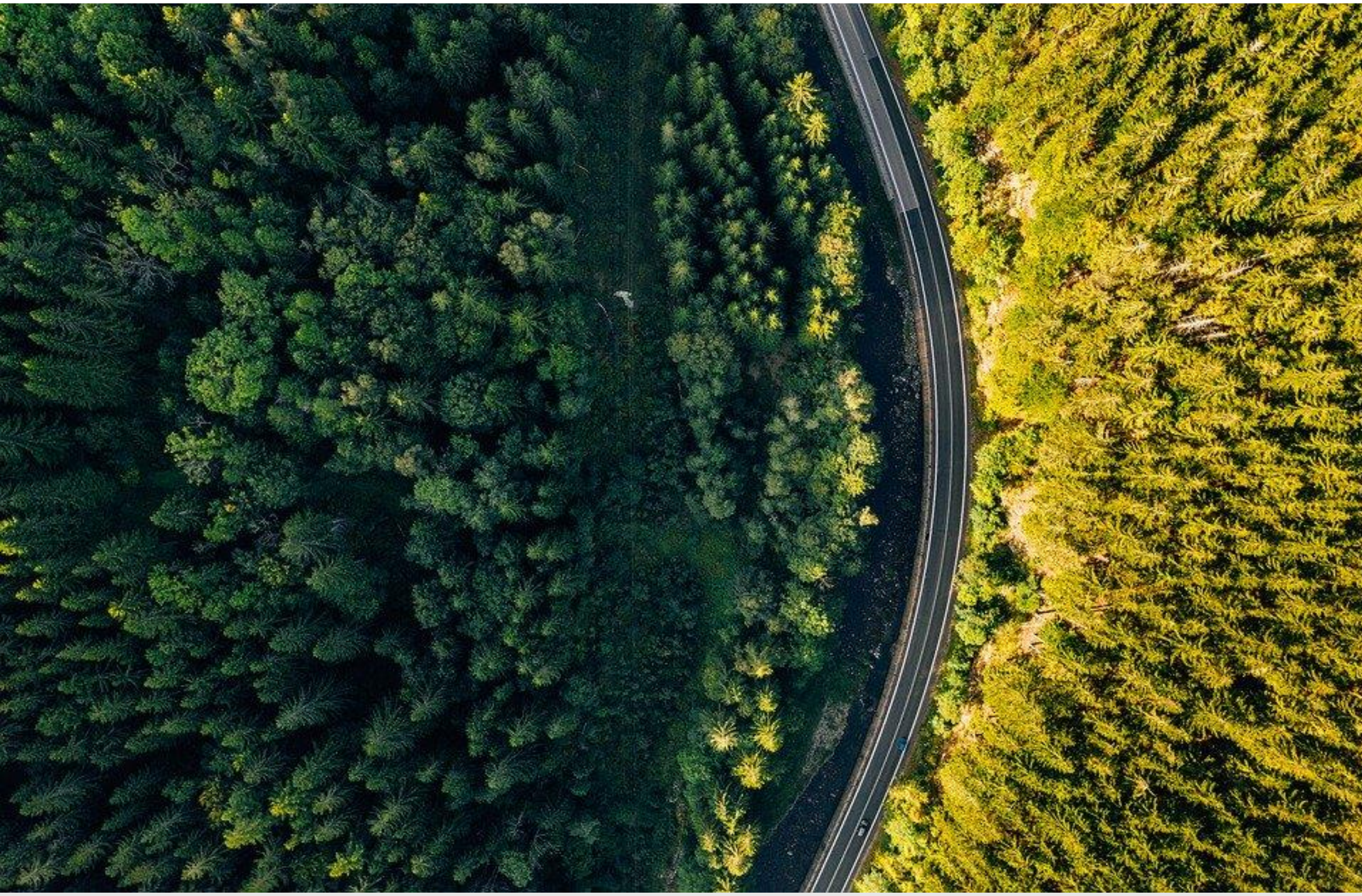

Canadian Advanced Air Mobility (CAAM)

Environmental Analysis and Framework

November 13, 2020

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Executive Summary

This report measures the direct and indirect environmental impacts associated with the integration of Advanced Air Mobility (AAM) technology, particularly electric vertical take-off and landing (eVTOL) technology in the Greater Vancouver Region through the completion of a streamlined Life Cycle Inventory (LCI). Brightspot Climate examined three scenarios or pathways – conventional ground transportation, helicopter transportation, and eVTOL transportation for a specific use case of the movement of radioactive time sensitive cancer fighting isotopes from BC Cancer - Vancouver, located next to Vancouver General Hospital (VGH) to BC Cancer - Victoria located next to Victoria Royal Jubilee Hospital (RJH).

The entire LCI considered all processes, from material extraction to end-of-life disposal and recycling, for each alternative studied. The environmental exchanges that are the focus of the analysis are the total emissions associated with greenhouse gases (GHG), nitrogen oxides (NO_x), sulphur dioxide (SO_2), total particulate matter (TPM) and volatile organic compounds (VOC) per patient treated. The data was analyzed in accordance with International Standard 14044 Environmental management — Life cycle assessment, with important parameters being gathered through interviews with technology operators, engineering estimations of emission factors and utilizing an LCA tool – GHGenius.

The findings indicate that the total emissions resulting from utilizing eVTOLs for the transportation of cancer isotopes between VGH and RJH is lower than the conventional ground transportation and helicopter transportation pathway. This result is expected as the eVTOL is powered electrically versus fossil fuel energy consumption in the other scenarios. Additionally, the eVTOL is the most effective for the specific use case as it is faster and subsequently the travel time decreases resulting in more cancer patients being treated per trip.

Life Cycle Assessment

Life Cycle Assessment (LCA) is a comprehensive tool that encompasses all the environmental impacts related to the life cycle stages of a product from cradle to grave.

The environmental LCA discussed in this report considers three pathways using different transportation technologies to transport cancer isotopes from BC Cancer - Vancouver, located next to Vancouver General Hospital (VGH) to BC Cancer - Victoria located next to Victoria Royal Jubilee Hospital (RJH).

Goal of the Study

The goal of this study is to compare the environmental aspects and potential environmental impacts of the integration of Advanced Air Mobility (AAM) technology in the Greater Vancouver Region with existing, functionally equivalent transportation pathways. The LCA considers the entire life cycle of the transportation technologies involved; from raw material acquisition through to end-of-life.

The LCA is performed following the Goal and Scope and Inventory subsections of the International Standard 14044 Environmental management — Life cycle assessment — Requirements and guidelines. The figure below describes the life cycle assessment framework. The goal and scope definition of the LCA is a compilation and evaluation of inputs, outputs and potential environmental impacts. The goal of the Life Cycle Inventory (LCI) phase is the quantification of inputs and outputs.

The Life Cycle Impact Assessment (LCIA) phase is an evaluation of the magnitude and significance of the potential environmental impacts. The final step, the Life Cycle Interpretation phase, is an evaluation of the LCI and LCIA in relation to the defined goal and scope in order to reach conclusions and recommendations. The scope of this report encompasses the LCI phase, and LCIA is planned for future study.

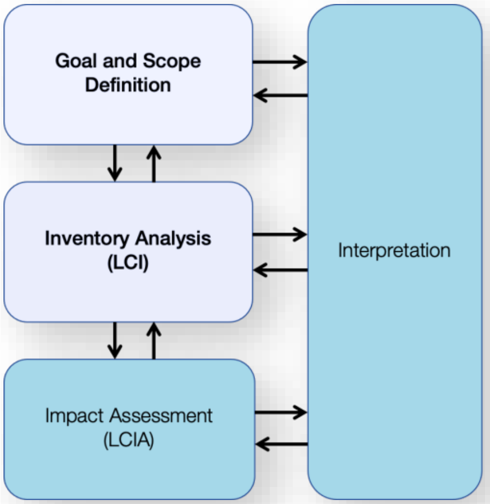

Figure 1: The LCA

CAAM's Vancouver AAM refers to the LCI as "the environmental inventory". The Vancouver AAM is the first triple bottom line analysis comprised of economic, social and environmental studies evaluating this technology. The environmental inventory completed for the Vancouver AAM has established a framework for environmental analysis for AAM in future scenarios.

Scope of the Product System Studied

The scope of the LCA is to quantify the greenhouse gas emissions (carbon dioxide, nitrous oxide, methane) and criteria air pollutant emissions (sulfur dioxide, nitrogen oxides, volatile organic compounds, and particulate matter) associated with the transportation of PET (Positron Emission Tomography) radioisotopes used for cancer treatment.

The system evaluates the emissions associated to the transportation of this isotope through three transportation pathways. Each of the three pathways involves a different set of vehicles, namely truck-ferry-truck (Conventional Ground Pathway), truck-helicopter-truck (Helicopter Pathway) and Advanced Air Mobility (AAM Pathway). The study has been designed to consider the environmental impacts along the entire lifecycle of each pathway, from material extraction and processing to end-of-life disposal and recycling.

All pathways are functionally equivalent, as each pathway transports the same radioactive isotope between VGH and RJH. The cargo is composed of an approximately fifty pound lead container carrying about two pounds of cancer isotopes. However, the radioactive half-life nature of this treatment enables faster, more efficient, pathways to treat more patients. This improvement is considered within the study and its implications are considered in the Inventory section below.

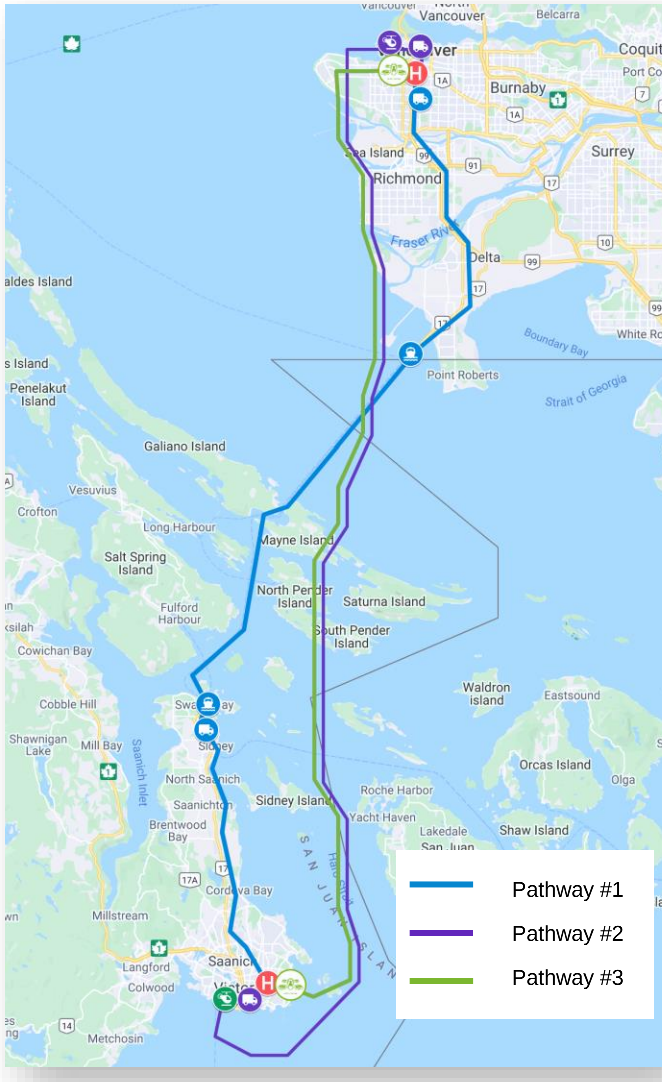

Figure 2: LCA Pathways

Figure 2 illustrates the most likely route for each transportation pathway, as represented by different coloured lines. Presently, the lines illustrate the most likely route determined through interviews with Helijet, NAV Canada and TForce Logistics. Furthermore, the routes displayed on the map represent the best case scenario, which accounts for average daily traffic and weather minima for visual flying rules.

Figure 3: BC Ferries' Spirit of British Columbia, one of the largest passenger ferries in the world to be converted from diesel to LNG propulsion was awarded the Shippax Retrofit Award in 2018[1]

The *Conventional Ground Pathway* represents the transportation of cancer isotopes from VGH to Tsawwassen ferry terminal via a conventional vehicle, ferried across the Georgia Strait to Swartz Bay ferry terminal via BC Ferries fleet and driven to RJH via the same conventional vehicle that began this route. The conventional vehicle route is solely dedicated to the transportation of the isotope, while the ferry also transports cargo and passengers for other purposes.

The *Helicopter Pathway* represents the transportation of cancer isotopes from VGH to Vancouver Harbour Heliport via a conventional vehicle, flown across the Georgia Strait to Victoria's Ogden Point Heliport via Helijet's fleet and driven to RJH via a different conventional vehicle than the one that began this route. The conventional vehicle routes are solely dedicated to the transportation of the isotope, while the helicopter also transports an average of ten passengers, crew and their respective cargo.

Figure 4: Helijet's Air Ambulance. Helijet is one of the largest providers of Air Medical services in Western Canada[2]

Figure 5: Lateral view of Joby's S4 eVTOL[3]

The most streamlined, *Advance Air Mobility Pathway* represents the transportation of cancer isotopes from the helipad at VGH directly to the helipad at RJH via an electric Vertical Take-Off and Landing aircraft (eVTOL). The eVTOL is assumed to hold one crew member and the certified cancer isotope transport container. This pathway presumes that the eVTOL obtains certification and communication for Class 'C' Airspace Access & Operation, equivalent to the certification attained by Helijet's current fleet.

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[1] BC Ferries – Spirit of British Columbia, https://www.bcferries.com/

[2] Helijet International – Air Medical Transport, Heath Moffatt Photography: 250-884-0262

[3] Joby S4, https://www.jobyaviation.com/

Inventory Analysis

The assessment between the three pathways studied must consider equivalent functionality to enable fair comparison between the technologies' resulting emissions. The radioisotope under consideration is fluorodeoxyglucose (FDG). FDG has a half-life of about 110 minutes, which results in FDG losing half of its radioactive efficacy for treatment after approximately two hours. Considering the different speed at which each pathway transports the isotope between hospitals, the potential number of patients treated differs between pathways. Consequently, a **functional unit**, defined as **emissions per cancer patient treated**, is used to normalize the performance difference between pathways. The resulting transportation times and equivalent patients treated attributed to each pathway's performance characteristics are illustrated below.

11 Patients per Day

4.5 hours one-way

14 Patients per Day

2 hours one-way

20 Patients per Day

1 hour one-way

The primary purpose of a functional unit is to provide a defined and measurable reference to which the input and output data are normalized. In this study, the unit of emissions per patient treated is consistent with the function, goal and scope hitherto described. The lifecycle results are reported as mass of pollutant (GHG, NO_x, SO_2, TPM and VOC), emitted throughout the lifecycle emissions of the technologies under consideration, per cancer patient treated.

System Boundary and Cut-off Criteria

Figure 5: Comecer's shipping container for the radioactive isotope[4]

The lifecycle of each transportation technology is exemplified through a process flow diagram, on the following page. The process flow is grouped by categories representing the total exchanges with the environment (i.e. emissions and fuel consumption). The dashed lines on these diagrams represent the cut-off threshold based on environmental significance determined by the mass of emitted pollutants per patient treated. For example, emissions from infrastructure related to development of roads, marine routes and airways were excluded from this study because the resulting emissions are distributed amongst all the vehicles traversing through these paths. Once these emissions are distributed from all trips, the resulting emissions become smaller than the accuracy of the study and therefore beyond the environmental significance threshold.

[4] "Type A" external case for radiopharmaceuticals transport, https://www.comecer.com/

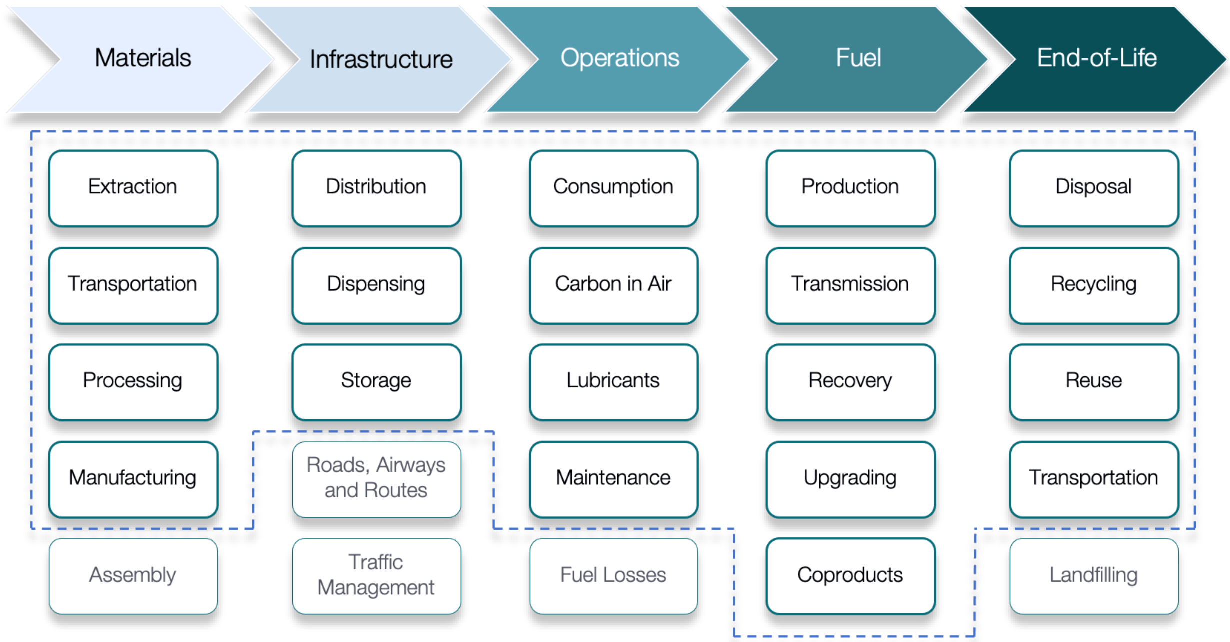

Figure 6: Process Flow Diagram showing the environmental exchanges

Methodology

The system of methods used in the environmental study considers existing lifecycle analysis tools and scientific studies to estimate the environmental impacts associated with the considered technologies. The data used in this inventory is gathered through interviews with the technology operators. The interview data was corroborated through comparison with publicly available data. Furthermore, any data gap was filled with publicly available data. All assumptions were logged and qualified according to their source and their regional, technological and time coverage.

Figure 7: The GHGenius model utilized regional inputs of British Columbia

Methodological Framework

The inventory methodology uses the GHGenius model, version 5.0, under the regional and time inputs for British Columbia forecasted for the year 2020. GHGenius enables the customization of the emission factors associated to each technology. These emission factors covered materials and assembly emissions, accounting for a discount factor for the materials recycling and disposal. The emission factors utilized are limited to the province of British Columbia, Canada. The inventory considered other public sources where GHGenius did not have an applicable emission factor. These alternative data sources are elaborated on the page below.

Data Quality

Data quality assurance follows the general requirements outlined in the ISO 14044 Standard for Environmental Management. The data was evaluated against time-related coverage, geographical coverage and technological coverage. The data also addresses precision, completeness, representativeness, consistency, reproducibility and data sources.

While the model is able to estimate emissions from any region, the data analyzed takes place in the period between 2019 and 2020. The geographical location encompasses British Columbia. The technology coverage is the four technologies studied across the pathways: vehicle, ferry, helicopter and eVTOL.

Data precision and accuracy was established by comparing the primary data sources with publicly available information. The completeness of data was ensured by estimating all relevant emission sources for all relevant technologies. A fair level of representativeness is demonstrated through the dataset which reflects the true population of interest – transportation carriers of the cancer isotope in the Vancouver - Victoria region. The methodology is applied uniformly across various components of the study; each technology's parameters are collected through interviews and internet sources, the level of complexity in data collection is same across the components, and emissions are calculated in the same manner.

The reproducibility of the study is demonstrated for the specific case scenario, where any municipality in need of time sensitive medicine can opt for any of the pathways considered in this study. Similarly, reproducibility of the model can be established by comparing pathways associated with case studies different to the transportation of cancer isotopes.

Allocation

Allocation under this study refers to the method used to distribute emissions. This study relied on technologies that are public and shared between different users for various purposes. Consequently, it would be inaccurate to assign all emissions generated for the ferry portion of the conventional ground route between Vancouver and Victoria to the transportation of the isotope. It is necessary to allocate emissions according to a unit that could be shared amongst the transportation technologies involved.

The transportation technologies share various factors under which allocation could be considered such as volume, mass, time, among others. The common and most reasonable denominator between all technologies was determined to be mass of cargo transported. Under this approach, emissions from any trip that was deemed shared between different users were divided by the average cargo transported and multiplied by the weight of the cargo required for the transportation of the isotope.

Carrying on the previous ferry example, historical data for the average passenger and vehicle capacity was used to determine the average mass of cargo transported between Vancouver and Victoria. In this case, the total mass of cargo required for the transportation of the isotope (the mass of the isotope container, vehicle and driver) was divided by the average mass of cargo carried by that vessel route. This resulted on a 0.35% mass of cancer isotope cargo per average cargo. Consequently, the resulting emissions for the total trip were assigned to be 0.35% allocated to the transportation of this isotope. In contrast, the eVTOL under the AAM pathway is conservatively considered to be used for the sole purpose of the transportation of the isotope, resulting in 100% allocation.

Scientific Studies and Public Data

The secondary method for data gathering was the use of scientific studies or publicly available data based on manufacturing specifications. The data gathered through these sources was also used to corroborate the reliability of data provided throughout the interviews. For example, the fuel consumption provided as an average for the Helijet fleet was corroborated against the fuel consumption defined by the manufacturer specifications. Where both sources of information reasonably agreed, the information gathered from the interview became prevalent as this would most closely reflect the day to day operations and other circumstantial factors that would vary according to operational environment. A set of the factors referenced solely from publicly available data is tabulated below.

Table 1: Referenced Values

Parameter	Value
Weight of Toyota Prius[5]	4,007 lbs
Weight of Ford Ranger[6]	4,293 lbs
Marine Diesel HHV (Sulphur Petroleum diesel)[7]	38.60 MJ/L
Low-S Diesel HHV[7]	45.58 MJ/kg
Low-S Diesel Density[7]	3,206 g/gallon
Fuel Consumption - Total Energy Consumption 8L34DF[8]	7,460 kJ/kWh
B.C. Electricity Grid Factor[9]	29.90 gCO_2e/kWh
Jet A Fuel EF[10]	9.570 kg CO_2/gal
Fuel Consumption - V Class[11]	54 L/km
Spirit Horsepower[11]	21,394 HP
Quad E Energy Burn[12]	1,070 MJ
Quad E Speed[12]	87.10 kt
Quad E Endurance[12]	0.86 h

[5] Toyota 2021 Prius Specifications, https://www.toyota.ca/toyota/en/vehicles/prius/models-specifications

[6] Ford 2020 Ranger XLT Specifications, https://www.ford.com/trucks/ranger/models/ranger-xlt/

[7] US Department of Energy – Biomass Energy Data Book, https://www.co.shasta.ca.us/docs/libraries/resource-management-docs/spi-feir/3_Exhibit_2.pdf?sfvrsn=a9006c9e_2

[8] Wärtsilä 34DF Product Guide, https://www.wartsila.com/

[9] BC Government - Electricity Emission Intensity Factors for Grid-Connected Entities, https://www2.gov.bc.ca/gov/content/environment/climate-change/industry/reporting/quantify/electricity

[10] The Climate Registry - General Reporting Protocol, https://www.theclimateregistry.org/tools-resources/reporting-protocols/general-reporting-protocol/

[11] BC Government - 2018 B.C. Methodological Guidance for Quantifying Greenhouse Gas Emissions, https://www2.gov.bc.ca/assets/gov/environment/climate-change/cng/methodology/2018-pso-methodology.pdf?bcgovtm=CSMLS

[12] NASA Research Center - VTOL Urban Air Mobility Concept Vehicles for Technology Development, https://hummingbird.arc.nasa.gov/Publications/files/vtol-urban-air-2.pdf

Assumptions

The study depended on a set of assumptions regarding data collection and the quantification of emissions. These assumptions were recorded and qualified to ensure that all assumptions were equivalent for all aspect of the technologies studied.

Interviews

Interviews were conducted with technology operators of each pathway to collect information which would be used in the quantification of the LCI. Each of these organizations are involved in the transportation of the cancer isotope directly or indirectly.

The interview with BC Cancer, a comprehensive cancer control program for B.C. advanced the understanding of shipping procedures for the cancer isotope, licensing requirements and the maintenance of the isotope container.

The interview with BC Ferries, one of the largest ferry operators in the world, provided information regarding fuel consumption of the ferries, the utilization of the vessels and their operating capacity.

The interview with Helijet International, a helicopter airline and charter service based in Vancouver, broadened the understanding of the isotope transportation procedures and containment, the fuel consumption, blend, infrastructure and sources used in Helijet helicopters and their maintenance.

NAV CANADA, Canada's civil air navigation services provider provided information about flight routes and rules, airspace access and access limitations and impacts.

TForce Logistics, a transportation provider with extensive coverage across the United States and Canada supplied information on the vehicles and fueling stations utilized and the average workdays of employees.

Data Gaps and Engineering Estimates

Engineering estimates are relevant when data cannot be gathered by alternative methods. The estimate is then used to determine the most likely value for the missing information. Estimating the missing data requires an understanding of the category of data being calculated and the potential values resulting from this estimate. A reasonableness check is performed in addition to the engineering estimate to corroborate its accuracy.

The LCI model relied primarily on data collected through interviews, models and other publicly available sources. However, there were instances in which data could not be obtained. In these cases, an engineering estimate was used. The result obtained was compared against values for similar parameters with publicly available data.

Resulting Assumptions

Figure 8: Comecer's shipping container for the radioactive isotope[4]

For the cancer isotope, the following is assumed through interviews and engineering estimates:

- Trips per week: 9
- Gross Container Weight: 50 lbs
- Half-life of Isotope: 110 minutes
- Trips per roundtrip: 2

An electric hybrid Toyota Prius and the Ford Ranger are the two cars that are used to transport the isotope in Pathways #1 and #2.

For the car aspect of the pathways, the following assumptions are developed:

- Operating allocation: 100%
- Average Vehicle weight: 4,150 lbs
- Distance travelled in Pathway #1: 70 km
- Distance travelled in Pathway #2, from VGH to Vancouver Harbour Heliport: 5 km
- Distance travelled in Pathway #2, from Victoria Harbour Heliport to RJH: 7 km
- Transportation Time in Pathway #1: 1.33 hours
- Transportation Time in Pathway #2 – Vancouver: 0.25 hours
- Transportation Time in Pathway #2 - Victoria: 0.25 hours

Figure 9: Toyota Prius[13]

Figure 10: Ford Ranger[14]

[13] Toyota 2021 Prius, https://www.toyota.com/prius/photo-gallery/exterior/2

[14] Ford 2020 Ranger XLT Specifications, https://www.ford.com/trucks/ranger/models/ranger-xlt/

In addition to these assumptions, some parameters are common across the three pathways. These assumptions, determined through interviewing the technology operators, are listed below.

Table 2: LCI Assumptions

Assumptions	Pathway #1 **Car → Ferry → Car**	Pathway #2 **Car → Helicopter → Car**	Pathway #3 **eVTOL**
Type of Fuel	Blended Marine Diesel 95% Marine Diesel, 5% Biodiesel Liquified Natural Gas 97% LNG in Spirit Class Ferries Gasoline	Jet-A Fuel Aviation Turbine Fuel Gasoline	Electricity Sourced from British Columbia's Grid
Roundtrip distance travelled	159 km Total distance from VGH → Tsawwassen Ferry Terminal → Swartz Bay Ferry Terminal → RJH	127 km Total distance from VGH → Vancouver Harbour Heliport → Victoria Harbour Heliport → RJH	115 km Total distance from VGH → RJH
Roundtrip Transportation Time	540 minutes Total time from VGH → Tsawwassen Ferry Terminal → Swartz Bay Ferry Terminal → RJH	240 minutes Total time from VGH → Vancouver Harbour Heliport → Victoria Harbour Heliport → RJH	123 minutes Estimated total time from VGH →RJH
Number of Patients Treated	11 Highest demand on a historical basis	14 Highest demand on a historical basis	20 Estimated assuming a half-life of 110 minutes and using the parameters from Pathway #2
Fleet	Spirit Class Spirit of British Columbia Spirit of Vancouver Island Coastal Class Coastal Celebration Coastal Renaissance Queen of New Westminster	Sikorsky 76 A, B, C+ and C++	Quad E Battery-powered Electric Quadrotor type eVTOL
Average Cargo	Variable ~1.2 million lbs per vessel Passengers (200 lbs each) + Vehicles + Cargo + Isotope	2150 lbs 10.5 Passengers (200 lbs each) + Cargo + Isotope	250 lbs 1 Pilot (200 lbs) + Isotope

Assumptions	Pathway #1 **Car → Ferry → Car**	Pathway #2 **Car → Helicopter → Car**	Pathway #3 **eVTOL**
Average Operating Allocation	0.35% Weight of cancer isotope per average ferry cargo	2.86% Weight of cancer isotope per average helicopter cargo	100% Solely used for transportation of the isotope
Pathway Feature	Emission Reduction Spirit Class Ferries run on 97% LNG and 3% Diesel Toyota Prius is an electrical hybrid vehicle	Effectiveness Lesser transportation time Emission Reduction Toyota Prius is an electrical hybrid vehicle	Effectiveness Lesser transportation time Zero Emission Runs on renewably sourced clean electricity

Limitations

The limitations of this scientific model are emphasized by the fact that this model does not represent complete scenarios. This study considers the transportation of cancer isotopes under the parameters obtained through interviews and publicly available data. However, these factors could be influenced by external factors not considered in this study. Some of the external factors that were not included in the study relate to infrastructure development emissions that, once allocated, become too small to be considered under the study. Additionally, the study assumes that air navigation will be granted to the eVTOL under the AAM pathway, considering that there are no particular restrictions innate to AAM technology that would prevent them from flying these routes.

The use of this study is for the purpose of an estimate under the assumptions abovementioned under the conditions pre-stated under the methodology outlined above. Variation from this model could take place; however, best efforts were made to approach the actual emissions allocated to the transportation of cancer isotopes for the pathways under consideration.

Results

The results produced by the model compare the emissions of GHG and other pollutants between the three previously defined pathways.

Each pathway considered the entire life cycle emissions, namely materials, assembly, infrastructure development, upstream fuel emissions, vehicle operations and end-of-life. Emissions are presented in the table below under each pollutant category on the basis of *grams of pollutant per patient treated*.

Table 3: Emissions per Patient Treated

	Emissions per Patient Treated (g)				
Pathway	CO_2e	NO_x	VOC	SO_2	TPM
Conventional Ground	4,120	11.9	4.68	4.21	0.843
Helicopter	5,020	11.5	0.792	2.99	0.523
AAM	1,270	0.0369	0.00179	0.0264	0.00607

The *maximum total emissions to treat the most patients in a year* are portrayed in the table below. However, this table does not consider the shorter distance and time attained by the Helicopter and AAM pathways. These efficiencies allowed each pathway to treat a greater number of patients.

Table 4: Potential Emissions in 2020

	Potential Emissions in 2020 (kg)					Treatments
Pathway	CO_2e	NO_x	VOC	SO_2	TPM	in 2020
Conventional Ground	10,600	30.6	12.1	10.9	2.18	2,580
Helicopter	16,500	37.7	2.60	9.84	1.72	3,290
AAM	6,020	0.175	0.00848	0.125	0.0288	4,750

The table below represents the total quantity of *emissions that would be generated to treat the total number of expected patients)*. The number of potential patients treated depends on the speed at which the isotope may be transported. For this reason, the efficiency of a more streamlined pathway can attain significantly more emission reductions while treating a greater number of patients.

The table below quantifies the efficiencies attained by the quicker most efficient pathways. In other words, expected emissions for 2020 (about **3,290** patients treated) increase for the conventional ground pathway, remain the same for the helicopter pathway and decrease for the AAM pathway.

Table 5: Annual Emissions per Current Number of Treatments

	Annual Emissions per Current Number of Treatments (kg)				
Pathway	CO_2e	NO_x	VOC	SO_2	TPM
Conventional Ground	13,500	39.0	15.4	13.8	2.77
Helicopter	16,500	37.7	2.60	9.84	1.72
AAM	4,160	0.121	0.00587	0.0867	0.0199

Critical Review

The critical review process ensured that the methods used in the LCA are consistent, technically valid, reasonable and transparent.

Reviewer

The critical review was performed by an internal expert, a member of Brightspot, who did not participate in the development of the LCA. The critical review was performed by P. Eng. Jeanna Brown.

Jeanna Brown is a professional engineer with thirteen years of experience. Jeanna's work in greenhouse gas quantification includes scenario modelling for regulatory compliance, quantification of corporate inventories and consulting on offset project development. Her extensive expertise assessing the technical merit and economic feasibility of break-out technologies is invaluable to Lifecycle Analysis and models of this nature.

- B.Sc., Chemical Engineering, University of Saskatchewan, Canada, 2003
- Professional Engineer, Association of Professional Engineers and Geoscientists of Alberta
- GHG Validation and Verification, ISO 14064-3, University of Toronto, 2017

Results

The internal review considered data gathering and methodology assumptions. It also reviewed the consistency and validity of the model. Various improvements were identified by the critical reviewer. All of these were implemented to address consistency and accuracy within the model. Comments resulting from the review performed confirmed the accuracy of the quantification spreadsheet.

Additional clarifications on assumptions based on interviews were corroborated and clarified. The mathematical equivalency of the methods used in the inventory was verified.