White Paper – Guidance for Calculating Scope 3 Emissions for the Use Phase of Space-related Products

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I. Introduction

The Greenhouse Gas (GHG) Protocol and publicly available sources of emissions factors provide critical guidance and estimating methodologies to support development of a company's emissions footprint, but these sources do not cover the specificity and nuance needed to calculate the Scope 3 emissions footprint for reporting companies in the space industry. Calculating emissions for space products can be particularly complex because of their non-traditional use-phase emissions, the specialized supply chains, and highly variable products with low production volumes. This paper addresses the complex nature of space products by providing guidance on calculating GHG emissions specifically space-related products and recommending a standard approach for categorizing Scope 3 emissions. It should be noted that the focus of this guidance is strictly for calculating the Scope 3 emissions for the use-phase of space-related products and does not cover sources of emissions stemming from ground-based activities such as mission control, launch support, and/or data management. Members of the International Aerospace Environmental Group 3 – Emissions Calculations, with representation from across the aerospace industry, have developed these recommendations to provide suppliers, manufacturers and customers of space-related services a methodology for calculating emissions reported to regulatory bodies, with defined standards.

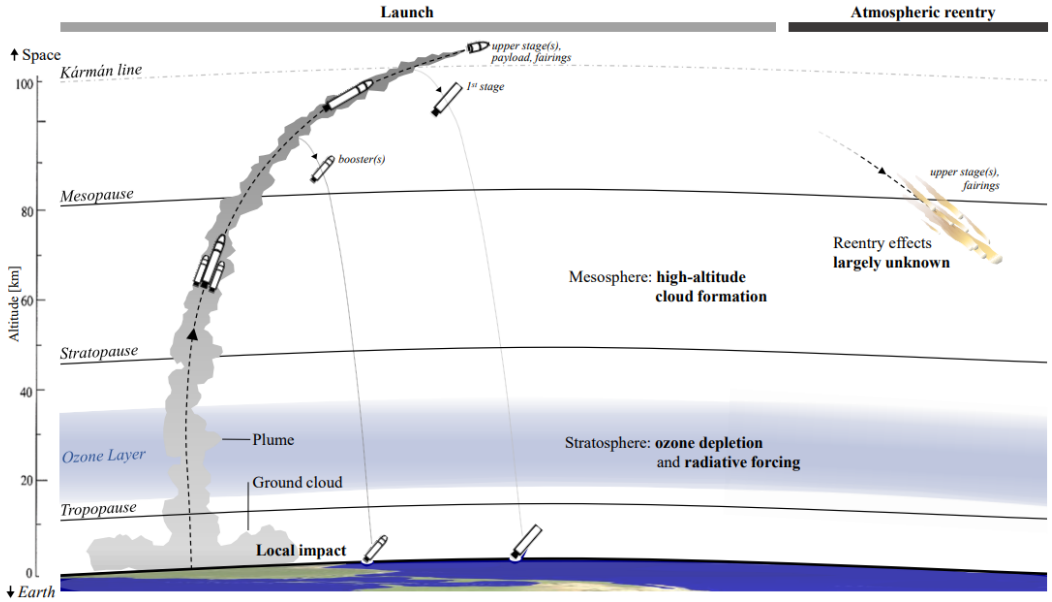
This document describes an industry-specific methodology, provides discussions on the input data needed to apply this methodology and includes examples illustrating how application of this methodology may be different depending on the reporting company's role within the industry's value chain.

II. Context And Purpose Guidance

While space flight is a mode of transportation and emits GHGs similar to automobiles and airplanes in its use phase, the associated climate and ozone-related impacts for this category of vehicle are unique. The emissions of common carbon-based fuels used in conventional modes of transportation are well understood and well documented; the emissions generated during space launches and by space vehicles vary widely by both fuel type and where the fuel burn occurs within the atmosphere. For example, fuels used for space launch and flight can be a liquid (e.g., hydrazine or kerosene), a cryogenic liquid (e.g., liquid hydrogen), solid based (e.g., ammonium perchlorate), or a combination of the above depending on the size and make of the rocket. In addition to the varying fuel types, according to research published by the US National Oceanic and Atmosphere Administration (NOAA) in the Journal of Geophysical Research Atmospheres, "rockets are the only direct source of human-produced aerosol pollution above the troposphere", the lowest region of the atmosphere, which extends to a height of about 5 to 10 miles (8-16 km) above the Earth's surface (Beaumont & Stein, 2022). In addition, the frequency of space launches continues to grow. NOAA's research goes on to indicate that launch rates have more than tripled in recent decades and accelerated growth is anticipated in the coming decades and that a "10-fold increase in hydrocarbon fueled launches is plausible within the next two decades, [which could] damage the ozone layer, and change atmospheric circulation patterns". However, according to NOAA (Beaumon & Stein, 2022) and supporting research by Maloney, Portman, Ross, and Rosenlof (2022), comparatively speaking, some believe that the CO_2 emission from rockets to be insignificant when observed from the global climate lens (Aerospace Corporation, 2021). The NOAA article goes on to assert that "aviation represents about 3 percent of the annual global CO_2 emission. Rockets burn less than 0.01 percent of the fuel that aircraft burn every year and emit less CO_2 than jets do per kilogram of fuel, so rockets emit less than 0.01 percent of the CO_2 than aviation" (Beaumont & Stein, 2022; Maloney

et. al., 2022). While the impact for spaceflight may be limited relative to the global carbon budget, it is also understood that rockets emit other materials that can have climate and ozone-related impacts. This includes substances such as black carbon (BC), alumina (Al_2O_3), dust particles, gaseous chlorine and water vapor, the impacts of which are fraught with uncertainties and largely site climatic impacts that might arise in the future. For example, in the research article by Maloney, Portmann, Ross, and Rosenlof 2022, the authors discuss the effects of BC on atmospheric ozone and asserted that this pollutant historically has not resulted in lasting atmospheric effects given the infrequency of space launches to date. However, with the rapid growth anticipated for this industry, higher volumes of BC sources could damage stratospheric ozone, compromising progress made through enactment of the Montreal Protocol (Maloney et. al., 2022). Alternatively, other research indicates that rocket emissions remain insufficiently studied despite the growth of the space sector and call for more detailed research using more in-situ measurements and global atmospheric modeling (Sirieys, Gentgen, Jain, Milton, & de Weck, 2022). While BC and other non-Kyoto pollutants may have atmospheric and climate impacts, they are excluded from this guidance as they fall outside the scope of the GHG Protocol, which is limited to Kyoto-defined gases. Figure 1 depicts the impacts that launch vehicles can have on different layers within the atmosphere.

Figure 2.1: Trajectory of a Launch Vehicle Delivering Payload



Trajectory of a typical launch vehicle through atmospheric layers during the ascent phase and the atmospheric reentry, with corresponding environmental impacts. (Sirieys, Gentgen, Jain, Milton, & de Weck, 2022, Fig. 2) http://creativecommons.org/licenses/ by/4.0/.

Outside of environmental impacts, it is becoming increasingly important for manufacturers and customers to develop a complete GHG inventory as environmental, social, and governance (ESG) principles into standard business practices. Trends in emission disclosures are steadily transitioning from voluntary to mandatory and soon it is likely that all industries will be expected to transparently, accurately, and responsibly disclose climate impacts for their entire value chain. This includes emissions associated with the use phase and disposition of products. While some of the more mainstream industries have well-established methodologies for calculating emissions for the product use phase, this does not yet exist for space products. To support industry continuity and standardization, it will be easier to guarantee freedom of action for space systems if the environmental impacts of every stage in

spaceflight's life cycle impacting our Earth's climate are understood and can be accurately accounted for. The sections below are intended to set the scope and provide recommendations for a standard approach to calculating Scope 3 emissions for space-related activities.

III. Scope

This document provides space-related service providers with supplemental guidance to support the calculation of Scope 3 emissions in alignment with concepts outlined by the GHG protocol. The IAEG team has reviewed the emissions and life cycle for space-related products as described in the background section above and are recommending that the following sections are important to cover within the scope of the guidance material proposed within this white paper. It is recognized that the methodologies outlined in this document do not reflect every emissions scenario an industry member might encounter, and that it is up to each reporting company to ensure that the methodology they employ for estimating emissions for space-related products adheres to all applicable regulatory and/or contractual requirements. The scoping discussion for this guidance document is divided into two parts: (1) Emission sources; (2) scoping rationale for space-related activities.

A. Emissions Sources

As discussed in the introduction and context section of this paper, this guidance is focused on emissions associated with the use-phase of space-related products. Emissions from ground-based operations are excluded, as they fall under standard organizational Scope 1 and 2 reporting rather than product-level Scope 3 accounting or can be accounted for with established methodologies like those developed for data centers. With this context in mind, emissions generated for the use-phase of space-related products can be attributed to the manufacture of rocket fuels, the combustion of propellants during the launch phase, and a smaller percentage of emissions generated during the re-entry phase. What is unique about characterizing emissions for space products is the variety of fuels that can be used to power rockets during a launch. Currently the four most common fuels used in rocket launches include kerosene, hypergolic fuels, liquid hydrogen (cryogenic), and solid fuels (Marais, Balhatchet & Eastman, 2022). Emissions common in the combustion of these propellants include water vapor (H_2O) and nitrogen oxides (NOx) but may also include BC from carbon-based fuels and alumina (Al_2O_3) and gaseous chlorine form non-carbon-based fuels. In addition, some of the binders used in solid rocket motors may emit CO_2 even if the primary fuel source does not emit GHGs. While all of these emissions sources may have an impact on the environment, this guidance will focus on the generation of the seven greenhouse gases recognized under the Kyoto Protocol: carbon dioxide (CO_2), methane (CH_4), nitrous oxides (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3). These GHGs are recognized under Kyoto Protocol and Paris agreement and are listed because of their significant role in global warming. These gases are tracked by most GHG reporting systems (including GHG Protocol and ISO 14054); as such, the measurable global warming potential (GWP) allows standardized assessment of emissions across industries and/or products making their emissions footprint more comparable.

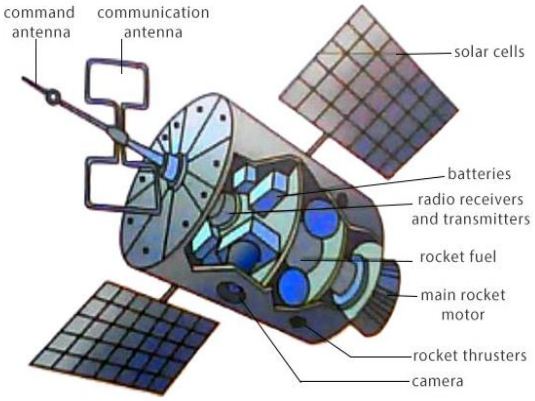
B. Scoping rationale for Space-related activities

After reviewing the most common components, operations, and activities associated with the manufacture and delivery of space-related products, there are two use cases that Scope 3 emissions are primarily attributable. This includes the lifecycle emissions of fuels used during the operation of the spacecraft in orbit, and the combustion emissions generated as a result of the launch event itself. A brief description of the launch-related activities associated with space-related products that were

reviewed are included below. Within each description below, a rationale is provided for whether the particular scenario is included or excluded in the context of this white paper.

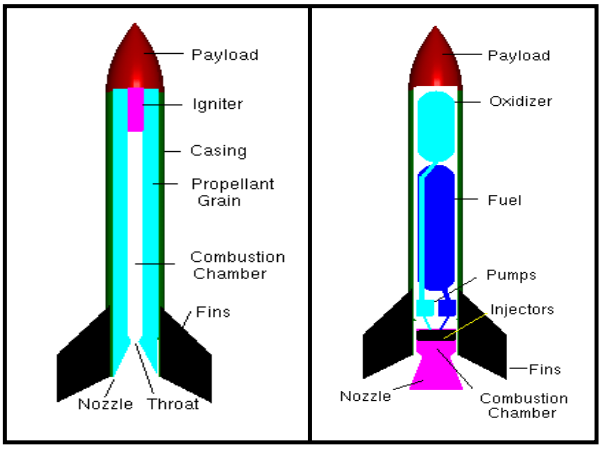
1. **Operation of the Spacecraft (In Scope):** The primary emissions associated with the operation of spacecraft occur while it is in orbit outside of Earth's atmosphere. As such, combustion emissions associated with the ongoing operation of spacecraft outside Earth's atmosphere during its lifetime have negligible impact on clima te change. However, it is recognized that there are lifecycle emissions associated with the extraction and manufacture of the fuel sources, which should be considered when calculating the emissions associated with the use of these sold products (Category 11). It is also recognized that the direct spacecraft body may emit pollutants within the troposphere during re-entry, but it is anticipated these emissions do not materially contribute to climate change.

Figure 3.1: Base Components of a Satellite



2. **Launch Event (In Scope):** The launch of the vehicle and associated payload is the primary source of direct emissions for space-related products. A launch event entails the launch vehicle (i.e., rockets) firing individual motors at specific stages, or intervals, of the launch process. The motors may be constructed of solid fuel combined with a binding material, liquid fuel, and/or an oxidizer; these are the primary source of direct emissions for the use phase of both the launcher and payload. Emissions considered for the launchers include the harvesting of the natural resources for the propulsion unit production in addition to the combustion emissions related to the burn of first, second, and third stage motors directly related to the motor type (solid vs liquid).

Figure 3.2: (NASA Glenn Research Center, n.d., Fig. 1 &



Solid Propellant Rocket **Liquid Propellant Rocket**

3. **Ground-based Operations related to Launch (Out of Scope):** Activities related to the pad or launch mission operations and integration are considered operationally discreet from the production and emissions related to the launch of the rocket. Ground systems that are operating to manage the launch integration, launch operations and pad maintenance are not aligned to the operational mission for rocket delivery and launch capability, and therefore out of scope for this guidance.

4. **Ground-based Mission Control (Out of Scope):** Ground stations, data centers, and other control facilities necessary to operate the spacecraft while in flight or within orbit are excluded from the scope of this white paper. The systems and facilities are often used by multiple organizations and multiple space missions. It can be difficult to allocate their emissions given operating practices and parameters of the individual missions. Because of this variability, this scenario in not included in the scope of this white paper, but it may be an important component of a reporting company's calculation methodology for disclosure purposes.

5. **Control Centers for Data Processing (Out of Scope):** Depending on the mission, data processing can become significant in terms of GHG emissions profile. Nevertheless, these Scope 3 emissions sources are not unique to the space industry and the reporting company is better served referencing other industry specific guidance (e.g., buildings, datacenters, IT equipment, etc.) rather than including it in this guidance document.

6. **Ground-based Integration and Test (I&T) (Out of Scope):** Static fires, qualification testing of spacecraft and launchers, or other precursors activities are considered nominal in relation to the emissions for the rocket motor firing, launching and orbit raising. In addition, these emissions would be attributable to the company conducting the testing and reported as operations-based Scope 1 or 2 emissions.

7. **Re-entry into Earth's atmosphere Satellites and Upper stages of Launchers (Out of Scope**): Emissions from re-entry of satellites and upper stages of launchers are excluded from this guidance document because the particulates and compounds produced upon re-entering Earth's atmosphere are not covered under the Kyoto Protocol gases. However, some research indicates that re-entry emissions may contribute to ozone depletion and alter radiative balance (Maloney et al., 2022 and 2025), but these impacts are an emerging area of research and are distinct from conventional CO_2 emissions accounting despite having a broader climate and environmental impact.

IV. Description Of Accounting Methodology

A. Scope 3 Categories

There are multiple Scope 3 categories of emissions for space-related products that may be relevant for IAEG members to calculate given the nature and circumstances in which space-related products operate. Unlike other mainstream product categories where use conditions are more discretely defined, the operational boundary for determining the appropriate category of scope 3 emissions for space-products may depend on the contractual parameters under which the product is deployed. For example, some contracts for launch vehicles may require the manufacturer of the rocket to also provide launch services, while another contract may specify the sale of the rocket, but the launch is completed by a separate 3rd party. Similarly, a reporting company performing emissions accounting for a spacecraft that is transported via launch vehicle for placement in orbit, may find the specific contract requirements will dictate the appropriate scope 3 emissions category. While there may be multiple ways for a reporting company to interpret the operational boundary for their product, the focus of this guidance is on providing calculation methodologies for calculating GHG Corporate Protocol Scope 3 Transportation Emissions (Categories 4 & 9) and emissions from the use of sold products (Category 11) for launch vehicles and spacecraft. It is recommended that reporting companies evaluate contractual parameters to determine the appropriate categorization of the emissions associated with space-related products and services and to avoid double counting. Additional details on the Scope 3 emissions categories presented in this guidance is provided below.

1. Scope 3, Category 3: Fuel/Energy -Related Activities Not included in Scope 1 or Scope

This category is inclusive of emissions related to the production of fuels and energy purchased and consumed by the reporting company that are not included in Scope 1 or Scope 2. For space-related products, this would include emissions associated with extracting raw materials (e.g., kerosene, liquid oxygen, liquid hydrogen) and or emissions from refining, liquefying, and transporting propellants and fuel to the launch site. For the launch event, this would be relevant to launch service providers.

2. Scope 3, Category 4: Upstream Transportation and Distribution

Third-party transportation and distribution services purchased by the reporting company in the reporting year (either directly or through an intermediary), including inbound logistics, outbound logistics (e.g., of sold products), and third-party transportation and distribution between a company's own facilities. For space-related products the table below shows different reporting scenarios where this category might be applied.

3. Scope 3, Category 9: Downstream Transportation and Distribution

The GHG protocol defines this category as including "emissions from transportation and distribution of products sold by the reporting company in the reporting year between the reporting company's operations and the end consumer (if not paid for by the reporting company), in vehicles and facilities not owned or controlled by the reporting company.

4. Scope 3, Category 11: Use of Sold Products

The calculation guidance provided by the GHG Corporate Protocol defines two types of emissions from the use of sold products:

i) Direct use-phase emissions (Required)

   a) Final Products: Emissions from products that directly consume energy (fuels or electricity) during use. The table below provides some scenarios when it may be appropriate to use this emissions category.

   b) Intermediate products: Consistent with GHG Technical Guidance for Calculating Scope 3 Emissions, companies that sell intermediate products that directly consume energy – fuels or electricity – during use are required to include these direct use-phase emissions in their Category 11 calculations. A reporting company may select a simple allocation method based on mass ratio or a hybrid allocation method. Scenarios where this approach may be appropriate are provided below.

ii) Indirect use-phase emissions (Optional)

   a) Emissions from products that indirectly consume energy (fuels or electricity) during use. However, indirect use-phase emissions should be included if they are significant in scale and materially impact the product's total emissions footprint. Scenarios of when impactful indirect emissions may need to be considered are provided below.

B. Calculating Space Product-Related Emissions

Calculating the estimated emissions for space products in accordance with the GHG Corporate Protocol requires a detailed understanding of how the products will be used, determination of emission factors applicable to the energy consumed, the activity for which emissions are being calculated, and detailed documentation of data sources and assumptions. Key data elements included in the Scope 3 calculations for space products include:

<u>Product Data</u>

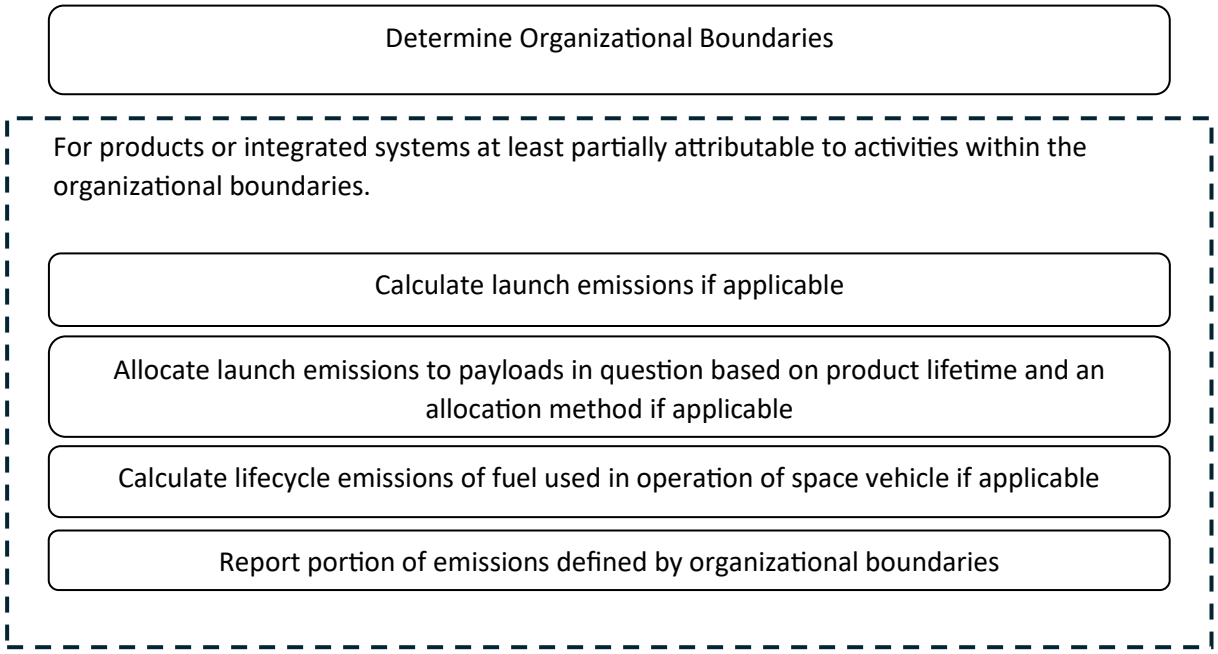
- Quantities of product sold
- Type of fuel consumed by product
- Mass of fuel consumed by product
- Launch vehicle payload capacity
- Weight of payload

<u>Emissions Factors</u>

- Production emission factors by fuel type
- Combustion emissions factors by fuel type

The overall approach to calculating Scope 3 emissions for space-related products is dependent on the organizational boundary of the reporting company in relation to the Scope 3 category being calculated. Considerations for determining the organizational boundary are illustrated in the figure below:

Figure 4.1: Organizational Boundaries for Space



Defining the organizational boundary determines which operations are included in the company's calculations and how emissions from each operation are consolidated by the reporting company. For example, Scope 3 Category 11 emissions, the organizational boundary defines the portion of product use phase emissions attributed to the reporting organization. The company has three options for defining its organizational boundaries: equity share, financial control, or operational control. A consistent consolidation approach should be used across Scope 1, Scope 2, and Scope 3 emissions inventories.

V. Launch Vehicle Manufacturer Emissions

Emissions associated with launch events are primarily attributable to fuel burn from the launch vehicle's rocket motors. Since the launch vehicle can be characterized as providing transportation and distribution of the final product (category 4 or 9) or as the use of a sold product, a reporting company should calculate the estimated emissions of the launcher and then allocate the emissions according to the reporting company's organizational boundaries. Calculation of the launch vehicle's direct or indirect use-phase emissions by identifying the fuel makeup, which is unique to each type of launch vehicle. To help demonstrate launch vehicle types, they can often be categorized by the total capacity they can carry. The table below provides some high-level information on the different classes of launch vehicles, the types of payloads the launchers can carry (by weight), and fuel types typically used.

Table 5.1: Launch Vehicles are Built for Purpose

Class	Payload to LEO	Typical Use Case	Example Launch Vehicles	Stages	Propellant Mix
Small-lift launch vehicles	Up to 2,000kg	Small satellites, cubesats, dedicated rideshares	Rocket Lab Electron	2+kick Stage	RP-1/LOX
			Firefly Alpha	2 Stages	RP-1/LOX
			ABL RS1	2 Stages	RP-1/LOX
Medium-lift launch vehicles	2,000-20,000kg	Larger satellite payloads, ISS resupply, some lunar missions	SpaceX Falcon9	2 Stages	RP-1/LOX
			Soyus 2.1b	3 Stages	RP-1/LOX
			Ariane 6 (A62)	3 Stages	LH_2/LOX) core & upper) + Solid Boosters
			GSLV MK III	3 Stages	HTBP, UDMH/N_2O_4, LOX/LH_2
Heavy-lift launch vehicles	20,000kg – 50,000kg	Large satellite, multi-payload launches, interplanetary probes	Delta IV Heavy	2 Stages	LH2/LOX
			Falcon Heavy	2 Stages	RP-1/LOX
			Ariane 6 (A64)	2 Stages	(LH_2/LOX) core & upper) + Solid Boosters
Super heavy-lift launch vehicles	Over 50,000kg	Crewed lunar/Mars missions, space station components	SpaceX Starship	2 Stages	CH4/LOX
			NASA SLS Block 1	3 Stages	LH_2/LOX (core & upper) & ACPC (solid rocket boosters)

Details regarding the configuration of launchers, including the payload capacity, the fuel mix by launcher and/or stage, and the total weight of the fuel types may be publicly available, but is also likely provided by the launch service provider for products being launched. For example, in 2011, NASA published an environmental assessment on launches for routine payloads. Within this document, the agency includes tables with details on typical launch vehicles, the types of motors included, and the potential maximum propellant needed for launch and payload capacity. Having information like payload capacity and the amount and type of fuel will be critical for determining the emissions output of the launch.

Figure 5.1: Calculating Emissions for Payload Capacity – Launch Vehicle

$$Launcher\ Emissions = \sum Stage_X(Mass\ of\ Fuel_X(kg) x\ Fuel_X EF) + Stage_Y(Mass\ of\ Fuel_Y(kg) x\ Fuel_Y EF)$$

$$\left(\frac{Launcher\ emissions\ (CO2e)}{(Total\ payload\ capacity)\ (Kg)}\right) = Emissions/unit\ Payload(CO2e)$$

The location of the launch and the orbit to which the payload is being launched is relevant when determining the amount of fuel used for the mission, so include those variables. Calculating these emissions will be more precise if they come directly from the launch provider but may also be calculated using more generic information on the launcher type; this may be less accurate as launch site and destination within orbit may not be considered.

Table 5.2: Data needed to calculate final products emissions:

Input	Potential data sources
Launcher Emissions	Total emissions from fuels used in each stage of launch
Total payload capacity	Total amount of weight the launch vehicle is designed to carry as payload.
Stage	Made up of its own engines and fuel systems, so may need to calculate emissions from multiple stages of launcher.
$Fuel_n$ Emissions Factor (EF)	Emissions factors for the fuel type and may need to be identified by rocket stage, if the configurations and fuel types differ.

Note that the calculation methodology for the fuels may differ based on the fuel's configuration. For example, for a launch vehicle utilizing solid rocket motors, the propellant used may not have a combustion emissions factor, but the binder, which is typically an inert substance that aids the propellant burn and helps define and shape the motor will have an emissions factor. For liquid motors, the fuel and oxidizer may or may not have combustion (direct) emissions depending on the mix but could have a significant upstream (indirect) emissions footprint depending on the process to manufacture the fuel and oxidizer. If indirect emissions are a significant contributor to the fuel's emissions footprint, then it is

best practice to include upstream emissions in the calculations for a space-related product. Below is an example of how the equations may differ when calculating emissions for a motor containing a solid fuel verse a liquid fuel.

Figure 5.2: Emissions Calculations – Launch Vehicle by Fuel Type

Determining fuel mass using fuel ratio (Oxidizer/Fuel)

$$M_{fuel} = \frac{Mpropellant}{1+ O/F\ Ratio} \quad and \quad M_{oxidizer} = M_{propellant} - M_{fuel}$$ (Fuel Ratio equation)

Solid Fuels

$$E_{(SRM)} = \sum(M_{fuel} \times CEF_{binder})$$ (Solid Rocket Fuel Equation)

$$E_{(SRM)} = \sum\{[(M_{fuel} \times UEF_{fuel}) + (M_{binder} \times LCEF_{binder})] + (M_{oxidizer} \times PEF_{oxidizer})\}$$ (Lifecycle Equation)

Liquid Fuels

$$E_{(CLRE)} = \sum(M_{fuel} \times CEF_{fuel})$$ (Combustion Equation)

$$E_{(PLRE)} = \sum\{(M_{fuel} \times PEF_{fuel}) + (M_{oxidizer} \times PEF_{oxidizer})\}$$ (Production Equation)

$$E_{(LRE)} = \sum\{[(M_{fuel} \times CEF_{fuel}) + (M_{fuel} \times PEF_{fuel})] + (M_{oxidizer} \times PEF_{oxidizer})\}$$ (Lifecycle Equation)

When determining emissions for any rocket fuel sources, it will be important to understand the fuels makeup. For example, in some cases, the total mass of the fuel will be provided in launch-related specifications or can be found publicly. However, the actual emissions associated with the fuel source will be influenced by the fuel's configuration.

For example, the mixture RP-1/LOX could have an oxidizer to fuel ratio of 2.5:1. If, in this scenario, the total mass of propellant is provided (e.g., 30,000 kg), it can be assumed that the amount of oxidizer will be approximately 2.5 times more than the mass of the fuel in the mixture. Applying the equation above, the total mass of each component of the propellant can be calculated as shown below.

$$M_{fuel} = \frac{30{,}000}{(1+2.56)} = 8{,}426.9\ kg\ of\ RP\text{-}1 \quad and \quad M_{oxidizer} = 30{,}000\text{-}8{,}426.9 = 21{,}573.1\ kg\ of\ LOX$$

Once the mass of the propellant components has been determined and an emissions factor assigned, emissions for each component of the propellant mixture can be calculated. The table below provides additional description to support the equations written above.

Table 5.3: Description of potential data sources:

Input	Potential data sources
O/F Ratio	Oxidizer/fuel ratio
E_{SRM}	Emissions of a solid rocket motor (SRM)
E_{LRE}	Emissions of a liquid rocket engine (LRE): P – Production; C – Combustion; L - Lifecycle
M_{Fuel}	Mass (M) of the fuel component of the propellant
$M_{propellant}$	Mass (M) of total propellant burned during launch (kg)
CEF	Combustion Emissions Factor (CEF) – Combustion of fuel source when in use (kgCO2/Kg)
LCEF	Lifecycle Emissions Factor (LCEF)
$M_{oxidizer}$	Mass (M) of oxidizer component of the propellant
PEF	Production Emissions Factor (PEF) – Emissions associated with the upstream manufacture and transport of fuel or oxidizer.

A. Scope 3 Category 11: Use of Sold Products

1. Direct Use- Phase Emissions – Launch Vehicle

The methodology for calculating direct use-phase emissions for launch vehicles is demonstrated in the equation as shown in Figure 5.1. Since the combustion emissions of a launch vehicle is expended in a singular event, it is important to consider each launch event separately, or group similar launch vehicle configurations when estimating the aggregate use of sold products delivered in a given year. The equation below is what a launcher manufacturer would use to aggregate combustion emissions for the use of sold products.

Figure 5.3: Direct use-phase emissions- Launcher

$$\sum Launch\ vehicle\ type \left(Number\ of\ delivered\ vehicles\ x \begin{matrix} Expected\ emissions \\ of\ launch\ event \end{matrix} \right)$$

2. Direct Use-Phase Emissions – Intermediate Products – Launch Vehicle

Consistently with GHG Technical Guidance for Calculating Scope 3 Emissions, companies that sell intermediate products that directly consume energy – fuels or electricity – during use are required to include these direct use-phase emissions in their Category 11 calculations. However, the

inclusion of indirect use-phase emissions is optional.

The formula starts with determining the emissions factor of the combustion propellant used for the launch vehicle. Then, a second calculation is performed to define the percentage of the emissions that should be allocated to the sold intermediate product. **The allocation methodology is similar for both direct and indirect use-phase emissions**.

Figure 5.4: Direct use-phase emissions- Sold Intermediate Products (Launcher)

$$Launcher\ EF\ (CO2e)\ =\ (Mass\ of\ Fuel_x\ (kg) x\ Fuel\ EF) * Number\ of\ stages \quad \textit{(Precursor equation)}$$

Total Intermediate Product Emissions (kgCO2e) = $\sum \left\{ \begin{matrix} Number\ of \\ delivered\ products \end{matrix} x\ \left[Launcher\ EF\ x\ \frac{mass\ of\ intermediate\ product}{mass\ of\ launch\ vehicle} \right] \right\}$

The equation above uses a mass-based approach to determine the proportion of launch emissions allocated to the intermediate product. The emissions factor for the launcher is derived based on type and includes fuel weights, motors, and propellant emissions factors.

Table 5.4: Description of potential data sources

Input	Potential data sources
Launcher Emissions Factor (EF)	These are specific to the launcher used and should be inclusive of all applicable production and emissions factors (e.g. a Falcon 9 or an Ariane 5). Units: $kgCO_2e$/launch.
Mass of intermediate Product	Expressed in unit Kg and includes fuel weight (wet)
Mass of Launch vehicle	Expressed in units Kg. Available from internal company information, launch records, and/or public information on the launch vehicle.

3. Launch Vehicle Manufacturer Example Calculations

***Scope 3 Category 11 Calculation Scenario #1* – Use of Sold Products**

Launcher manufacturer is reporting emissions for launcher that was sold to customer who contracted with a separate launch service provider to launch their payload to LEO.

Table 5.5: Launcher Example

Variables	Example	Example Values
Product	Launcher	Total emissions from Launch vehicle unknown
Reporting Category	Cat 11: Use of Sold Products	Launcher
Payload Capacity	Capacity to LEO	20,000 kg (3% of total wt)
Propellant Ratio	APCP	Ammonium Perchlorate (65%), binder (20%), Al+ (15%)
Emissions Factor (Combustion)	Oxidizer: AP Binder: PBAN Fuel: Aluminum powder & other (AL+)	0 2.46 $kgCO_2$/kg fuel 0
Propellant Mass	Solid	Unknown (but propellant is approximately 85% of total launcher mass)
Total Launch mass	Includes payload, propellant, and structure weight	700,000 Kg

- **Step 1:** Determine the Propellant Mass by using information available.

$$\text{Propellant Mass} = 666{,}667\ x\ .85 = \ 595{,}000\ \text{kg of propellant}$$

- **Step 2:** Calculate breakdown of propellant by component

$$\text{AP}= \frac{595{,}000}{0.65} = 387{,}750\text{kg} \quad \text{PBAN} = \frac{595{,}000}{0.2} = 119{,}000\text{kg} \quad \text{Al+} = \frac{595{,}000}{0.15} = 89{,}250\text{kg}$$

*Breaking down the total propellant by the percentage makeup of each component allows you to isolate the total mass of the material that contributes to combustion emissions. In this case, the only material that generates combustion emissions is PBAN, a polymer-based binding material.

- **Step 3:** Calculate emissions associated with combustion of PBAN

E_{PBAN} = 119,00kg x 2.46 = 292,740 $kgCO_2$= Emissions of Launch

In this scenario, the launcher manufacturer sold a launch vehicle to downstream customer who will be conducting the launch separately. In this case, the launch vehicle manufacturer is calculating emissions associated with the use of its sold product and would account for all emissions generated as a result of launch.

Scope 3 Category 11 Scenario #2 – Use of Sold Products – Intermediate Products

A rocket motor manufacturer sells two of the same rocket motors to a downstream customer outfitting a launch vehicle.

Table 5.5: Use of Sold Products: Rocket Booster Example

Variables	Example	Example Values
Product	Solid Rocket Booster	589,670 kg
Reporting Category	Category 11	Intermediate launch product
Orbit	LEO	
Propellant Ratio	APCP	Ammonium Perchlorate (65%), binder (20%), Al+ (15%)
Emissions Factor	Oxidizer: AP Binder: PBAN Fuel: Aluminum powder & other (AL+)	1.51kgCO_2/USD (PEF) 2.46 kgCO_2/kg fuel (PEF + CEF) ~15kgCO_2/kg AL (PEF)
Propellant Mass	Solid	Unknown (but propellant is approximately 85% of total launcher mass)
Number of Boosters sold	Solid Boosters	2
Total weight of launch vehicle	Space Shuttle	1,995,806kg

**Assume the orbit location and build of each satellite sold are the same.*

- **Step 1**: Calculate breakdown of propellant by component

AP= 589,670 x .65= 383,285.5kg | PBAN = 589,670 x .2= 117,934kg | Al+ = 589,670 x .15 = 88,450.5kg

- **Step 2**: Calculate total emission for propellant or propellant components

AP= 383,285.5kg x 1.51 kgCo2e/kg AP = 578,761 kgCO2e | PBAN = 117,934kg x 2.46 = 140,588 kgCO2e | Al+ = 88,450.5kg x 15kgCOe/kg AL+ = 8,845,050 kgCO2e

Total MTCO2e/rocket motor = (578,761 + 140,588 + 8,845,050)/1,000 = 1,0874 MTCO2e

- **Step 3**: Calculate emissions for annual rocket motor sales

Total IP emissions (MTCO2e) = 2 x 737.03= 1,474.06 MTCO2e

VI. Launch Service Provider Emissions

Launch service providers offer services to transport payloads, such as satellites and cargo, into space. These companies are typically responsible for the logistics, technology, and operations required to launch payloads into specific orbits or trajectories. In some cases, launch vehicle manufacturers may also serve as the launch service provider, but in others, the act of launching a rocket may be a completely independent business transaction.

A. Scope 3 Category 3: Fuel and Energy-related Emissions

While the fuel burn from launch would be part of the launch service provider's Scope 1 emissions, the production and delivery of that rocket fuel should be reported under Scope 3 Category 3 Fuel and Energy related Emissions (not considered S1 or S2). The equation below provides guidance on how those emissions should be calculated.

Figure 6.1: Fuel and Energy related Emissions not considered S1 or S2 – Launch Service Provider

$$E_{(PSRM)} = \sum\{(M_F \, x \, PEF_F) + (M_{ox} \, x \, PEF_{ox}) + (M_{bind} \, x \, PEF_{bind}\} \quad \text{(SRM Fuel Production Equation)}$$

$$E_{(PLRE)} = \sum\{(M_F \, x \, PEF_F) + (M_{ox} \, x \, PEF_{ox})\} \quad \text{(LRE Fuel Production Equation)}$$

The equation above options for both solid and liquid fueled rockets and includes emissions factors only associated with the upstream emissions associated with the production and delivery of the rocket fuel. The downstream emissions resulting from the burning of the fuel would be captured as Scope 1 emissions by the launch service provider. Note, that in instances where the launch services are contractually bundled with the sale of the launch vehicle, it may also be appropriate for the OEM to report the fuel production and delivery emissions for any fuels and components of the fuel not considered part of its Scope 1 or Scope 2 inventory.

Table 6.1: Description of potential data sources for Launch Service Provider equation

Input	Potential data sources
E_{PSRM}	Production emissions of a solid rocket motor (SRM)
E_{PLRE}	Production emissions of a liquid rocket engine (LRE)
M_F	Mass (M) of the fuel component of the propellant
M_F	Mass (M) fuel used in motor or liquid engine (kg)
M_{ox}	Mass (M) of oxidizer component of the propellant
PEF	Production Emissions Factor (PEF) – Emissions associated with the upstream manufacture and transport of fuel (F), oxidizer (ox), and/or binder (bind).

1. Launch Service Provider Example Calculations

A launch service provider is set to launch a medium-lift launch vehicle into LEO.

Table 6.2: Use of Sold Products: Launch Service Provider Example

Variables	Example	Example Values
Reporting Entity	Launch Services Provider	Medium-lift Launcher
Reporting Category	Cat 3: Energy and Fuel related emissions not considered Scope 1 & Scope2)	Upstream emissions associated with the production and delivery of fuel
Payload Capacity	Capacity to LEO	20,000 kg (3% of total wt)
Propellant Ratio	RP-1 LOX	1:2.5
Emissions Factor (Production)	Fuel: RP-1 Oxidizer: LOX	0.45 kg CO2e/kg fuel 0.10 kg CO2e/kg fuel
Fuel Mass	RP-1 LOX	100,000 kg 250,000 kg

- **Step 1**: Calculate production emissions for each component of fuel.

$$\text{RP-1} = 100{,}000 \text{ x } .45 = 45{,}000 \text{ kg CO2e}$$
$$\text{LOX} = 250{,}000 \text{ x } .10 = 25{,}000 \text{ kg CO2e}$$

- **Step 2**: Sum the production emissions of the rocket fuel.

E_{PLRE} = $45{,}000 \text{ kg CO2e (RP-1)} + 25{,}000 \text{ kg CO2e (LOX)} = 70{,}000$ kg CO2e

In this example, the emissions calculated are only for the production and delivery of the fuel used in the liquid rocket engine that the launch service provider is launching on behalf of a customer. The launch of the rocket would be accounted for in the launch service provider's scope 1 emissions.

VII. Spacecraft Manufacturer Emissions

Most use-phase emissions attributable to operation of the spacecraft occur outside the Earth's atmosphere and thus are not directly impactful to the Earth's atmosphere. However, portions of the launch event and the upstream emissions associated with production of the fuel used in the spacecraft should be evaluated and attributed to the spacecraft manufacturer as appropriate.

A. Scope 3 Category 4 & 9: Transportation and Distribution

To determine which allocation methodology to use for the launch vehicle emissions, the reporting company should consider the parameters around which the launch is occurring within the lifecycle of the payload and contracting requirements. For example, if launch services are contracted in the sale of the payload, then the reporting company would report launch emissions under Category 4. If the end user of the payload contracts for launch services outside the contract of the OEM that manufactured the payload, then launch services may be best reported as Scope 3 Category 9 emissions. The equations for allocating transportation is the same whether calculating as upstream emissions (Category 4) or downstream (Category 9). The allocation of the launch vehicle emissions according to payload can be calculated using the following equation.

Figure 7.1: Description of potential data sources for Transportation and Distribution emissions

$$\left(\frac{Total\ Launch\ CO2e}{\substack{(Total\ payload\ capacity)\\(Kg)}}\right) = Emissions/unit\ Payload(CO2e) \qquad \text{(Precursor equation } \textit{see Fig. 1.1}\text{)}$$

$$\frac{\substack{Total\ Payload\ Capacity\\(kg)}}{\substack{(Payload\ X+Payload\ Y)\\(kg)}} = Capacity\ Factor \qquad \text{(Equation 1)}$$

$$Paylod\ X * Capacity\ Factor * Emissions\ per\ unit\ payload\ = Payload\ X\ Emissions\ (CO2e) \qquad \text{(Equation 2)}$$
$$Payload\ Y * Capacity\ Factor * Emissions\ per\ unit\ payload = Payload\ Y\ Emissions\ (CO2e)$$

When allocating emissions from launch to the reporting company payload, be sure to calculate a capacity factor for the launcher. While launch service providers strive to match payloads with launchers that closely match the total capacity, there are instances where the total payload being launched is less than the total payload capacity of the launcher. Since rocket fuel is typically expended to completion, whether the rocket is full or not, emissions from the burned fuel need to be allocated to the payloads being launched. Creating a capacity factor to include in the allocation methodology, ensures that all emissions generated from fuel combustion during launch are properly accounted for.

Table 7.1: Data sources for transportation and distribution calculation

Input	Potential data sources
Total Payload Capacity	Launch Records *or* publicly available data
Payload X/Y	Weight (kg) of payload(s) as indicated by internal company information
Capacity Factor	Calculated using the total payload capacity divided by the total weight of the individual of payloads being launched.
Emissions per unit payload	See Direct use-phase emissions – Launch Vehicle calculation above

1. Direct Use-Phase Emissions – Spacecraft

Direct use-phase emissions for the physical maneuvering of spacecraft are negligible as these emissions occur above the stratosphere and therefore have limited impact on the Earth's atmosphere. Therefore, there is no associated calculation for determining the direct use-phase emissions of spacecraft and other space-related products while in orbit.

2. Indirect Use-Phase Emissions – Spacecraft & Intermediate Products

As stated above, the inclusion of indirect use-phase emissions is optional when calculating emissions associated with the use of sold product according to the GHG protocol; however, reporting companies may be required to report on indirect emissions in certain markets if those emissions are significant. Calculating indirect emissions for space products also may be useful to understand the full lifecycle emissions of propellants used in these products. Indirect emissions for space products can be calculated using the equation below.

Figure 7.2: Methodology for calculating Indirect use-phase emissions – Spacecraft

Indirect use-phase emissions – Spacecraft/Satellites

$$\text{Indirect Spacecraft (CO2)} = \text{UpstreamEF}_{\text{propellant}} \times M_{\text{fuel}} \quad \text{(Equation 1)}$$

$$IP\ (CO2e/Kg) = \sum \left\{ \frac{Number\ of}{delivered\ products} \ x\ \left[UpstreamEF_{propellant}\ x\ M_{propellant} \right) x\ \frac{mass\ of\ \ intermediate\ product}{mass\ of\ spacecraft} \right] \right\} \quad \text{(Equation 2)}$$

Calculating indirect use-phase emissions for intermediate spacecraft products is similar to calculating direct use-phase emissions. However, the reporting company will use the upstream emissions factor for the propellant rather than the combustion emissions factor since fuel burn occurs outside of Earth's atmosphere. Irrespective of Scope 3 category to which the allocated emissions are being applied, the calculation methodology remains the same.

Table 7.2: Data sources for calculating indirect emissions for Spacecraft

Input	Description
Upstream Emissions Factor (EF)	Production and transportation emissions upstream of product delivery. Available from company data or other private sources.
Mass (M) Product Fuel	Mass of fuel used in product
Mass (M) Product	Mass of craft in orbit
Intermediate Product (IP)	Subcomponents of a spacecraft in orbit

3. Satellite Manufacturer Example Calculations

Scope 3 Category 4 Upstream Transportation and Category 9 Downstream Transportation

A spacecraft manufacturer procures launch services to transport their own spacecraft into LEO that they will operate as part of business operations. Only emissions that are associated with the launch are included in this category. (Manufacture of spacecraft is captured in reporting companies S1 & S2 emissions)

Table 7.3: Upstream Transportation: Satellite manufacturer example

Variables	Example	Example Values
Product	Satellite	1,200 kg Satellite
Reporting Category	Cat 4: Upstream Transportation	
Payload Capacity	Capacity to LEO	1,350 kg
Propellant Ratio	RP-1/LOX	(2.5:1)
Emissions Factor	Combustion EF (RP-1)	3.16 $kgCO_2$/kg fuel
Propellant Mass	Liquid	60,000kg

- **Step 1:** Determine the mass of RP-1 from the total propellant mass.
  $M_{fuel} = \frac{60{,}000(kg)}{(1+2.5)}$ = 17,142.8 kg RP-1
  **Note LOX does not have any combustion emissions associated with it as it does not produce carbon when burned.*

- **Step 2:** Calculate emissions associated with combustion of RP-1
  E_{CLRE} = 17,142.8(kg)*3.16 = 54,171.248 $kgCO_2$

- **Step 3:** Calculate emissions/unit Payload (CO_2)
  $\frac{54{,}171.248}{1{,}350}$ = 40.127 $kgCO_2$/kg payload

- **Step 4:** Calculate the capacity factor for the launch vehicle
  Capacity Factor = $\frac{1{,}350\ kg}{1{,}200 kg}$ = 1.125

- **Step 5:** Calculate Upstream Transportation (S3 Category 4) Emissions for launch of Satellite to LEO.
  1,200 x 1.125 *40.127 = 54,171.45 kg CO_2 or 54.171MTCO_2

In this scenario, the total launch emissions would be allocated to the satellite being launched for the satellite manufacturer's Scope 3 reporting purposes. Even though the weight of the satellite does not equal the total launch capacity weight, the satellite is the reason the launch took place, and therefore the satellite manufacturer should account for all emissions associated with the launch. The differences between the total in Step 2 and the total in Step 5 are due to rounding. The process for calculating Scope 3 Category 9 emissions would be similar to the example above, but conversely the service to launch the satellite into orbit is built into the contract for sale of the satellite being launched.

Scope 3 Category 11 Scenario – Use of Sold Products – Indirect Emissions for Satellite

Satellite manufacturer is reporting emissions of GEO satellites sold to a downstream customer where launch emissions were considered Scope 3 transportation-related.

Table 7.4: Use of Sold Products: Indirect emissions of satellite manufacturer example

Variables	Example	Example Values
Product	GEO Satellite	6,000kg
Reporting Category	Cat 11: Use of Sold Products	Indirect Emissions
Orbit	GEO	
Propellant Ratio	MMH/NTO	1.65
Emissions Factor (upstream)	Fuel: Monomethylhydrazine (MMH) Oxidizer: Nitrogen Tetroxide (NTO)	12kg CO_2e/kg of fuel 5 kg CO_2e/kg of fuel
Propellant Mass	Liquid	1,000 kg
Number of Satellites sold in year	GEO Satellite*	3

**Assume the orbit location and build of each satellite sold are the same.*

- **Step 1**: Calculate the mass of each component of the fuel

M_{fuel} = $\frac{1{,}000 kg}{1+\ 1.65}$ = 377.36 kg (MMH) and $M_{oxidizer}$ = 1,000kg – 377.36kg(MMH) = 622.64 kg (NTO)

- **Step 2**: Calculate the lifetime emissions for each component of propellant
  MMH = 377.36 kg x 12kgCO_2e/kg fuel = **4,528.32** Kg CO_2e
  NTO = 622.64kg x 5 kg CO_2e/kg fuel = **3,113.2** kg CO_2e
  Total lifetime emissions for GEO satellite = **7,641.52 kg CO_2e**

- **Step 3**: Calculate annual total emissions for use of sold products (GEO Satellite

Use of Sold Product (Annual) = 7,641 kg CO_2e x 3 = **22,924.56 kg CO_2e**

In this scenario, only the upstream emissions were considered for the satellite propellant. Since combustion of these propellants occurs outside of Earth's atmosphere, this portion of the fuel's lifecycle does not contribute to climate change. As a result, only the indirect emissions associated with production and transportation (well-to-wake) of propellant components are considered.

4. End User Allocation Methods

The way an end user allocates Scope 3 emissions depends directly on how the contract for spacecraft, launch services, or related logistics is structured. If the contract arranged is for transport services (e.g, payload delivery to orbit), emissions can be allocated under Category 4, using either a mass- or cost-based method depending on whether the contract specifies payload share or financial contribution. If the contract is for the purchase of a spacecraft or hardware, those emissions may fall under Category 1 or 2, with impacts tied to the good itself rather than the transport service. In cases where launch enables a company's downstream operations, emission could also be treated under Category 11. Thus, the contractual arrangement defines whether emissions are allocated by payload mass, cost share, or treated as embodied product impacts. However, end users should be very clear on the organizational boundaries they are using for the emissions calculations to avoid double counting. Below are some scenarios for determining the appropriate allocation method.

a) Government Agency scenario: A government agency purchases 3rd party launch services to deploy spacecraft they own and will operate. Launch services are contracted separately from the spacecraft's acquisition.

i. Category 4: In this scenario, the act of launching the payload can be considered "transport" and thus it would be appropriate to assign the allocated emissions to Category 4. Depending on the nature of the contract, the reporting company could use a mass-based approach, as demonstrated in section VII, or a simpler cost-based approach may be the best choice if it is a shared launch or a hosted payload arrangement.

b) Telecommunications company scenario - Telecommunications company purchases 3rd party launch services to deploy a satellite into orbit they have purchased service on. The reporting options for this scenario depend on the parameters of the launch, but may include:

i. Category 4 – The launch is functionally equivalent to a specialized freight service that is contracted to move goods and a mass- or cost-based approach should be used for allocation. OR

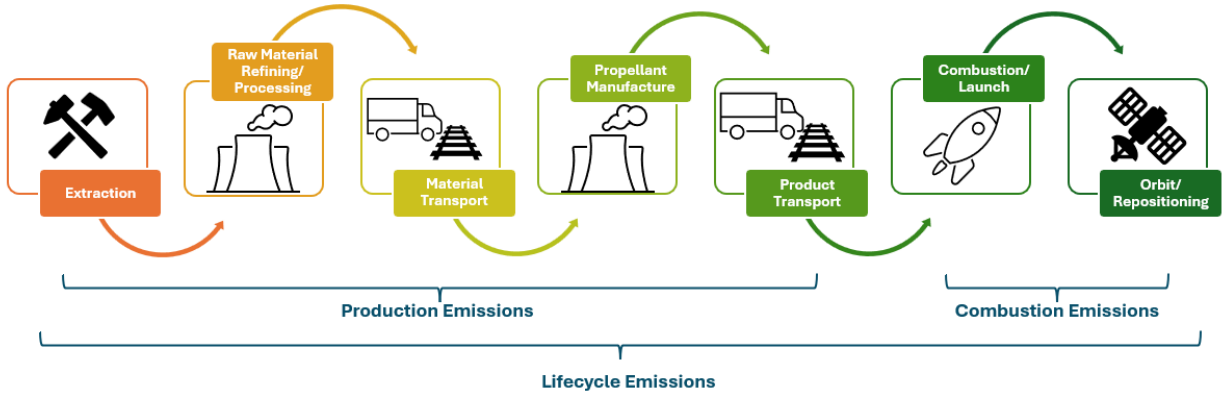
ii. Category 1: If the contract is structured, so that the launch service is imbedded in the purchase, then the emissions may be grouped under Category 1. OR

iii. Category 11: if the launch is considered integral to enabling downstream revenue services (e.g., telecom capacity), some organization would disclose emissions under Category 11: Use of Sold Products.

VIII. Emission Factors Associated With Space-Related Products

As specified in the GHG Protocol Technical Guidance for Calculating Scope 3 Emissions, fuel lifecycle emission factors are used for reporting Scope 3 Category 11 Use of Sold Products Emissions typically. However, as this paper demonstrates, for space products, the lifecycle emissions factor may not always be appropriate for calculating for the use phase emissions for certain space products. The illustration below shows how this paper truncates the emissions profile of fuel, so that the reporting company can isolate the most representative emissions factor for the product boundary.

Figure 8.1: Lifecycle of Rocket Fuel



For space-related products, reporting companies will likely need to use combustions emissions factors of propellants and fuels for calculating Scope 3 Category 4 and 9 emissions, but depending on the reporting boundary scope, a company may need to use lifecycle or other production (inclusive of production and transportation) emissions factors for fuel and propellant usage to calculate category 11 emissions. Unfortunately, both combustion and production emissions factors are not well documented publicly. Variations in combustion efficiency, engine design, and mission profile, among other things, complicate efforts to develop standardized combustion emissions factors. Similarly, production emissions factors will vary by fuel type and will be dependent on the energy sources and processes used to manufacture the fuel. Given the lack of publicly available data, determining the appropriate emissions factors is one of the more difficult aspects of developing a Scope 3 emissions inventory for space-related products. While OEMs of these products may have better access to the information needed to calculate emissions factors, this lack of publicly available information can make it especially difficult for manufacturers of intermediate products to understand product-related emissions. As a result, reporting companies may need to rely on private sources of information, including launch records, design specifications or a subscription-based lifecycle inventory database to identify the information needed to help calculate these Scope 3 emissions. While there is not a comprehensive publicly available resource that provides lifecycle emissions factors for these propellants, this section provides information on a variety of fuel types typically used in space-related products and associated characteristics that may influence where the primary sources of emissions may occur (e.g., upstream or combustion).

Table 8.1: Common Formulations of Rocket Fuel and their potential environmental impacts

Type	Common Name	Fuel State	Fuel Description	Upstream Emissions Characteristics	Combustion Emissions Characteristics
Liquid	Hydrolox	Cryogenic	Oxidizer: Liquid Oxygen (LOX) Fuel: Liquid Hydrogen (LH2)	Energy intensive especially when manufactured from electrolysis or natural gas	Low to no combustion CO_2 emissions
Liquid	Methalox	Cryogenic	Oxidizer: Liquid Oxygen (LOX) Fuel: Methane (CH_4)	Fossil fuel Refinement and energy intensive from electrolysis	Some CO_2, BC*, and NO_X emissions
Liquid	Kerolox	Liquid	Oxidizer: Liquid oxygen (LOX) Fuel: Kerosene (RP-1)	Fossil fuel Refinement and energy intensive from electrolysis	CO_2, BC*, and NO_X emissions
Liquid	Nitrogen Tetroxide	Hypergolic	Oxidizer: Dinitrogen tetroxide, commonly (NTO) Fuel: Unsymmetrical dimethylhydrazine (UDMH)	Complex hazard chemical production for both hydrazine and NTO	Some CO_2 and NO_X emissions
Solid	APCP	Composite	Propellant: Ammonium perchlorate (AP) Binder: polybutadiene acrylic acid acrylonitrile prepolymer (PBAN*) or hydroxyl-terminated polybutadiene (HTPB), powdered metal (typically aluminum), and burn rate catalysts.	Aluminum powder, used in AP manufacture involves high-energy process and is chemical intensive	Combustion CO_2 emissions associated with binder

*Black Carbon is out of scope of this white paper and guidance document

IX. Conclusion

Calculating Scope 3 emissions for the use phase of space-related products within the scope of this guidance document presents a uniquely complex challenge. Unlike more mature emissions-calculating sectors, the space industry operates across highly specialized, globalized supply chains, with mission-specific hardware and limited transparency in upstream and downstream processes; especially as it relates to fuel production and use. These factors compound the difficulty of quantifying emissions for manufacturers of intermediate products and for calculating indirect emissions associated with the production of fuel.

Despite these barriers, there is an opportunity to help ensure accurate, consistent, and transparent Scope 3 accounting practices across the industry through the development and publication of common emissions accounting methodologies and assumptions. As emissions reporting expectations increase across industries, space companies must be proactive in establishing emissions baselines, collaborating with suppliers, and aligning with accepted standards such as GHG Protocol and ISO frameworks.

X. Reference Materials

Adams, James; Volz, Stephen M.; Blackwood, Daniel; Callister, Kathy; Dahl, Mark; Lyver, John; Kumor, Kenneth; Norwood, Tina; Tahu, George; Wennerberg, Linda; Gironda, A. John, et al. (2015). *Final Environmental Assessment for Launch of NASA Routine Payloads on Expendable Launch Vehicles*. National Environmental Satellite, Data, and Information Service, Office of Program Planning and Integration, NOAA. https://www.nasa.gov/wp-content/uploads/2024/01/routine-payloads-ea.pdf

Aerospace Corporation. (2021, January 19). *What's the impact of the space industry on climate change?* Medium. https://medium.com/the-aerospace-corporation/whats-the-impact-of-the-space-industry-on-climate-change-819ab9cfdb01

Beaumont, K., & Stein, T. (2022, June 21). *Projected increase in space travel may damage ozone layer*. National Oceanic and Atmospheric Administration (NOAA). https://csl.noaa.gov/news/2022/352_0621.html

Sirieys, E., Gentgen, C., Jain, A., Milton, J., & de Weck, O. L. (2022). *Space sustainability isn't just about space debris: On the atmospheric impact of space launches* [Figure 2: *Title or description of the figure*]. *MIT Science Policy Review, 3*, 143–151. https://doi.org/10.38105/spr.whfig18hta.

Maloney, C. M., Portmann, R. W., Ross, M. N., & Rosenlof, K. H. (2022). *The Climate and Ozone Impacts of Black Carbon Emissions From Global Rocket Launches*. *Journal of Geophysical Research: Atmospheres*, 127(12), e2021JD036373. https://doi.org/10.1029/2021JD036373

Maloney, C. M., Portmann, R. W., Ross, M. N., & Rosenlof, K. H. (2025). Investigating the potential atmospheric accumulation and radiative impact of the coming increase in satellite reentry frequency. *Journal of Geophysical Research: Atmospheres, 130*(17), e2024JD042442. https://doi.org/10.1029/2024JD042442

National Aeronautics and Space Administration (NASA). (2011). National Environmental Policy Act; NASA Routine Payloads on Expendable Launch Vehicles. Federal Register, 76(225), 72218–72220.

NASA Glenn Research Center. (n.d.). Practical rocketry [Figure 1&2: brief description]. In TRC Rocket: K–12 teaching resources. Retrieved [Month Day, Year], from https://www.grc.nasa.gov/www/k-12/rocket/TRCRocket/practical_rocketry.html

Ryan, R. G., Marais, E. A., Balhatchet, C. J., & Eastham, S. D. (2022). *Impact of rocket launch and space debris air pollutant emissions on stratospheric ozone and global climate*. Earth's Future, 10, e2021EF002612. https://doi.org/10.1029/2021EF002612

XI. Glossary

The glossary below provides definitions for common terms known within the space sector and by practitioners of GHG emissions accounting. These are brought forward to support understanding of concepts in the white paper but may not be a comprehensive list of definitions to support all readers' needs.

- **Binder**: provides the structural glue/matrix in a composite propellant to hold together solid granular ingredients, oxidized as fuel for the rocket motor.
- **Direct Emissions:** GHG emissions from sources owned or controlled by the reporting entity.
- **GEO:** Geostationary Orbit
- **GHG Protocol:** the most widely used international framework for measuring and managing greenhouse gas emissions. It provides standardized methodologies to report: scope 1: Direct emissions; scope 2: Indirect emissions from purchased electricity/energy; scope 3: All other indirect emissions from the value chain.
- **In-direct Emissions:** GHG emissions that result from the activities of the reporting entity but occur at sources not owned or controlled by it.
- **ISO 14054**: A series of international standards from the International Organization for Standardization that provide guidance for quantifying, monitoring, and reporting GHG emissions**.**
- **Hybrid allocation method:** A method that combines process-based LCA data with economic or input-output data to attribute emissions. It can be more accurate for complex supply chains and used when direct process data are incomplete or missing.
- **Kyoto Protocol:** A 1997 international treaty under the UNFCCC that legally binds developed countries to reduce GHG emissions using specified targets and six key GHGs (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6). Many emissions reporting systems (including GHG Protocol) still use Kyoto GHGs as the default reporting scope.
- **Launcher:** A space launch vehicle that transports payloads (e.g., satellites, crew capsules) from Earth into space.
- **LEO:** Lower Earth Orbit
- **Liquid propellant:** the working fluid substance (e.g. fuel, gas, oxidizer or chemical combination) that undergoes chemical and thermodynamic changes in a rocket engine.
- **Paris Agreement:** A 2015 global climate agreement to limit global warming to well below 2°C, aiming for 1.5°C. (1) Requires all countries to submit national climate plans (NDCs); (2)Encourages transparency, ambition, and carbon neutrality by mid-century.

- **Simple allocation method:** A method to attribute GHG emissions to a product or activity based on proportional factors such as: Mass, Energy content, Revenue.

- **Solid Propellant**: any single or mixed version of oxidizer, fuel, and other substance processed to constitute the finished grain.

- **Space-related activities:** All operations involved in supporting or enabling space missions, including: launch operations; mission control; ground station operations; satellite integration and testing; manufacture, transport, and assembly of space products.

- **Space Products:** Products specifically designed and manufactured for space missions. These include: Launch vehicles, satellites, spacecraft, & components (e.g., propulsion systems, thermal protection systems).

- **Stage**: Distinct section of launch vehicle with its own engines and fuel systems designed to operate during a specific phase of flight.

- **Use-phase Emissions:** GHG emissions that occur during the use of a product.