

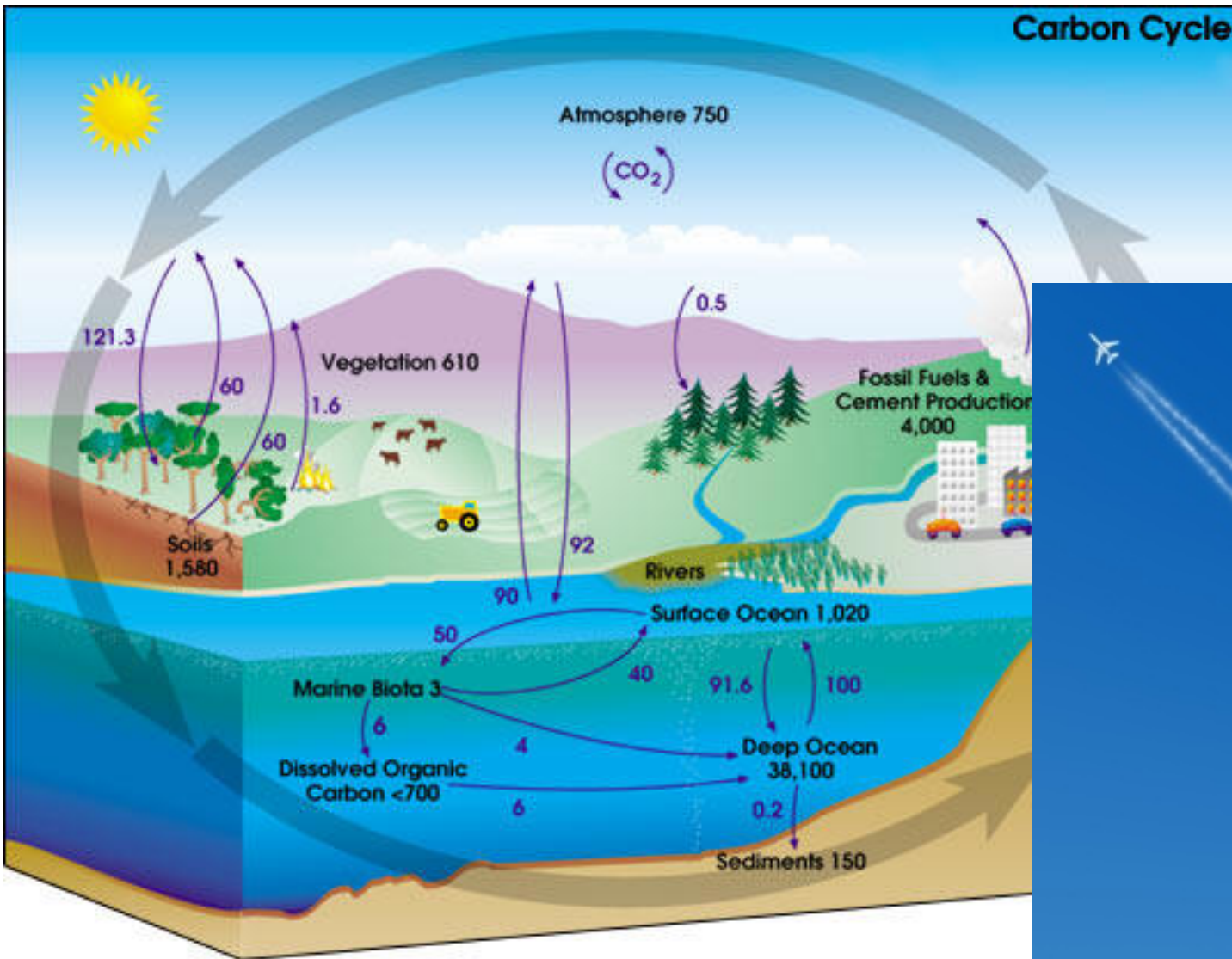
CO₂ Impacts from Space Exploration.



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Environmental Impacts of Space Exploration

What is the Carbon Footprint of NASA's current fleet of Space Craft?



Current Fleet (vs) Proposed Fleet

Discovery

Atlas V

Ares I

Ares V

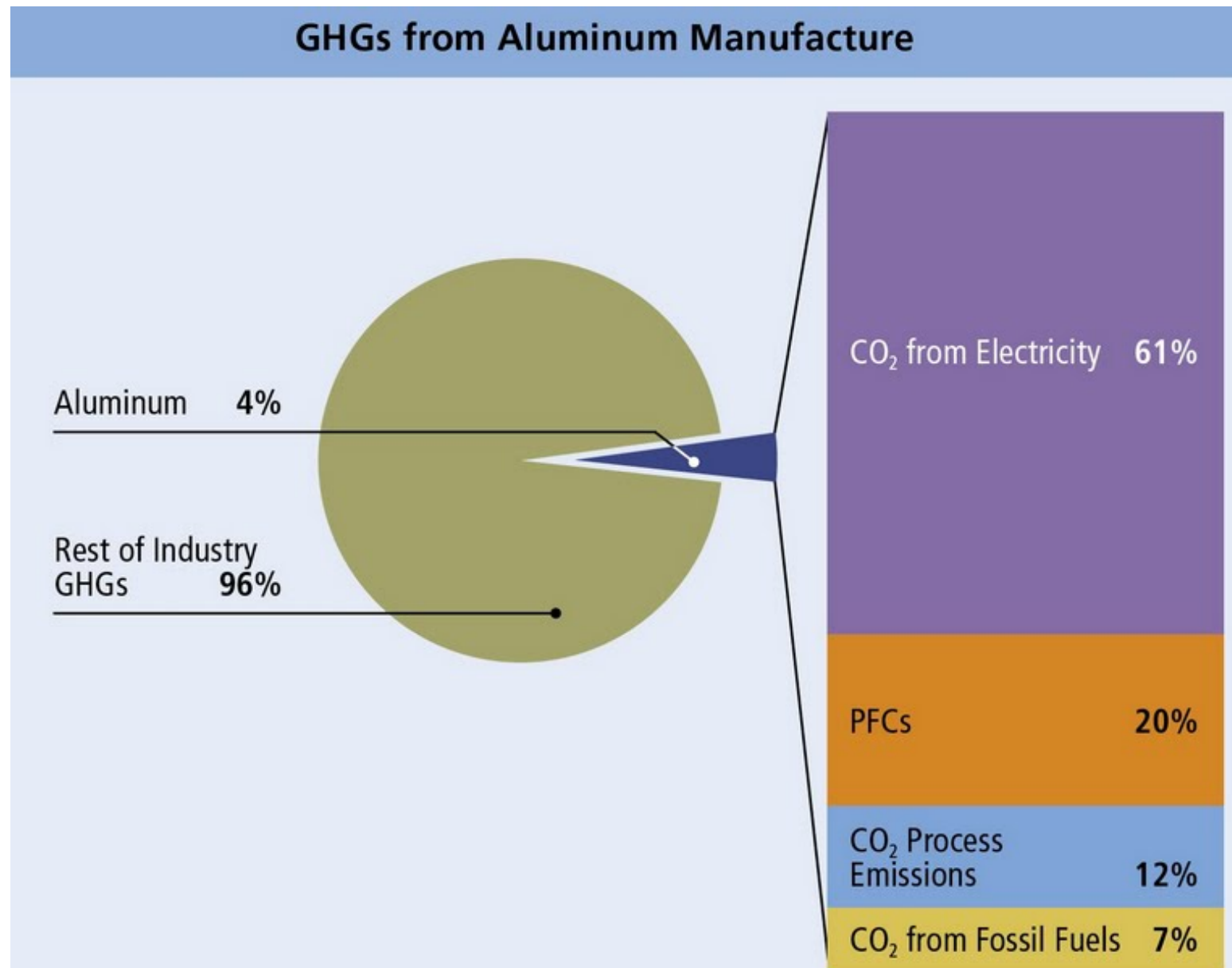


Payload capacity LEO	24,400 kg (25 ton)	9,750 - 29,420 kg ^[1] (25 ton)	25,000 kg (25 ton)	188,000 kg (188 ton)
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Production Emissions

What is a Rocket made of?

Our Estimate:
80% Aluminum
20% Titanium,
Silicon, Plastic,
etc.



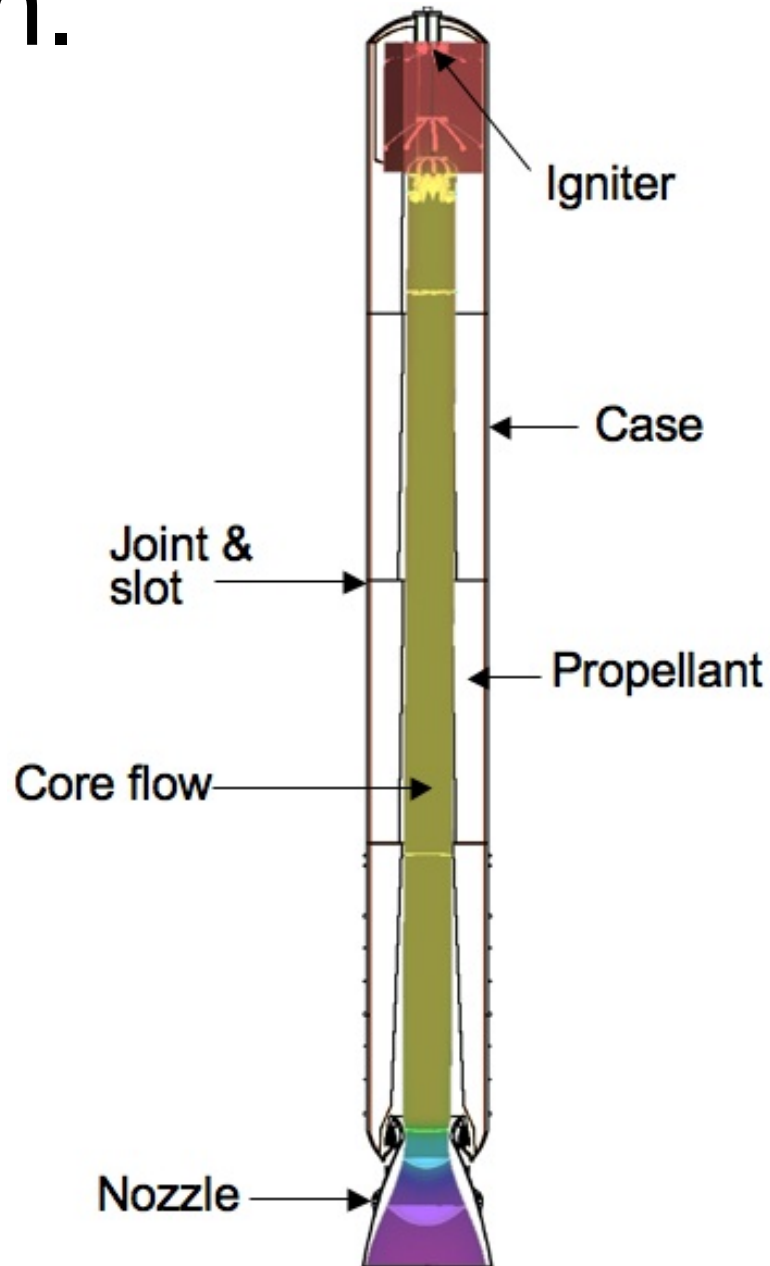
Sources & Notes: IEA, 2004a,b. See Appendix 2.A for data sources Appendix 2.B for subsector definition. Absolute emissions in this subsector, estimated here for 2000, are 324 MtCO₂.

CO₂ Footprint from (SRB) Rocket Shell Production.

100% Aluminum =
4-16 tons of CO₂ per
ton of Al.

Each SRB = 360 -
1440 tons of CO₂.

**Conservative/Worst
Case Estimate =
1440 tons**



Ares I = 1 SRB
Ares V = 2 SRB
Shuttle = 2 SRB
Atlas = 5 SRB
estimate Atlas SRBs ~ 50 tons

1 SRB shell = 70 - 90 tons

* Assuming all metal
Aluminum/titanium/lithium alloy

Liquid Rockets

The primary performance advantage of liquid propellants is the oxidizer.



Space Shuttle External Tank

- liquid hydrogen fuel and liquid oxygen oxidizer.
- supplies the fuel and oxidizer to 3 main engines
- jettisoned ~10 seconds after Main Engine Cut Off
- external tanks have not been re-used.

They break up before impact in the Indian Ocean (or Pacific Ocean in the case of direct-insertion launch trajectories, which are currently utilized) away from known shipping lanes.

Types of Rockets and Fuel used

Solid Rocket

(SRB) Aluminum perchlorate
 NH_4ClO_4

Atlas Liquid Rocket

RP-1 fuel mix + LOX
 *1 ton of RP-1 produces ~3 tons of CO_2 .

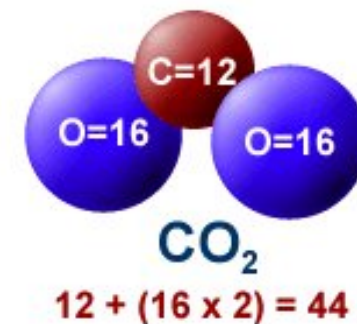
Ares & Shuttle Liquid Rockets

Liquid Hydrogen (LH_2)
 and Liquid Oxygen (LOX)
 * no CO_2 release from burn of
 $\text{LOX} + \text{H}_2$ rockets.



Fuel Rocket Type	1 H_2 + LOX + 2 SRB	RP-1 / LOX + 1-5 SRB	H_2 + LOX + 1 SRB	H_2 + LOX + 2 SRB
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CO₂ from Production of Stack



	Shuttle	Atlas V	Ares I	Ares V
Reused Space Craft	(eg. Discovery) 2000 tons / 100flights 16 = 320 tons CO ₂	0	(Orion) 8.5 tons / 10 flights x 16 = 14 tons CO ₂	(Orion) 8.5 tons / 10 flights x 16 = 14 tons CO ₂
SRBs	2 Reusable SRB @ 1/5 1440 x 2 /5= 580 tons	1-5 SRB 1440 x 5 = 7200 tons	1 Reusable SRB @ 1/5 1440/5= 290 tons	2 Reusable SRB @ 1/5 1440 x 2 /5= 580tons
Main Engine Fuel	LH ₂ /LOX Fuel Mixture 0	RP-1 / LO ₂ Fuel Mixture 3 x 280 =840 tons	LH ₂ /LOX Fuel Mixture 0	LH ₂ /LOX Fuel Mixture 0
Mass Expendables	25 ton payload + 35 ton tank = 60 tons x 16tons CO ₂ /ton Al. = 960 tons CO ₂ .	(547ton booster +25 ton payload x 16 = 9200 tons CO ₂	25 ton payload + 20 ton booster = 45 tons x 16tons CO ₂ /ton Al. = 720 tons CO ₂ .	188 ton payload + 160 ton booster = 350 tons x 16tons CO ₂ /ton Al. = 5600 tons CO ₂ .
CO ₂ per launch	1860 tons	17,240 tons	1024 tons	6200 tons

Compare with Other CO₂ Emissions

Emission Facts:

Light Truck Emissions

- 8 tons of CO₂ annually.

Passenger Car

- 5.725 tons of CO₂ annually.



Jane's Ford F-150
1/2 ton pick-up truck

The calculations for Total Annual Pollution Emitted and Fuel Consumed are based on an average annual passenger car mileage of 12,500 miles and an average annual light truck mileage of 14,000 miles. Fuel consumption is based on fleetwide average in-use fuel economy of 21.5 miles per gallon (mpg) for passenger cars and 17.2 mpg for light trucks, as reported in the 19th edition of the "Transportation Energy Data Book," prepared for the U.S. Department of Energy.



So, 1000 - 17,000 tons of CO₂ per launch is equivalent to 125 - 2000 people's annual driving per year.

That does not seem so bad.

Yet...



BUT what about other emissions?

Limits on the Space Launch Market Related to Stratospheric Ozone Depletion

Martin Ross a; Darin Toohey b; Manfred Peinemann a; Patrick Ross c

TABLE 1 Approximate Emission for the Four Main Propellant Types Given as Mass Fraction for each Component.

	Inert N ₂	Inert CO ₂ + CO	OH source H ₂ O + H ₂	Radicals ClOx, HOx, NOx	Radical reservoirs HCl	Particles Alumina soot
NH ₄ ClO ₄ /Al (solid)	0.08	0.27	0.48	0.1	0.15	0.33
LOX/H ₂ O (cryogenic)	—	—	1.24	0.02	—	—
LOX/RP-1 (kerosene)	—	0.88	0.30	0.02	—	0.05
UDMH/N ₂ O ₄ (hypergolic)	0.29	0.63	0.25	0.02	—	Trace

Note: The Total Mass Fraction Exceeds Unity because of the assumption that air mixed into the plume oxidizes CO and H₂.

Although CO₂ Emissions are lower than expected, other ozone depleting substances are present, and could potentially have devastating effects on our ozone as space travel increases. Should we limit the number of launches into space, including low earth orbit?

A silver lining to Ares?

New Generation of Re-usable Hardware

Ares V Heavy Lift Vehicle



Re-usable SRB's and common hardware between Ares I and Ares V make operations more cost effective and reduce environmental impacts from production and manufacture of NASA Space Craft.

Aluminum/Titanium Alloy & Carbon Fiber Orion Capsule

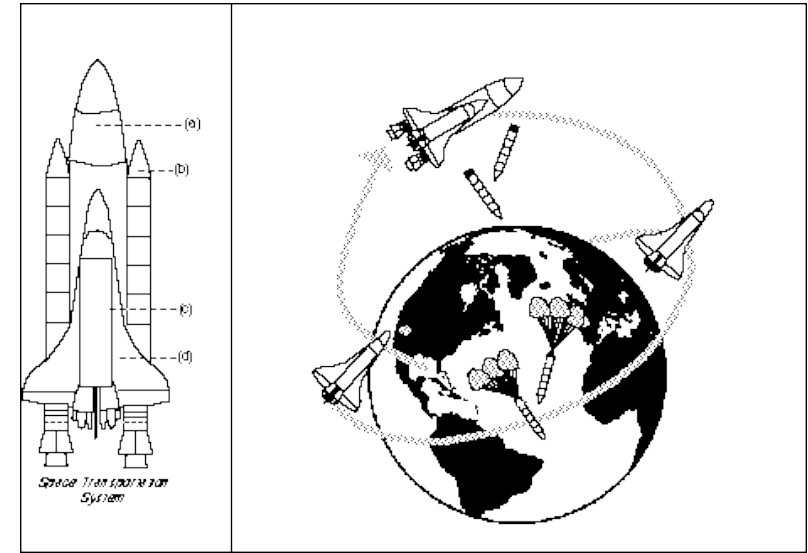
New carbon fiber molded panels allow for easy and cost effective reproduction of parts. NASA aims to reuse each craft for up to ten flights, allowing it to build a fleet of both manned and unmanned Orion Capsule Modules.

Currently being developed and built by Lockheed Martin Corporation.



Re-usable SRB

Ares I spacecraft used re-usable SRB's which had been used 5 times previous to the Ares I launch.



Thrust < 40K lb.- force
First Stage separation
begins +123 secs
at 130 k feet

Apogee: 150 kft

USS/CM/LAS
uncontrolled
descent

Separation +193 secs
Chute deployment begins

Range: 128 nm

Booster, Parachutes
and
Recovery



Pitch over

Launch

However, the external liquid fuel tank is also jettisoned after launch, however it burns up during re-entry.

Calculation Concepts and Discrepancies

- What factors really determine the whole carbon footprint?
- What are the possible discrepancies in calculating CO₂ emissions arise?
- What have we not accounted for?
- How could we better improve our footprint calculations?

What sort of limits on Space Craft launches should be mandated?

Should the EPA regulate emissions from Space Travel?



Results for Space Policy

As you can see from reviewing the data, there is a significant range of calculation results, however it is important for humans to understand the impacts to our earth from space travel.

What is a reasonable number of launches per year, that would still help us negotiate negative impacts to the Ozone and Climate Change?

Should NASA and other private space agencies be required to regulate their manufacture emissions as well as launch emissions?



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