



How Green is Green: Space Elevator's Minimal Environmental Impact for Settling Space

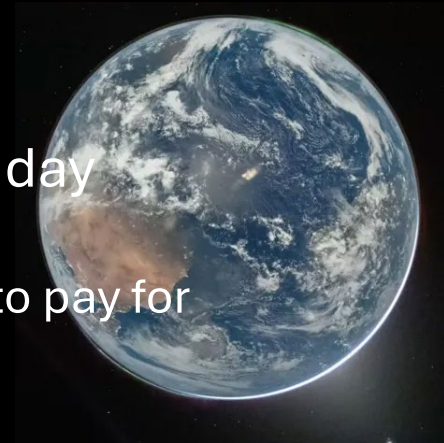
Rocket Solution Amplifies Air
Pollution

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2026 International Space Development Conference

Viabile Space Settlement & Space Economy

- Initial Outbound Target Goal of 1 million KG per day
 - Support Five Basic Missions
 - Moon
 - Mars
 - Solar
 - O'Neill Colonies
 - Sunshade
 - Launch to other places in the solar system
 - Large-scale GEO space manufacturing
- Initial Earth-bound Target Goal of 1 million KG per day
 - Large-scale GEO space manufacturing
 - Bring back wealth from space (asteroid mining, etc.) to pay for settlements
 - Space Tourism



Preliminary Assessment of Mars Mission

- One billion kg of mass of cargo and personnel to Mars over a 20-30 year timeframe
- Capability of Falcon 9 Heavy and Starship
 - 59000 Falcon 9 heavy launches required
 - 12500 SpaceX Starship launches required
- Annualized Launches

	20 Year Mission	30 Year Mission
Falcon 9 Heavy	2950	1967
Starship	625	417



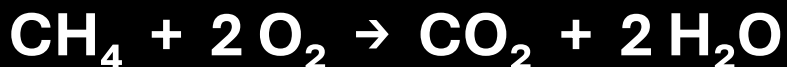
Rocket Chemistry is Different

Falcon 9 Heavy uses a legacy kerosene / LOx system

Kerosene is a mixture of various paraffins, naphthenes, and aromatics but stoichiometrically ...



Starship uses a Methane / LOx combustion process



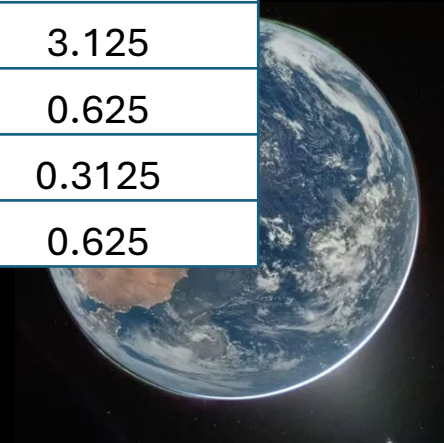
Combustion Byproducts per launch

Byproduct	FH (kg)	FH (% of total exhaust)	Starship (kg)	Starship (%)
CO ₂	863,000	49.7%	2,627,000	53.5%
H ₂ O (vapor)	544,000	31.4%	2,163,000	44.0%
CO	300,000	17.3%	124,000	2.5%
Black Carbon (soot)	13,100	0.75%	~1,000	<0.02%
H ₂ + HC fragments	~3,000	~0.17%	~5,000	~0.10%
NO _x (NO + NO ₂)	~200	~0.01%	~500	~0.01%
Unburned CH ₄	N/A	N/A	~1,000	<0.02%
TOTAL	~1,723,300	100%	~4,921,500	100%



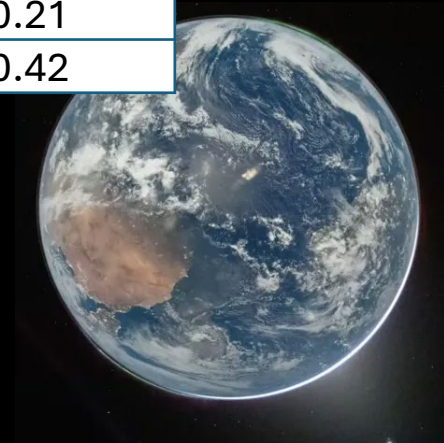
Annual combustion byproducts 20 Year Mars Mission

Byproduct	Falcon 9 Heavy per Launch Kt	Falcon 9 Heavy Annual Mars Mt	Starship per Launch Kt	Starship Annual Mars Mt
CO ₂	863	2545.85	2627	1641.875
CO	300	885	124	77.5
H ₂ + HC Frag	3	8.85	5	3.125
Black Carbon	13.1	38.645	1	0.625
NO _x	0.2	0.59	0.5	0.3125
Unburned CH ₄	0	0	1	0.625



Annual combustion byproducts 30 Year Mars Mission

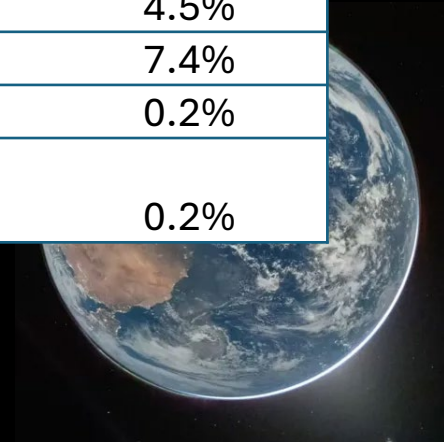
Byproduct	Falcon 9 Heavy per Launch Kt	Falcon 9 Heavy Annual Mars Mt	Starship per Launch Kt	Starship Annual Mars Mt
CO2	863	1697.2	2627	1094.58
CO	300	590.0	124	51.67
H2 + HC Frag	3	5.9	5	2.08
Black Carbon	13.1	25.8	1	0.42
NOx	0.2	0.4	0.5	0.21
Unburned CH4	0	0.0	1	0.42



Mars Mission Rocket Byproducts

20 Year Mission

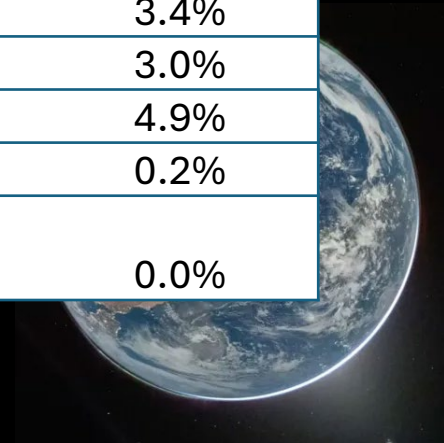
Byproduct	Falcon 9 Heavy Annual Mars Mt	Starship Annual Mars Mt	Annual Global Mass (all sources) Mt	Falcon 9 Heavy % Annual	Starship % Annual
CO2	2545.85	1641.88	41600	6.1%	3.9%
CO	885.00	77.50	1500	59.0%	5.2%
H2 + HC Frag	8.85	3.13	70	12.6%	4.5%
Black Carbon	38.65	0.63	8.5	454.6%	7.4%
NOx	0.59	0.31	130	0.5%	0.2%
Unburned CH4	0.00	0.63	348	0.0%	0.2%



Mars Mission Rocket Byproducts

30 Year Mission

Byproduct	SpaceX Falcon 9 Heavy Annual 30 year Mars Mt	SpaceX Starship Annual 30 Year MarsMt	Annual Global Mass (all sources) Mt	Falcon 9 Heavy % Annual	Starship % Annual
CO2	1697.2	1094.6	41600	4.1%	2.6%
CO	590.0	51.7	1500	39.3%	3.4%
H2 + HC Frag	5.9	2.1	70	8.4%	3.0%
Black Carbon	25.8	0.4	8.5	303.1%	4.9%
NOx	0.4	0.2	130	0.3%	0.2%
Unburned CH4	0.0	0.0	348	0.0%	0.0%



Falcon 9 Heavy Issues

- CO and Carbon Emissions from Falcon 9 Heavy for supplying all transportation for Mars mission will drastically increase air pollution
- Starship adds less than 10% but the effects at various altitudes are unknown



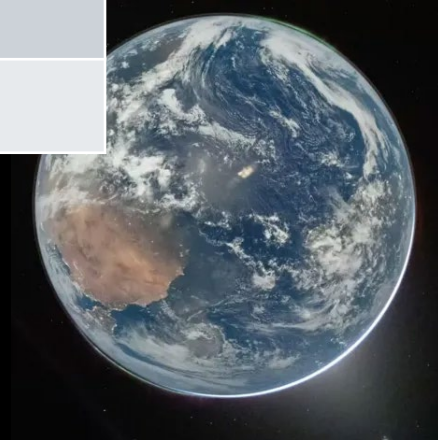
Altitude Effects: Troposphere (0-12 km)

Product	Falcon Heavy (kg in tropo)	Starship (kg in tropo)	Atmospheric Fate
CO ₂	~390,000	~1,183,000	Disperses; no tropospheric chemistry impact
H ₂ O	~245,000	~974,000	Condenses, rains out within days–weeks
CO	~135,000	~56,000	Oxidized to CO ₂ by OH radicals within days
Black Carbon	~5,900	~450	Wet/dry deposition within days–weeks
NO _x (NO+NO ₂)	~100	~225	O ₃ chemistry; acid rain precursor (HNO ₃)



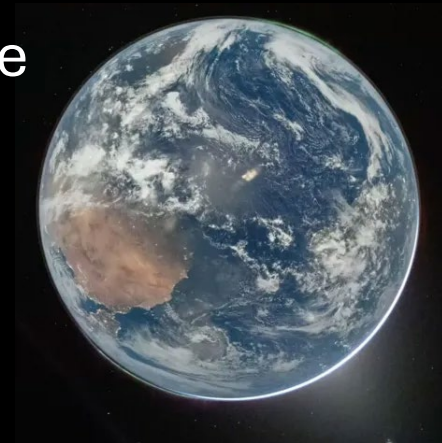
Altitude Effects:

Altitude Layer	Range (km)	Key Products Injected	FH Fraction (% total)	Starship Fraction (% total)
Troposphere	0–12	CO ₂ , H ₂ O, CO, BC, NO _x	~45%	~45%
Stratosphere	12–50	CO ₂ , H ₂ O, CO, BC (stratospheric)	~48%	~45%
Mesosphere	50–80	H ₂ O, CO ₂ , metals, radicals	~6%	~8%
Thermosphere	80+	H ₂ O, CO ₂ , OH, reactive species	~1%	~2%



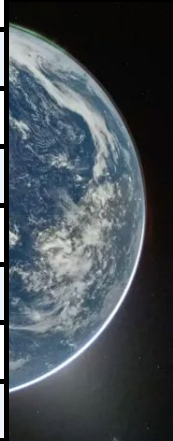
Initial Assessment of Byproducts

- CO and Soot are major byproducts when compared to Global annual production for supporting a Mars mission with Rockets
- Falcon 9 Heavy with its kerosene-based propulsion system, has a larger impact in general compared to Starship
- Electrically driven Space elevators do not have the environmental impact of rockets
 - Depending on the electric power source, there could be minor impacts
 - Nuclear, solar, natural gas, coal, oil, and hydroelectric should all be assessed to provide an accurate comparison



Electric Power Plant CO2 LC

Technology	Status	Typical Size (MW)	Capacity Factor (%)	LCOE (\$/MWh)	Lifecycle CO (gCO eq/kWh)
Coal (Pulverized/IGCC)	COM	300–1,200	42	65–150	750–1,095
Natural Gas — Combined Cycle	COM	400–1,000	57–60	45–90	403–513
Natural Gas — Simple Cycle/Peaker	COM	50–400	10–25	110–228	540–700
Nuclear — Large (Gen II/III)	COM	600–1,700	92	89–198	5–12
Hydroelectric (Conventional)	COM	1–22,500	34–45	25–100	6–147
Pumped-Storage Hydroelectric	COM	100–3,300	25–30 (stor.)	150–270 (LCOS)	~6
Wind — Onshore	COM	10–500	34	27–73	7.8–16
Wind — Offshore	COM	100–1,500	40–48	72–140	12–23
Solar PV — Utility Scale	COM	5–2,000	23	29–92	8–83
Concentrating Solar Power (CSP)	COM	50–400	35–50	115–193	27–122
Geothermal (Hydrothermal)	COM	5–150	85–90	48–100	15–55
Biomass / Biogas	COM	10–200	50–75	89–134	16–74+
Diesel / Oil (Reciprocating)	COM	0.5–500	15–30	200–400	650–900
Tidal / Wave / Ocean Current	EM	0.5–20	25–40	150–300	10–20
Small Modular Reactors (SMR)	EM	50–300	90–95	89–140	5–12
Hydrogen Power (Gas Turbine/Fuel Cell)	EM	1–500	20–60	100–300	0–50 (green H)
Nuclear Fusion (Tokamak/ICF)	R&D	500–1,000 (proj.)	~85 (proj.)	80–150 (proj.)	~3–5 (proj.)



Electric Space Elevator CO2

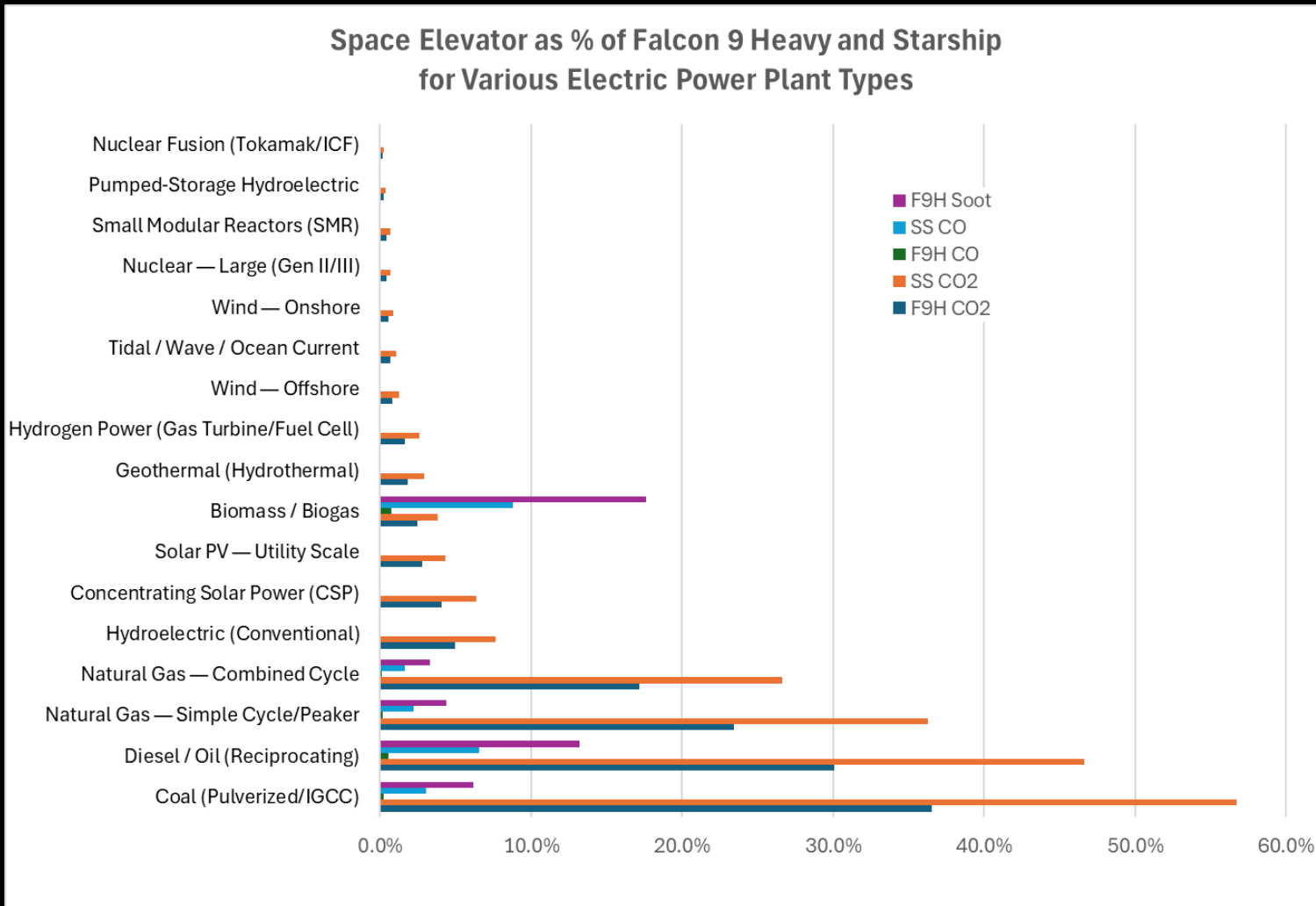
Millions of Tons

Technology	SE 20 Year	SE 30 Year	Falc 9 20 Year	Falc 9 30 Year	Starship 20 Year	Starship 30 Year
Coal (Pulverized/IGCC)	930.75	620.5	36.6%	36.6%	56.7%	56.7%
Diesel / Oil (Reciprocating)	765.85	510.5667	30.1%	30.1%	46.6%	46.6%
Natural Gas — Simple Cycle/Peaker	595.85	397.2333	23.4%	23.4%	36.3%	36.3%
Natural Gas — Combined Cycle	436.9	291.2667	17.2%	17.2%	26.6%	26.6%
Hydroelectric (Conventional)	125.8	83.86667	4.9%	4.9%	7.7%	7.7%
Concentrating Solar Power (CSP)	104.55	69.7	4.1%	4.1%	6.4%	6.4%
Solar PV — Utility Scale	71.4	47.6	2.8%	2.8%	4.3%	4.3%
Biomass / Biogas	62.9	41.93333	2.5%	2.5%	3.8%	3.8%
Geothermal (Hydrothermal)	47.6	31.73333	1.9%	1.9%	2.9%	2.9%
Hydrogen Power (Gas Turbine/Fuel Cell)	42.5	28.33333	1.7%	1.7%	2.6%	2.6%
Wind — Offshore	20.4	13.6	0.8%	0.8%	1.2%	1.2%
Tidal / Wave / Ocean Current	17.85	11.9	0.7%	0.7%	1.1%	1.1%
Wind — Onshore	14.45	9.633333	0.6%	0.6%	0.9%	0.9%
Nuclear — Large (Gen II/III)	11.05	7.366667	0.4%	0.4%	0.7%	0.7%
Small Modular Reactors (SMR)	11.05	7.366667	0.4%	0.4%	0.7%	0.7%
Pumped-Storage Hydroelectric	5.95	3.966667	0.2%	0.2%	0.4%	0.4%
Nuclear Fusion (Tokamak/ICF)	4.25	2.833333	0.2%	0.2%	0.3%	0.3%



Electric Space Elevator

CO₂, CO, and Soot for Various Power Plants



Interest in Special Study

- ISEC has laid claim that space elevators are the clean road to space
- An initial assessment of large-scale missions (Mars) highlights the impact of air quality due to thousands of rocket launches
- A more detailed analysis and comparison is warranted to highlight one of the benefits of the space elevator

Engage and be part of the study





CLEAN ASCENT ENABLES SPACE SETTLEMENT

International Space Elevator Consortium Special Study

► TOPIC

Comparison of clean space elevators with rocket exhaust for large scale space settlement missions

► TECHNICAL SKILLS

- Chemistry
- Rocket Propulsion
- Atmospheric composition
- Environmental impact assessor

► CONTACT

ISEC Special Studies
Director

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► PURPOSE

Large Scale Space Settlement will require thousands of rocket launches or space elevators. Considering the number of launches per year to meet a 20-30 year Mars settlement requiring one billion kilograms of mass in cargo and personnel, that question becomes, will all that rocket exhaust create a devastating environmental impact?

► SIGNIFICANCE

Identified Issue

ISDC 2026 has a presentation on a first assessment of a comparison between the air pollution contribution of SpaceX Falcon 9 Heavy and SpaceX Starship exhaust compared to the expected overall system pollution of a space elevator. These two rocket's platforms were selected due to their low cost in the heavy lift rocket category. The results indicate that CO₂ generated by humans will increase globally by up to 6%. More devastatingly is the increase of human-generated CO and Black Soot can increase globally to 60% and 450% respectively.

Initial Study Effort

The International Space Elevator Consortium plans to expand this assessment and conduct a much more detailed analysis of combustion byproducts and their atmospheric impacts at various altitudes. Large-scale launch cycles that account for launch windows and the mass required for a Mars mission (one billion kilograms) would be conducive to a 20-30-year space-settlement mission.

Space elevators are electrically driven but can have various environmental air quality impacts depending on the source of the electric power. Coal-fired electric power plants have greater air-quality impacts than nuclear, solar, or wind power plants. Various energy requirements and overall system performance will result in pollutants from electric power sources. These need to be accounted for as a fair comparison to the rocket pollutants.



EXPLORING DESIGN IN SPACE TRANSPORTATION

International Space Elevator Consortium Special Study

► TOPIC

Interplanetary space vehicle design, flight paths, launch windows, and operational capabilities enabled by Space Elevator-based interplanetary transportation vehicles

► TECHNICAL SKILLS

- Astrodynamics
- Rocket Propulsion
- Space Vehicle design
- New mission concepts
- Personnel & cargo specialists
- Zero-g low-g assembly
- Conceptualization

► STUDENT COMPETITION

► CONTACT

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► PURPOSE

Space elevators have been argued for interplanetary launch platforms. They have unique capabilities not available to rocket-based solutions. Transportation needs for one billion kilograms of cargo and personnel will differ in the design and accommodation of personnel versus cargo.

► SIGNIFICANCE

Identified Opportunity

When the shape, dimensions, and volume of a transportation vehicle are unbounded by the concept of a rocket, then what would they look like, how would their flight profiles change, and what additional operational concepts can be envisioned if extra fuel can be carried? Interplanetary transportation vehicles can be more fully explored when the restriction of rocket-based shaping is eliminated. This creates a great opportunity to explore many new design and operational concepts not envisioned before.

Initial Study Effort

The International Space Elevator Consortium plans to explore alternative interplanetary travel vehicles that can be launched from the space elevator tether. Release velocities based on tether location departure angle with various forms of flight trajectory correction will be assessed. Vastly larger transportation vehicles that can be assembled at GEO and beyond will provide 10, 100, or 1000 times more volume than rocket solutions can. Additional fuel that can be reached to the space transportation vehicle can also provide various flight missions and delta-v changes with rendezvous planets, asteroids, or other objects.

Various studies and design competitions can be conducted during this special study. Opening up the design space allows for art and science to explore together. New concepts for space transportation vehicles must have potential for a working solution that meets the design teams goals for mission and personnel/cargo transportation needs.

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