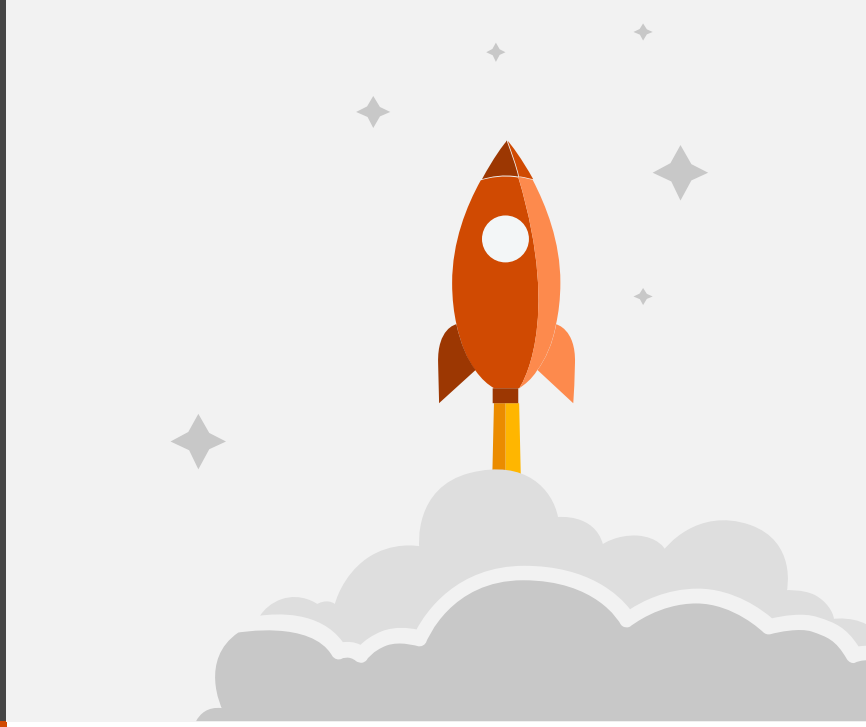
Sustainable rocket propellants:

A costless contribution of the space industry to climate change mitigation



UN/Austria Symposium 2023: Space for Climate Action
Greening Space Systems Engineering

pwc

The space economy is lifting up and expected to exceed a trillion USD by 2040

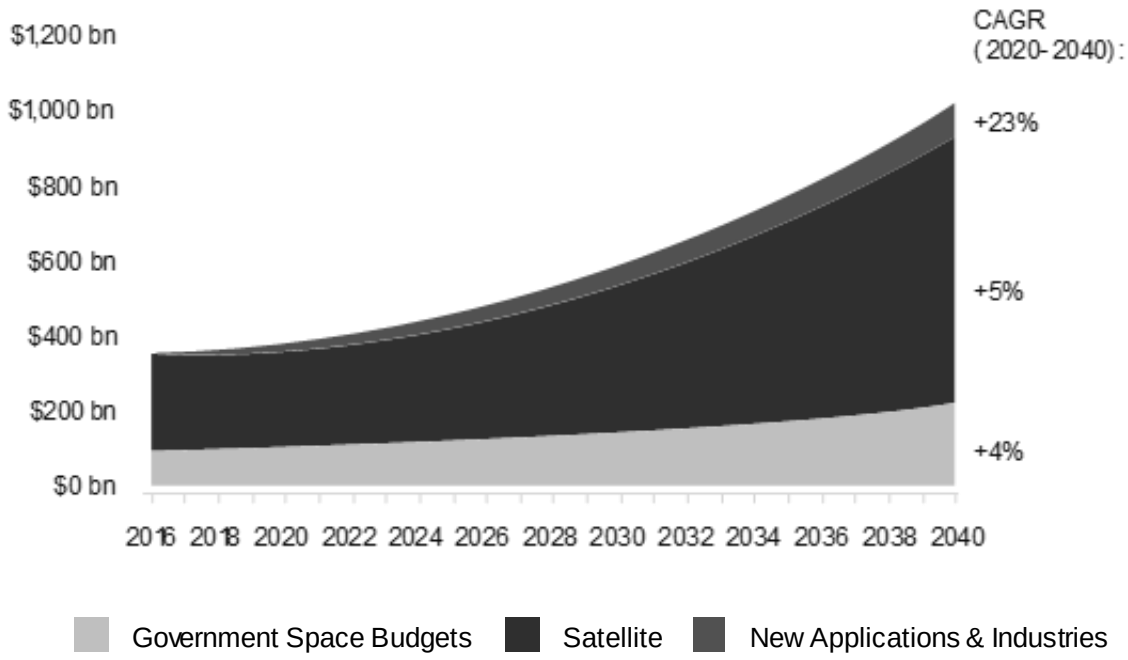
The global space economy is expected to grow from $371 billion in 2020 to over $1 trillion by 2040

Much of this projected growth will come from the satellites market dynamics (constellations, increased usage…)

New markets requiring heavy lifting capabilities are also emerging (commercial stations, space infrastructures…)

Access to space is thus expected to boom in the coming decades, with implications on carbon footprint overall

Expected growth of the Space Economy by 2040



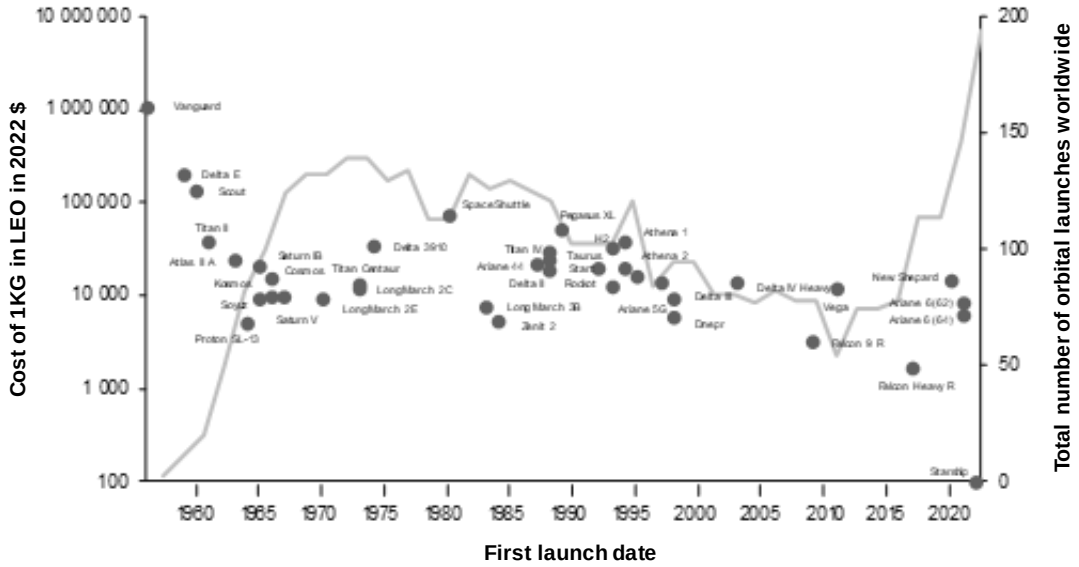
Cost of access to space has dramatically decreased, stirring the demand and volume of launches

Cost of launch has considerably decreased making access to space even more affordable and pushing demand

We already observe a steady increase in the number of orbital launches. Every year comes with a new record in launches

So far, sustainability hasn't been at the core of considerations. Space tourism has put access to space under the spotlight

Number of orbital space launches and payload costs (1961 to 2023)

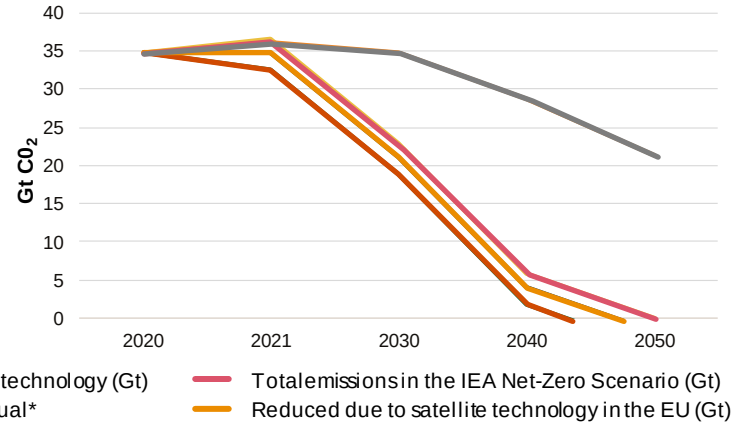


Evolution of the number of orbital launches

The space sector will contribute to the race towards Net Zero but for that it needs to be exemplary itself

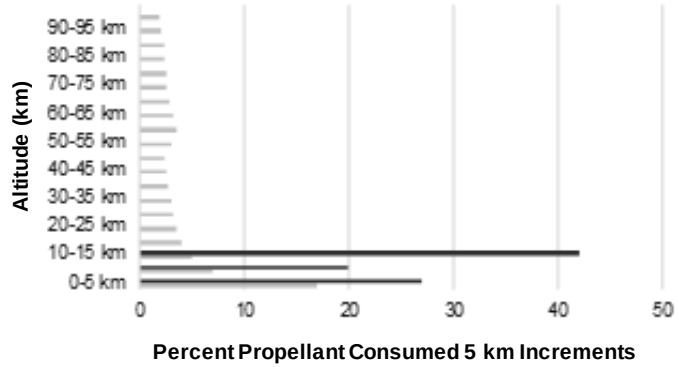
The Space sector can also play a role towards Net Zero

- According to InMarsat, Up to 4 Gt of CO_2 could be avoided today if satellite technologies were adopted globally + 9 Gt when including satellite-enabled tech.
- Moving forward, a vibrant space industry yields greenhouse gas (GHG) emissions reduction potential across many sectors of the global economy.
- However, that growth comes with its own environmental costs not least through a growing CO_2 footprint from increased launch requirements to place satellites in orbit.



A call for the development of more sustainable launchers

- A handful of particle emissions due to launch campaigns (CO_2, Soot, Aluminum & Chlorine, water vapor).
- Still difficult to estimate concrete impact of space industry's carbon footprint.
- Despite seemingly unharmful, water vapor emitted at very high altitude could be damaging for the environment.
- Manufacturing processes are great emitters and a decarbonation of the space industry is impossible without addressing it.



A growing transition of the sector towards more sustainable practices is taking place, with advancements needed

The entire industry is transitioning

- Institutional initiatives from space agencies to develop new standards and hardware
- Development of cross-national working groups to develop R&D efforts towards sustainable propulsion
- Increased involvement from the industry itself, sustainability becoming not only a goodwill but also a commercial priority

Emerging space nations put sustainability forward in the latest regulatory frameworks and practices

Source: PwC analysis

Fitting of CSG Kourou for biosourced hydrogen

CSG is Engaged its ecological transition by building 2 photovoltaic plants that will be operational in 2023 as well as 2 biomass units for initial investments estimated between 140M and 180M Euros

FAA scrutiny over SpaceX Boca Chica Starbase

Environmental assessment of the Federal Aviation Administration (FAA) → led to a series of over 75 mitigation measures needed from SpaceX to resume of operations. Increased scrutiny following latest launch attempt and generated debris

Accounting for environmental objectives in application of SIA

"take into account the mitigations proposed…to limit the effects of emissions contributing to climate change from spaceflight activities"
- Department of Transportation 2021 guidance on application of Space Industry Act (2018) -

Space Sustainability Roadmap

Targets a net-zero Scottish space sector by 2045 via an action plan that includes the phasing out of toxic propellants for greener solutions developed locally by UK launcher projects like Orbex or Skyrora

We looked at what would be the cost and impact on emissions of a transition to greener methods of propellant production

We developed a cost-assessment model to look the cost of transitioning today and the impact it would have on emissions

3 We focus on 3 emblematic access to space vehicles: Ariane 64, Falcon-9 and New Shepard

We calculate the CO_2 emissions associated with a launch when using fossil fuels & then with renewable resources

We calculate the total and relative cost differences between fossil and renewable fuel options.

For this short presentation, we focus on our analysis for a Falcon-9 launcher. **Other 2 analysis available in the paper.**

LAUNCHER	 ARIANE 64	 FALCON 9	 NEW SHEPARD
Activity	Orbital	Orbital	Suborbital
Operator	Arianespace	SpaceX	Blue Origin
Payload mass launch capacity to LEO (t)	20.6t	22.8t	0.5 t
Fuel type & quantity	26t LH2 488t HTPB/AP/Al	247t RP1	3t LH2
Oxidizer mass	154t LOx	148t LOx	19t LOx
Total propellant mass (t)	668t	385t	22t
Total launcher mass (t)	860t	549t	57t
Total flight cost (Million US$)	US$130 million	US$67 million	US$7.5 million
Cost/kg to LEO (US$) [36] [37]	US$6.300	US$2.900	US$14.700
Embedded net CO_2 emissions of a launcher [38] (tCO_2/rocket built)	**2023 - 3,400t_{CO2}** 2030 - 2,300t_{CO2} 2040 - 600t_{CO2} 2050 - 0t_{CO2}	**2023 - 2,400t_{CO2}** 2030 - 1,600t_{CO2} 2040 - 400t_{CO2} 2050 - 0t_{CO2}	**2023 - 500t_{CO2}** 2030 - 300t_{CO2} 2040 - 100t_{CO2} 2050 - 0t_{CO2}
Part of the net embedded CO_2 resulting exclusively from propellant [36] (tCO_2/launch)	622 t_{CO2}	948 t_{CO2}	40 t_{CO2}
CO_2 abatement potential from switching to sustainable propellants (tCO_2/launch) [39]	418 t_{CO2} (67%)	824 t_{CO2} (87%)	37 t_{CO2} (93%)
Current estimated CO_2 intensity of launching a ton of payload to LEO	30.2 t_{CO2}/t	41.4 t_{CO2}/t	79 t_{CO2}/t
Expected CO_2 intensity of launching a ton of payload to LEO after switching to sustainable propellants	9.9 t_{CO2}/t	5.4 t_{CO2}/t	5.3 t_{CO2}/t

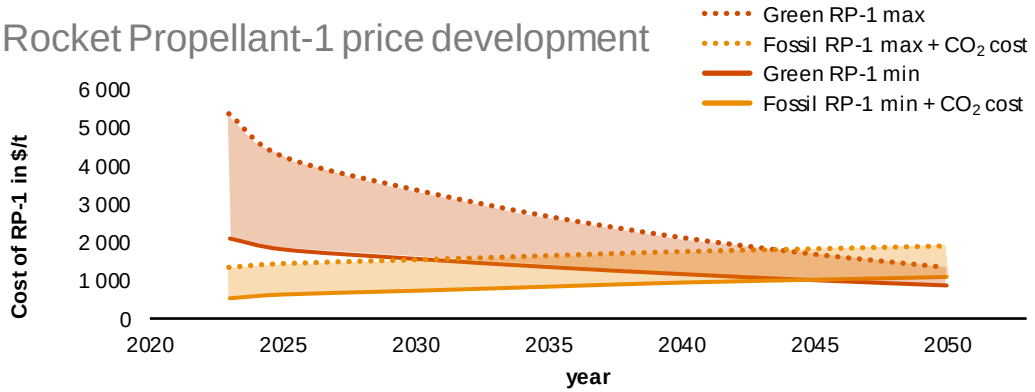
Falcon-9 uses RP-1 and producing it sustainably can become cost cost competitive within this decade

Key findings:

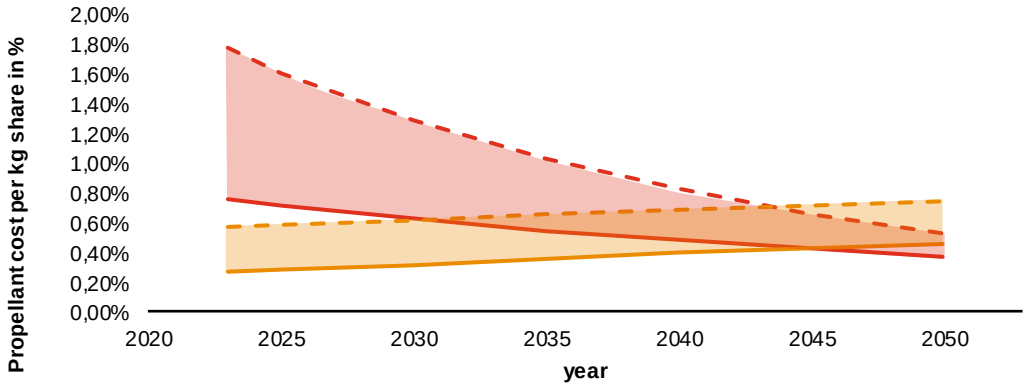
- Fischer-Tropsch production process is mature and ready to be deployed to the space market
- Synthetic RP-1 production cost will be cost competitive by end of this decade and latest early 2040s
- Fuel share of overall launch cost to stay well below 2%, which is much lower compared to aviation industry

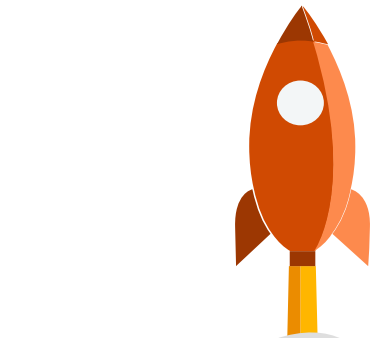
Source: PwC analysis

Rocket Propellant-1 price development



Falcon 9 – Propellant cost share per kg



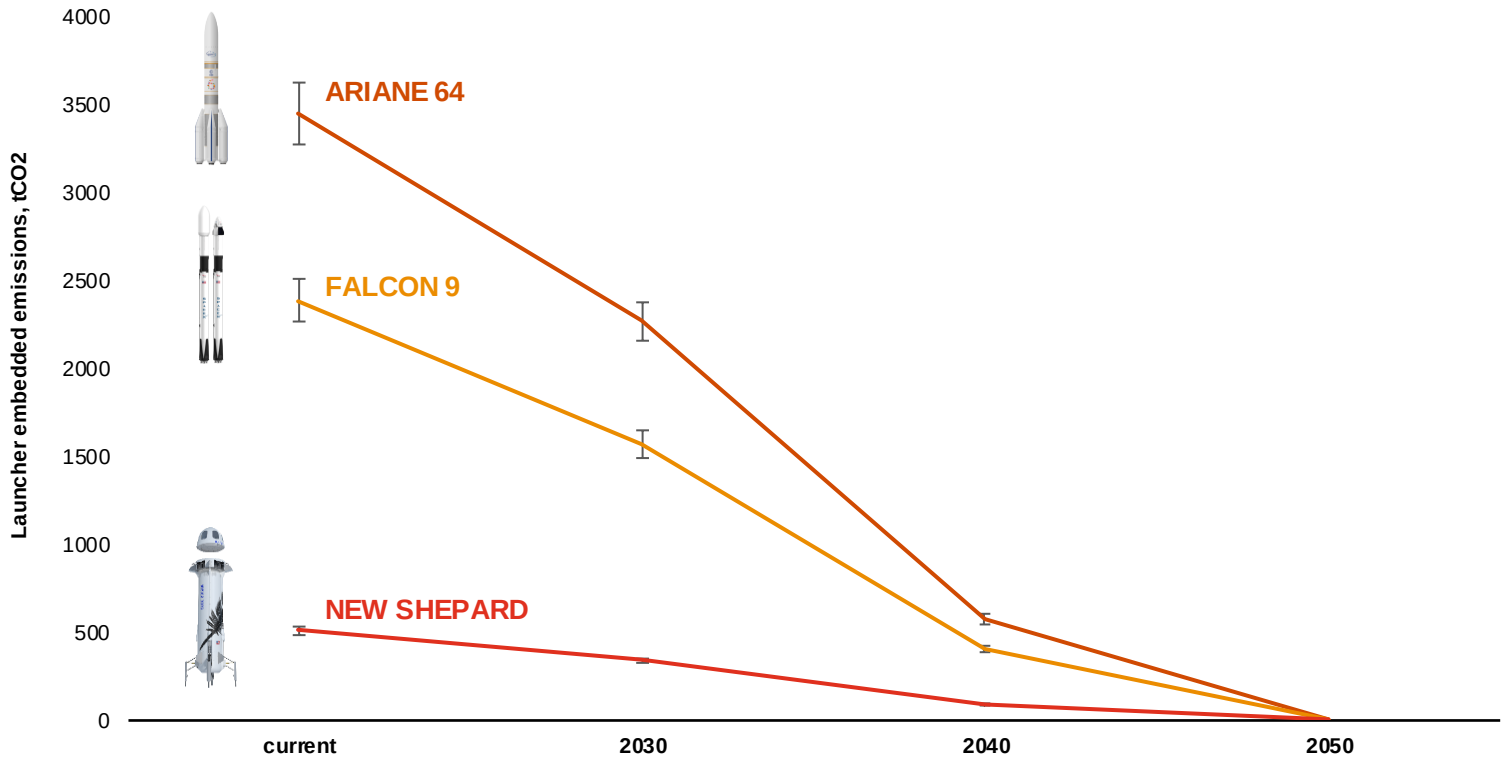


In addition to sustainable propellant cost the embedded carbon footprint of launchers can be massively reduced

Key findings:

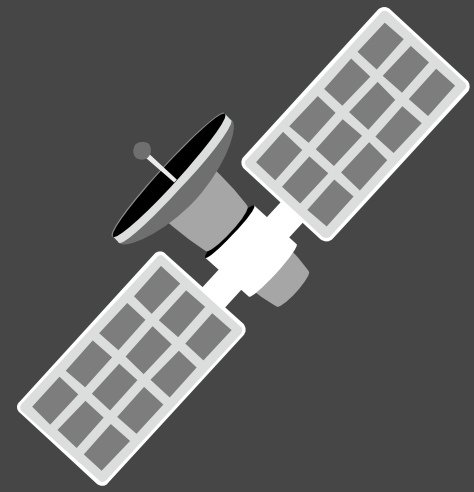
- With the decarbonization of other sectors, according to the IEA net-zero scenario, the launch vehicle carbon footprint can reach net-zero
- Example Aluminum: current CO_2 intensities of almost 16.6t CO_2/t will decrease close to 0 due to the use of renewable electricity
- Example Titanium: A fast track CO_2 reduction option is switching from primary to recycled materials resulting in GHG emission savings of 13,7 tCO_2-eq/ton of Titanium
- Widespread use of reusable launchers will avoid the construction of new rockets for each launch
- New composite materials will reduce overall weight reduction and also fuel use.

Carbon Footprint per Rocket under NET Zero Scenario for total CO_2



What to do to lower the greenhouse gas footprint of rocket launches?

1. Be proactive in working with clients and suppliers to create a SRP and green material supply roadmap.
2. Build demonstration plants to show that propellant quality standards can be met.
3. Produce fuels locally to the launch site as many sit in renewable resource rich areas.
4. Own your own SRP production plants to guarantee price certainty, particularly in times of energy price uncertainty.
5. Expand the use of reusable launchers as they mitigate the need to build new rockets for each launch.
6. Maximise switch from primary to recycled materials to reduce emissions through the supply chain and use innovative materials to cut dry rocket weight down.
7. Encourage suppliers to set themselves net- zero targets to reduce supply chain emissions.
8. Benchmark your progress on integrating SRP through reporting.



Thank you

About the PwC Space Sector

The PwC Space practice is part of the PwC Advisory practice, which includes strategy and consulting. The PwC space team is fully dedicated to the space sector. Our teams include specialists from all space sectors who are supported by consultants from the global PwC network. Our expertise covers the entire space sector and spans the value chain, from upstream to downstream. We help entities, public and private, face their business, technological and governance challenges in constantly changing environments.

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