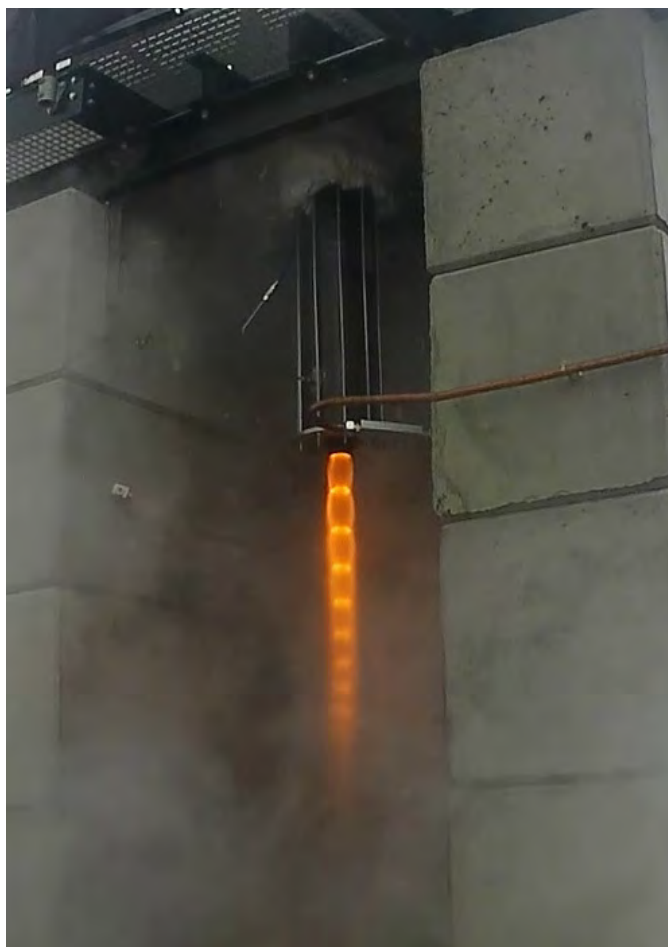




WHITE PAPER

BRIDGING THE GAP : AUTOPHAGE
PROPULSION AS AN ENABLER FOR
EUROPEAN MICRO-LAUNCHERS



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EXECUTIVE SUMMARY

European micro-launch services cannot compete with global providers such as SpaceX on cost and launch frequency. To become competitive, European micro-launchers face four critical challenges:

- Achieving launch costs below current rideshare pricing of \$7,000/kg.
- Scaling operations to 35–50 launches per year within five years of entering service.
- Remaining technologically competitive through innovation.
- Meeting increasingly stringent environmental sustainability requirements.

To address these challenges, Alpha Impulsion is developing an autophagy propulsion system, a rocket architecture in which the vehicle's combustible fuselage is consumed as fuel during flight, improving mass efficiency. Autophagy propulsion reached TRL 4 following successful testing of a demonstrator in 2025, with larger-scale testing planned for 2026–2028. This architecture offers several key advantages:

- Lower costs: Eliminating tanks, feed systems, structural components, and stage separation reduces manufacturing complexity and operational costs. Launch costs could fall to around

\$4,600/kg, making dedicated launches competitive with rideshare services.

- Higher performance: By minimizing structural deadweight, autophagy propulsion can increase payload capacity or reduce launcher mass. The technology could double payload capacity compared with conventional micro-launchers.
- Improved reliability: Removing structural components, tanks, feedlines, and stage separation mechanisms eliminates systems responsible for many launch failures.
- Environmental benefits: A lighter launcher requires less propellant, reducing emissions. The approach could lower the carbon footprint of launch operations by more than 38%.

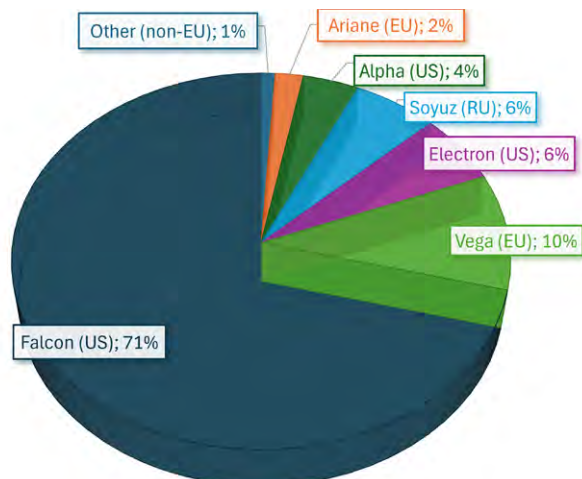
Beyond launch vehicles, autophagy propulsion also offers advantages for in-space propulsion. An autophagy thruster could reduce mission launch costs by up to 31% while using safer propellants.

Overall, the white paper positions autophagy propulsion as a disruptive architecture capable of enabling a viable generation of small satellite launchers.

INTRODUCTION AND CONTEXT

Spacecraft miniaturisation and the advent of low-cost launches have favoured the emergence of small satellite platforms, a market segment in which Europe is actively participating. Aerospacelab (Belgium) is opening the third largest satellite factory in the world, capable of producing 500 satellites per year. And it is not the only company scaling up its manufacturing capacity. Other examples include Berlin Space Technologies (Germany, 200 small satellites per year) and U-Space (France, 300 nanosatellites per year). But European launch capabilities are not keeping up.

Between 2020 and 2025, 88% of the 269 nanosatellites built by European manufacturers were launched by non-European rockets



Launch vehicles of European nanosats, 2020-2025

In 2025, seven successful orbital launches were carried out by European actors: three Vega-C and four Ariane 6. The vast majority of smallsats (71%) were launched by the Falcon family of rockets operated by SpaceX. The uncontested dominance of SpaceX in the small satellites launch market can be explained by the three criteria smallsats operators prioritize:

launch schedule availability, orbital destination, and launch cost.

While European providers offer only a few launches per year, SpaceX conducts more than one hundred annually, ensuring high schedule availability. In terms of pricing, the company currently charges \$7000 per kilogram for payloads that fully comply with the rideshare user's guide, with prices increasing by \$500 per kilogram each year. Tailored to small satellites customers, this standardized pricing model offers lower-cost and more predictable alternative to case-by-case negotiations with other launch providers. A broader range of orbital destinations remains the only missing element in SpaceX's offering to fully complete the trifecta of schedule, orbit destination, and price. The company only conducts up

to five rideshare missions per year and occasionally opens Starlink launches to secondary payloads.

Trying to compete by offering sovereign solutions, the market has seen the emergence of micro-launchers.

These vehicles, 10 to 100 times smaller than traditional launchers, are designed to provide dedicated launches at a high cadence, with many targeting 35 to 50 launches per year. They reduce the logistical complexity associated with rideshare missions and fulfil two of the three key criteria for customers: choice of orbital destination and launch schedule. Yet, like taking a taxi instead of a bus,

this dedicated service is three to ten times more expensive than rideshares.

This cost difference is prohibitive for most small satellite operators, for whom launch expenses account for 30 to 50% of the total mission budget. For example, a 300kg small satellite initially budgeted at \$3.9 millions with rideshare could see its total mission cost increase to \$9.5 millions when launched by the current micro-launcher market leader Rocket Lab. Because of this competitive disadvantage, the company has struggled to capture significant market share. Its Electron launcher represents only a small fraction of European nanosatellite launches (5.6%), and the company achieved 75 successful launches over nine years. This falls short of the critical mass required to compete on availability and pricing.





MICRO-LAUNCHERS' NEEDS

To be commercially viable and achieve sustainable growth, micro-launchers must address four essential needs:

02

Remain technologically relevant in the long term

Reusability is reshaping the economics of space access, with the potential to dramatically reduce launch costs and increase operational cadence. To avoid obsolescence, European micro-launchers must pursue clear innovation goals, focusing on reusability, manufacturing automation, Industry 4.0 integration, modular architectures, and other high-impact technologies capable of delivering substantial performances and cost improvements.

01

Compete with rideshare pricing of \$7000/kg

Despite offering greater flexibility, micro-launchers remain too expensive for many customers. To capture meaningful market share, they must reduce their launch cost below that of rideshare.

03

Reach 35 to 50 successful launches per year, within five years of flight operation

The Falcon 9 launcher, developed by SpaceX, reached 20 launches per year in 2020 after 12 years of operations and exceeded 160 launches in 2025. Enabled by large-scale investments and innovation, this approach generated significant economies of scale and reduced costs. To meet commercial expectations, amortize development costs, and lower per-launch expenses, micro-launchers must reach industrial ramp-up, with scalable and reliable production and operations.

04

Answer growing demands for environmental sustainability

Most launch vehicles generate significant CO₂ emissions per flight and lack comprehensive strategies for end-of-life disposal and space debris mitigation. Future launch systems must comply with emerging regulatory frameworks such as the EU Space Act. These requirements include declaring the environmental footprint of the entire mission lifecycle, designing spacecrafts to minimize debris and enable in-orbit servicing, implementing collision-avoidance measures, and reducing light, radiofrequency, and other forms of environmental pollution.

To answer those challenges, Alpha Impulsion, as a launch service provider, was incorporated in 2022.

The company's unique technology: the autophage engine, has applications for launchers, in-space propulsion, and defense. In this document, the focus is on Garnet, Alpha Impulsion's autophage launch vehicle, which targets seven objectives to answer the needs identified above.

Need Alpha Impulsion's Objective

01 01

Compete with rideshare pricing of \$7000/kg

Drive operating cost below \$7000/kg to enable commercial solution at a price competitive with rideshare. This includes the direct decrease of the cost of the propulsion system itself and indirect cost reduction due to the vehicle architecture simplification and higher engine efficiency.

02 02

Remain technologically relevant

Complete by the early 2030s the technological maturation and qualification of an autophage engine delivering 15 tons of thrust.

03 03

Reach 35-50 successful launches per year within 5 years of operation

Eliminate components responsible for at least 30% of mission failure root causes.

04

Provide an industrial ramp-up to 50 Garnet manufactured per year by 2040. This will be mainly achieved thanks to manufacturing cost reduction, simplified Assembly, Integration & Testing (AIT), and a shorter supply chain.

04 05

Answer growing demands for environmental sustainability

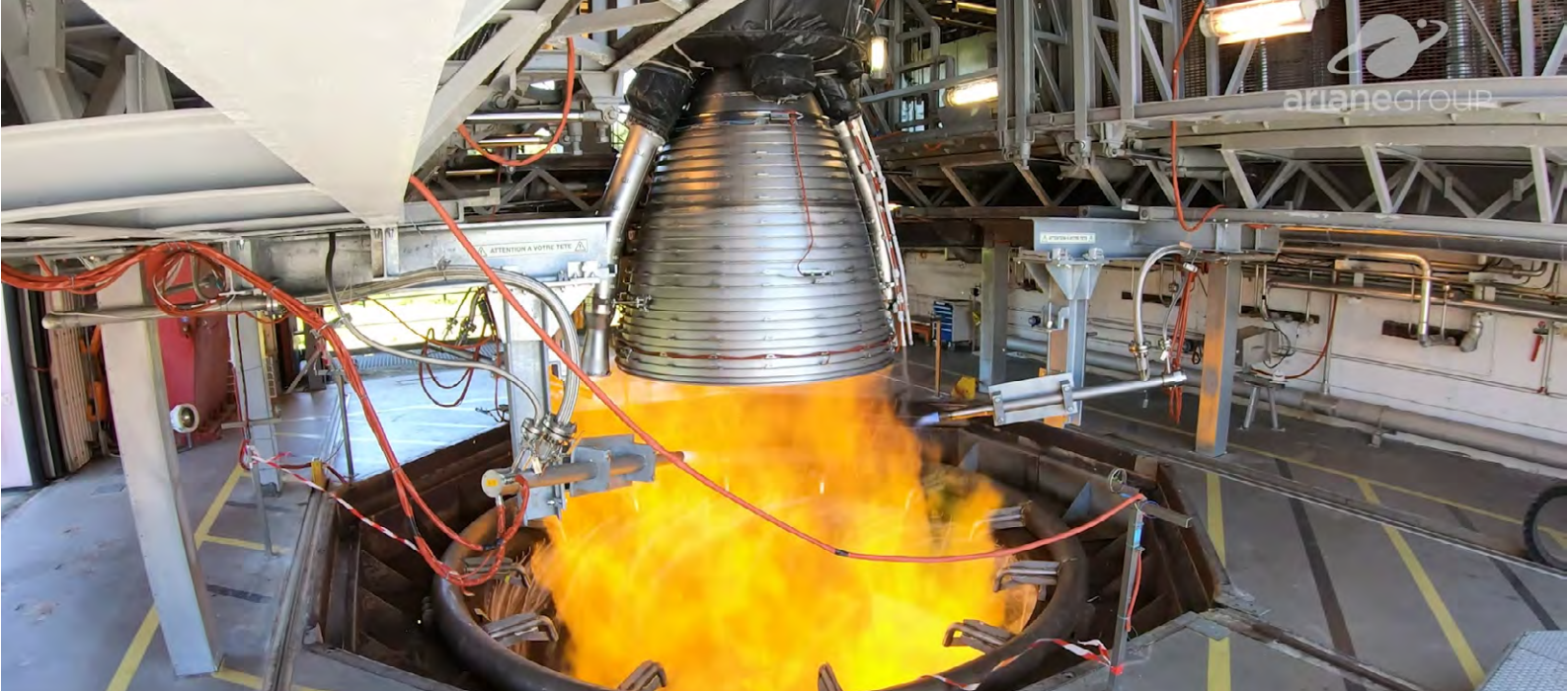
Enable a reduction of the carbon footprint of launch activities by more than 38%. Aligned with the EU Space Act Proposal (June 25, 2025), the solution helps launch actors assess and lower their environmental impact, supporting compliance with the Paris Accords and the French 2025 Carbon Reduction Roadmap, to which Alpha Impulsion contributed.

06

As part of its pledge with the signature of the ESA Zero Debris Charter, Alpha Impulsion aims to drastically reduce the amount of debris both in space and on the ground during nominal and emergency procedures.



Photo: Garnet on the launch pad



CURRENT PROPULSION SOLUTIONS

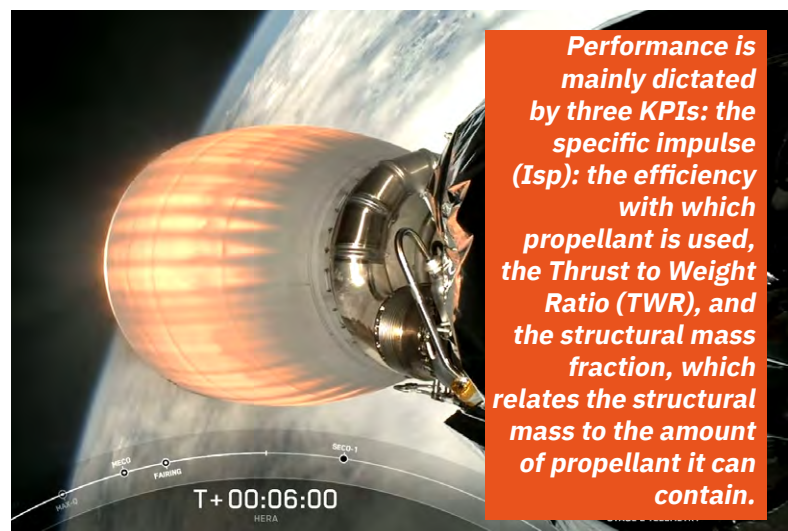
In 1903, Konstantin Tsiolkovsky published his rocket equation for the motion of rocket-propelled vehicles.

$$\Delta V = I_{sp} \ln \left(\frac{M_w + M_u}{M_d + M_u} \right)^1$$

It relates the velocity increment ΔV achieved by the vehicle to the efficiency of its engine, its mass and the amount of propellant. 20th-century rocket scientists focused on building more performant engines, transitioning from solid rocket motors to liquid rocket engines in the 1920s. They also began developing larger launch vehicles capable of carrying greater amounts of propellant. However, the higher the propellant load, the larger the tanks must be. Larger tanks (and their associated structure and systems) add mass, which in turn requires even more propellant. These diminishing returns reflect the exponential nature of the rocket equation.

To counter this exponential increase in mass, engineers introduced staged rockets: once a tank is emptied and becomes dead weight, it is discarded. Single-stage rockets would be a less complex, less costly, and a more reliable solution. However, they have historically lacked the performance needed

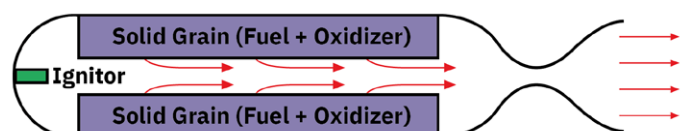
to reach orbit. To this day, the single-stage-to-orbit (SSTO) rocket remains one of the holy grails of astronautics.



SpaceX second stage burn - ESA's Hera mission
Photo credit: SpaceX

Performance is mainly dictated by three KPIs: the specific impulse (I_{sp}): the efficiency with which propellant is used, the Thrust to Weight Ratio (TWR), and the structural mass fraction, which relates the structural mass to the amount of propellant it can contain.

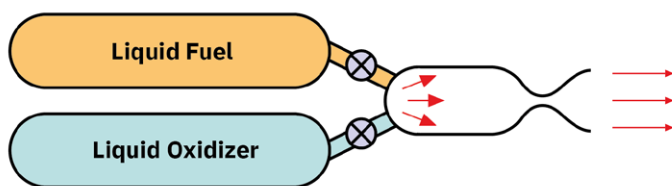
Solid Propulsion



Solid rocket motors employ mixed powdered oxidiser and fuel in a binder, along with some additives. The grain self-pressurises the combustion volume and creates the flow of hot combustion products to generate thrust in the nozzle. They are cheap and easy to scale up, giving them a natural application as

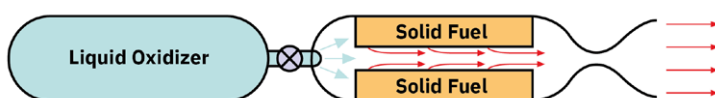
rocket boosters to generate a high amount of thrust for liftoff. They are however hard to refurbish after flight, the resulting solid propellant is explosive and cannot stop burning once ignited, and their exhaust products are noxious to the environment. With low specific impulse due to available propellants, and high structural mass due to the large pressurised chamber volume, fully solid launch vehicles are complex and rely on 4 to 5 stages to reach orbit. For these reasons, they do not fulfil the needs of modern micro-launchers.

Liquid Propulsion



Liquid engines rely on liquid fuel and oxidiser. The combustion chamber is very small, and modern tanks rely on light, but costly materials, such as special aluminum alloys or carbon composites. Compared to solids, liquid propulsion systems are throttleable, have higher specific impulses and a lower stage structural mass fraction, but they are more complex and costly to operate. With this, liquid launchers can reach orbit with two stages, and some of them are even able to achieve a single-stage-to-orbit flight, albeit without any significant payload.

Hybrid Propulsion



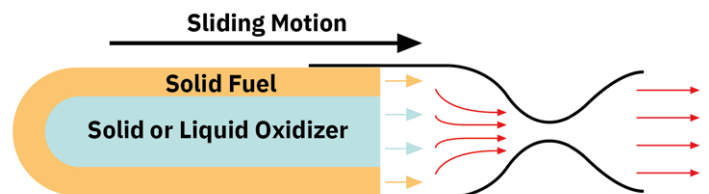
Hybrid rocket engines have long been an emerging propulsion technology. The combustion chamber is filled with a solid fuel grain which does not contain oxidiser. The liquid oxidiser is typically fed to the chamber through a blow-down cycle, though other feed systems are possible. This engine is simpler than liquids as it only requires a single fluid line, and is throttleable, unlike solids. In addition, hybrids rely on non-explosive propellants, making it

inherently safer than both solid and liquid systems. Yet hybrid propulsion systems remain mass inefficient, with a high structural mass fraction, due to the large combustion chamber made thick to withstand the pressure. For these reasons hybrid launch vehicles usually require at least three stages, and few launch actors have committed to the technology.

If conventional propulsion methods make sense for larger launchers, a major limitation emerges for micro-launchers: the scalability of the structural mass fraction.

As the vehicle gets smaller, the structural mass fraction increases, and the payload fraction decreases. This is why Falcon 9 achieves a payload fraction of around 4%, whereas the SS-520, the smallest orbital launch vehicle in the world, reaches only 0.15%

Autophagy Propulsion



What if the structure could be removed from the equation entirely? The best part is no part. It weighs nothing, costs nothing, and cannot fail. It requires no logistics, generates no pollution, and creates no debris, neither on Earth nor in orbit.

This approach is autophagy propulsion. By using the structure as propellant, the structure's scalability constraint is bypassed, and the vehicle can be made much smaller than conventionally possible. An autophagy rocket burns like a candle: it progressively shortens during ascent. At liftoff, the vehicle consists of a long combustible fuselage, up to dozens of meters in length. By the end of the flight, only the engine and the payload are left. No deadweight, only what is strictly necessary to reach orbit: engine, propellant and payload. This is the theoretically perfect solution with almost no structural mass.



AUTOPHAGE SYSTEMS PROGRESS

The idea of an autophage launch vehicle dates back to 1936 (Louis Damblanc), with further improvement being made on the concept in 1958 (L.W. Mullane) and 1960 (Z.A. Typaldos). However, a key material was missing: a structural fuel simultaneously strong enough to withstand launch and with excellent combustion properties.

Research efforts on autophage propulsion were revitalised in the 2000s through the work of V. Yemets at the Oles Honchar Dnipro National University (Ukraine)

Advancement in chemical science led to the apparition of strong engineering plastics, which had been independently used in hybrid engines. Over the past two decades, the Ukrainian research team developed and scaled their autophage technology from an initial 16 mm diameter lab-scale rocket testbed body to a 40 mm version entering testing in 2026. They employ two unmixed solid propellants, one of which is a thermoplastic tube intended to serve as the launcher's structure. A new component, the vaporiser, is used to vaporise the propellants on a hot metallic wall using chamber heat conducted through the wall. The resulting gases are injected into the combustion chamber, sustaining the cycle. Many issues related to the thermal management of the

combustion chamber arose during testing due to the high heat flows necessary to consume the fuel. The Ukrainian research group published a feasibility study for launchers (Golubek et al., "Assessing the possibility of using a variable-length launch vehicle with a polymer body for orbiting payload", 2024) funded by the EU program Horizon 2020.



Tested system - Dnipro / Promin Aerospace
perchlorate ammonium / polyethylene

Backed by Google in 2022, the group reorganised as a private company: Promin Aerospace. Their long-term plan includes the realisation of Zaarbird, a nano-launcher with a payload capacity of 3 kg, due to the limited thrust of the system. In 2024, the Ukrainian startup started relocating to Maine, USA.

Funded by the UK's Defence and Security Accelerator, the University of Glasgow has continued activities on autophage technologies.

The Ouroboros-3 engine (100N of thrust) solves the inefficiency of solid propellants with a tribrid architecture. A bi-liquid combustion ignites the structural fuel, which represents up to 15% of the fuel flow (Bzdyk, "Experimental development and performance investigation of a self-consuming, hybrid autophage rocket propulsion system", 2024). Liquid combustion increases the efficiency of the engine, as well as the complexity, with the need for two fluid lines in addition to autophage components. To store the liquid fuel and oxidiser, the University of Glasgow is investigating the use of collapsible tanks. The engine itself also remains prone to thermal management issues due to its internal architecture.



Ouroboros 3 - University of Glasgow
Gaseous oxygen / propane / polyethylene

Alpha Impulsion's hybrid autophage rocket engine sets out to solve both the complexity and heat management issues.

This architecture is simplified: the combustion is identical to hybrid propulsion, burning the liquid oxidiser directly with the solid polymer fuel. The fuel shields most of the chamber's wall from heat, avoiding thermal management issues. By being directly in contact, the combustion's heat transfer is maximised without risks, and the fuel is consumed at the maximum rate. Scale-up is possible and has been demonstrated in hybrid rocket engines ("Large-Scale CAMUI Type Hybrid Rocket Motor Scaling, Modelling, and Test Results", Tor Viscor et. al. 2021). Alpha Impulsion was able to demonstrate ignition and combustion of the largest autophage engine yet in May 2025, , reaching TRL 4, as part of the 1kN Amber subscale demonstrator test campaign¹. The company is currently hiring for upcoming test campaigns in 2027 and 2028.



Alpha Impulsion
Hydrogen peroxide / polyethylene

¹Gros, M., David, A., & Filleul, T. (2025, September 29). Static fire test of a piston-fed hybrid autophage engine.



TECHNICAL BENEFITS

Polymer fuel performance

In autophage propulsion, all structures and tanks are replaced by a combustible fuselage. This fuselage is made of a polymer such as High-Density Polyethylene (HDPE) or Nylon (PA6), selected for their excellent combustive properties and adequate mechanical characteristics. Polymers that are industrially available at low cost are weaker than alloys used in aerospace structures. But contrary to conventional tanking, there is no need to optimise the fuselage thickness to reduce mass. Instead, fuselage thickness is determined by the optimal mixture ratio of Oxidiser-to-Fuel (O/F) to be burned in the chamber. Thicker walls mean more fuel and less oxidiser, resulting in a lower O/F ratio.

Achieving optimal combustion conditions therefore leads to a much thicker combustible fuselage compared to conventional tanks: up to 70 times thicker. This thickness also allows the structure to withstand mechanical loads while providing effective thermal insulation.

The table below compares static and dynamic structural performance, as well as combustion performance, to a conventional LOX/RP-1 propulsion system with a 2195 Al-Li tank (such as a Falcon rocket stage). Autophage fuselages can withstand 6 times higher static loads (illustrated by burst pressure) and bends 2 times less for the same dynamic load (illustrated by bending stiffness).

	Average density	Thickness	Burst pressure	Bending stiffness	Specific Impulse
LOX/RP-1 propulsion system with a 2195 Al-Li tank	1020 kg/m3	4.76 mm	18 bar	7 GPa.m ⁴	351s
Autophage LOX/HDPE (cryogenic)	1080 kg/m3	340 mm	115 bar	15 GPa.m ⁴	351s
Autophage HTP/HDPE (storable)	1317 kg/m3	181 mm	20 bar	3 GPa.m ⁴	335s
Autophage HTP/ABS (storable)	1313 kg/m3	212 mm	42 bar	7 GPa.m ⁴	333s
Autophage HTP/PA6 (storable)	1340 kg/m3	223 mm	112 bar	13 GPa.m ⁴	335s

Propellants combination performance ¹

¹ O/F optimised for vacuum specific impulse (NASA-CEA 30 bar chamber pressure, 200 nozzle expansion, frozen at throat); 3.7 m diameter fuel; burst pressure by Tresca criterion; Bending stiffness approximates structures to a 12 Euler-Bernoulli 1D beam

According to United Launch Alliance, structures can account for up to 25% of a rocket's cost, as they are large precision-machined parts, made from expensive alloys. By contrast, the cost of the combustible fuselage is significantly lower

	HDPE	PA6	ABS	RP-1
Sourcing (European Plastic News)	1.00	3.00	5.00	-
Manufacturing (10 year depreciation)	1.90	1.51	1.60	-
Power (France reference)	0.21	0.21	0.21	-
Personnel	0.15	0.15	0.15	-
Total	3.26	4.87	6.96	1 to 4

Cost per kg of fuel (2025 euros)

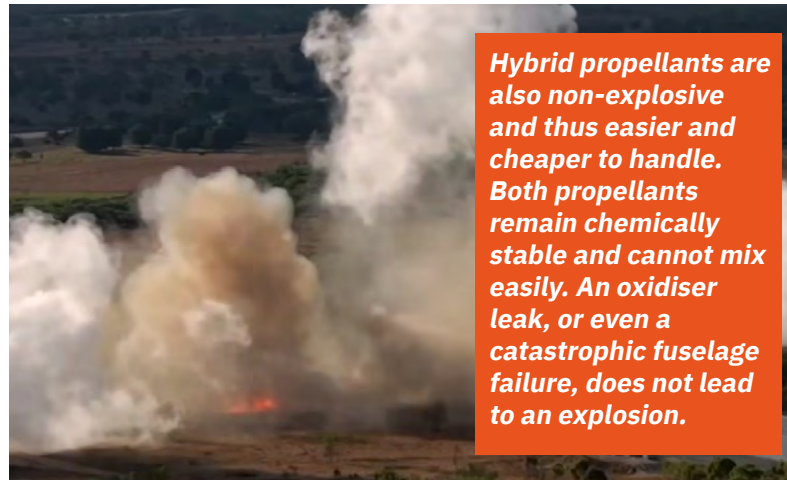
Regarding Global Warming Potential (GWP) of the fuel, combustion produces several byproducts including soot and CO₂. However, soot represents the vast majority of CO₂e emissions due to its high GWP, estimated at 1,116kgCO₂e/kg, based on assumptions similar to those used by leading researchers in the field: Dr Martin Ross, Dr Guillermo Dominguez Calabuig and Lois Miraux. As pollutants in the upper atmosphere can take up to centuries to be neutralised¹, this estimation is yet to be validated for higher altitudes, where soot impact could be 1000 times higher. A trade study assessing both technical feasibility and environmental performance of several fuselage polymers showed that polyethylene is the best fuel choice, emitting four times less soot than ABS.

	HDPE	PA6	ABS
Polymer production (worst case)	5.5	26.6	7
Fuselage manufacturing & logistics	2.9	3.2	2.8
Combustion	229.4	260.1	187.4
Total	237.8	289.9	797.2

Carbon footprint per kg of fuel in kgCO₂e

20g of soot per kg of propellant is the accepted value for most open cycle hydrocarbon-based engines such as KERO/LOX engines². Thanks to its closed-cycle design and assuming normal combustion effi-

ciency, Alpha Impulsion estimates that an autophage HDPE/LOX system would release approximately 10g of soot per kg of propellant.



Gilmour Space launch attempt - 2025

Eliminating structural mass

A rocket stage's wet mass M_w is the sum of propellant mass M_p and dry mass M_d (which includes all propulsion-related equipment and interfaces, as well as tanks and structure). The velocity increment ΔV imparted by the stage to a useful mass M_u (which can be anything from a satellite payload to another stage) is described by Tsiolkovsky's rocket equation:

$$\Delta V = I_{sp} \ln \left(\frac{M_p + M_d + M_u}{M_d + M_u} \right)$$

$$= I_{sp} \ln \left(\frac{M_w + M_u}{M_d + M_u} \right)$$

Every kilogram saved on dry mass can be added to the useful mass. To increase ΔV , one can rely on a higher specific impulse I_{sp} or additional propellant. With more propellant however, comes larger tanks, increasing dry mass and diminishing returns on ΔV : the tyranny of the rocket equation.

The disruptive nature of autophage propulsion resides in eliminating dry mass, especially structures, tanking and feedlines. As opposed to conventional stages, an autophage system's wet mass is independent of its dry mass. Theoretically, as much propel-

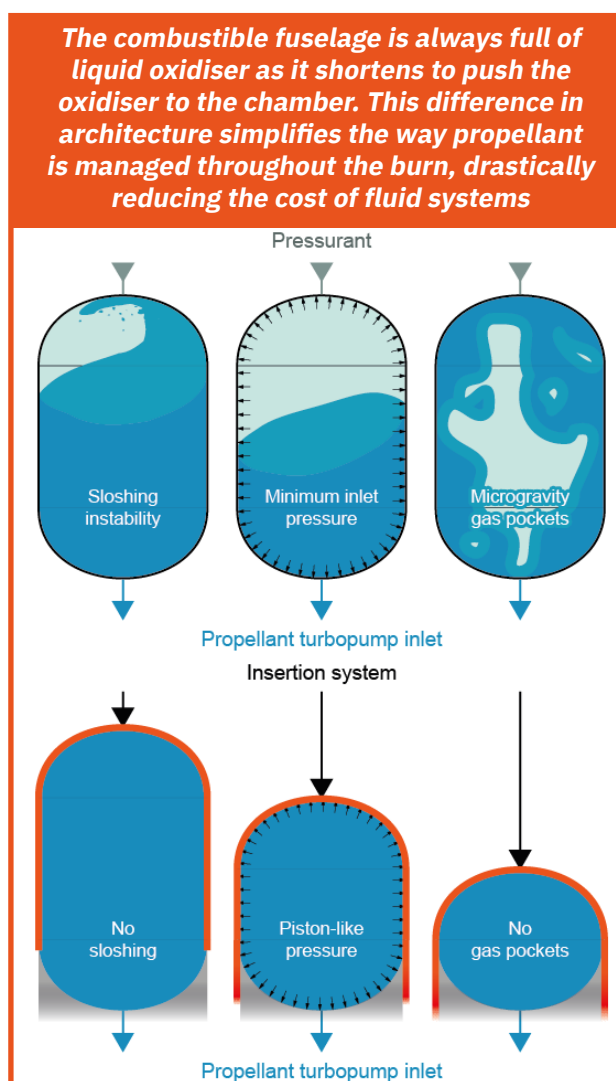
¹ The potential impact of solid rocket propellants on the atmosphere: An overview, N. Slavinskaya, et al. EUCASS

²Eco-design of future reusable launchers : insight into their life cycle and atmospheric impact, Guillermo J, et al, EUCASS

lant can be added without ever increasing dry mass.

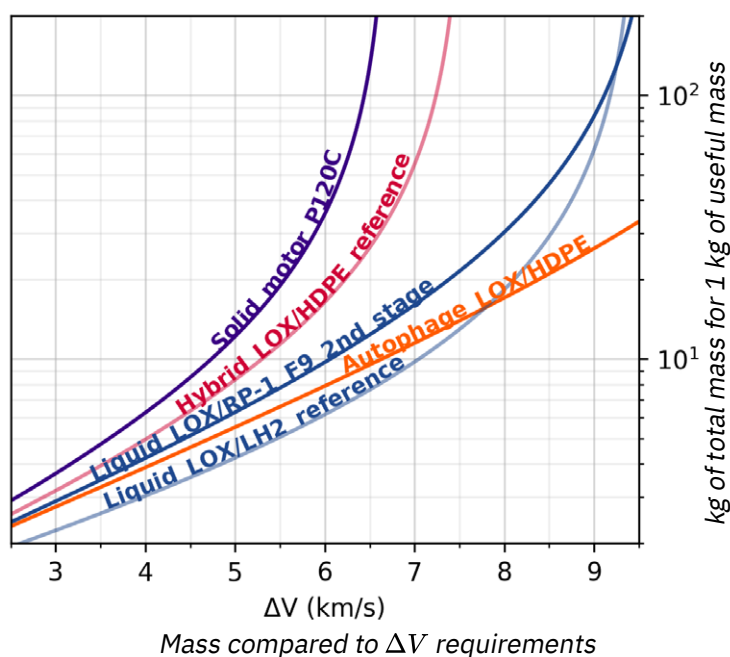
For an autophagy system, the only practical limit is the engine's TWR for the launcher to be able to lift off (between 50 to 184 in the state of the art). When used as 1st stage propulsion system, this translates into clear benefits for launch manufacturers. Comparing an autophagy engine with a TWR of 70 to a state-of-the-art liquid stage, autophagy propulsion can either provide a lighter vehicle wet mass (-32%) or a higher useful mass (+29%)¹. For 2nd stages, the engine does not have to lift off the full weight of the vehicle. Going as low as a TWR of 2, this results in even greater performance: -86% wet mass or a 600% increase in useful mass.¹

¹ Compared to Falcon 9's 2nd stage: 3.9 t of dry mass, 96.6 t of wet mass, 340 s specific impulse and 6800 m/s ΔV , and considering $TWR = M_w / M_d$ for autophagy





INFINITE-STAGE-TO-ORBIT VEHICLE



The graph above describes the mass of a rocket stage depending on the ΔV it must achieve. To propel a 1-ton upper stage and payload, a solid first stage with 4.5 km/s of ΔV would weight 8.5 tons at liftoff, an hybrid first stage 6.4 tons, a liquid stage a minimum of 3.6 tons, and an autophase first stage would weight 4.6 tons. In this ΔV range, specific impulse is the dominant factor. Technologies which have the most efficient engines lead to the smallest launcher's mass.

The case of reaching orbit

However, as ΔV increases, overall mass-efficiency becomes much more valuable than specific impulse. The RP-1/LOX Falcon 9 second stage becomes lighter than the hydrogen stage, despite using a less efficient fuel. This is because hydrogen is a cryogenic, requiring additional tanking complexity and consequently, mass.

To reach orbit, a minimum of 9.5 km/s of ΔV is necessary, which is conventionally achieved with multiple stages. The most performant solid propulsion system cannot exceed 6.5 km/s in a single stage, and hybrid propulsion can reach a little higher than 7 km/s. Only liquid propulsion, in the very best conditions, can reach 9.5 km/s in a single stage. Theoretically, a launch vehicle of 13 tons employing similar technologies as Falcon 9's upper stage (310 s of specific impulse, mass ratio of 24.8) could bring 50 kg of payload to LEO in a single stage. The dry mass of the vehicle would be 520 kg. As the vehicle is a single stage, any increase in dry mass would drastically impact payload capacity: a 10% dry mass increase would reduce payload capacity to 0 kg. This is why SSTO are unfeasible in practice.

An autophage propulsion system fundamentally changes this limitation by continuously consuming part of the vehicle’s own structure as propellant during ascent. In this sense, the vehicle behaves as an “infinite-stage-to-orbit” (“ISTO”) system, constantly shedding, or consuming, small portions of itself rather than relying on staging events. Equipped with such a system, the 13 tons vehicle discussed earlier could theoretically deliver ten times more payload (500 kg) while reducing dry mass to less than half (210 kg). Thanks to its exceptionally low dry mass, an autophage system outperforms any other options at high ΔV . This leaves a lot more margin for the ISTO launch vehicle and greatly reduces sensitivity on dry mass: a 10% increase would reduce payload capacity only marginally, from 500 kg to 475 kg.

Double the payload

An autophage ISTO can be more performant than a two-stage launcher using conventional propulsion. When compared to two-stage liquid micro-launchers, it leads to a drop of the structural deadweight from 7% to 2% of lift-off mass, which cascades into lower amounts of propellants and therefore a much lighter vehicle. The next table offers a subsystems-level decomposition comparing the 13 tons Electron micro-launcher and the same vehicle using an autophage engine, showing the large advantage in dry mass.

	Liquid	Autophage
Faring and adapter	0.28	0.28
Engines	1.75	0.40
Tanks and separation	5.58	-
Propellant	56.5	29.3
Lift-off mass	64.11	29.98
payload to SSO	1.56%	3.33%
500km	of lift-off mass	of lift-off mass
	<i>kg for 1 kg of payload¹</i>	

At mini-launcher scale, an autophage application demonstrates significantly improved

performance, with twice the payload at an equivalent size than a state-of-the-art launcher. This performance result directly halves every “per kilogram” metric, such as the “price per kg” or the “carbon footprint per kg”.

Lower cost

To reduce cost, all modern commercial vehicles have converged to reducing the number of rocket stages and the number of parts. Each stage is an added complex system, which needs to be manufactured, independently tested, transported, mated, fuelled, etc. For an autophage ISTO, the full cost of the second stage and its separation system can be removed from the equation. Naturally, the cost of the rest of the vehicle (such as avionics or payload bay) is completely unrelated to the propulsion system and remains strictly identical. This results in a drastic cost improvement.

Reference data from the \$OLSTICE costing method is used, with a lower cost of structures, lower cost of pressurisation, no separation systems, no second stage, and twice the payload capacity for autophage. For all other cost drivers, the cost estimates of the reference case are used. Due to its intrinsic advantages, autophage’s launch cost per kg is found to be 4600 \$/kg: 6 times lower than \$OLSTICE’s reference. This pricing, which is already competitive against rideshare on larger launchers, can get lower with less conservative hypotheses than \$OLSTICE: increased launch rates and the “learning curve” effect of lower manufacturing costs for higher manufacturing rates.

Often criticised, this price per kilogram of payload metric is highly dependent on the assumed launch rate, launch orbit, and which cost elements are included. Nevertheless, it allows for a quick comparison between differing launchers and remains a good illustration of the economies of scale applicable to large launchers.

Lower GWP

Regardless of the propulsion system employed, global warming power (GWP) is primarily driven by launch exhaust, which account for up to 48% of total emissions. Propellant production represents a smaller fraction of the overall footprint, typically between 6% and 12%. Emissions from other sources, most notably manufacturing, logistics, and vehicle integration, make up the remainder and are approximately proportional to the size of the launcher.

The most effective measure of GWP reduction thus advocates for lower propellant consumption. Mass reduction of the autophage launcher translates to reduced propellant requirements and consequently fewer pollutants are released at each altitude. Due to that mass advantage, GWP of an autophage launch exhaust is seven times lower than that of a kerosene launcher (high soot) and is comparable to that of a methane launcher. Indeed, one kilogram of methane pollutes less than HDPE, but the autophage launcher is two third of the size.

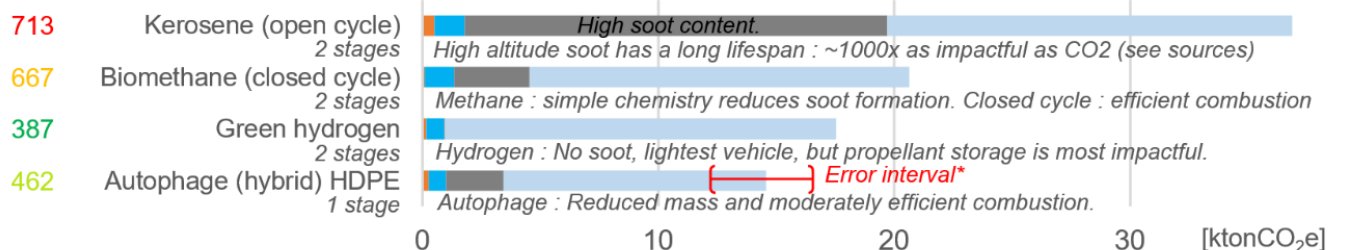
Autophage propulsion offers clear advantages in this regard: fewer components and lower propellant requirements reduce the overall carbon footprint more effectively than conventional green alternatives.



For an ISTO launcher, no stage separation occurs, with no resulting debris falling back in the ocean. Once in orbit, autophage propulsion is a re-ignitable technology, ensuring the capability to de-orbit at the end of the mission.

Launcher lift-off
mass (ton)

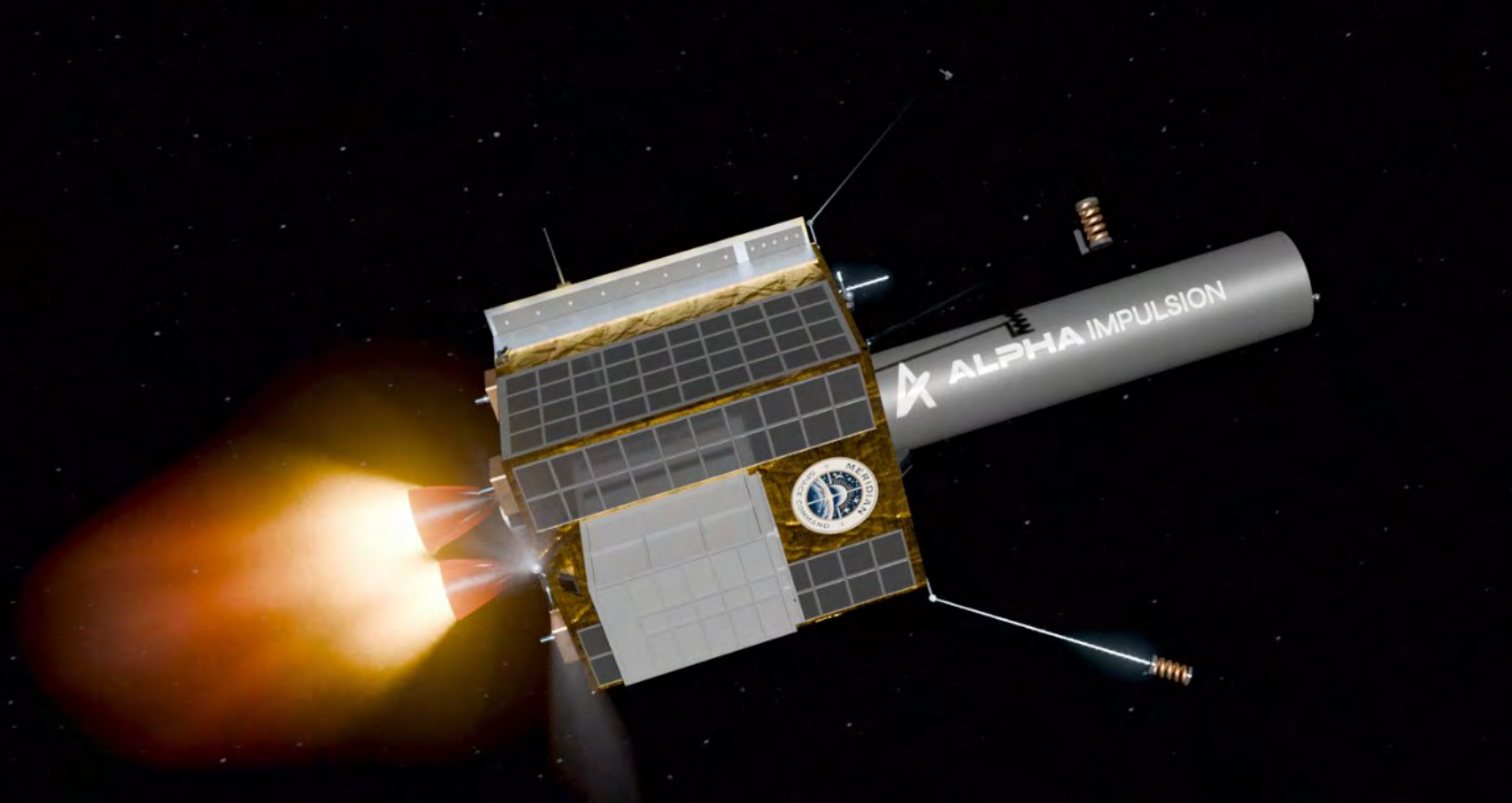
Carbon footprint of generic launchers
CO₂-equivalent per launch (scale: 20-ton payload)



*The error interval captures variations in soot emissions: ranging from no soot to levels equivalent to open-cycle kerosene, and in lifecycle modeling: from no simplification brought by autophage to complete omission of second-stage impacts.

Sources: Dominguez Calabuig 2022 (DOI:10.13009/EUCASS2022-7353), Schabedoth 2020 (NTNU Open), Alpha Impulsion

Fuel Production Oxidant production
Launch exhausts Other lifecycle stages



SATELLITE APPLICATIONS

Current solutions

The market for satellite chemical engine (high thrust, high Isp) is largely dominated by conventional bipropellant systems. Legacy chemical thrusters (e.g. the S-family by ArianeGroup) benefit from extensive flight heritage. However, their flexibility is limited: even minor modifications to feed lines, tank materials, or pressure regimes typically require full requalification. To optimise cost, emerging companies introduced mass-produced modular thrusters, like Dawn Aerospace's B20, which can be combined to reach desired thrust and impulse. It improves scalability but comes with a higher dry mass, raising launch costs. Conversely, systems for ambitious or high ΔV missions are often bespoke, involving high capital expenditure and little to no scalability. In addition, commonly used propellants are frequently toxic, adding operational complexity. As a result, high-efficiency electric propulsion is becoming increasingly widespread. While highly effective for orbit maintenance, they provide very low thrust. Manoeuvres which require minutes with chemical propulsion will last months with electric systems, leading to a

prolonged Launch and Early Orbit Phase, commercial delays, and associated financial losses.

Autophage propulsion is relevant for ΔV requirements exceeding 1500 m/s

The dry mass of conventional chemical propulsion systems for satellites is also subject to the tyranny of the rocket equation. For small missions (100-1000 kg), propulsion typically represents 20–30% of the total system's mass¹. For these applications, Alpha Impulsion is developing a 300 N engine named OPAL, based on its subscale autophage rocket engine demonstrator. Depending on the mission need, the length of the thruster is adapted to match the amount of propellant required, always keeping the same dry mass of 15kg. The propulsion system runs on storable, green and non-explosive propellants (PA6/HTP) and can also be used in a cluster to propel larger vehicles. A preliminary study led in partnership with the Space Business Catalyst of Thales Alenia Space highlighted how autophage propulsion can offer significant savings compared to state-of-the-art

Use case	Usefull mass (kg)	Thruster	total mass (kg)	Propellant mass (kg)	Propulsion mass (kg)	Launch cost (\$M)	Launch cost reduction
1	50	SOTA	374	285	40	2.62	26%
		Autophage	277	213	15	1.94	
2	50	SOTA	659	561	49	4.61	31%
		Autophage	451	386	15	3.16	

Gains of in-space autophage propulsion¹

(SOTA) thrusters. Two scenarios have been considered:

1. Transfer of a 50 kg vehicle from LEO (rideshare) to LLO, estimated ΔV of 4.5 km/s.
2. Multi-mission space tugs of 50 kg delivering ΔV of 6 km/s.

A simplified mass model is used to estimate the performance of the engine. To match efficiency, the analysis assumes the same nozzle expansion ratio of 330.

Across the two scenarios investigated, using autophage propulsion can reduce launch cost by up to 31% due to the reduced dry mass. At the same time, the propellants used on OPAL (PA6/HTP) simplify operations and further reduce costs, as they are non-toxic, non-explosive and safely storable.

Additionally, autophage systems are ideally positioned to launch spacecrafts to the moon. As validated by the UK Space Agency in 2026, an autophage spacecraft would be able to send a 50 kg payload to Low Lunar Orbit at €65 000/kg. Five to ten times cheaper than conventional systems. The key to this cost advantage is the very low dry mass of the OPAL engine, enabling the use of widely available low-cost rideshare to LEO.



¹ Scenarios 1 and 2 use official Falcon 9 rideshare pricing tools

TO GO FURTHER

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