# More Added Value? – An Investigation on the Commercial Benefit of Different EP Technologies for Orbital Propulsion

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**Abstract: With full-electric and hybrid propulsion platforms gaining more and more appearance this investigation – as part of H2020-GIESEPP - is aiming at assessing the commercial impact of the chosen electric propulsion system and technology, not only on a short-term at platform realization but on its full life cycle until de-orbiting. Several representative use cases are proposed and different parameters are suggested for adaptation. Comparison is done mainly between gridded ion engine – type systems (GIE) and Hall-effect thrusters (HET). It is showed that in select cases significant added value can be obtained using the most suitable technology.**

## Nomenclature

| | | |
|---|---|---|
| BEP | = | Break-Even Point |
| EOL | = | End-of-Life |
| EOR | = | Electric Orbit Raising |
| EP | = | Electric Propulsion |
| EPS | = | Electric Propulsion System(s) |
| FSS | = | Fixed Service Satellite |
| Gbps | = | Gigabit per second |
| GEO | = | Geostationary Orbit |
| GIE | = | Gridded Ion Engines |
| GIESEPP | = | Gridded Ion Engine Standardized Electric Propulsion Platforms |
| GS | = | Ground Station |
| GTO | = | Geostationary Transfer Orbit |
| ISP | = | Specific Impulse |
| LEO | = | Low Earth Orbit |
| LEOP | = | Launch and Early Orbit Phase |
| HET | = | Hall-Effect Thrusters |
| HEMPT | = | High Efficiency Multistage Plasma Thruster |

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| | | |
|---|---|---|
| HTS | = | High Throughput Satellite |
| H2020 | = | Horizon 2020 |
| MEO | = | Medium Earth Orbit |
| OR | = | Orbit Raising |
| PP | = | Procurement Price |
| ROI | = | Return on Investment |
| SK | = | Station Keeping |
| S/C | = | Spacecraft |
| TCO | = | Total Cost of Ownership |

## I. Introduction

IN the frame of EU´s Horizon 2020 Research and Innovation Programme several technologies are being fostered, whereat electric propulsion technologies for space applications are considered. Indeed both validated EP technologies and to-be-confirmed technologies receive a non-negligible quantum of support.

At the same time the market for space-related equipment, systems and services has been dramatically evolving in the last five years or so with more and more disruptive players showing up with corresponding concepts and business ideas. This has led to a dramatic increase in commercial pressure on confirmed market participants all along the value chain, from service providers down to satellite system houses and to equipment manufacturer.
In this context GIESEPP – Gridded Ion Engine Standardized Electric Propulsion Platforms - is engaged as H2020´s program for Gridded Ion Engine technology, conceiving a range of differential, modular EPS for LEO, MEO and GEO applications, extendable for deep space exploration. Even though – as by nature – a particular emphasis is given on the technical setup of the solution, competitiveness is clearly a key driver. Thus this investigation has been initiated to extend the engineering-centric view to a more holistic approach. Instead of simplistically reflecting a technical solution to a set of platform requirements ending up with calculated procurement costs for the EPS, the extended related life cycle has been considered, from planning the platform to its de-orbiting. Doing this, transparency on the impact of a technical choice on the overall cost situation was searched.

The intention of this document is not to emit "given truths" but to invite further deliberations by all concerned stakeholders in order to gain a further added value all along the value chain and also to consider a means helping to estimate the TCO of any satellite setup according to defined inputs. This paper focuses on telecommunications satellites. A further work will be developed in order to add new cases such as navigation and observation satellites and also to compare other EP technologies.

## II. Methodology

WHILE variances addressing the topic are countless a classical systematical approach has appeared to be of the essence. As such a "traditional" engineering proceeding for space mission, payload and spacecraft designs

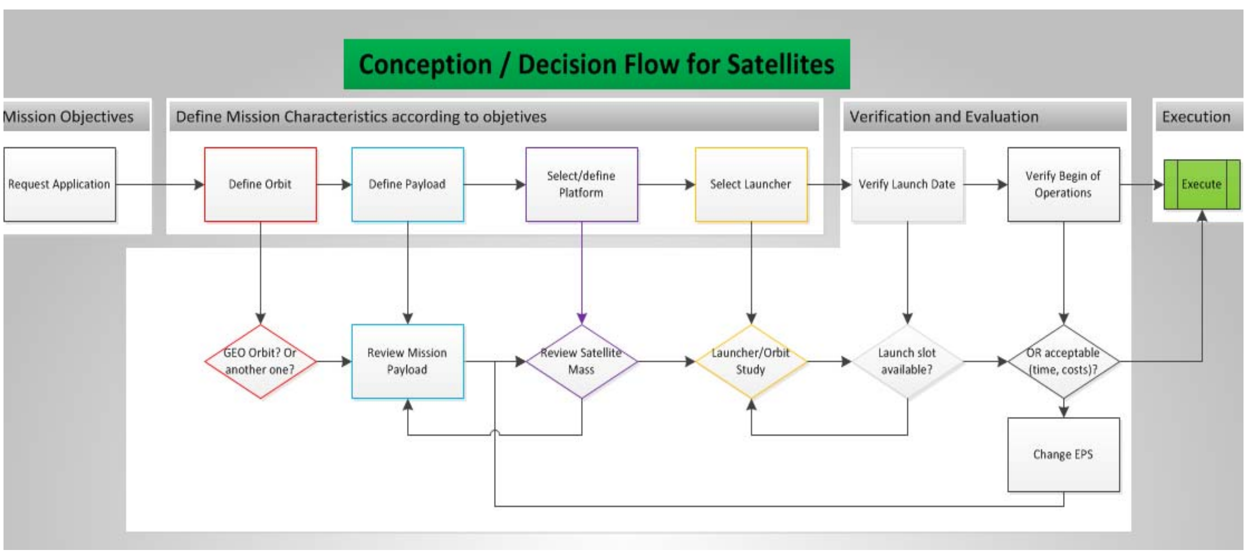


**Figure II-1 Decision Flow Chart for a Typical Satellite Mission and Design**

has been taken as bottom line as derived from general references[1,2] and reflected in the flow diagram in Figure II-1. Based on this a defined quantity of technical parameters on different levels has been identified for appropriate assessment. Table II-1 lists all select parameter directly inducing costs by engineering considerations. Whereby four distinct parameter types can be differentiated: a) parameter to be given as input, b) parameter that are set fix following the given input under a), c) parameters that will either set fix or be calculated in an individual iteration loop, and d) the dedicatedly calculated parameters. In parallel a commercial assessment has been derived investigating both the costs and the revenues. Table II-2 shows the commercial parameters following the same logic and directly linked to inputs given as just mentioned.

**Table II-1 Technical Parameters considered for each iteration loop**

| **Input Parameter** | Satellite Type (Mission, Class) | Operational Orbit | Ejection Orbit | Operational Lifetime | EPS Type |
|---|---|---|---|---|---|
| **Derived Fixed Parameter** | Available electric Power | De-orbiting Time | | | Thruster Characteristics (Thrust, ISP) |
| **Derived Variable Parameter (fixed or calculated)** | Satellite Payload (transponder qty & data rate) | Launcher Type | OR ΔV | Thruster Quantity | SK ΔV |
| **Calculated Parameter** | OR Time | Propellant Mass | Satellite Wet Mass (effective) | | |

**Table II-2 Commercial Parameters considered for each iteration loop**

| **Input Parameter** | Propellant Price | | | | |
|---|---|---|---|---|---|
| **Derived Fixed Parameter** | Procurement Time | Basic Satellite Procurement Price (platform) | Insurance to Orbit | Insurance in Operations | Costs of Operations |
| **Derived Variable Parameter (fixed or calculated)** | Financing Costs | Payload Price | | | |
| **Calculated Parameter** | Propulsion Price (EPS + Prop.) | Total Procurement Price | Launch Costs | Total Costs per year | Revenue per Year |

At first a broad segmentation of the investigated life cycle has been sketched in order to enable a distinct evaluation of the relevant impacts. The four deduced phases are defined as:

1. Planning and Procurement.
2. LEOP.
3. Operations.
4. De-orbiting.

For this investigation the ground rule was set that the main cost drivers were influenced in period 1) Planning and Procurement and 2) LEOP while 3) and 4) has been widely left unaltered.

In brief the major topics of interests per phase can be summarized as follows:

1. After the mission has been defined the main characteristics of the system, the orbit definition, the payload and platform will see continuous iterative assessments along going with the launch and orbit

transfer elements and the operational setup. All those get both technical and commercial considerations until all necessary trade-offs will reach a system freeze.

2. It includes the Launch Preparation, the Launch itself and OR. Even though the costs related to this phase have been widely specified in phase 1) individual cost influence can derive through the finally selected launch service supplier with the effective OR operations requested.
3. Once the satellite is on orbit and functions are confirmed, the satellite engages the revenue phase. A relatively constant cost factor counts against to ensure the proper operations until the EOL of the Satellite. The duration of this phase would then be linked to the EPS technology and its deduced need on propellant for both SK and EOL disposal.
4. The EOL phase represents the end of the satellite operations and the request for its de-orbiting. Duration and nature of this phase is assumed pre-defined per regulation for a respective orbit. In this period, the satellite does not create any more revenues, but it still needs to be operated to a certain extent.

Based on the proceeding and parameters an iteration plan was established to systematically elaborate where and how much the choices made would have a higher impact considerably on costs and where it was rather negligible. A comparable systematics was used for every distinct use case as described in III Use Cases. As a particular consideration with regard to added value the operational life time potential of the satellite was reflected based on the EPS specific total impulse that typically can be expected, respectively has been qualified. For further potential added value a direct injection option for GEO was investigated.

## III. Use Cases

IN order to get a maximized broad view and benefit of this investigation while not getting lost in complexity the use cases have been limited to communications satellites for this report. A few use cases have been down-selected following literature assessement[3,4,5,6] that would on one hand address “typical” confirmed platforms like “heavy GEO” but that on the other hand consider also emerging solutions like constellations. Further use cases extended to other missions and platforms but also other EPS might be subject to future updates and enhancements of the document.

As said in the introduction, the intention is to suggest approaches for better results as a baseline and inspiration for further discussions among relevant stakeholders.

### A. Referential Missions and Platforms

Table III-1 illustrates the four use cases investigated with their related mission and platform type. The designation is generic as the high-level data are searched to be representatives of their categories.

**Table III-1 Use Cases per mission and platform**

| Use Case | Mission Name | Final Orbit | Satellite Dry Mass [kg] | Qty of Thrusters | Payload Capacity Equivalent | Ejection Orbit | Total electric Power [kW] | Comments |
|---|---|---|---|---|---|---|---|---|
| 1 | Heavy GEO | GEO | 4700 | 4 | 100 Gbps | GTO | 25 | Direct injection to be considered. |
| 2 | Small GEO | GEO | 3000 | 3 | 50 transponders | GTO | 10 | Direct injection to be considered |
| 3 | LEO Constellation, small sat | LEO | 140 | 1 | 8 Gbps | LEO | 2 | Orbit supposed at 1000 km; no OR; 700 sats / constellation |
| 4 | LEO Constellation, medium sat | LEO | 280 | 2 | 20 Gbps | LEO | 4 | orbit supposed at 500 km; no OR; 1200 sats / constellation |

## B. Assumptions and Conventions

Several assumptions have been done in order to ensure that the model would be a viable representation of the "real world".

***General:***

- Technical:
  - Available typical values of well-established EP systems in a comparable performance range have been chosen as working baseline. Those are detailed in Table III-2.

**Table III-2 Generic technical parameter of representative EPS**

| Thruster Type | Thrust OR [mN] | Isp OR [s] | Power OR [W] | Thrust SK [mN] | Isp SK [s] | Power SK [W] | Mass Thruster Chain [kg] |
|---|---|---|---|---|---|---|---|
| HET - GEO | 320 | 1700 | 5000 | 150 | 2000 | 3000 | 36 |
| HET - LEO | 40 | 1600 | 700 | 17 | 1200 | 300 | 6 |
| HEMPT – GEO | 240 | 2200 | 5000 | 120 | 2000 | 3000 | 40.5 |
| GIE – GEO | 218 | 2500 | 5000 | 95 | 3500 | 3500 | 45 |
| GIE – LEO | 22.5 | 3000 | 700 | 9.6 | 2500 | 300 | 6.5 |

  - For a unitary approach one propulsion chain consisting of a thruster unit, a propellant management unit and power processing unit has been considered per "thruster quantity"; see a generic sketch as of GIESEPP in Figure III-1.
  - 85% of max. electric power is available for EOR.
  - Nominal operational life time is 15 years for GEO and 5 years for LEO constellations
  - De-orbiting to a graveyard orbit, at least 300km higher than the original altitude for GEO and Re-orbiting timeline of 25 years for LEO as requested per regulations but here only considered as a minimum time but propellant optimized operation.
  - Satellite Payload is oriented on current confirmed solutions and does not reflect anticipated future technological developments.
  - For SK ΔV representative values as specified within GIESEPP have been used.
  - To calculate propellant mass a multi-iteration calculation using the rocket equation has been applied (see below).
  - For reason of comparability a reached mass saving through better ISP was not accounted to a higher payload even though this could be a viable option.

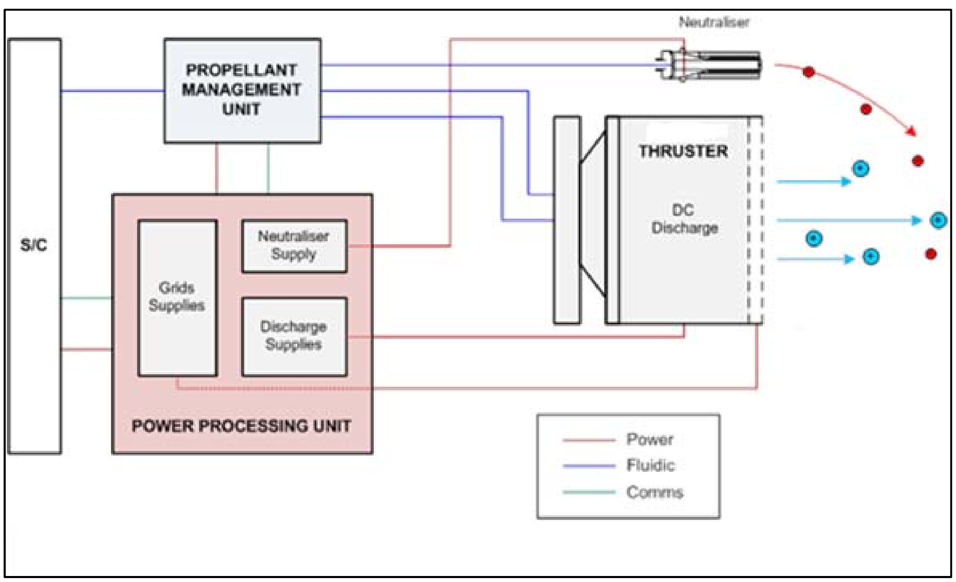


**Figure III-1 Generic electric propulsion chain**

- Revenues: To calculate the revenues two possible simplified approaches have been defined:
    - o The first one is leasing complete transponder slots to determine the revenue of a satellite. As guideline a value of 1.1 MUS$ per year of 1 Equivalent 36 MHz transponder was used.
    - o The second approach, mainly driven by HTS with multiple spot beams, is calculation based on the data rate of the satellite in Gbps. This approach has been applied for LEO Satellites. Therefore it has been assumed that this value rounds 100$/Mbps /month. It has been considered a fixed rate to different services and transponder bands in order to simplify the model also with regard to equalize the variances from region to region.
    - o Further, to reflect current continuous price decline on the satellite service market a yearly decreasing factor of 3% has been introduced as an average.
- Costs: The cost model has been divided in three parts:
    - o The first one corresponds to the Planning Phase. Here, assumption was made that costs consist of satellite procurement costs including propellant on one hand and financing costs on the other. Therefore most recent available reference values have been averaged. Financing is considered simplified with 1.5% p.a. interest rate on full procurement price until reach of break-even.
    - o Independently from the EPS type a common satellite procurement time has been assumed, 3 years for GEO, 2 years for LEO.
    - o As propellant only xenon has been considered with a relatively conservative price of 3000 US$ per kg.
    - o EPS procurement costs have been derived from GIESEPP costing for one single thruster chain. With a particular focus on the commercial impact of EPS procurement costs and thus to ensure a challenging setup for GIESEPP the alternative propulsion systems procurement costs have been set as 60% of GIE for HET and 80% of GIE for HEMPT.
    - o The second distinct cost consideration was on launch services. Therefore ArianeGroup internal data, external reports[7] and launcher user guides were used to setup a various data base.
    - o Insurance efforts in the launch phase are taken into account with an additional factor of 6%[8] on launch procurement costs.
    - o Last but not least, the last phase costs were estimated according to Ground Station utilization during the LEOP and during the nominal orbit operations. Also here a simplified approach was undertaken defining a yearly Ground Station cost in the order of 15 MUS$. On top an insurance factor of 0.6%[8] of the operating costs has been added to this phase.

***For GEO:***

- In order to consider a potential degradation on solar panels due to space radiation, especially when crossing the Van Allen belt, those values are expected to be somewhere around 4% (of total available power) for different orbit raising trajectories[9]. This value was used equally for all technologies since it is indicated that no significant degradation differences could be detected after 80 days and after 200. For one year of activity in GEO, the value was set at 0.5%. (only minimal deterioration on payload activity was reflected while SK activity was kept unaffected.)
- Launch costs are supposed to keep stable as long as they keep in a global range of ± 200 kg as long a no identified threshold could be passed (e.g. from one launcher type to another) thus only significant satellite wet mass saving would reflect on the pure launch price. Instead a plus in ejection orbit is eventually considered (e.g. from GTO to GTO+) if applicable.
- For the cost side only 1 Ground Station has been considered per satellite.
- A potential life extension has been assessed according to typical operational qualification hours of 14000 hours for HET[10] and 20000 h for GIE following executed tests at ArianeGroup on RIT-type thrusters[11,12], backed by further works at space agencies[13]. To ensure a conservative view the calculated total hours of firing have been given a safety factor of 1.5.

***For LEO constellations:***

- Launch costs have been considered in the global constellation context. Total launch price was divided by the number of satellites of the same type that one could carry on a single launch until the full constellation was reached. For commercial reasons a maximized launch with maximum amount of satellites per rocket were searched, thus favoring “big rockets” against “small launchers”, thus trying to minimize the total amount of launches needed.

- To keep the model "capable" no consideration of different planes has been foreseen; thus the total amount of satellites with given wet mass has been distributed on available launcher capacity. It was understood that all satellites would be ejected on target orbit.
- To establish ground station costs for one LEO satellite as part of a constellation an average cost ratio has been built from the total number of satellites and a representative according total amount of ground stations need for the constellation operation[14,15].
- For potential life extension it comes out that calculated necessary operational hours are widely uncritical as basically only SK is needed (~500 h) thus added value through life extension is aimed the way that the amount of launches is kept constant but the existing mass margin would be filled up completely with additional propellant and then deduce how long life can be extended without increasing launch costs (e.g., having 6.5 years of lifespan instead of 5.)

For the Fuel Mass the Rocket Equation was used and the values were reiterated after every phase of the Orbit. As the main parameter was the dry-mass of the satellite, the calculation started from the fuel needed for de-orbiting, going back to the SK phase and then going all the way back to the EOR. In every new step the S/C mass has been corrected with the amount of propellant needed for the previous step in order to have more coherent results. Equation (1) represents the formula used, where *Isp* is the specific impulse of the thruster, $g_0$ is the gravity acceleration on sea level and $\Delta v$ represents the Delta-v budget of the phase that the satellite is currently in. Equation (2) by its time, represents the formula used to estimate the OR time. It was considered that the thrusters would be fired only 75% of a normal day, for a more conservative proceeding and this is the reason behind multiplying the value by a factor of 4/3. Equation (2) if applied to SK also gives the total time in hours that the thrusters have been fired during their life and would then be compared to the designed characteristics. The delta-v budgets for SK were supposed constants yearly for a given mission while for OR and de-orbiting they have been calculated considering the transfer orbits involved and the mission objectives, either using a low thrust change from a circular orbit, Eq. (3), or a typical Hohmann Transfer budget with inclination correction as seen on Eq. (4). On those equations, $r_0$ states for the initial radius of the orbit, $r$ the final one, $i$ the orbit inclination and $\mu$ is earth's standard gravitational parameter. All equations were calculated using SI units.

$$m_{fuel} = m_0 (1 - \exp\left(-\frac{\Delta v}{g_0 Isp}\right)) \quad (1)$$

$$T_{ORdays} = 4/3 * (m_{fuelOR} * Isp * g_0)/(Thrust * 86400) \;\; = 4/3 * m_{fuelOR}/(\dot{m} * 86400) \quad (2)$$

$$\Delta v_{ORcirc} = \sqrt{\mu/r_0} - \sqrt{\mu/r} \quad (3)$$

$$\Delta v_{ORhohmann} = \sqrt{\mu/r + \; 2\mu r_0/(r * (r_0 + r)) - 2 * \cos(i) * \sqrt{\mu/r_0} * \sqrt{\mu/r}} \quad (4)$$

## IV. Results

THE results of this first iteration campaign are presented in the following trying to reflect a bottom-up stream starting from the detailed technical aspects going up to a ROI maximization over full life cycle. The logic behind is

1. At first for every use case the total EPS mass including propellant has been calculated and put in comparison to one-another
2. Then the physical impact of a representative EPS has been drawn by comparing its impact on the total satellite wet mass at launch
3. On the commercial side for every use case the break-even point has been extracted in terms of magnitude and timely range. To get it in comparable mode the magnitude has been calculated as % of the lowest procurement costs (assumed with HET).
4. To further evaluate the commercial perspective the ROI of each solution in accordance with EPS choice and capability of extended life has been shown, based on the lowest procurement cost (assumed with HET).

## A. EPS Wet Mass

Reflecting the relevant mission on GEO with the along going ISPs of the respective EP system the comparison shows that for use case 1, HEMPT would offer a mass saving of 17% and GIE up to 28% of the respective HET reference. For use case 2, the mass savings would sum up at 18% for HEMPT and 35% for GIE compared to HET EPS (see Figure IV-1).

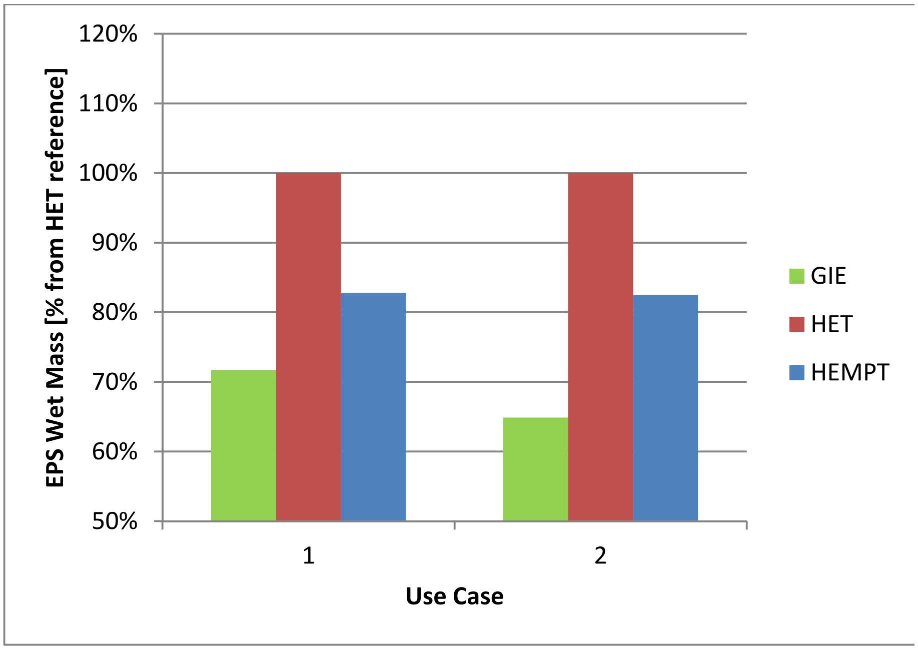


**Figure IV-1 EPS Wet Mass for GIE: HET and HEMPT for GEO**

Accordingly for the relevant missions on LEO comparison has been done. For reason of implementation a HEMPT system has not been considered in those use cases thus concentrating the assessment on HET and GIE. For use case 3 a mass saving of 30% and for use case 2 savings of 29% are realized with an adequate GIE EPS compared to a HET reference (Figure IV-2).

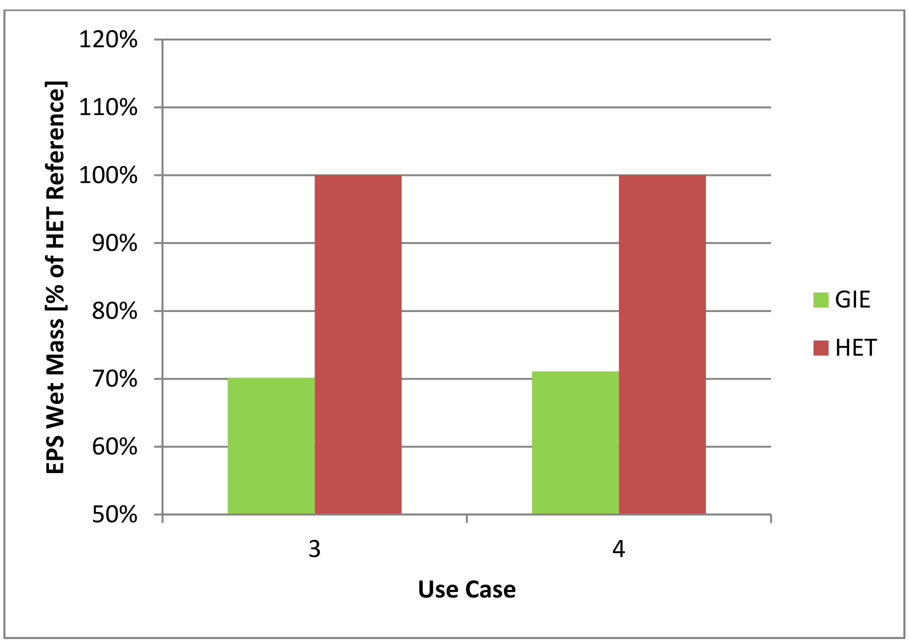


**Figure IV-2 EPS Wet Mass for GIE and HET for LEO**

## B. EPS Wet Mass impact on Satellite Wet Mass

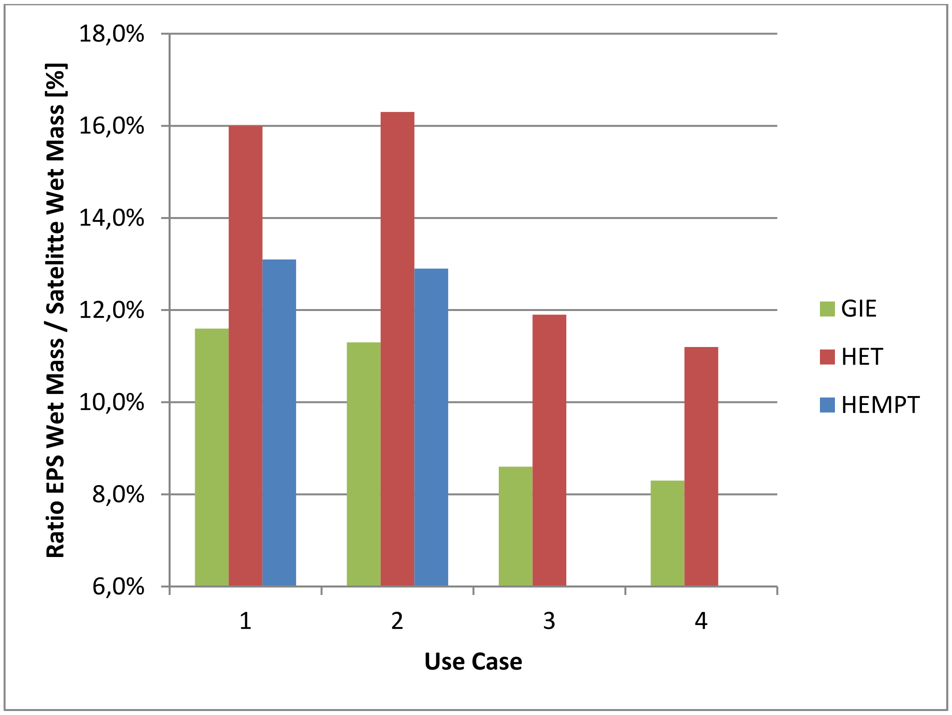


**Figure IV-3 EPS Wet Mass Proportion of Satellite Wet Mass per EPS and Use Case**

Following the trends of results as of A the propulsion mass (consisting of EPS hardware and requested propellant) for use case 1 takes 16% for a HET EPS, could be reduced to 13.1% with a HEMPT system and down to 11.6% with a GIE EPS. For use case 2 the distributions show 16.3% for HET, 12.9% for HEMPT and 11.3% for a GIE EPS.

For the LEO cases again in general EPS mass proportions do better with 11.9% (use case 3) and 11.2% (use case 4) for HET, reduced to a minimum with GIE at 8.6% for use case 3 and 8.3% for use case 4 (Figure IV-3).

## C. Break Even Point

To define break even, beside the procurement costs for satellite including the respective EPS and the along going amount of xenon, the complete launch / LEOP costs have been considered with adjacent insurance and operating costs until the satellite has reached orbit and is supposed operational. Above all a simplified financing costs add-on has been applied on 100% of satellite procurement costs from the beginning (but not on LEOP costs).

Revenues have been calculated as given per use case in III A and assumptions in III B.

To enable comparability BE values have been reflected in relation to the lowest procurement cost solution for each respective use case.

For use case 1 Heavy GEO (see Figure IV-4) the break-even value point varies minimally from 155% of lowest procurement reference for HET, over 155,5% of the same reference for HEMPT up to 156,3% of the reference for GIE. In accordance with this the break-even effective date shows minimal variation with 10.0 years for HET and 10.1 years for both HEMPT and GIE.

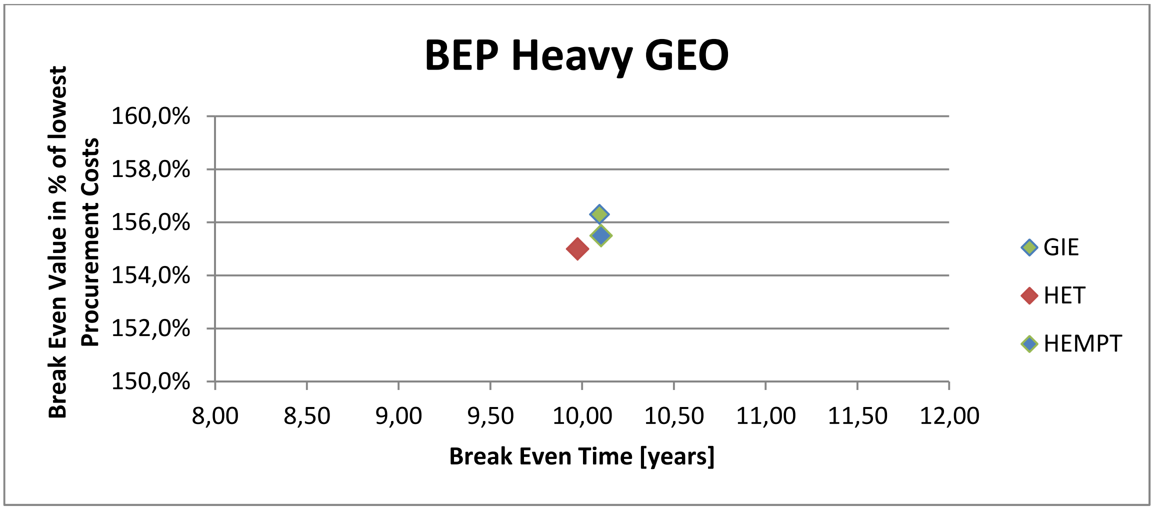


**Figure IV-4 Break Even Comparison for Use Case 1 Heavy GEO**

The Small GEO use case 2 (Figure IV-5) shows on one hand a significantly lower magnitude for BE than Heavy GEO but on the other hand the date BE is reached is roughly 50% later than for Heavy GEO. Also in this case the dots are quite next to one another for the different EPS: HET solution at 119.0% after 14.9 years, HEMPT solution at 119.7% after 14.9 years and GIE solution at 120.5% after 15.1 years.

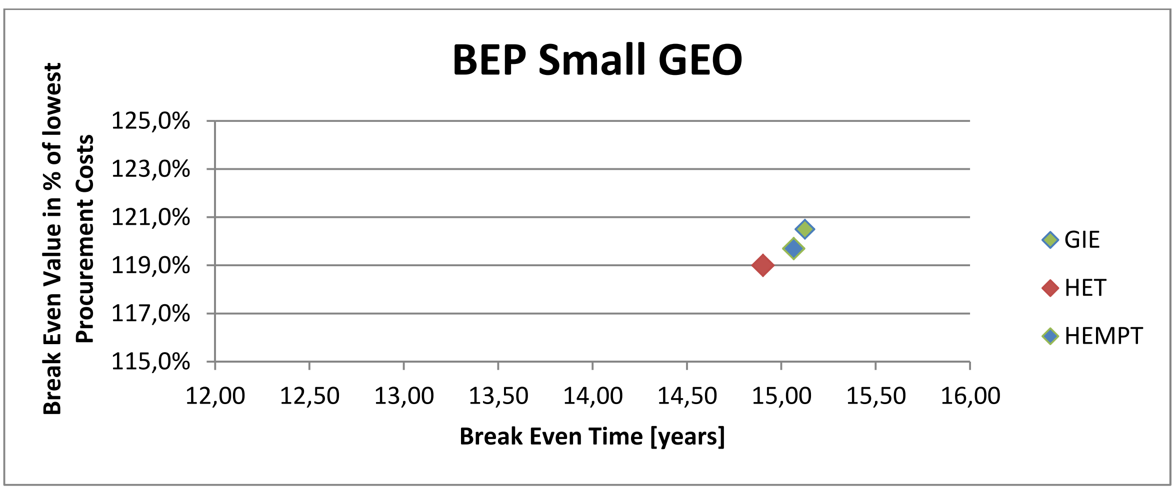


**Figure IV-5 Break Even Comparison for Use Case 2 Small GEO**

On the LEO side both use cases locate in a totally different domain by their nature of being part of a constellation instead of a singular solution. Thus BE levels are multiplied while the time until BE is reached is reduced to a fracture. Here again the comparison has been done between HET and GIE based systems only.

In Figure IV-6 use case 3 shows the BE situation for a small satellite as part of a constellation. Also here the EPS choice does not show a considerable impact on both break even values (HET: 297%, GIE: 294%) nor on duration until BE (HET: 5.33 years, GIE: 5.25 years). Nevertheless it is interesting to note that the general trend has been inverted compared to GEO with the GIE solution slightly taking advantage.

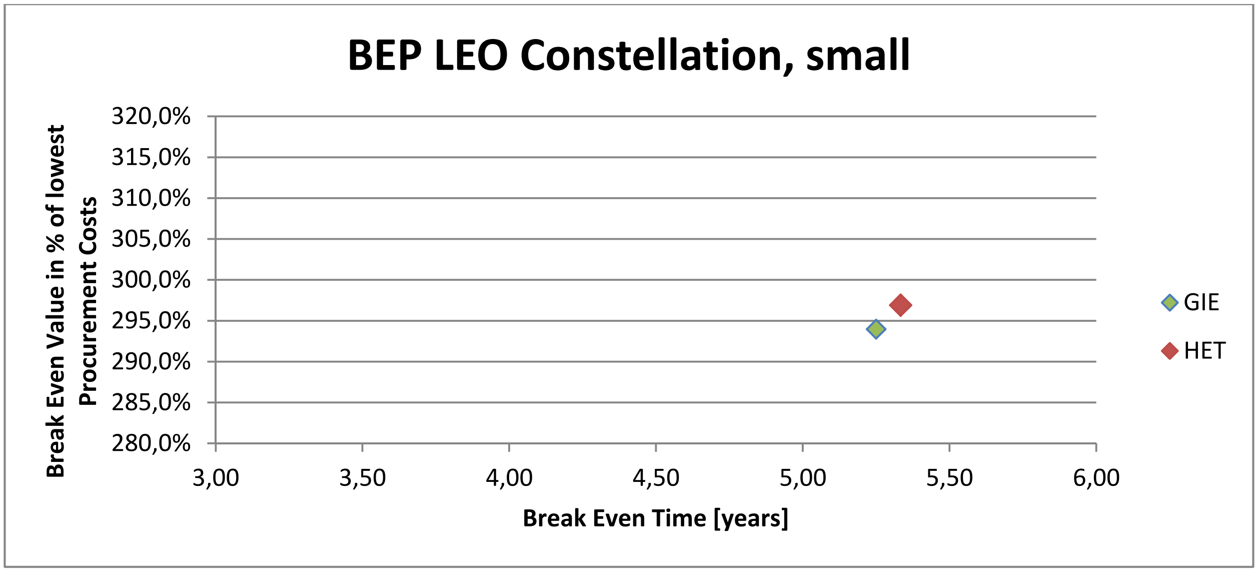


**Figure IV-6 Break Even Comparison for Use Case 3 LEO Constellation, small**

Those general trends and levels are confirmed in use case 4 (Figure IV-7) for a medium sized constellation satellite (with a dramatic increase on BE levels). The GIE-based solution situated at 620% after 5.13 years only reaches a minimal edge to the HET-based solution at 623% after 5.14 years.

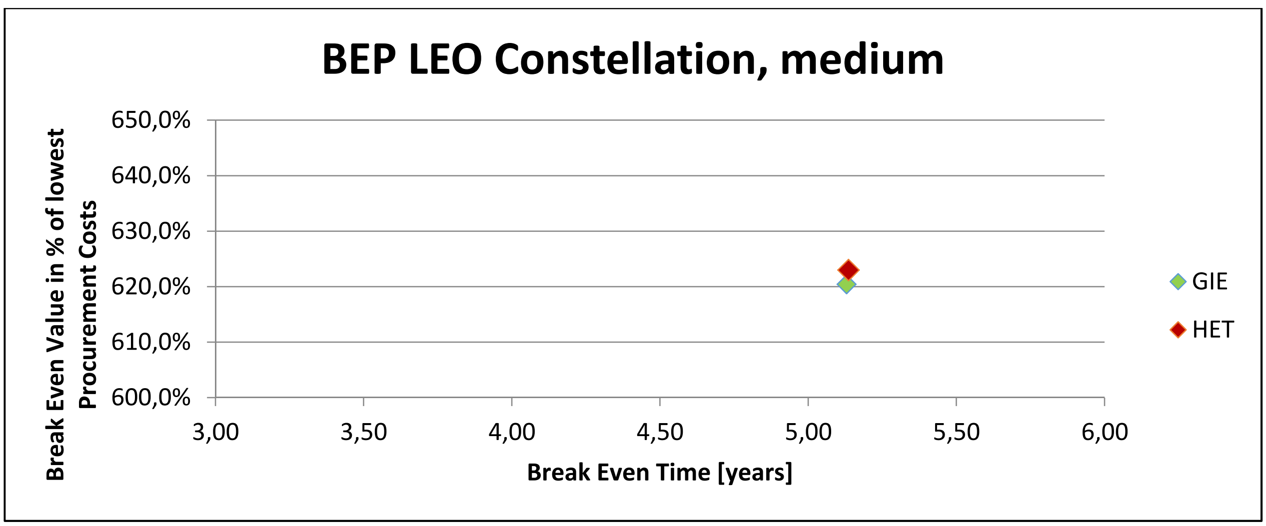


**Figure IV-7 Break Even Comparison for Use Case 4 LEO Constellation, medium**

### D. Return on Investment

To calculate the overall return on investment potential at EOL of every solution the full technical capability of every propulsion system has been considered, mainly being driven by its disposition to extend the nominal operational life with the intent to turn the operating satellites into “cash cows”. Being focused on EPS, no further technical evaluation of the satellites´ other subsystems has been undertaken here.

The ROI proper value was determined as the ratio of gross benefits at (extended) EOL on invested capital including procurement and launch/LEOP. With comparison in mind for every use case the minimal invested capital was kept as referential basis for every respective solution.

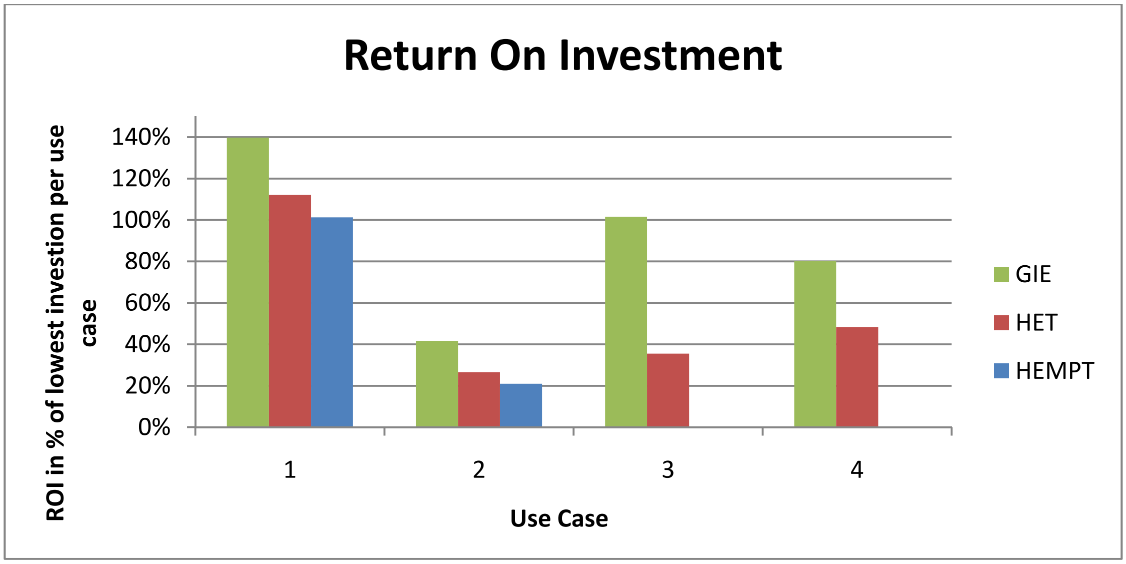


**Figure IV-8 ROI comparison for all 4 use cases**

Figure IV-8 shows very vividly the differences in ROI potentials for all use cases in each respective configuration. Following the approach given in chapter III B a possible life time extension for the GEO platform would reach 20 years for a GIE-solution while the HET and HEMPT would gain about 2 years more than nominal.

It starts with use case 1 reaching ROI up to 140% with a GIE, followed by HET at 112% and HEMPT at 101%. In use case 2 (small GEO) the extent is significantly lower but in the same order with GIE-based satellites at 42%, then HET-based at 27% and finally HEMPT-propelled satellites at 21%.

On LEO constellations the appraised results give analogous trends but with even more explicit gaps ranging GIE-EPS-satellites at 102% for use case 3 (small sat) and 80% for case 4 (medium sat) against HET-EPS-satellites at 45% for use case 3 and 59% for use case 4. This occurs as the EPS mass savings can directly increase the number of satellites per launch and also increase the lifespan. For Use Cases 3 and 4 calculation leads to a lifespan of 6.5 years for a GIE-based satellite while the HET-based would attain 5.5 years. Further, both in nominal and extended case the GIE solution allows 1 more satellite per launcher than the HET solution suggesting potential to reduce launch costs per satellite and finalizing constellation orbiting earlier.

## V. Conclusion

FOUR different use cases for communication platforms have been assessed comparing three different EP systems for GEO applications, respectively two different most common for LEO applications whereby it was the intention to select those use cases as representative as can be for current state-of-the-art. It is reminded here that the aim was less to precisely establish the effective levels of the examined values but to carve out the differences in the impact the respective choice of propulsion system would have on the given platform. Consolidating the obtained results for all use cases and EPS´ the following key findings can be summarized:

1. The selection of the EPS strongly influences the effective overall propulsion system mass at launch (including propellant) with savings achievable up to 35% with GIE compared to a HET-based system.
2. As consequence a non-negligible satellite wet mass saving can be obtained with the GIE-EPS in an order of magnitude of up to 5% compared to a HET-propelled satellite.
3. Even though it is understood that a HET-thruster system typically offers a higher-thrust-but-lower-ISP at given power level than a GIE-thruster (and HEMPT being somewhere in-between) and thus is more susceptible to attain operational orbit earlier, a valuable compensation shall be considered by reflecting the launch mass gain in a significantly higher transfer orbit under equal conditions.

4. Doing so it came out that the break-even points for every solution prove to be almost identic and do not show any particular differentiation.
5. Last but not least, capitalizing the full potential of the right EPS-solution – be it by extending the operational lifetime or by maximizing the possible launch mass - would draw the prospect of boosting ROI in a very significant manner, with impacts promising even more than 100% improvement with the use of a GIE system. This, of course, suggests that the evaluation of the remaining subsystems of a satellite would be an interesting thing to do in order to take full profit of the advantage.
6. As particular use case the direct injection of Heavy GEO satellites would indicate further improvement on ROI. But in this investigation it turned out that, only the GIE-propelled satellite would keep below the requested launch mass threshold for this.

Of course it is not obvious to deduce a targeted recommendation out of those findings until it gets clear what will be the main trends of the satellite industry, not only in the telecommunication sector itself but also in an extended way with On-Orbit-Servicing getting closer to reality[16] and thus enabling totally new TCO considerations.

In any case, even if HET may appear the most commonly used EPS technology until now, GIE technologies showed their technical potential all over the years with remarkable space missions from the Artemis project up to BEPI Colombo, both from the European Space Agency, understanding that GIE has ever been the most suitable choice for science and exploration and interplanetary missions. From the present investigation its competitive use in the highly commercial markets like communications appears very promising. In addition, with more new generation launchers arriving on the next years from all over the world, having a higher flexibility to choose a launcher and the desired transfer orbit will be a solution booster for every kind of mission.

Hence, this investigation is intended to be pursued even further e.g. with other use cases such as MEO, other applications such as navigation and space exploration, other EPS technologies.

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