Titanium Life-Cycle Assessment Report

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Prepared for : 6K Additive

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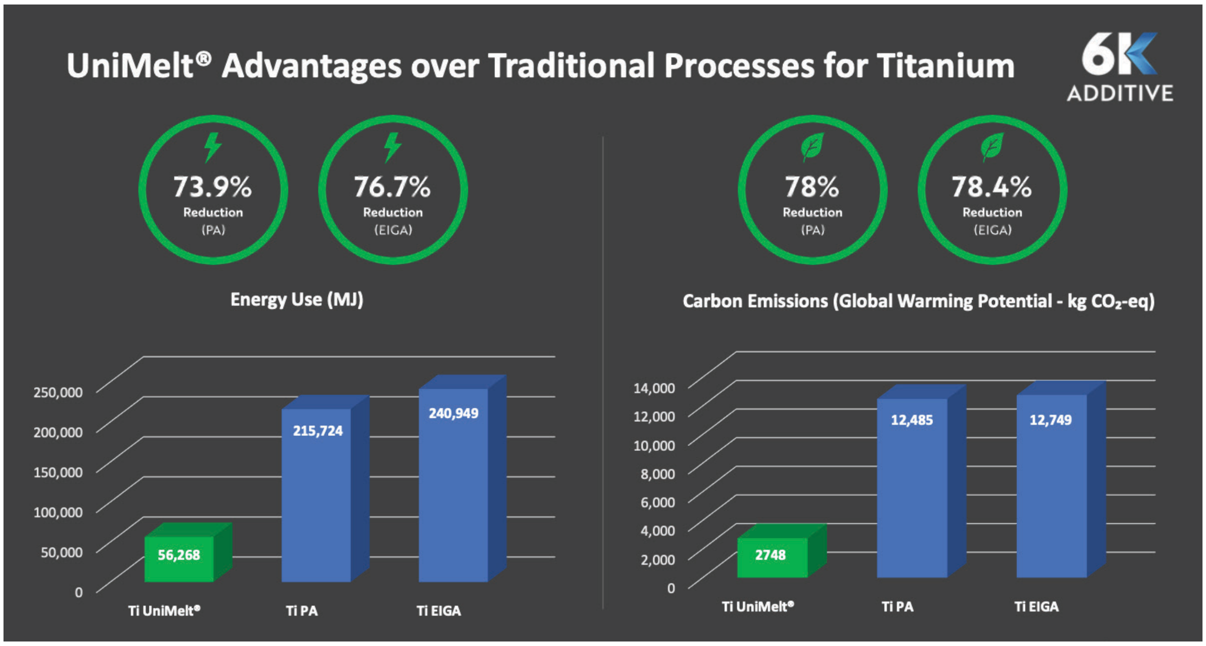
Abbreviated Version

Abstract

This study was conducted to quantify the environmental impacts associated with the production of Printable Metal Powders and specifically compare those impacts from traditional production methods to 6K Additive's UniMelt® technology.

While many impact categories were modeled and are included in this report, the two most relevant categories showcasing how 6K Additive's UniMelt process could significantly reduce environmental impacts associated with the production of Printable metal powders were **Global Warming Potential & Energy usage**.

It was found that for Ti, 6K's UniMelt process used 56,268 MJ of energy and produced 2,748kg CO2-eq for every 100kg delivered to the customer. This is, at minimum, a 74% energy reduction and 78% carbon emission reduction from traditional processes in the Cradle-to-End User Scope.



Methodology

Sphera's GaBi software for life-cycle assessments is a sustainability software product that empowers business to perform life cycle assessments by providing rich datasets from across the globe that detail the costs, energy and environmental impact of sourcing and refining every raw material or processed component of a manufactured item. The following datasets were purchased and used:

- Gabi Professional Database
- Ecoinvent v3.7
- Extension database XVIII: NREL USLCI Integrated

Investigated System

The subject of this study is a functional unit of 100kg of printable powder. Three methods of powder production were studied, Ti Printable Powders (UniMelt, EIGA, and PA). All processes were modeled to occur at the 6K Additive site at 541 Steubenville Pike, Burgettstown, PA 15021.

Goal and Scope of Assessment

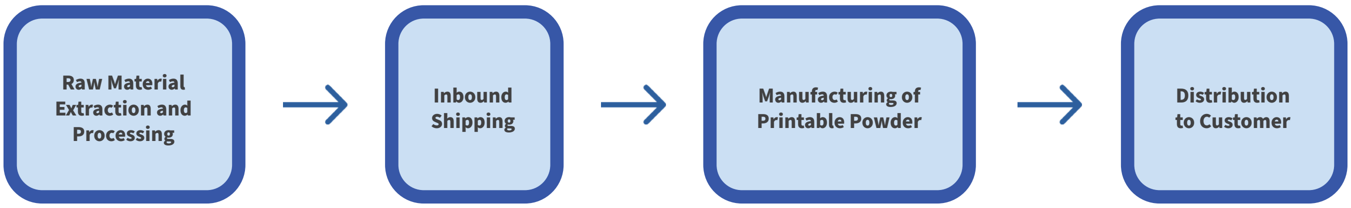
The following life cycle stages were included in the scope of this study: raw material extractions, transportation of raw materials, manufacturing of the product, and distribution of the product. All stages after the Cradle-to-End User were excluded based on the goal of the study.

LCA Model Study Parameters

The following are included in this study: goal and scope, inventory analysis, impact assessment and interpretation. TRACI 2.1 LCIA methodology was used to evaluate impact categories using the GaBi software.

System Boundaries

This assessment only considers the Cradle-to-End User stages of the UniMelt technology life cycle. This includes all known industrial processes and materials from raw material acquisition, pre-processing, production, and distribution.



Raw Material Extraction and Processing

This stage includes the extraction of all raw virgin material and reclamation of non-virgin feedstock. Reclamation of non-virgin feedstock refers to any additional processes needed to make a waste stream a valuable input. All resources and emissions associated with the extraction and processing of raw material into a usable form are included.

Inbound Shipping

This stage includes all impacts associated with the transportation and storage of raw materials and packaging to the manufacturing site.

Printable Powder Production

This stage includes all the relevant manufacturing processes and flows, including the impacts from energy use and emissions at the manufacturing facility. Production of capital goods, infrastructure, manufacturing equipment, and personnel related activities are not included.

Distribution to Customer

This stage includes the delivery of the product, including packaging, from the manufacturing facility to the end-user.

Process Modeling

The analysis included the following 3 Manufacturing Processes:

1. Titanium UniMelt,
2. Titanium Advanced Plasma Atomization (APA),
3. Titanium Electrode Induction Melt Inert Gas Atomization (EIGA).

All processes are modeled identically and completed in an inert vacuum environment. The only differentiating factors are the feed stock type and manufacturing processes. See Figure 1 for basic flow overview with identification of what determines the Manufacturing Process being modeled.

Printable Powder Production Model

Figure 1 shows the basic flow for all Manufacturing Processes included in this study. The highlighted fields are what is changed depending upon the process being modeled. As they are changed, it will change the amounts of all other flows to reflect the specific process.

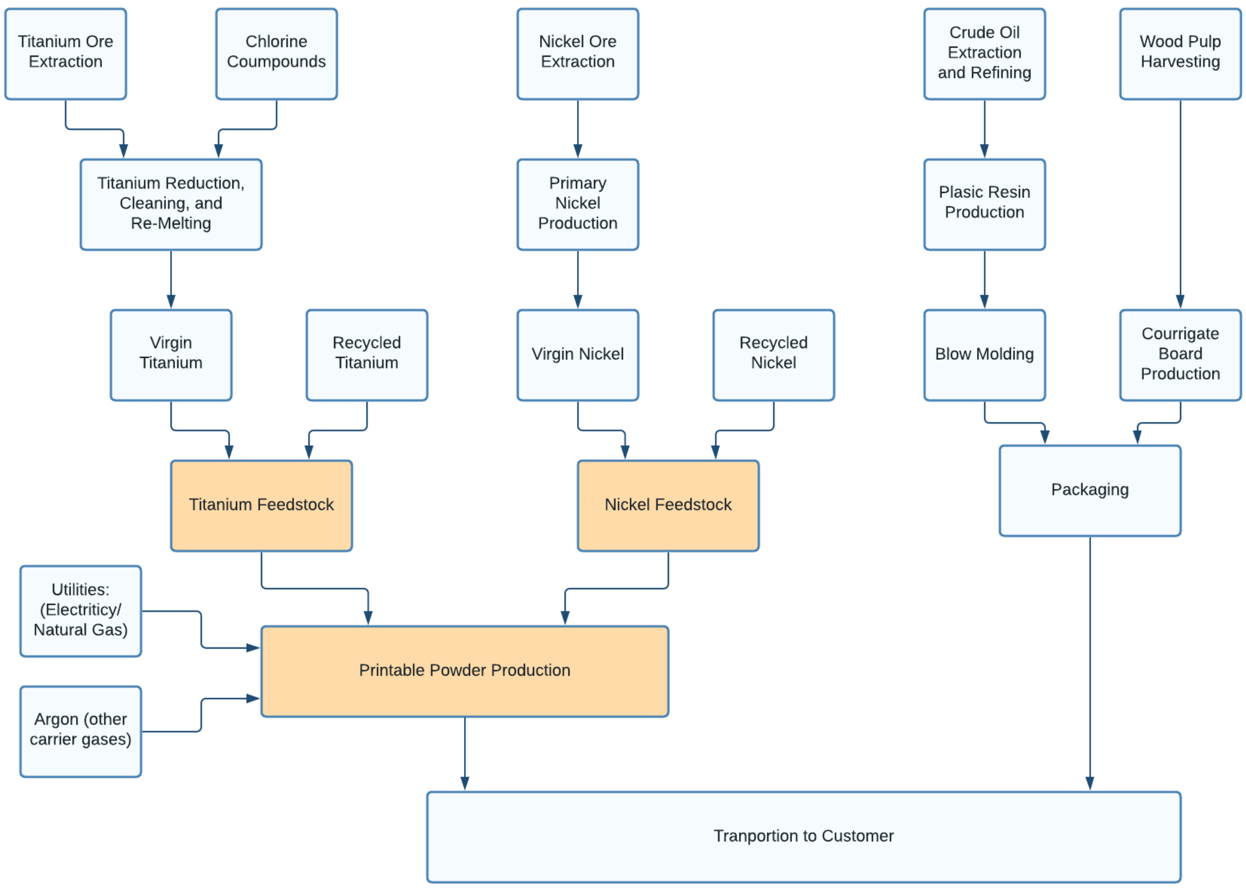


Figure 1. Flow Overview of Printable Powder Production

Data Quality

The following data quality requirements were considered when building the LCA:

- **Time Related Coverage:** Primary data collected shall not be older than a year. No datasets used shall be older than 10 years to be representative of current practices, methods, and technology.
- **Geographical Coverage:** Representative is from the same or similar geographical region when possible.
- **Technology Coverage:** Technology utilized in the LCA represented the current technologies in use.

When available, primary data was used. If primary data was unavailable, secondary data sets and assumptions were used from published or reputable sources. When multiple secondary data sets were available, the most relevant (time/geographical/technology) was used. Any processes or flows that resulted in <1% of total impact was excluded from this study.

Primary data was collected for facilities under 6K's operational control. This includes the following manufacturing processes: Titanium UniMelt. Additionally, primary data was used for the packaging amount and processes. This does not include any upstream packaging processes.

End of Life

Gate-to-Gate waste management is included in this study. Other End-of-Life consideration is not included in this study.

Product Composition

Table 1.1 and 1.2 provide the material composition of each product included in this LCA Study, both in kg per functional unit and in percentage of total weight.

Process	Material Resource	Amount per 100 kg product (kg) (%)
Ti UniMelt®	Recycled Ti, Non-Renewable: 25/75 Waste Powder and HDH	125 (100%)
Ti CIF	Ti Wire: 80/20 Scrap and Virgin Ti, Non-Renewable	286 (100%)
Ti EIGA	Ti Wire: 80/20 Scrap and Virgin Ti, Non-Renewable	286 (100%)

Table 1.1 Composition amounts for each process studied. Amounts were based on the amount of raw material to produce 100kg of finished product.

Process	Corrugated Cardboard per Functional Unit (kg) (%)	HDPE per Functional Unit (kg) (%)
Ti UniMelt®	0.50 (41%)	0.72 (59%)
Ti CIF	0.50 (41%)	0.72 (59%)
Ti EIGA	0.50 (41%)	0.72 (59%)

Table 1.2 Packaging amounts for each process studied.

Transportation and Distribution

Below are descriptions of the secondary data used for all transportation distance used in this study Table 1.4 shows the shipping distances and types for each raw material input.

Raw Material Acquisition and Pre-Processing

All transportation prior to material being shipped to the production stage was included in the study and is based on 6K provided data or from BIFMA PCR for Storage: UNCPC 3812.

Distribution to Customer

It was assumed that the average distance to a 6K customer is 1,000 miles of truck freight.

Life Cycle Modeling and Inventory Analysis

Below are descriptions of the secondary data used for all transportation distance used in this study
Table 1.4 shows the shipping distances and types for each raw material input.

Assumption and Data Sources

Data was reviewed for completeness, consistency, and representativeness. Results of this review can be found in the Data Quality Review section of this LCA Report

All LCA modeling was completed by using GaBi ts software, DB vs. 9.2.0.58. All data pertaining to material, transportation, and processing specifications were included and obtained from GaBi ts, DB vs 9.2.0.58 and EcoInvent 3.7 database. Both meet the data requirements of this LCA.

LCI Results

Table 2.1 shows the results of the aggregated inventory flows for water and energy for all cases studied. See Table 3.1 for breakdown of stages for energy usage.

Process Studied	Net fresh water Usage (kg)	Primary Energy Demand (MJ)	Non-Renewable Energy[2] (MJ)	Renewable Energy (MJ)	Miscellaneous Fuels[3]
Ti UniMelt®	3.83	56,268	46,163	10,104	0
Ti CIF PA	1,950	215,724	160,314	55,410	0
Ti EIGA	1,950	240,949	171,952	68,997	0

Table 2.1: LCI results for water and energy usage.

Life Cycle Impact Assessment (LCIA)

LCIA Methodology

The following environmental impact categories and associated category indicators were used in this study as results reported in the LCA report for the printable powder functional unit.

- Global Warming Potential (GWP 100 years) [kg CO2-eq] – IPCC (AR4)
- Acidification Potential (AP) [kg SO2-eq] – TRACI 2.1
- Photochemical ozone creation potential (PCOP) [kg O3-eq] – TRACI 2.1
- Eutrophication potential (EP) [kg N eq] – TRACI 2.1
- Ozone Depletion Air [kg CFC 11-eq] – TRACI 2.1

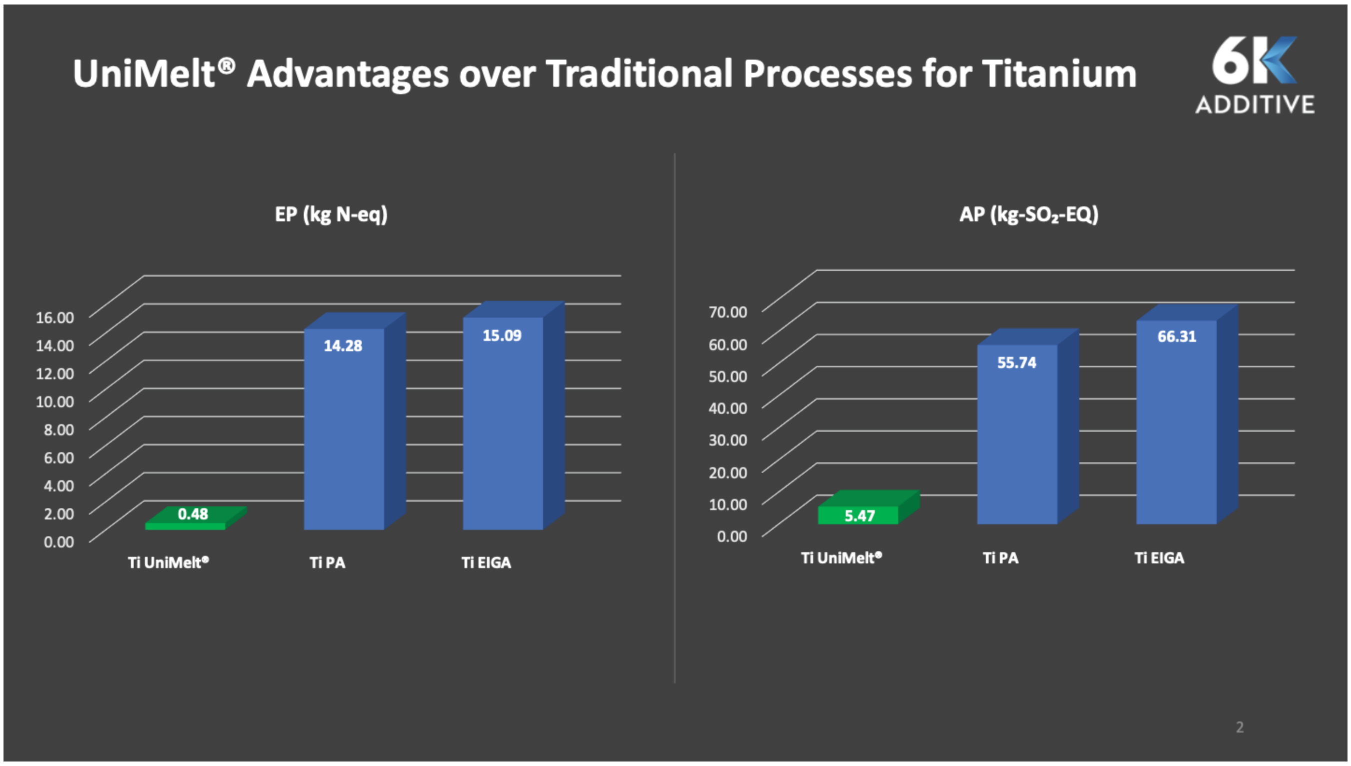
LCIA Impact Category Calculations

Table 3.1 shows the LCIA results for all processes studied from Cradle-to-End User.

As mentioned in LCIA Methodology, IPCC AR5 model was used for calculating Global Warming Potential (GWP 100). TRACI 2.1 Characterization Models were used for calculating the following impact categories: Acidification, Eutrophication, Ozone Depletion, and Photo Chemical Smog Formation. TRACI 2.1 impact categories were characterized at the midpoint level.

The relevance of the LCIA results were not decreased due to any allocation methods used. No by products were produced so the LCIA results reflect the impact of a functional unit.

IPCC (AR5) and TRACI 2.1 Life Cycle Impact Assessment results were calculated using the LCA software, GaBi ts vs 9.2.0.58 and are presented in Table 3.1.



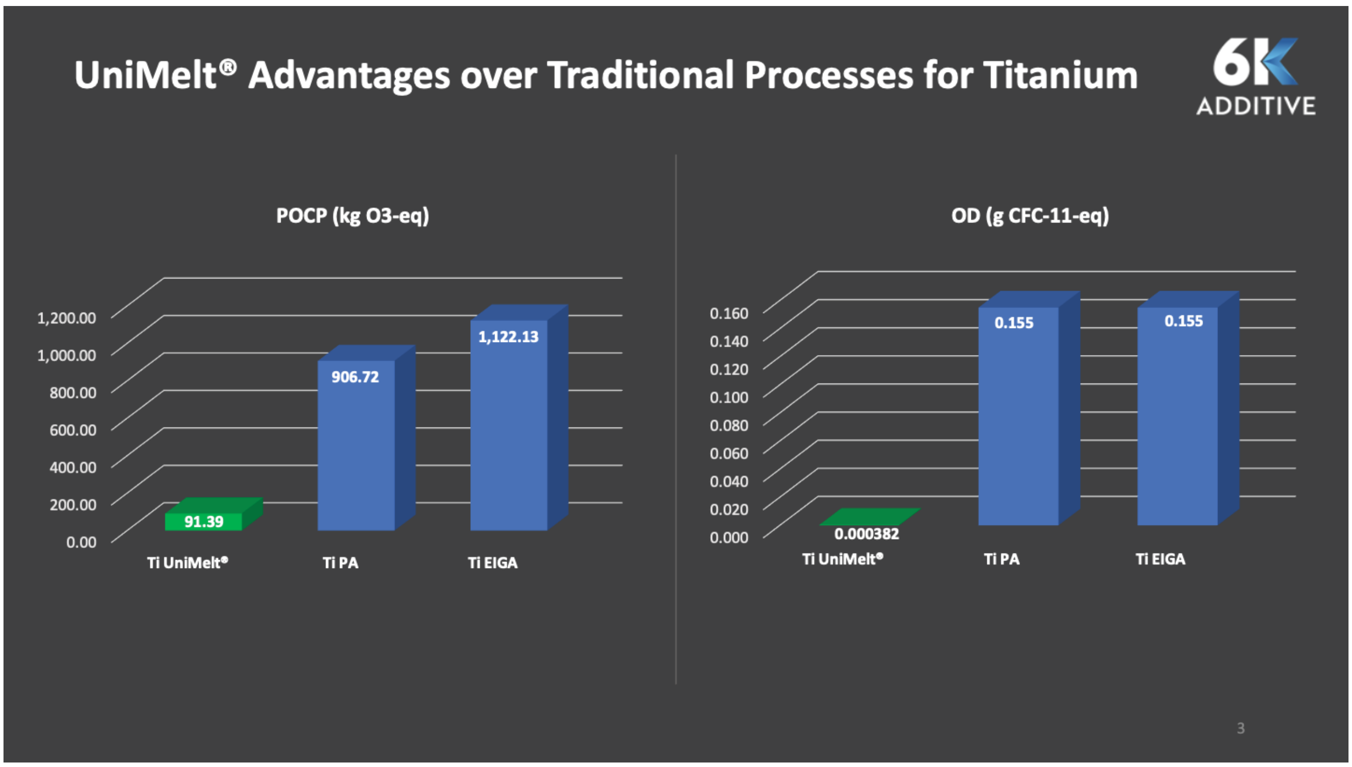


Table 3.1 - TRACI 2.1 and IPCC Life Cycle Impact Assessment results of printable powder. Results are shown for a functional unit of powder (100 kg) from Cradle-to-End User.

Interpretation Conclusion

6K's UniMelt process reduces all environmental impact categories included in this study for Titanium Powder Production. The most impactful aspects of the UniMelt process is how it uses a recycled feed stream and its lower impactful powder production. Raw extraction of virgin material is by far the most environmentally impactful stage of production. The Ti PA and EIGA processes had a 20% virgin feedstock, even at this ratio, it still accounted for 17% of the energy and carbon. 6K's UniMelt ability to use a fully recycled feed stream greatly reduces all impacts in the Cradle-to-Gate boundary.

To better understand the processes comparatively independent of raw material sourcing, the Gate-to-Gate boundary was isolated and examined. Within this boundary, the UniMelt® process is still more much more energy efficient and provides greater yield. This allows its impact to be reduced by minimum of 72% for Ti within the Gate-to-Gate boundary.

If all processes used the same feed stock, 6K's UniMelt® method would still result in the smallest environmental footprint of this study. However, in tandem with the impact reduction of the recycled feed stock, the more efficient and controllable Gate-to-Gate process of 6Ks UniMelt® technology leads to large reductions in environmental impacts across the Cradle-to-End User boundary of Printable Metal Powders compared to conventional methods.