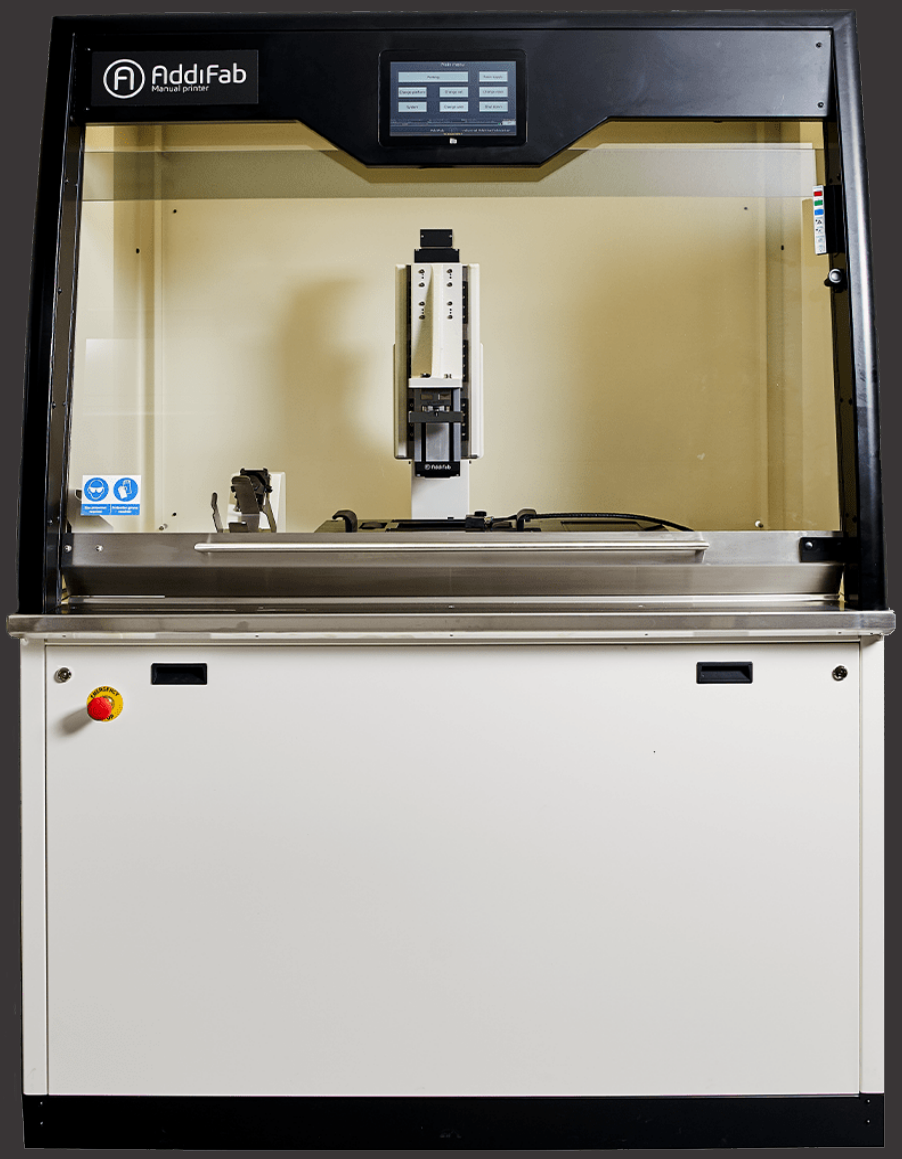
AddiFab Life Cycle Assessment Summary Report by Deloitte, Denmark



AddiFab

Executive Summary

AddiFab is the inventor of Freeform Injection Molding, a process based on the use of 3D-printed tool cavities to produce small quantities of injection-molded components. It can be used to replace the conventional prototyping of injection-molded components, which is based on the use of metal tool cavities.

AddiFab has commissioned a comparative life cycle assessment (LCA) study to compare the environmental impacts resulting from product development of the medical device, QuickFact using the Freeform Injection Molding process (hereafter referred to as FIM), against a standard new product development process (referred to as Standard NPD hereafter). The aim of this study is to demonstrate the potential savings on GHG (Green House Gas) emissions. Overall, the results of this LCA are intended to communicate potential advantages of AddiFab's Freeform Injection Molding process to prospective and current AddiFab customers.

The main results can be summed up as follows:

1. When the functional unit[1] is to deliver five units of a first testable version of the medical device, QuickFact, FIM has much lower GHG emissions than Standard NPD (~75% lower).
2. When the functional unit is to deliver 200 units of the prototype of the medical device, QuickFact, that are ready for clinical trial, FIM has slightly higher GHG emissions than Standard NPD (25% higher).
3. In injection molding product development, a rule of thumb is that out of 10 development projects started, only one will succeed. Using this rule of thumb, doing nine projects that get to first testable version and one that gets to clinical trial, FIM has a much lower GHG emissions than Standard NPD (~60% lower).
4. The savings in time and money described under 3) above could also be used to run three times as many product development projects at a slightly higher GHG emissions (~16% higher) with FIM than Standard NPD.

This summary report compiles the main findings of the LCA Background Report. The LCA Background Report is available from AddiFab Management upon request.

The LCA Background Report has been compiled in accordance with the International Reference Life Cycle Data System (ILCD) Handbook and in alignment with ISO 14040 (Environmental management — Life cycle assessment — Principles and framework) and ISO 14044 (Environmental management — Life cycle assessment — Requirements and guidelines), except that a critical review has not been performed by another third-party assurance provider, and no uncertainty analysis has been performed.

This summary report will proceed to describe:

1. The results of the analysis where the functional unit is 5 units of a first testable prototype
2. The results of the analysis where the functional unit is 200 units that are ready for clinical trial
3. A scenario analysis considering 10 new product development projects

[1] A functional unit is a qualitative and quantified description of the function of a product sustem that serves as the reference basis for all calculations regarding impact assessment.

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Who is AddiFab?

AddiFab is an enabler of magnificent objects with delightful materials through our platform, Freeform Injection Molding (FIM).

We exist to bring Additive Manufacturing and Injection Molding together on one platform because the world deserves a set of cheaper, faster, and more flexible tools for bringing new products to market. We allow unseen possibilities and freedoms by enabling developers to move from concept to commercialization at the speed of 3D Printing, and with the versatility and scalability of Injection Molding through the FIM process. We thus also enable manufacturers to postpone or eliminate the need for metal mold tools, which support a greener and more sustainable development process.

Freeform Injection Molding merges the best of both manufacturing platforms. It allows the known design freedoms, short lead-times, and low start-up costs from 3D-printing while providing access to the hundreds of thousands of materials already developed for the injection molding industry. We have built 3D Printers from the ground up and developed resins with the sole purpose of enabling highest possible precision and repeatability, while utilizing the required materials, which in turn allows manufacturers to produce prototypes and small-batches for themselves and their customers in the needed materials and with geometries that are both lighter and stronger.

Our **mission** is to enable the qualities of injection molding for low volume production, one-of-a-kind productions, prototyping, and personalization.

Our **vision** is to enable mass customization, support the global distribution of development and manufacturing, lower the barrier between corporations and individuals, and reduce the footprint of global manufacturing.

Who is Danish AM Hub?

Danish AM Hub is Denmark's national meeting point for Additive Manufacturing (AM). The goal is to change the way we traditionally understand 'production' by promoting the use of new production technologies such as Additive Manufacturing and 3D Printing (3DP) – in business and wider Danish context. Danish AM Hub wants to make Denmark the world leader in using AM for sustainability and help Danish production companies take the first steps towards a future where we produce with less waste, less material, less transport and with less CO2 emissions.

Danish AM Hub desires to gather the Danish ecosystem and together inspire, change, and collaborate with Danish businesses and thereby utilize many folded possibilities of the technology. Danish AM Hub works to future-proof competencies and bring new knowledge to the development of new business models and innovative solutions. All of this is done by developing and initiating programs and activities while simultaneously placing Denmark on the 'AM-World map'.

Danish AM Hub has been initiated and developed by the Danish Industry Foundation. The foundation is fully funded be the Danish Industry Foundation.

Comparative Life Cycle Assessment (LCA)

Product development using Freeform Injection Molding process vs. a Standard New Product Development process

- A case study on the product development of the medical device, QuickFact

Summary Report

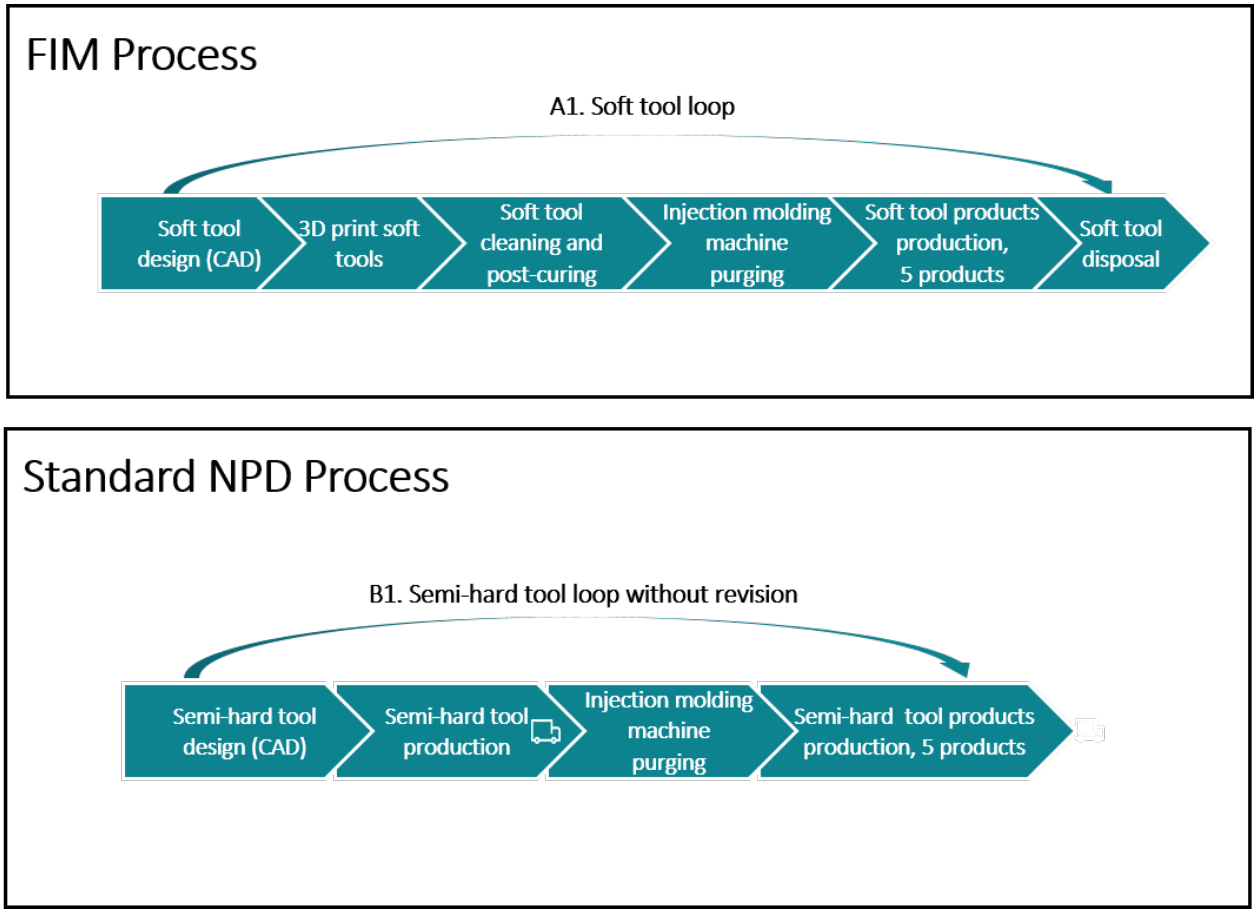
June 2021

Functional unit: deliver 5 units of a first testable prototype

The comparison is carried out based on the main function of the products, which is to deliver a first testable prototype of the medical device, QuickFact, that can be used to collect feces for pathogen/bacteria sample testing purposes. The functional unit is to deliver five units of a testable version of the medical device, QuickFact. Correspondingly, the reference flow for both FIM and standard NPD process is the first five units of a testable version of the medical device, QuickFact.

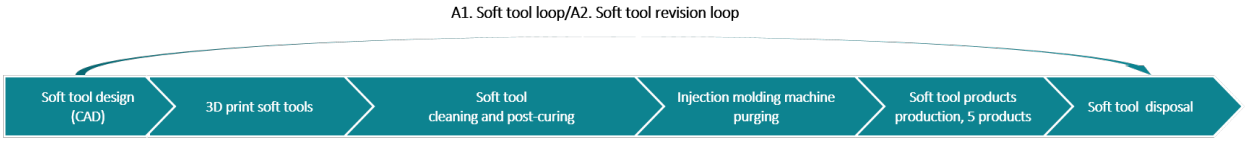
The system boundaries for the FIM process and the Standard NPD process are presented in Figure 1. It includes all life cycle stages for the product development process until the first testable components are produced. For each process in Figure 1, raw material extraction, production, use and End-of-Life (EoL) treatment are included in the boundary. The only exception is that the EoL of semi-hard tool in the Standard NPD process has not be included in the system boundary, as it possibly needs to be used in the following processes. A1 illustrates the system boundaries for the FIM process ("Soft tool loop") whereas B1 illustrates the system boundaries for the Standard NPD process ("Semi-hard tool loop without revision").

Figure 1 The system boundary of the FIM process and the Standard NPD process



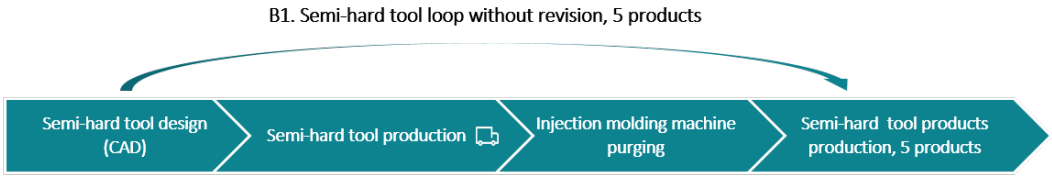
The flow diagrams of processes A1 (Soft tool loop) and B1 (Semi-hard tool loop without revision) are illustrated in Figure 2 and 3 below, including estimates of global warming potential (kg CO_2 eq). A2 (Soft tool revision loop) is essentially the same process as A1.

Figure 1 The flow diagram and inventory of the FIM process



	11. Soft tool design (CAD)	12. 3D print soft tools	13. Soft tool cleaning and post-curing	14. Injection molding machine purging	15. Soft tool products production, 5 products	16. Soft tool disposal
Electricity	Computer: 0.78 kWh (65 Watt X 12 Hours/1,000)	3D printer: 0.9 kWh (calculated based on real electricity consumption)	Cleaning stations: 15.2 kWh (calculated based on real electricity consumption)	(included in process)	(included in process)	
Material		3 kg plastic (Polymethyl methacrylate)	• Cleaning liquid (2-Propanol): 0.48 liter (0.374 kg) • Demolding liquid (4% Sodium Hydroxide in demin. water): 17 liter (0.68 kg Sodium hydroxide, and 17 kg deionized water) • Rinsing liquid (deionized water): 0.12 liter/kg	HDPE plastic: 3 kg	HDPE plastic: 0.2 kg/product X 5 products	
Process				Injection molding processing: 3 kg	Injection molding processing: 0.2 kg/product X 5 products	
Waste		Waste plastic to incineration: 0.9 kg (30% X 3 kg, estimation)	Average wastewater treatment: 17.6 kg	Waste plastic to market: 3 kg	Waste plastic to market: (0.2 kg-0.02 kg)/product X 5 products	Waste plastic to incineration: 2.1 kg (70% X 3 kg, estimation)
Transport						

Figure 3 The flow diagram and inventory of the Standard NPD process



	21. Semi-hard tool design (CAD)	22. Semi-hard tool production	23. Injection molding machine purging	24. Semi-hard tool products production, 5 products
Electricity	Computer: 5.2 kWh (65 Watt X 80 hours/1,000)	(included in process)	(included in process)	(included in process)
Material		Low-alloyed steel: 80 kg	HDPE plastic: 3 kg	HDPE plastic: 0.2 kg/product X 5 products
Process		Metal working, average for steel product manufacturing: 70 kg	Injection molding processing: 3 kg	Injection molding processing: 0.2 kg/product X 5 products
Waste		Steel scrap for market: 10 kg	Waste plastic to market: 3 kg	Waste plastic to market: (0.2 kg-0.02 kg)/product X 5 products
Transport		Lorry transport: 17.5 tkm (ton km) (250 km X 70kg/1,000)		

The comparative LCA result for GHG emissions of the FIM (soft tool loop) and Standard NPD processes (semi-hard tool loop without revision) is presented in Figure 4 and Table 1. The FIM process has at least 70% lower emissions in all environmental categories, in comparison with the standard NPD process. This is because the standard NPD process requires the production of steel molding tools from the beginning, which is an emission-intensive material. Moreover, the quantity of steel that is required to produce the molding tool is significant (70 kg), which results in substantial emissions. In comparison, the FIM process only requires a comparably small quantity of plastics, which is less emission-intensive than steel. Therefore, the FIM process is more environmentally friendly, in comparison with the Standard NPD process.

Figure 4 Life cycle impact assessment result comparison between FIM process (soft tool loop) and Standard NPD process (semi-hard tool loop without revision) until the first testable prototype of the medical device, QuickFact

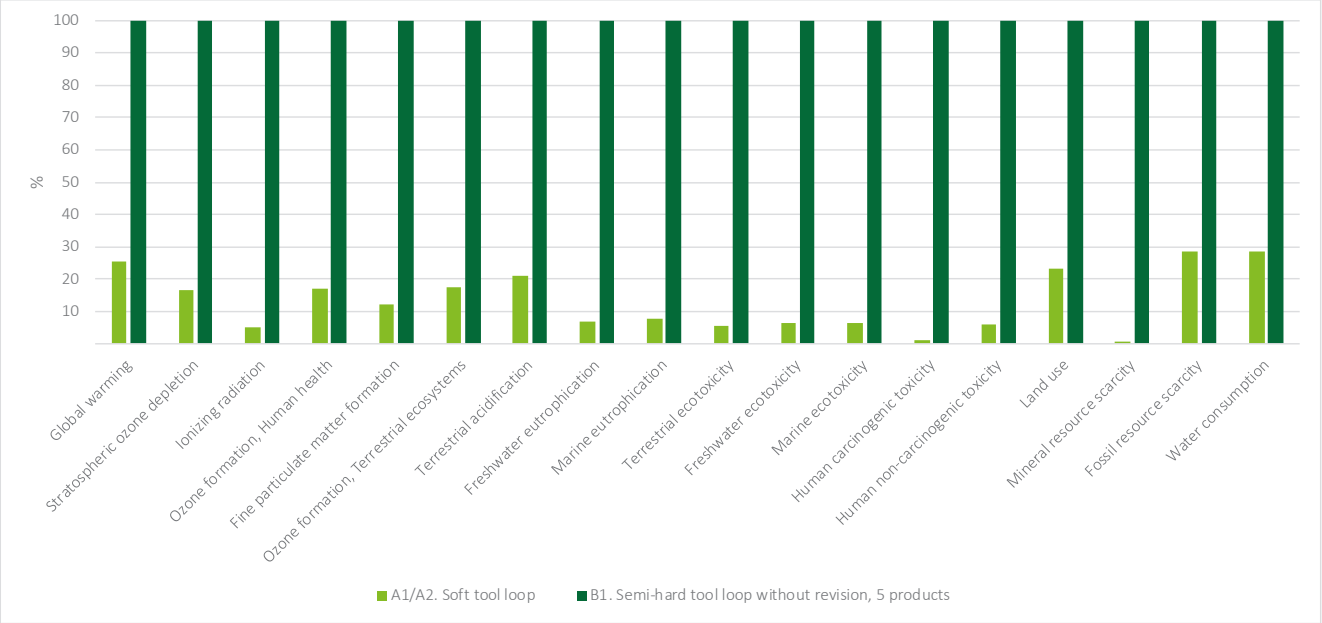


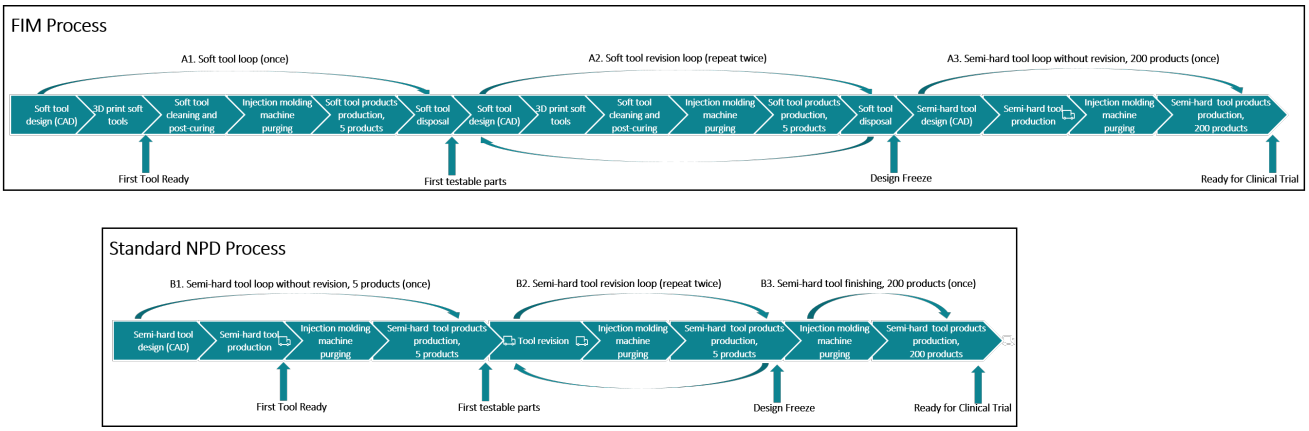
Table 1 Comparison of GHG emissions between the FIM process and the Standard NPD process for first testable component.

	UNIT	FIM	STANDARD NPD PROCESS
GHG EMISSION	kg CO_2 eq	62.2	243

Functional unit: deliver 200 units that are ready for clinical trial

We have further investigated the potential environmental savings from the FIM process until the clinical trial phase, where an additional comparative LCA was carried out. Here, the functional unit is to deliver 200 units of the prototype of the medical device, QuickFact, that are ready for clinical trial. Correspondingly, the reference flow is 200 units of the prototype of the medical device, QuickFact, that are ready for clinical trial. The system boundary in Figure 5 is used. Note that in order to produce medical device, QuickFact, ready for clinical trial, a semi-hard tool is eventually needed in the FIM process, so that it is suitable for mass production, as required in a clinical trial. The EoL of semi-hard tools in both FIM and NPD processes have not been included in the system boundary, as they need to be used in the following processes.

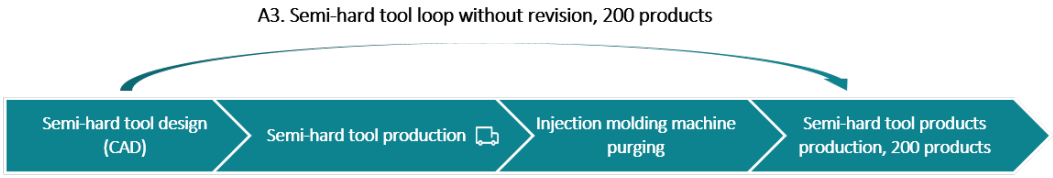
Figure 5 The system boundary of the FIM process and Standard NPD process to produce products that are ready for clinical trial.



Penneo dokumentnøgle: TZA2E-HZAMS-JOTZO-TY6E8-QBBFP-SDQGT

The flow diagrams of processes A3 (Soft tool loop without revision, 200 products), B2 (Semi-hard tool revision loop) and B3 (Semi-hard tool loop finishing, 200 products) are illustrated in Figures 6 and 7 below, including estimates of global warming potential (kg CO_2 eq).

Figure 6 Flow diagram of A3 Semi-hard tool loop without revision, 200 products



	21. Semi-hard tool design (CAD)	22. Semi-hard tool production	23. Injection molding machine purging	26. Semi-hard tool products production, 200 products
Electricity	Computer: 5.2 kWh (65 Watt X 80 hours/1,000)	(included in process)	(included in process)	(included in process)
Material		Low-alloyed steel: 80 kg	HDPE plastic: 3 kg	HDPE plastic: 0.02 kg/product X 200 products X (1+20% waste)
Process		Metal working, average for steel product manufacturing: 70 kg	Injection molding processing: 3 kg	Injection molding processing: 0.02 kg/product X 200 products
Waste		Steel scrap for market: 10 kg	Waste plastic to market: 3 kg	Waste plastic to market: (0.02 kg X 20% waste)/product X 200 products
Transport		Lorry transport: 17.5 tkm (ton km) (250 km X 70 kg/1,000)		

Figure 7 Flow diagram of B2 Semi-hard tool loop revision loop and B3 Semi-hard tool finishing, 200 products

	25. Tool revision	23. Injection molding machine purging	24. Semi-hard tool products production, 5 products
Electricity	Computer: 1.3 kWh (65 Watt X 20 hours/1,000)	(included in process)	(included in process)
Material	Low-alloyed steel: 2.5 kg (including 0.5 kg waste)	HDPE plastic: 3 kg	HDPE plastic: 0.2 kg/product X 5 products
Process	Metal working, average for steel product manufacturing: 2 kg	Injection molding processing: 3 kg	Injection molding processing: 0.2 kg/product X 5 products
Waste	Steel scrap for market: 0.5 kg	Waste plastic to market: 3 kg	Waste plastic to market: (0.2 kg-0.02 kg)/product X 5 products
Transport	Lorry transport: 35 tkm (ton km) (250 km X2 X 70 kg/1,000)		

23. Injection molding machine purging	26. Semi-hard tool products production, 200 products
(included in process)	(included in process)
HDPE plastic: 3 kg	HDPE plastic: 0.02 kg/product X 200 products X (1+20% waste)
Injection molding processing: 3 kg	Injection molding processing: 0.02 kg/product X 200 products
Waste plastic to market: 3 kg	Waste plastic to market: (0.02 kg X 20% waste)/product X 200 products

The result of the estimate of GHG emissions is presented in Table 2 below. It shows that the FIM process does not save GHG anymore in comparison with the standard NPD process. This demonstrates that the FIM process is more environmentally friendly in the design phase only, before producing the semi-hard tool. A process through Freeform Injection Molding that goes all the way to clinical trials will have a higher GHG emission than a comparable Standard NPD process.

Table 2 Comparison of GHG emissions between the FIM process and the Standard NPD process until ready for clinical trial.

	UNIT	FIM	STANDARD NPD PROCESS
GHG EMISSION	kg CO_2 eq	440.6	352.7

Table 3 and 4 below displays the GHG emissions by overall phase.

Penneo dokumentnøgle: TZA2E-HZAMS-JOTZO-TY6E8-QB8FP-SDQGT

Table 3 GHG emissions of the Standard NPD process until ready for clinical trial.

	Design	Build	Mold & test	Revise	Revise	Mold & test
GHG (kg CO_2 eq)	2	216	24	37	37	36

Table 4 GHG emissions of the FIM process until ready for clinical trial.

	Design	3D print	Mold & test	Reprint	Reprint	Design	Build	Mold & test
GHG (kg CO_2 eq)	0	26	36	62	62	2	216	36

Scenario analysis

Injection molding companies usually undertake many product development projects over the course of a year. A rule of thumb in the industry is that out of 10 development projects started, only one will succeed. This means that there is value in being able to test concepts, parts and hypotheses cheaper and faster – because most of them will not continue to become actual products. In order to test whether FIM can help companies save resources during the design phase, three scenarios are established for comparison. In all three scenarios, 90% of the projects fail in the design phase. Only 10% of projects successfully make it to the clinical trial:

- Standard NPD Baseline: 10 Standard NPD projects (9 projects fail after first testable part; 1 project succeeds to clinical trial)
- FIM Scenario 1 (cash in savings): 10 FIM projects (9 projects fail after first testable part; 1 project succeeds to clinical trial)
- FIM Scenario 2 (boost innovation): 30 FIM projects (27 projects fail after first testable part; 3 projects succeed to clinical trials).

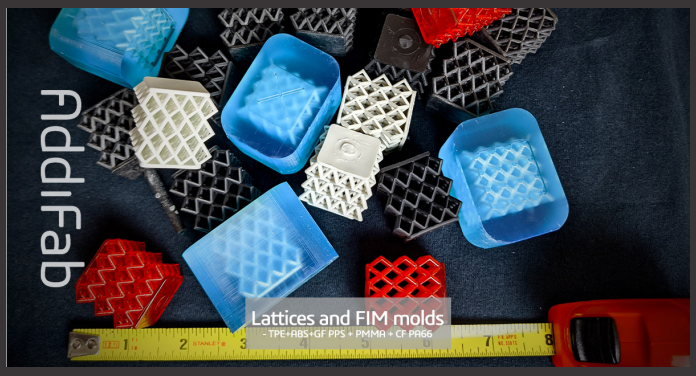
Table 5 Comparison of GHG emissions for three product development scenarios.

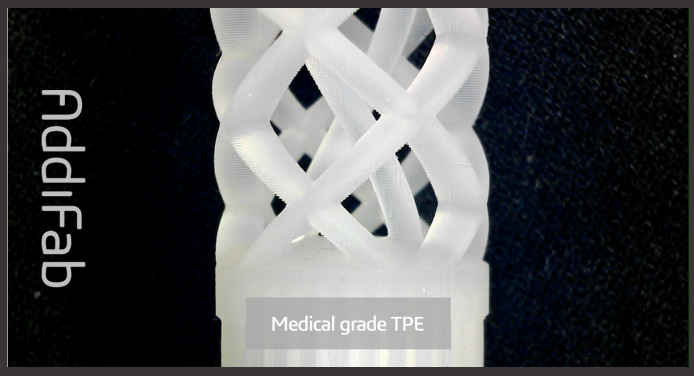
	UNIT	BASELINE: 10 STANDARD NPD PROJECTS	SCENARIO 1: 10 FIM PROJECTS	SCENARIO 2: 30 FIM PROJECTS
GHG EMISSION	kg CO_2 eq	2,537	1,001	3,002
INNOVATION	# of products to clinical trial	1	1	3

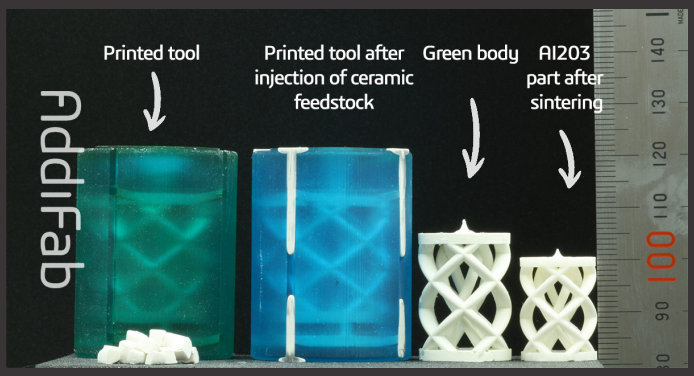
The result demonstrates that to get one product successfully to clinical trials, FIM can save ~60% in GHG emissions (comparison result between baseline Standard NPD and FIM Scenario 1 in Table 5).

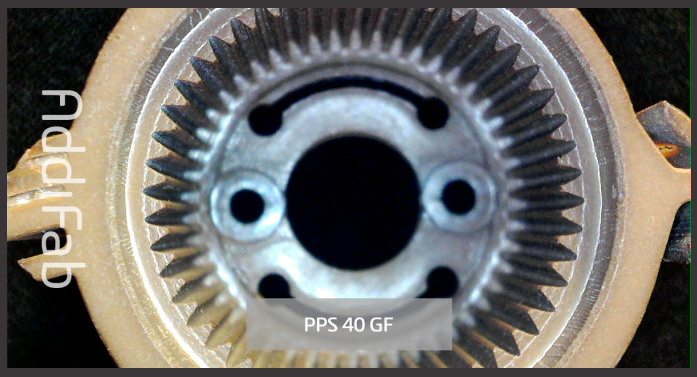
Looking at scenario 2, with slightly more GHG emissions, FIM can deliver three times as many product development projects – and three times as many products to clinical trials (comparison result between baseline NPD and FIM Scenario 2 in Table 5).

This demonstrates that FIM can help companies bring the resource cost of testing hypotheses down, which can enable either direct savings (same number of hypotheses tested at a lower resource cost) and/or increased innovation for roughly the same resource consumption.









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