LCA Studio

Life cycle assesement of thermochemical plastic recycling for unit TDU2000®

Green +Future

LCA practitioner:

LCA Studio s.r.o.

Šárecká 1962/5, 160 00 Praha 6, Czech Republic

VAT ID: CZ10774424

www.lcastudio.cz

Contact persons:

Ing. et Ing. Tatiana Trecáková, Ph.D. (tatiana.trecakova@lcastudio.cz)

Contractor of LCA study:

Gree-Future.cz a.s. Stračovská Lhota 50, Mžany 503 15, Czech Republic

Michal Pivrnec, CEO, info@green-future.cz

Summary:

This study was developed for the purpose of calculating environmental impact categories for the process of thermochemical plastic recycling for Green-Future.cz a.s. according to EF 3.1 and ISO 14064 methodology. The study was developed in accordance with the requirements of ISO 14040, 14044.

Notice:

This document contains sensitive data of Green-Future.cz a.s. It is not allowed to pass this document to third parties without specific permission of Green-Future.cz a.s.

CONTENT

CONTENT

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

1 GENERAL CHARACTERISTICS OF THE LCA STUDY

1.1 INFORMATION ABOUT THE COMPANY

Green-Future.cz a.s. is a pioneering company in thermochemical plastic recycling. The technology is considered to be the best way to turn plastic waste into high-value raw materials without any emissions. From plastic waste, the technology can produce a green alternative to common fossil resources, but also energy gas, hydrogen or carbon powder, which can be used, for example, in agriculture. For the recycling is used so-called TDU2000® thermochemical unit, which was developed in the Czech Republic and manufactured in Slovakia.

Background of the technology: The TDU2000® thermochemical recycling technology was developed by the Enress company team led by Jaroslav Pátek, who has been developing thermochemical recycling technology for more than ten years. Among others, the Czech University of Technology (ČVUT) and the University of Jan Evangelista Purkyně (UJEP) participated in the consultations and development.

Green-Future.cz a.s. has exclusive rights to build and operate these units anywhere in the world as part of an exclusive strategic partnership.

The entire technology process is hermetically sealed and excludes spontaneous leakage of substances from the entire process. The sensitive self-diagnostic system has immediate shut-down fuses, which use a quick intervention to interrupt the operation at the slightest indication in case of emergency. The nature of the chemical reaction does not carry the risk of the release of harmful substances.

The entire TDU2000® system is designed from the beginning in order to not to pollute the environment in any way. Its operation produces no emissions or odours. All reactions take place without access to air, which prevents spontaneous leaks.

The entire TDU2000® system is noiseless. It does not contain any noisy mechanical parts and the units themselves are mounted in such a way that they do not allow any vibrations which would spread to the surroundings.

Simplified principle of the thermochemical recycling

Plastics are made of durable and long hydrocarbon molecules. After all, this is the key to their unrivalled service life, which, however, makes their recycling significantly more difficult. If the plastics are exposed to heat, new substances are created. However, the reaction must be precisely controlled. Thermochemical recycling technology enables the processing of diverse waste plastic, including its mixtures. The result of this process is oil, gas and a carbonaceous residue. Polymers (plastics) are therefore transformed back into monomers (=depolymerization) in an ecological way, the monomers are intended for example for the production of new plastics. When they reach their end of life, thanks to thermochemical recycling, they will get another chance for usage.

Figure 1: Illustration of the main TDU2000® technology product (oil).

More information can be found on the website https://www.green-future.cz/.

1.2 INFORMATION ABOUT THE ASSESSED PRODUCT

Thermochemical plastic recycling unit TDU2000® is a functional technology, which can turn plastic waste into clean raw material.

The main marketable products are oil and process gas. The main characteristics of the oil are available in Table 1. The characteristics of the gas are available in the appendix of this report.

Characterization of the main product (oil)

Table 1: Overview of main components and parameters of the oil.

Parameter	Result	Unit	Method
C	85.90	% wt.	Internal
H	13.49		
N	0.36		
S	39	mg/kg	ASTM D5453
Cl	119		Internal
Pb	2.6		ICP, internal
Cd	0.12		
Fe	0.09		
Mo	<0.1		

Ti	<0.1		
Zn	0.3		
Al	1.7		
Ca	0.39		
Na	0.67		
Micro Conradson residue	0.25	% wt.	ASTM D4530
Water content (K. Fischer)	0.03		ASTM D4928
Undissolved substances	<0.01		EN 12662
Kinematic viscosity at 40°C	0.826	mm^2/s	ASTM D7042
Density at 15°C	776.8	kg/m^3	ASTM D4052
Saturates arom.	87.1	% wt.	EN 12916
Monoaromatics	10.9		
Diaromatics	1.8		
PAH	0.3		
Acid number	0.66	mg KOH/g	ASTM D664
Bromine number	68.6	g Br/100g	ISO 1998

1.3 THE AIM OF THE STUDY

The aim of the study is to assess environmental impacts of the thermochemical plastic recycling unit TDU2000® according to ISO 14067 and EN 15804 + A2 (based on EF 3.1 methodology).

Furthermore, the aim is to assess the impact of electricity grid mix change (residual grid mix vs. nuclear energy) on the generated environmental burdens.

2 GOAL AND SCOPE DEFINITION

2.1 LCA METHODOLOGY

The Life Cycle Assessment (LCA) method is an analytical tool based on the measurement of technological, operational and environmental parameters of individual organisations or industrial enterprises involved in the production, transport, operation or disposal of any material, equipment, fuel or energy carrier entering any stage of the life cycle of a product.

The LCA method is performed according to ISO 14040 (ISO 14040:2006) and EN ISO 14044 (ISO 14044:2006). It is a robust and transparent tool for quantifying the potential environmental impacts associated with individual input and output materials and energies. LCA is an internationally used method recommended by United Nations Environment Program (UNEP) and is currently being discussed in the context of the transition to a circular economy.

The essence of the LCA method is to determine the material and energy flows into and out of the system under consideration. Their quantity, composition, nature and environmental significance are monitored. The causes and consequences of these flows then determine the resulting changes in the environment. The basic data shall be compiled by means of an inventory analysis. A predefined part of the life cycle of the system under assessment is divided into unit processes and the flows between them are mapped. This is followed by an environmental impact assessment and a final interpretation.

In this study, EN 15804 + A2 (based on EF 3.1 methodology), recommended by European Comission and ISO 14067 are used.

Values of Greenhouse Gases (GHG) are expressed as Global Warming Potential (GWP) in kilograms of carbon dioxide equivalents (kg CO2eq).

2.2 FUNCTIONAL UNIT

The functional unit used in this study is 1 kg of the pure oil as a product from the thermochemical plastic recycling process.

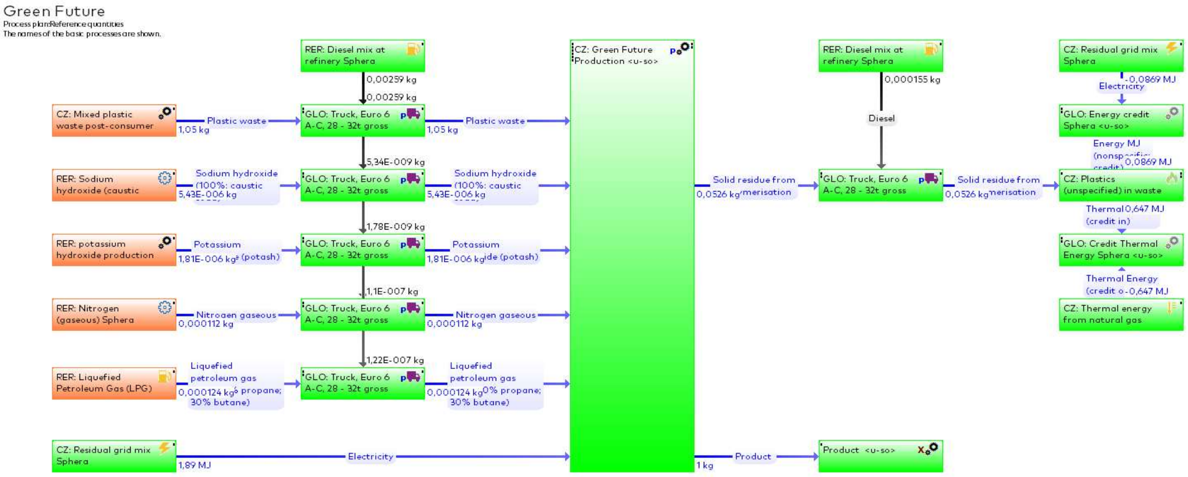
2.3 PRODUCT SYSTEM AND BOUNDARIES OF THE SYSTEM

The product carbon footprint provided in this study is calculated under a cradle-to-gate system. It covers the processing of input materials, all relevant transport down to the process unit and handling of solid residue from the depolymerization. Transportation to the customer , the use phase and EOL of the product are therefore not part of the system.

The boundaries to nature cover the flow of materials and energy resources from nature to the system. All relevant elemental flows (emissions) to air, water and land across the system boundary are counted if are emitted or leave the product system.

In the Fig. 2 is available flowsheet (LCA for Experts, Sphera) of the product life cycle's model. The upstream module is shown in orange, the core module is shown in green.

Figure 2: Flowsheet of the product life cycle's model.



2.4 ASSUMPTIONS FOR THE STUDY

The product system does not include the manufacturing processes of the capital goods or spare parts and/or maintenance. The environmental impact of infrastructure for general management, office, and headquarters operations is not included. Product system does not include the consumption of natural gas for sanitary and heating system for the staff's comfort. The energy consumption was sourced from the Czech residual energy mix.

2.5 ALLOCATION AND CUT OFF CRITERIA

All material and energy flows were assigned to one production line and two marketable products: oil and process gas. Mass allocation was applied.

For secondary material, the allocation of impacts is based on the polluter pays principle. No secondary fuels are used in the production.

More than 99 % of flows were included.

2.6 GEOGRAPHIC BOUNDARIES

All emission factors used for the calculation are specified for Czech conditions, if available. Otherwise, European or Global datasets are used.

3 LIFE CYCLE INVENTORY (LCI)

3.1 DATA SOURCES AND COLLECTION

Based on the operational data provided by Green-Future.cz a.s., product system models were created. All relevant data were used. Generic data from Sphera databases were used. Sphera database is internationally used with process data-sets validated at European level.

Site specific data from producer are based on a pilot operation in 2023 (reference period 9-12/2023). The integrity of generic data records is ensured by Sphera (LCA software provider).

All data used for this LCA study was collected in Green-Future.cz a.s.

Data was collected and provided by: Michal Pivrnec, CEO, info@green-future.cz

The following assumptions were accepted in this LCA study:

1. Czech residual electricity grid mix is assumed.
2. The technology is considered as emission-free as stated by the manufacturer.

Specific data were used for modelling of processes, which are operated by the producer (manufacturing of products) and modelling of some input materials. Also, specific parameters for some generic processes were considered (site-specific distance in transportation processes). Generic data were used for modelling of other processes (production of raw materials, components, generation of electricity and heat, general transport processes).

Accuracy of data is according to the operating documentation of the manufacturer and no variability is available. Completeness is reached due to considered flows, which is accounted for according to cut-off rules.

The following rules for time scope of data were applied:

< 10 years for background data,
< 2 years for manufacturer's data.

3.2 DATA INVENTORY

Generic and specific process data were used for the study. Specific data were obtained directly from the company and were used in relevant production processes. If there were no specific data available, then generic data from the Sphera database were used in calculations as is summarized below.

This database is internationally used with process data-sets validated at European level. This study used the professional LCA software LCA for Experts, developed by Sphera.

Production of electricity consumed within Green Future.cz a.s. production was based on the Czech residual electricity grid mix and modelled based on a process from Sphera database.

The following generic and specific process data were used in calculations:

Table 2. Specific and generic processes.

Generic process	Produced material/component
CZ: Residual grid mix Sphera	Electricity consumption in Czech Rep.
GLO: Truck, Euro 6 A-C, 28 - 32t gross weight / 22t payload capacity Sphera gross	Transportation by truck
RER: Diesel mix at refinery Sphera	Diesel consumption
RER: Sodium hydroxide (caustic soda) mix (100%) Sphera	NaOH production
RER: Potassium hydroxide production ecoinvent 3.9.1	KOH production
RER: Nitrogen (gaseous) Sphera	N_2 production
RER: Liquified Petroleum Gas (LPG) (70% propane, 30% butane) Sphera	LPG production
CZ: Green Future Production <u-so>	Production process
CZ: Plastics (unspecified) in waste incineration plant	Incineration of residual waste

The following table illustrates the data relating to transport, inputs and outputs.

Table 3: Inventory of the model.

Inputs	Value
Mixed plastic waste post-consumer	1,05 kg
Sodium hydroxide (caustic soda) mix (100%)	5,43E-006 kg
Potassium hydroxide production	1,81E-006 kg
Nitrogen (gaseous)	0,000112 kg
Liquified Petroleum Gas (LPG)	0,000124 kg
Energy consumption for production	0,526 KWh
Transportation by truck	
Mixed plastic waste post-consumer	100 km
Sodium hydroxide (caustic soda) mix (100%)	40 km

Potassium hydroxide production	40 km
Nitrogen (gaseous)	40 km
Liquified Petroleum Gas (LPG)	40 km
Outputs	
Marketable product (oil and process gas)	1 kg
Solid residue from depolymerisation (carbon dust)	0,0526 kg

RESULTS

4 LIFE CYCLE IMPACT ASSESSMENT (LCIA)

For contribution analysis purpose, results in ISO 14067 and EN 15804 + A2 (based on EF 3.1 methodology) are assessed. The detailed results and discussion are available in the upcoming sections.

4.1 CARBON FOOTPRINT ASSESSMENT

In the conducted LCA study were evaluated two methodologies. The reason for this is that there is no clear standard for environmental impact evaluation methodology in the sector.

In ISO 14067 GWP (based on IPCC AR6) methodology, the following carbon footprint is declared for cradle-to-gate system:

0,3651 kg CO2 eq.

In EN 15804 + A2 (based on EF 3.1 methodology), Carbon footprint – total value for the declared cradle-to-gate system is:

0,3649 kg CO2 eq.

4.1.1 ANALYSIS OF ISO 14067 IMPACT CATEGORIES (GWP)

The contribution analysis is performed on the results of the LCA study based on the different ISO 14067 impact categories. As shown in Table 4, the far highest contribution have fossil GHG emissions ranging up to 100 %. Biogenic GHG emissions and Biogenic GHG removal have approx. 6% contribution – the biogenic GHG removal represents the GHG sequestration, therefore resulting in an environmental benefit.

Table 4: Contribution analysis results – life cycle phases contribution to the total result.

Type	Total [kg CO2 eq.]	Contribution
ISO14067 GWP100, Air craft emissions	6,19E-08	0,00%
ISO14067 GWP100, Biogenic GHG emissions	2,11E-02	5,78%
ISO14067 GWP100, Biogenic GHG removal	-2,13E-02	-5,84%
ISO14067 GWP100, Emissions from land use change (dLUC)	9,60E-05	0,03%
ISO14067 GWP100, Fossil GHG emissions	3,65E-01	100,00%

4.1.2 ANALYSIS OF EN 15804 + A2 (BASED ON EF 3.1 METHODOLOGY) IMPACT CATEGORIES (GWP)

For EN 15804 + A2 (based on EF 3.1 methodology), the highest contribution to produced CO2 emissions have fossil GHG emissions as well. In case of EN 15804, the biogenic emissions are calculated as a sum biogenic GHG emissions and biogenic GHG removal, as in case of ISO14067. The environmental contribution of the biogenic GHG removal (in the corresponding table shown as EN15804+A2 (EF 3.1) Climate Change, biogenic [kg CO2 eq.]) are much lower, than the values from ISO14067.

Table 5: Contribution analysis results – life cycle phases contribution to the total result.

Type	Total [kg CO2 eq.]	Contribution
EN15804+A2 (EF 3.1) Climate Change, fossil [kg CO2 eq.]	3,65E-01	100,03%
EN15804+A2 (EF 3.1) Climate Change, biogenic [kg CO2 eq.]	-2,20E-04	-0,06%
EN15804+A2 (EF 3.1) Climate Change, land use and land use change [kg CO2 eq.]	9,60E-05	0,03%
01 EN15804+A2 (EF 3.1) Climate Change - total [kg CO2 eq.]	3,65E-01	100,00%

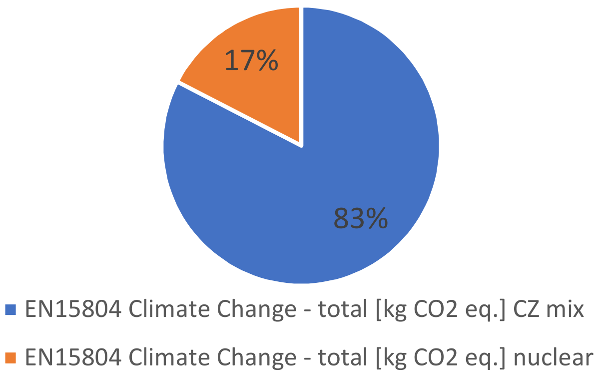
4.1.3 COMPARISON OF GHG EMISSIONS FOR DIFFERENT ENERGY SOURCES

For enhanced discussion, the GHG emissions are compared with case study where nuclear energy was used as main energy source for the recycling process.

The Czech energy grid mix is mostly composed from 57,4% fossils, 35% nuclear energy and 7,6% renewables. Due to the high amount of fossils' presence in the mix, it is crucial to compare discharged emissions of GHG between the Czech residual energy mix and the nuclear energy as energy source (Toktarova et al., 2022).

As can be sen in Fig. 3, the GHG emissions produced by usage of Czech energy mix are almost 5 times higher, than the ones from usage of nuclear energy as an energy source.

Figure 3: Comparison of GHG emissions for different energy sources.



Nuclear energy has low GHG emissions primarily because its production does not rely on burning of fossil fuels, which release significant amounts of carbon dioxide and other greenhouse gases into the atmosphere. According to the Intergovernmental Panel on Climate Change (IPCC 2011), nuclear power is recognized as a low-carbon energy source, emitting on average about 12 grams of CO2 equivalent per kilowatt-hour (gCO2eq/kWh) of electricity generated, compared to around 820 gCO2eq/kWh for coal-fired power plants and approximately 490 gCO2eq/kWh for natural gas-fired power plants.

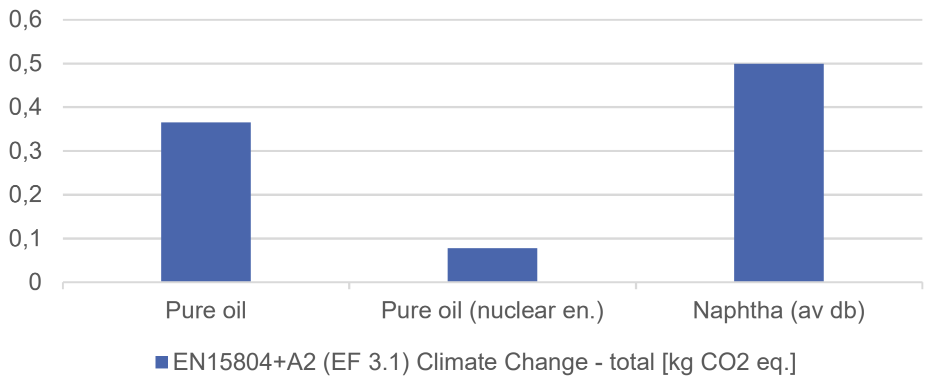
Results of other categories will be discussed in the following chapter.

4.1.4 COMPARISON OF CARBON FOOTPRINT WITH PRIMARY MATERIAL

The carbon footprint of 1 kg of pure oil is compared with the carbon footprint of 1 kg of primary raw material, in this case the naphtha.

As can be sen in Fig. 4, the carbon footprint of pure oil is app. 25% lower than primary naphtha production (according to average LCA database data).

Figure 4: Comparison of pure oil and primary raw material



4.2 ENVIRONMENTAL IMPACT INDICATORS

This process is consisting generaly from two modules, the upstream and the core module (the depolymerisation process, product processing and production waste management). Overview of results of all impact categories for the original case, where the Czech residual energy mix was used, is shown in Tab. 6 (EN15804).

Table 6: Overview of results of all impact categories for EN15804 (CZ residual energy mix).

1. Environmental impact indicators	**Total**	**Core**	**Upstream**
Climate Change - total [kg CO2 eq.]	3,65E-01	3,65E-01	1,12E-04
Climate Change, fossil [kg CO2 eq.]	3,65E-01	3,65E-01	1,11E-04
Climate Change, biogenic [kg CO2 eq.]	-2,20E-04	-2,21E-04	6,38E-07
Climate Change, land use and land use change [kg CO2 eq.]	9,60E-05	9,60E-05	1,80E-08
Ozone depletion [kg CFC-11 eq.]	1,89E-12	1,80E-12	9,60E-14
Acidification [Mole of H+ eq.]	6,58E-04	6,58E-04	3,77E-07
Eutrophication, freshwater [kg P eq.]	2,60E-07	2,58E-07	2,06E-09
Eutrophication, marine [kg N eq.]	1,21E-04	1,21E-04	6,71E-08
Eutrophication, terrestrial [Mole of N eq.]	1,31E-03	1,31E-03	7,42E-07
Photochemical ozone formation, human health [kg NMVOC eq.]	3,46E-04	3,45E-04	3,08E-07
Resource use, mineral and metals [kg Sb eq.]	1,38E-08	1,37E-08	5,33E-11
Resource use, fossils [MJ]	4,52E+00	4,51E+00	7,01E-03
Water use [m³ world equiv.]	1,64E-02	1,64E-02	5,41E-06
2. Resource use indicators	**Total**	**Core**	**Upstream**
Use of renewable primary energy (PERE) [MJ]	5,22E-01	5,22E-01	1,41E-04

Total use of renewable primary energy resources (PERT) [MJ]	5,22E-01	5,22E-01	1,41E-04
Use of non-renewable primary energy (PENRE) [MJ]	4,52E+00	4,51E+00	7,02E-03
Total use of non-renewable primary energy resources (PENRT) [MJ]	4,52E+00	4,51E+00	7,02E-03
Use of net fresh water (FW) [m3]	1,75E-03	1,75E-03	1,85E-07
3. Output flows and waste categories	**Total**	**Core**	**Upstream**
Hazardous waste disposed (HWD) [kg]	4,15E-11	4,15E-11	3,46E-14
Non-hazardous waste disposed (NHWD) [kg]	3,58E-03	3,58E-03	7,94E-07
Radioactive waste disposed (RWD) [kg]	8,49E-04	8,49E-04	3,52E-08
4. Optional indicators	**Total**	**Core**	**Upstream**
Particulate matter [Disease incidences]	4,81E-09	4,81E-09	2,37E-12
Ionising radiation, human health [kBq U235 eq.]	5,51E-02	5,51E-02	6,60E-06
Ecotoxicity, freshwater [CTUe]	1,33E+00	1,33E+00	5,46E-03
Human toxicity, cancer [CTUh]	2,28E-11	2,27E-11	9,25E-14
Human toxicity, non-cancer [CTUh]	1,30E-09	1,30E-09	2,91E-12
Land Use [Pt]	1,20E+00	1,20E+00	1,23E-04

The impacts on Ecotoxicity, freshwater, are much higher for case, where CZ residual energy grid mix is used (as can be seen in the tab 10 – 1.33E0 CTUe (eqivalents of comparative toxic units) (= 1,33) than in case when nuclear energy would be used (2,62E-01, or 0,26). Nuclear energy is associated with lower combustion and related produced pollutants that can harm freshwater ecosystems. Nuclear power plants require less water for cooling than fossil fuel power plants (Wang et al. 2001). Aditionally, nuclear power generation does not lead to production of freshwater pollutants such as sulphur dioxide, nitrogen oxides or heavy metals, which are compounds commonly produced during fossil fuel combustion (Brandt et al. 2014).

Thanks to these actions, the use of nuclear power exhibits environmental benefits for several categories (Particulate matter or Human toxicity cancer & non-cancer). Over of values for all impact categories are available in tab 7.

Table 7: Overview of results of all impact categories for EN15804 (nuclear power).

1. Environmental impact indicators	**Total**	**Core**	**Upstream**
Climate Change - total [kg CO2 eq.]	7,71E-02	7,70E-02	1,12E-04
Climate Change, fossil [kg CO2 eq.]	7,73E-02	7,72E-02	1,11E-04
Climate Change, biogenic [kg CO2 eq.]	-2,77E-04	-2,78E-04	6,38E-07
Climate Change, land use and land use change [kg CO2 eq.]	8,75E-05	8,75E-05	1,80E-08
Ozone depletion [kg CFC-11 eq.]	2,57E-14	-7,04E-14	9,60E-14
Acidification [Mole of H+ eq.]	1,35E-05	1,32E-05	3,77E-07
Eutrophication, freshwater [kg P eq.]	4,25E-08	4,05E-08	2,06E-09
Eutrophication, marine [kg N eq.]	6,77E-06	6,70E-06	6,71E-08
Eutrophication, terrestrial [Mole of N eq.]	9,96E-05	9,89E-05	7,42E-07
Photochemical ozone formation, human health [kg NMVOC eq.]	7,11E-06	6,80E-06	3,08E-07
Resource use, mineral and metals [kg Sb eq.]	-3,25E-09	-3,30E-09	5,33E-11
Resource use, fossils [MJ]	5,09E+00	5,08E+00	7,01E-03
Water use [m³ world equiv.]	1,50E-02	1,50E-02	5,41E-06
2. Resource use indicators	**Total**	**Core**	**Upstream**
Use of renewable primary energy (PERE) [MJ]	-7,84E-03	-7,98E-03	1,41E-04
Total use of renewable primary energy resources (PERT) [MJ]	-7,84E-03	-7,98E-03	1,41E-04

Use of non-renewable primary energy (PENRE) [MJ]	5,09E+00	5,09E+00	7,02E-03
Total use of non-renewable primary energy resources (PENRT) [MJ]	5,09E+00	5,09E+00	7,02E-03
Use of net fresh water (FW) [m3]	1,71E-03	1,71E-03	1,85E-07
3. Output flows and waste categories	**Total**	**Core**	**Upstream**
Hazardous waste disposed (HWD) [kg]	-2,32E-10	-2,32E-10	3,46E-14
Non-hazardous waste disposed (NHWD) [kg]	2,28E-03	2,28E-03	7,94E-07
Radioactive waste disposed (RWD) [kg]	2,03E-03	2,03E-03	3,52E-08
4. Optional indicators	**Total**	**Core**	**Upstream**
Particulate matter [Disease incidences]	-1,66E-11	-1,90E-11	2,37E-12
Ionising radiation, human health [kBq U235 eq.]	1,31E-01	1,31E-01	6,60E-06
Ecotoxicity, freshwater [CTUe]	2,62E-01	2,57E-01	5,46E-03
Human toxicity, cancer [CTUh]	-1,47E-12	-1,56E-12	9,25E-14
Human toxicity, non-cancer [CTUh]	-3,74E-10	-3,77E-10	2,91E-12
Land Use [Pt]	8,86E-03	8,73E-03	1,23E-04

4.2.1 UPSTREAM MODULE AND CORE MODULE

The LCA model consists of upstream module and core module. The contribution of these phases is calculated in table 8. The core module in total produces majority of the total GHG emissions, 99,97%, while the GHG emissions for the upstream module prove to be negligible, with only 0,03% contribution to total GHG emissions of the technology.

Table 8: Contribution analysis results – life cycle phases contribution to the total result (GHG emissions)

Life cycle phase	ISO 14067 GWP / kg CO2 eq.	Contribution
Total	3,65E-01	100,00%
Core module	3,65E-01	99,97%
Upstream module	1,14E-04	0,03%

In the table 9 are shown individual process contributions, which are considered to be significant contributors to the produced GHG emissions (i.e. >1% contribution to the total GHG emissions). The mixed plastic waste post-consumer material has carbon footprint equalling zero because of the polluter-pays-principle. The highest contribution to the emitted GHG is caused by usage of the energy, followed by the incineration of the residual waste and lastly transport of the mixed plastic waste to the unit. The values in the table have in sum higher value than 100%. That is given by a fact that e.g. burning of waste leads to production of energy, therefore to positive environmental benefits, which are represented by negative contribution to GHG emissions. In sum, when these negative values are considered, the result is always 100%.

Table 9: Contribution analysis results – all processes over 1% contribution to the total result (GHG emissions).

Process	Process name	Contribution
Electric energy for production	CZ: Residual grid mix Sphera	79,55%
Incineration of residual waste	CZ plastic (unspecified) in waste incineration plant	33,17%
Transport of the mixed plastic waste to the unit	GLO: Truck, Euro 6 A-C, 28 - 32t gross weight / 22t payload capacity Sphera	2,24%

CONCLUSION

5 CONCLUSION

The purpose of the study was to calculate the carbon footprint of thermochemical plastic recycling unit TDU2000® (=depolymerization) with respect to ISO 14067 and EN 15804 + A2 (based on EF 3.1 methodology). System boundaries are set to cradle-to-gate, the functional unit is 1kg of the product (pure oil from the depolymerization).

The carbon footprint obtained is 0,3651 kg CO2 eq. in ISO 14067 and 0,3649 kg CO2 eq. in EN 15804 + A2 (EF 3.1 methodology).

In case nuclear energy would be used as an energy source, the total GHG emissions would be almost 5 times lower, than for the conventional Czech residual energy mix. Usage of nuclear power leads to e.g. lower impacts on ecotoxicity of aquatic sytems.

The core module contributes mostly to the production of GHG emissions, compared to the upstream module (99,97% vs 0,03%, respectively).

Further considering the GHG emissions, taking into account the individual processes, the energy consumption is the most contributional with nearly 80 % contribution, followed by incineration of residual waste (33%) and transport of the mixed plastic waste to the recycling unit (2%).

A comparison of pure oil production with primary naphtha production (database data) shows that the carbon footprint of the pure oil production is app. 25% lower than primary naphtha production.

6 LITERATURE

- ISO 14040:2006 Environmental management — Life cycle assessment — Principles and framework
- ISO 14044:2006 Environmental management — Life cycle assessment — Requirements and guidelines
- ISO 14067:2019 Greenhouse gases - Carbon footprint of products - Requirements and guidelines for quantification
- Sphera: LCA for Experts, 2023, Sphera solutions.
- World Resources Institute (2019). The Greenhouse Gas Protocol - A Corporate Accounting and Reporting Standard. USA, World Resources Institute.
- GHG protocol guidance Scope 1, Scope 2, Scope 3, https://ghgprotocol.org
- https://www.green-future.cz/
- https://ec.europa.eu/eurostat/databrowser/
- Toktarova, A., Göransson, L., Thunman, H., Johnsson, F. Thermochemical recycling of plastics – Modeling the implications for the electricity system, 34, 133891, *Journal of Cleaner Production*.
- IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation (2011): Chapter 7 - Energy Systems Integration for GHG Mitigation.
- M. Wang, S. Huo, H. Arora, and M. Wu. "Well-to-Wheels Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems—North American Analysis," Environmental Science & Technology, 2001.
- M. J. Brandt et al. "Mortality and Morbidity Attributable to PM2.5 and Ozone Exposure in the United States," Nature Sustainability, 2014

7 APPENDIX

Characterization of the process gas

Table 10: Overview of flammable components content.

Flammable components	Mass fraction (%)
Hydrogen	1.37
Methane	15.91
Acetylene	0.01
Carbon monoxide	3.87
Ethylene	17.31
Ethane	17.29
Hydrogen Sulphide	0
Propadiene	0
Propylene	21.62
Propane	4.94
Butenes	7.59
i-Butane	0.33
n-Butane	0.77
Pentanes+	3.12

Table 11: Overview of non-flammable components content.

Non-flammable components	Mass fraction (%)
Water	0.01
Nitrogen	1.20
Oxygen	0
Carbon dioxide	4.66

Flammable limit

Lower Flammability Limit (%): 3.59, Upper Flammability Limit (%): 16.56.

Table 12: Overview values for energy.

Energy	**Unit**	**0°C**		**20°C**		**25°C**	
		Inferior	**Superior**	**Inferior**	**Superior**	**Inferior**	**Superior**
Mass calorific value	MJ/kg					49.93	47.63
Mass calorific value	KWh/kg					12.20	13.23
Volume calorific value	MJ/m3	49.65	53.82	46.21	50.10		
Volume calorific value	KWh/m3	13.79	14.95	12.84	13.92		
Wobbe index	MJ/m3	53.11	57.57	49.45	53.61		
Wobbe index	kWh/m3	14.75	15.99	13.73	14.89		
In-cylinder energy	kWh	2226.636					

Table 13: Overview of other parameters.

Parameters	
Methane number	46.67
Molecular weight (kg/kmol)	25.19
Water Dew-Point (°C)	-41.19
Relative density	0.87 (0°C), 0.87 (20°C)
Density (kg/m3)	1.13 (0°C), 1.05 (20°C)
Compression factor	0.99 (0°C), 0.99 (20°C)

www.lcastudio.cz

LCA
Studio