Indicative GHG balance for formic acid as a hydrogen carrier in transport

CE Delft
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Committed to the Environment

Through its independent research and consultancy work CE Delft is helping build a sustainable world. In the fields of energy, transport and resources our expertise is leading-edge. With our wealth of know-how on technologies, policies and economic issues we support government agencies, NGOs and industries in pursuit of structural change. For 35 years now, the skills and enthusiasm of CE Delft's staff have been devoted to achieving this mission.

Summary

The chemical *formic acid* (CH_2O_2) is an elementary chemical that can serve as a 'hydrogen carrier' for fuel cell powered drive trains.

In order to assess the sustainability merits of the application of formic acid in transport, this brief report describes an indicative greenhouse gas (GHG) footprint analysis, focussing on the GHG emissions of the production and application life cycles.

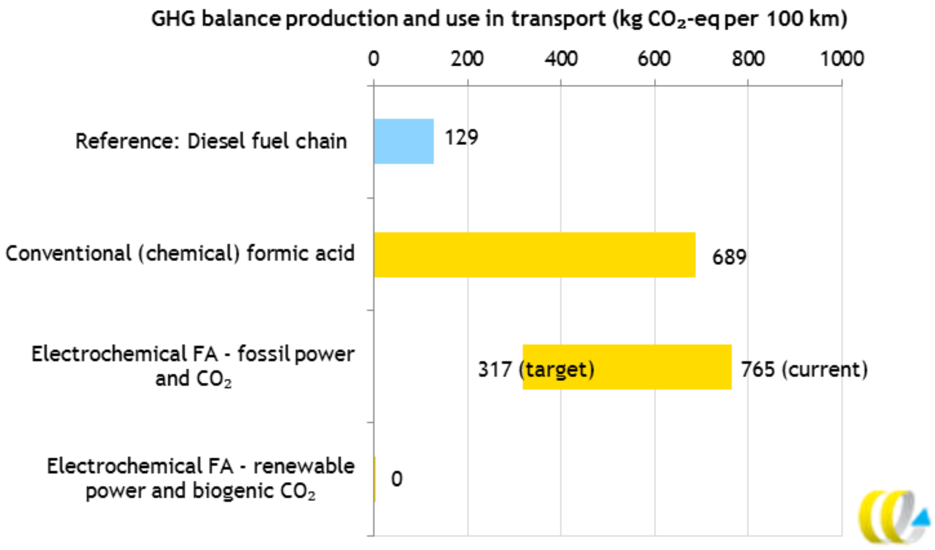
To elucidate the effects of applied production routes, CO_2 sources and energy sources, the following greenhouse gas balances are described:

- conventional chemical formic acid production route (from carbon monoxide and water); this is the reference for formic acid production;
- electrochemical formic acid production route (from electricity, water and CO_2), in two variants that reflect (more or less) the extremes with respect to the applied power source and source of CO_2:
  - using largely fossil fuel based electricity (current Dutch power grid mix) and fossil CO_2;
  - using renewable electricity and a biogenic CO_2 source.

In all cases, the comparison is made for application of the formic acid as a transport fuel in public transport buses, where also a comparison with the diesel fuel chain is made.

The results of the GHG balances are shown in Figure 1.

Figure 1 GHG balances



The results show that application of formic acid as a hydrogen carrier in transport only results in reduction of transport GHG emissions if renewable electricity and biogenic CO_2 are used in formic acid production. If conventional chemical or electrochemical formic acid (produced from grid electricity and fossil CO_2), is used, then the well to wheel emissions are significantly higher compared to the diesel reference case.

The current state of art electrochemical production will, when using grid based power, result in about 10% higher greenhouse gas emission per unit of formic acid compared with conventional production.
It is expected, however, that there is ample room to improve the process, which would also improve the GHG performance and may result in savings of over 50% compared to conventional formic acid, the reference for the production. In this case, replacement of conventional formic acid production by electrochemical formic acid will yield emission reduction, even if fossil power is used. But application in transport, where diesel would be the reference, would still result in a GHG emission increase.

Status of results and next steps
This study is a preliminary analysis of the power to formic acid life cycle, a more elaborate study is undergoing. The established results are indicative because of present limited availability of data.
In the ongoing study, more application areas are studied, including application in ships, stationary applications, more sensitivities are assessed, the impacts on (decentralized) renewable power systems are detailed, and we will put the technology in perspective of alternative sustainability options.

The study is part of the 'Power 2 Formic Acid' Joint Industry Project, which aims to develop the process innovations to bring the electrochemical reactor closer to the market. The Power 2 Formic Acid project is conducted under the VoltaChem[1] shared innovation program by a consortium of TNO, TU Delft, Coval Energy, Team Fast, CE Delft and Mestverwerking Friesland, supported financially by RVO.

1 Introduction

This brief report describes an indicative greenhouse gas footprint analysis for use of formic acid (FA) as a hydrogen carrier in transport. It is part of the 'Power 2 Formic Acid' Joint Industry Project, which is conducted by a consortium of TNO, TU Delft, Coval Energy, Team Fast, CE Delft and Mestverwerking Friesland, supported financially by RVO. Within this project, a full LCA will be conducted for utilization of formic acid as a hydrogen carrier in different transport modalities and decentralized power generation modalities. This brief report is a first indicative result of that work.

The aim of this brief study is producing indicative specific GHG emissions and illustrating the effects of applied production routes, CO_2 sources and energy sources.

In the preliminary analysis, three greenhouse gas balances for utilization of formic acid as a hydrogen carrier in transport are described, varying with respect to production routes for formic acid and with respect to applied raw materials and energy sources:
- conventional production, based on carbon monoxide and water ($CO + H_2O \rightarrow HCOOH$);
- two variants of the electrochemical production route being developed by Coval Energy ($CO_2 + H_2O \rightarrow HCOOH + O_2$):

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[1] See: www.voltachem.com/fa

- electrochemical production utilizing fossil fuels based power and CO_2 captured from flue gases of a modern coal fired power station[2];
- electrochemical production using renewable electricity and CO_2 from biomethane production.

The first of these alternative production routes represent the reference for formic acid production and is used in this study as a benchmark for evaluating the electrochemical production route. The two other alternatives concern (more or less) the extremes with respect to applied power source and source of CO_2, yielding the expected highest and lowest GHG impacts.

2 Applied data and basic assumptions

All greenhouse gas balances have been compilated for a city bus, traveling 100 kilometres. This basis for comparison was also utilized in the recent CHIC-project[3] in which 54 fuel cell electric buses with hydrogen as a fuel in nine cities in Europe and Canada were monitored over a six years period.
For comparison the same average diesel fuel consumption as determined in the CHIC-project (40.9 l of diesel/100 km) was assumed.

The greenhouse gas balances have been established utilizing standard greenhouse gas emission values for raw materials and energy adopted from the BioGrace I greenhouse gas calculation tool. The balances have also been established using the same system demarcation as considered in the BioGrace tool.

The reason to refer to the BioGrace I tool is that if hydrogen utilization by way of formic acid carrier is to be taken into account as an advanced transport fuel, according to the Renewable Energy Directive (RED) the associated potential greenhouse gas savings have to be calculated utilizing this standardized tool and the methodology behind it.

Greenhouse gas emission data for conventional formic acid production was adopted from the Ecoinvent database.
For the Coval Energy production process two values for the specific electricity consumption per unit of formic acid were considered, based on the information in the grant application of the consortium:

- a value of 6.7 kWh_e/kg formic acid, representing current ‘state-of-the-art’ technology;
- a value of 2.6 kWh_e/kg formic acid, the long term goal for Coval Energy.

Data for energy consumption in CO_2 capture at a modern coal fired power plant was adopted from design studies for the ROAD project, a 1 Mtonne/year CCS demonstration project aimed to be realised at the Uniper MPP3 power plant on Maasvlakte II.

For electrochemical production using renewable electricity and CO_2 from biomethane production it was assumed CO_2 is produced as a by-product without economic value. Hence, energy consumption associated with

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[2] In this variant it is assumed that the CO_2 utilized in formic acid production is captured from a modern coal fired and CO_2-capture ready power station, the MPP3 power station at Maasvlakte II in Rotterdam area. The captured and converted CO_2 is released again at the FA conversion to hydrogen.

[3] See: http://chic-project.eu/

biomethane production is allocated completely to the biomethane product and no energy consumption needs to be allocated to the CO_2 by-product.

Formic acid distribution has been neglected in this study in view of the indicative nature of current analysis.

3 Results and conclusions

Results

The resulting balances are included in Annex A. The greenhouse gas emissions per 100 kilometres, well to wheel, amount to:

- 130 kg CO_2-eq for the diesel reference;
- 690 kg CO_2-eq for conventional formic acid;
- 310–760 kg CO_2-eq for formic acid produced with the Coval Energy process and utilizing fossil based power and CO_2 captured from flue gases;
  the net emission varies as a function of specific electricity consumption per unit of formic acid
- 0 kg CO_2-eq for the Coval Energy route if renewable power[4] and CO_2 by-product from biomethane production are utilized.

Energy losses in the electrochemical production route

As indicated by the range in the greenhouse gas emission per unit of electrochemically produced formic acid, the balances for this production route are very strongly influenced by the specific electricity consumption in the electrochemical production process (itself).
The energy efficiency of this process amounts from 20-25% for current state-of-the-art up to 60% for Coval's long term efficiency goal.

Another 5% of energy – relative to the energy content of the regenerated H_2 - is lost during formic acid decomposition. Any energy required for CO_2 capture and conditioning will mean additional loss.

Consequently, as far as can be estimated on the basis of currently available information, the maximum percentage of renewable energy that may be supplied to the drive train of the bus amounts to an indicatively net 55% (compared with the original power supply).

Conventional formic acid production compared with electrochemical formic acid production

Utilizing conventional fossil fuel based grid power, the Coval Energy production process can result in 55% lower net greenhouse gases compared with conventional formic acid production if the long term specific power consumption target can be realised.

For current state-of-the-art electrochemical production technology utilization of conventional fossil fuel based grid power will give a 10% higher greenhouse gas emission per unit of formic acid, compared with conventional production.

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[4] In line with the demarcation of BioGrace, this omits indirect GHG emissions for renewable power production resulting from the construction of renewable power plants

Electrochemical formic acid production compared with diesel for transport

Formic acid as a hydrogen carrier in transport only results in greenhouse gas emission reduction in transport if renewable electricity can be used in formic acid production.

If Coval's long term goal for electricity consumption per unit of formic acid can be achieved, it would from an environmental perspective be more efficient to substitute conventional formic acid production first, given the comparatively limited greenhouse gas emission for the diesel reference.

Potential effect of potential future legislation

Future revision of the Renewable Energy Directory may influence which electricity source should be considered as representative in LCA's of future electrochemical production of formic acid.

In current revision proposal[5], electrochemically produced formic acid from renewable electricity may be counted as a [fully] renewable fuel if following legislative requirements are met:

- there should be a *direct connection* between the renewable power production capacity and the formic acid production location;
- in addition, the renewable power production should be specifically constructed for formic acid production and not have another grid connection.

Else - i.e. if the formic acid is produced with renewable electricity purchased with green certificates – according to the revision proposal, average EU wide or Member State specific grid electricity mix should be considered.

According to this proposal, a greenhouse gas balance for electrochemical formic acid production in The Netherlands with electricity purchased with green certificates should be conducted assuming an average electricity mix, which in The Netherlands has a 13% renewable electricity share.
For such a mix, utilization of formic acid as a hydrogen carrier for powering buses will give a 100% higher net greenhouse gas emission[6] compared with conventional diesel powered buses.

Status of the results

The established balances are yet very indicative by nature for several reasons, most important of which are:

- CE Delft has no information about hydrogen consumption for the Team Fast conceptual city bus. As an alternative, the average hydrogen consumption of current state-of-the-art fuel cell buses (9 kg's per 100 kilometres) was taken as an indication. However, how representative this specific consumption is for the quite different Team Fast design is unclear.
- There is still very little information concerning the Coval Energy production process – in fact only the near term and long term electricity consumption targets are mentioned. It is, for example, unclear what the selectivity of the process will be and whether e.g. distillation is required for isolating formic acid from unwanted by-products and for concentrating the formic acid product up to market specifications.

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[5] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52016PC0767R%2801%29 Art. 25.

[6] 87% x 317 (see Figure 2) = 235 kg CO_2-eq/100 kilometres.

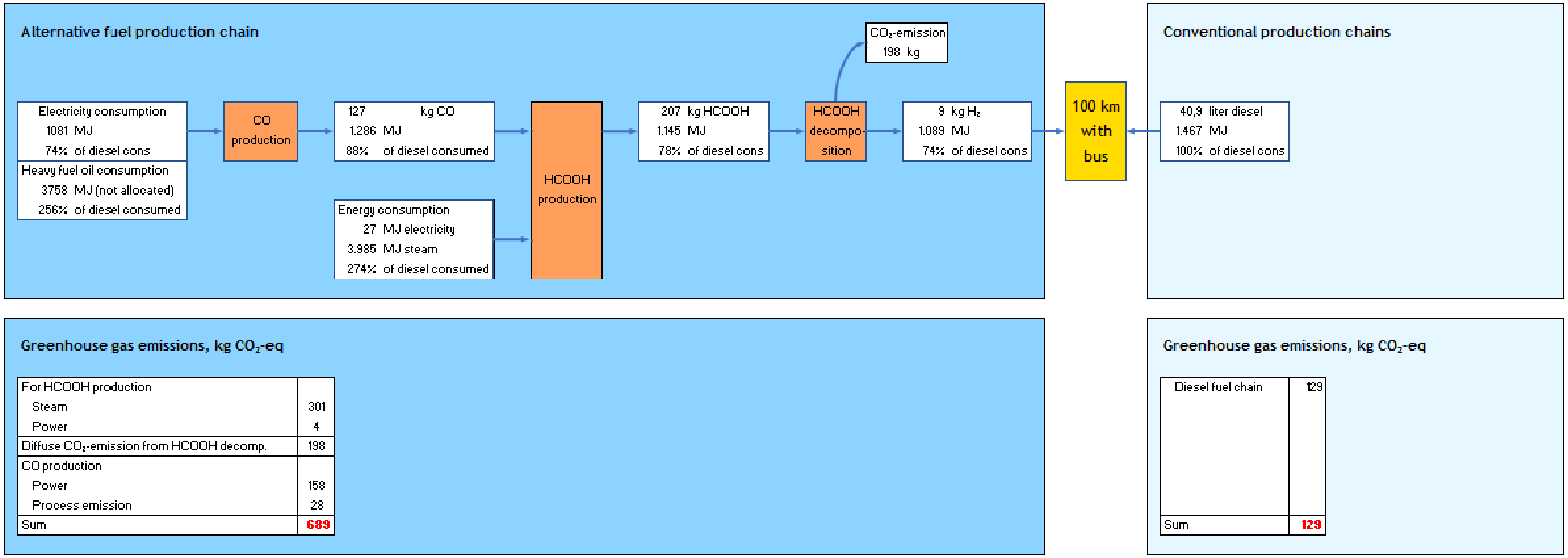
Next steps

CE Delft will conduct a full LCA study to elucidate how formic acid produced with the Coval Energy process compares under different applications (other than buses), depending on different combinations of sources for CO_2 and of power.

Within scope of the full study is also the question on in how far conversion of surpluses of renewable power to transport fuel compares with other options for ‘storing’ or ‘converting’ surpluses.

Annex A Balances

Figure 2 Balance for utilization of conventional formic acid



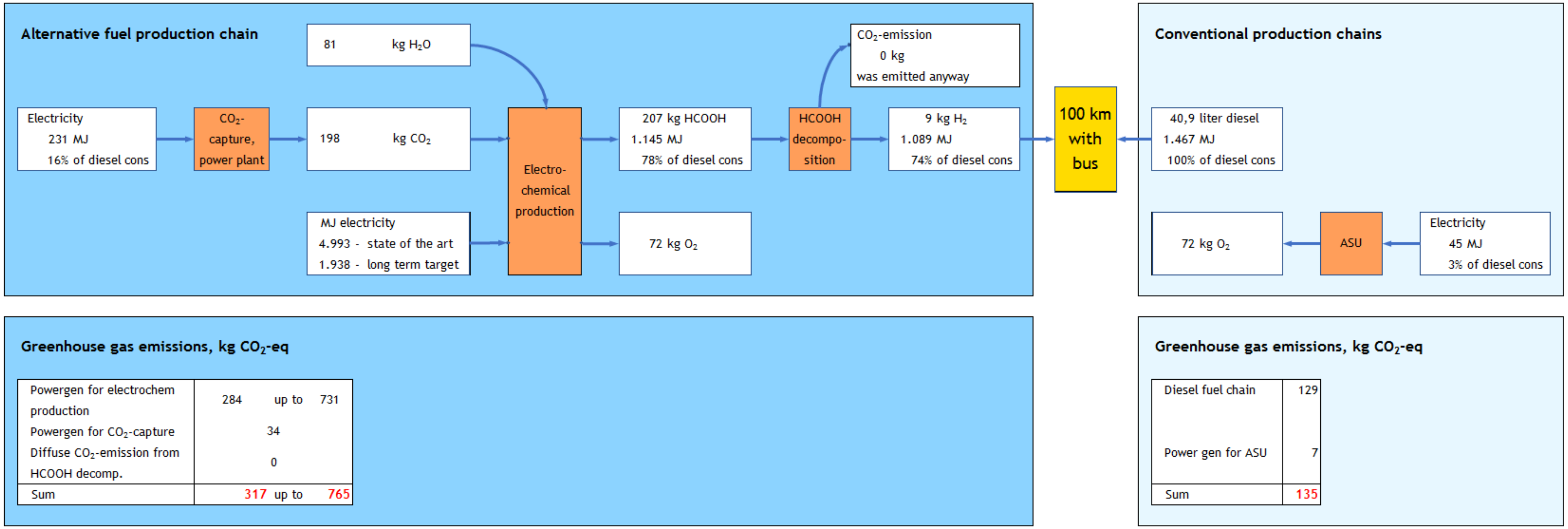
Greenhouse gas emissions, kg CO_2-eq

For HCOOH production	
Steam	301
Power	4
Diffuse CO_2-emission from HCOOH decomp.	198
CO production	
Power	158
Process emission	28
Sum	**689**

Greenhouse gas emissions, kg CO_2-eq

Diesel fuel chain	129
Sum	**129**

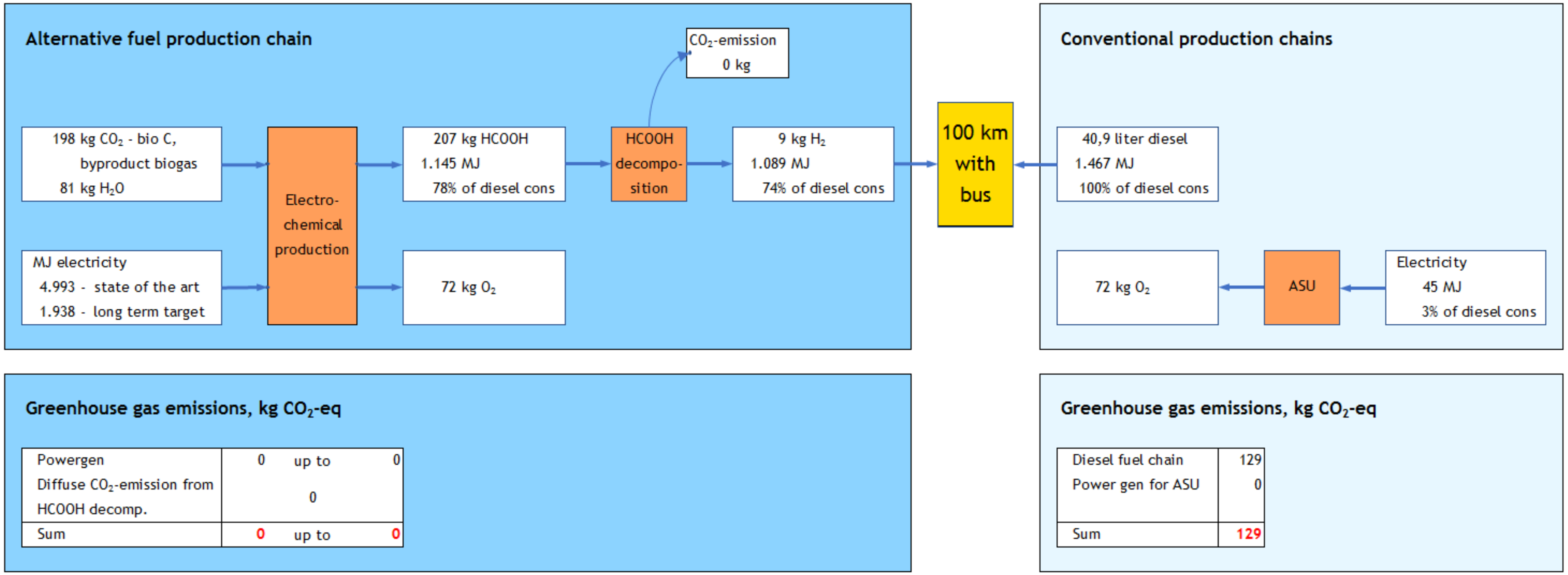
Figure 3 Balance for utilization of formic acid produced with the Coval Energy process, utilizing fossil fuel based power



Powergen for electrochem production	284	up to	731
Powergen for CO_2-capture		34	
Diffuse CO_2-emission from HCOOH decomp.		0	
Sum	317	up to	765

Diesel fuel chain	129
Power gen for ASU	7
Sum	135

Figure 4 Balance for utilization of formic acid produced with the Coval Energy process, utilizing renewable power



Greenhouse gas emissions, kg CO_2-eq

Powergen	0	up to	0
Diffuse CO_2-emission from HCOOH decomp.		0	
Sum	0	up to	0

Greenhouse gas emissions, kg CO_2-eq

Diesel fuel chain	129
Power gen for ASU	0
Sum	129