PPS-jaarrapportage 2019
De PPS-en die van start zijn gegaan onder aansturing van de topsectoren dienen jaarlijks te rapporteren over de inhoudelijke en financiële voortgang. Voor de inhoudelijke voortgang dient dit format gebruikt te worden. Voor PPS-en die in 2019 zijn afgerond is een apart format "PPS-eindrapportage" beschikbaar.
De jaarrapportages worden integraal gepubliceerd op de website het TKI's. Zorg er svp voor dat er geen vertrouwelijke zaken in staan.

De PPS-jaarrapportages dienen voor 1 maart 2020 te worden aangeleverd bij finance@tki-bbe.nl.

Algemene gegevens	
PPS-nummer	**BBE-1801**
Titel	**Proces systeem engineering studie gecombineerd met LCA voor agrarische restproduct torrefactie ter vervanging van kolen in poederkool verbrandingsketels. "Agritor"**
Roadmap	**Chemische conversie**
Uitvoerende kennisinstelling(en)	
Projectleider onderzoek (naam + emailadres)	**Naam: Dr. Luis cutz** **Bedrijf: Technische Universiteit Delft** **e-mail adres: luis.cutz@tudelft.nl**
Penvoerder (namens private partijen)	**Naam: Prof.dr.ir. Wiebren de Jong** **Bedrijf: Technische Universiteit Delft** **e-mail adres: wiebren.dejong@tudelft.nl**
Contactpersoon overheid (indien relevant)	
Adres projectwebsite	
Startdatum	**01-10-2018**
Einddatum	**31-09-2020**

Goedkeuring penvoerder / consortium	
De jaarrapportage dient te worden besproken met de penvoerder/het consortium. TKI BBE neemt graag kennis van evt. opmerkingen over de jaarrapportage.	
De penvoerder heeft namens het consortium de jaarrapportage	X goedgekeurd ☐ niet goedgekeurd
Evt. opmerkingen over de jaarrapportage:	

Inhoudelijke samenvatting van het project	
Probleemomschrijving	The Netherlands and Europe face an enormous challenge to decarbonize its energy matrix. During the last years, there has been an increase in electricity generation from renewable sources such as solar and wind energy. However, these sources are intermittent, unpredictable and with the current technologies, efficient storage of this energy is still limited. Meanwhile solar and wind realize their full potential, balancing technologies and fuels are needed to ensure power stability and quality. Renewable resources such as biomass, stored solar energy, provide reliable dispatchable power supply and a low-risk option to increase carbon mitigation potential. However, it is important to look at the sustainability and greenhouse gas emissions over the entire biomass value chain prior scalability. Several issues affect the sustainability of biomass value chains but the most important ones are: resource depletion, land use changes,

	competition with food and feed production, and techno-economics of biomass conversion. Major technical and economic barriers when using biomass as fuel are: high moisture content, low bulk density, rapid degradation and high transport costs. During the last decades, technologies such as stand-alone pelletization have offered a short-term solution to tackle some of these barriers. Nevertheless, challenges such as low energy density, hydrophobicity and rapid degradation still require further improvement. Among the most promising technologies to improve the quality of raw biomass is torrefaction. Torrefaction is a thermochemical pretreatment technique that dries and carbonizes biomass, woody or agricultural, without much energy loss, which therefore offers advantages in biomass storage, increased energy density and transport. There are two main types of biomass which are potential feedstocks for torrefaction: biomass from forestry and agriculture. Agricultural residual flows may be more attractive than woody biomass, especially given the short cycle time associated with their CO_2 cycle. This project aims to address technical barriers of biomass torrefaction and its impact on the three pillars of sustainability: economic, social and environmental.
Doelen van het project	This project studies the torrefaction of agricultural residues in the value chain up to and including the production of electricity and heat. To this end, potentially interesting agricultural waste flows are selected based on their availability, volumes, chemical composition and techno-economic feasibility to ensure sustainability throughout the chain towards power and heat generation. Subsequently, value chains of decentral and central torrefaction of the chosen agricultural waste flows are calculated using process simulation models. This is expected to provide insights about the energy efficiency and economic feasibility of the cases studied. These process simulation models then form the basis for implementing life cycle analyzes (LCAs) performed for the studied value chains. Herein, a selection will be made based on their corresponding emission impact categories, in particular the greenhouse gas emission potential, acidification potential, etc. In the phases of both process modeling and the LCA Pedigree analysis (expert consultation), the most recent modelling approach is used to reduce the uncertainty of used models. Such a combined system analysis is promising to point out emission 'hot spots' throughout the entire biomass transformation chain and to formulate measures to solve these.

Resultaten	
Beoogde resultaten 2019	-Identification of potentially sustainable large-scale agro-residue supply chains. - Process simulation of stand-alone torrefaction systems with torrefied pellets delivered to central power plant. - Integrated torrefaction system with (densified) agro-residues delivered to central power plant.
Behaalde resultaten 2019	During 2018 and 2019, Prof. De Jong and myself conducted several meetings with Mark Bouwmeester, project developer at RWE Generation NL and responsible project partner, where we defined the tasks and methods to meet the targets specified in the working packages (WP) included in the awarded proposal. Prof. De Jong and myself also had the opportunity to visit Mark at Amer power plant in Geertruidenberg, one of RWE's larger generation facilities and headquarters of RWE Generation NL. Mark provided us a tour of the Amer power plant and gave us valuable insight about the potential of torrefied pellets when co-fired with coal. During the first period of this project I dedicated myself to survey

potential biomass feedstocks and process configurations that could be of interest for dedicated case studies regarding biomass torrefaction. The potential availability of agricultural residues was estimated using a GIS-based modeling framework (WP1). This modeling framework considers the sustainability of forest and agricultural by-products towards power and heat generation. Results indicate that the main agricultural non-waste by-product in EU is cereal straw. At the European level, the countries with the highest potential regarding sustainable supply of straw are France (293 PJ/y), Germany (224 PJ/y), UK (213 PJ/y), Poland (157 PJ/y) and Romania (74 PJ/y). These values are consistent with finding of previous studies. Furthermore, it was observed that the available supply of straw obtained from the modelling surpasses significantly the expected use of agricultural residues for energy purposes in 2020, according to the targets set in the National Renewable Action Plans (NREAPs).

Based on the results from the supply assessment, we selected wheat straw to evaluate the potential environmental impacts of using wheat straw for production of torrefied pellets, using a life cycle perspective. This is due to based on the results of the supply assessment, wheat straw represents 75% of the total straw that could be collected in the top five European countries with the highest production of agricultural by-products. We use an LCA cradle-to-gate approach to describe the feedstock supply system and torrefaction of wheat straw. We refer to "cradle" when wheat seeds are planted to produce wheat grains and straw, and "grave" when wheat straw torrefied pellets are used for bioenergy purposes.

So far, we have placed special effort in estimating the environmental impacts of removing straw from the fields for the production of torrefied pellets. This, since removal of straw causes disturbances in the soil carbon pools and reduces the availability of nutrients from straw to the soil. The feedstock supply system of straw defined in the present study considers: cultivation, harvest, storage, bailing and transport to the torrefaction plant. The detailed quantities and substance specifications of all inputs required for wheat grain and straw harvest (seeds, fertilizer, pesticides, irrigation and diesel) have been calculated using Nemecek et al. [2014] and The Intergovernmental Panel on Climate Change (IPCC) methodology. Whenever data was not available to perform calculations, this was assumed from Ecoinvent 3. Besides considering the extra fertilization to compensate for nutrient losses due to straw removal, a novelty of this work is that we take into account changes in soil carbon (SOC) due to wheat straw removal.

So far, two scenarios have been considered for LCA analysis:

-Baseline scenario: Straw not removed from the field for bioenergy; business as usual.
-Scenario 1: use of straw for production of torrefied pellets in plants close to the harvest locations (<50km), decentralized torrefaction.
-Scenario 2: use of straw for production of torrefied pellets in plants annexed to CHP plants (<300km), centralized torrefaction.

The impact assessment of the different scenarios is performed using the CML 2001 methodology (CML, 2001). So far, LCA analysis have been conducted for straw harvesting (harvest module: cultivation, fertilization, etc.) and transport to the torrefaction plant. For scenario 1 and 2, preliminary results indicate that the straw harvest module is an environmental hotspot and its environmental performance depends on the impact category used as basis for comparison. For example, when comparing a "removal" practice with a "no removal" practice for scenario 1 and 2, both agricultural practices have similar impact on the global warming potential (GPW100a), less than 1% difference.

	Meanwhile, when these scenarios are compared regarding their effects on fossil depletion and ozone layer depletion (ODP), the difference between a "removal" and "no removal" practice is more than 100% for scenario 1 and over 500% for scenario 2. Other impact categories that carry a high environmental burden due to removal of straw are photochemical oxidation and human toxicity. Furthermore, results from the modeling indicate that emissions related to transport have negligible impact on a decentralized (scenario 1) and centralized (scenario 2) processing case regarding GPW100a. For scenario 1, the diesel used for transport to the torrefaction plant is the primary cause of fossil depletion and ozone layer depletion, more than 100% difference compared to a scenario where straw is not removed from the fields. When straw is removed for bioenergy purposes, petroleum production accounts for half of the fossil depletion and OPD impact category. Other relevant impact categories are marine aquatic ecotoxicity, around 68% difference compared to a scenario where straw is not removed from the fields. The main contributor to marine aquatic ecotoxicity is sulfidic tailing treatment (30%), related to diesel petroleum refinery operations. For scenario 2, trends are similar to scenario 1 regarding the removal of straw, the categories that have the highest environmental burden are the ones relying on diesel usage. Nevertheless, for scenario 2, petroleum production accounts for around two-thirds of the fossil depletion and OPD impact category, an increase of 10% compared to scenario 1. Other impact categories that carry a high environmental burden due to removal of straw are photochemical oxidation and human toxicity, more than 150% difference compared to a scenario where straw is not removed from the fields. With regards to photochemical oxidation, this impact category is mainly influenced by the diesel consumption required to transport straw to the torrefaction plant. Diesel related emissions due to transport and life cycle emissions associated with the powered 26-ton trucks account for 26% and 8% of photochemical oxidation, respectively. Human toxicity is mainly influenced by ferrochromium production which serves as raw material for phosphate fertilizer production, accounting for 21% of this impact category. When straw is not removed from the fields for bioenergy purposes, the ODP category is influenced by the diesel used in the farm operations (41%) and trichloromethane production (20%). With regards to photochemical oxidation and human toxicity, heat production involved in liquid manure spreading (16%) and ferrochromium production (32%) provide the higher environmental burden, respectively. Marine aquatic ecotoxicity under a "no removal" practice, is mainly affected by sulfidic tailing treatment (32%). Regarding the process simulation models (WP2), two process simulation models for torrefaction were built in Aspen Plus software: one for wheat straw and one for sugarcane bagasse. Both models comprise the most recent theoretical modelling approach and experimental data found in literature to simulate the kinetics of drying and torrefaction. The use of sugarcane bagasse for the production of torrefied pellets was defined based on a request from our private partner. Results of the process simulation of wheat straw indicates that optimal drying is obtained when the residence time of straw in dryer is below 30 min. With respect to the torrefaction unit, the torrefied wheat straw HHV reaches an optimum when the torrefaction temperature is set at 257 °C. The production cost of torrefied wheat straw pellets is in the range of 190-230 €/t. At this cost, torrefied pellets are more expensive than conventional wood pellets, whose price varied between 150€/t to 191€/t in 2019. Meanwhile, results of sugarcane bagasse torrefaction suggest

	that 17,108 kg/hr of torrefied pellets can be produced at an optimum torrefaction temperature of 280 °C with a thermal efficiency of 78%. Under the assumptions made in this work, the cost of producing sugarcane bagasse torrefied pellets under such conditions is 35.03 €/MWh. LCAs are still in progress and we expect to deliver the final results including the torrefaction plant in 2020. Besides working on this project, I have also had the opportunity to promote networking and join the different activities at TU Delft. For example, I have attended to the Large-Scale Energy Storage group meetings (once every two weeks), “Meet the energy Leaders” Lectures (once a month) and Van’t Hoff Lectures. I have also had the opportunity to provide tours to TU Delft industrial partners regarding the current developments at the Process and Energy department. Further information regarding the additional activities that I have performed during this time can be found below, in the section “Overig (Technieken, apparaten, methodes etc.)”.
Beoogde resultaten 2020	- LCA for decentralized processing case (WP3) - LCA for centralized processing case (WP3) - Reporting and publications (WP3)

Opgeleverde producten in 2019 (geef de titels en/of omschrijvingen van de producten / deliverables of een link naar de producten op de projectwebsite of andere openbare websites)

Wetenschappelijke artikelen:

H. Gilvari, L. Cutz, U. Tiringer, JMC. Mol, W. de Jong and D.L. Schott. The Effect of Environmental Conditions on the Degradation Behavior of Biomass Pellets. *Polymers* 12(4):970 (2020) DOI: 10.3390/polym12040970.

L. Cutz, U. Tiringer, H. Gilvari, D.L. Schott, JMC. Mol and W. de Jong. Implications of biomass pellet storage in the global bioenergy transition. To be Submitted in 2020.

L. Cutz and W. de Jong. Sustainability of wheat straw torrefaction in Europe: closing the gap. To be submitted in 2020.

Externe rapporten:

Artikelen in vakbladen:

Inleidingen/posters tijdens workshops, congressen en symposia:

L. Cutz, E. M. Moghaddam and W. de Jong. Biomass torrefaction: closing the gap**. TU Delft BioDay 2019**. TU Delft, The Netherlands, July 2nd, 2019.

TV/ Radio / Social Media / Krant:

Overig (Technieken, apparaten, methodes etc.):

Master’s Thesis Co-supervision

J. De Koning. The valorization of volatiles released during torrefaction of various kinds of agricultural biomass. May 2020. Supervisors: Prof. Dr. W. de Jong, Prof. Dr. A. De Haan and Dr. L. Cutz.

Bachelor’s Thesis Co-supervision

B.S. Fluttert, S.H.J. Hartman, L.M.D. Hendriksen and S.C.M.M. Veraart. Development and optimization of a thermoelectric generator powered by a top lit updraft cookstove (TLUD). December 2019. Supervisors: Prof.Dr. D.J.E.M. Roekaerts and Dr. L Cutz. This project was awarded the best presentation of Bachelor Eindprojecten for 2019-2020.

Research grant scouting and application

-I applied to the **TWAS Visiting Expert Programme 2019** to provide a series of lectures and conferences to students and faculty at the Faculty of Chemical Engineering of Universidad de San Carlos de Guatemala in Guatemala for a period of two weeks (March 16 until March 27th 2020). This programme is aimed to countries with limited outside contacts to establish long-term links with world leaders in areas of science other than mathematics and physics, and help develop capacity-building in their country. I submitted my proposal on 23 of January 2019.

-I collaborated in writing part of the proposal “CLEAN SHIPPING: Thermo-chemistry and inclusive supply chains design for sustainable production of biofuels in the marine transport industry”, submitted in September 2019 to the programme **Value from Biomass supported by NWO**. This project was awarded funding in December 2019.