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Letter to the Editor

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Response to Comment on "Life Cycle Carbon Footprint of Linear Alkylbenzenesulfonate from Coconut Oil, Palm Kernel Oil, and Petroleum-Based Paraffins"

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We thank Professor Alain Favre-Réguillon for the thoughtful comments. He states correctly that "This correspondence aims to highlight that the mandatory transitioning from petroleum-based to renewable-based products is not a panacea and will not resolve the problem of GHG for all chemical products". We agree absolutely with this statement, and that is why, in our view, it is necessary to employ tools such as life cycle assessment (LCA) to gain a better understanding of the environmental implications of any such transition steps, on a case-by-case basis. We are pleased to provide the following responses to the specific comments.

1. Greenhouse Gas Contribution: This comment refers to two of the main points in the article dealing with the emission sources of CO_2 from the LAS life cycle and the manner of handling fossil versus biogenic carbon. One of the main objectives of the study was to understand the most important stages in the renewable and fossil LAS life cycles for emission of greenhouse gases. End-of-life (EoL) treatment of LAS in wastewater treatment systems was found to be the source of the greatest emissions of CO_2 due to microbial oxidation of LAS to CO_2, based on studies published in the literature (and we did investigate and report in the article on uncertainty in this EoL conversion efficiency). Emission of biogenic CO_2 in wastewater treatment was not counted toward the GHG totals, whereas fossil CO_2 was counted, according to the carbon neutral assumption of biogenic C (no sequestration credit of biogenic CO_2 for growth of palm and coconut and therefore no emission for biogenic CO_2 later in the life cycle). However, if biogenic CH_4 were to be emitted from the renewable LAS life cycle, those emissions were included (see response to comment 5 also).
2. Fatty Acid Composition: The comment is correct in that the study assumed that the entire fatty acid carbon length distributions derived from PKO and CO were processed into renewable paraffin and then to renewable LAS. The issue of oil mill effluent was mentioned in the comment, which we assume to be the palm oil extraction mill rather than the palm kernel oil extraction mill. From the literature sources for a palm oil extraction mill cited in the article (reference 12), palm kernel is a co-product and therefore some of the total palm oil extraction mill inventory must be allocated to the kernel, and then ultimately to the KPO paraffin. This upstream process was mistakenly omitted from the study, although the palm fruit bunch cultivation was included using allocation factors appropriate for the palm kernel. As a result, the potential methane emission from treatment of palm oil mill effluent (POME) was not included in the study either. We have conducted a revised analysis after including palm oil extraction mill inputs (diesel fuel, electricity, water inputs) as well as the methane emissions from POME treatment taken from reference 12 assuming no methane capture, which is the most common current practice. The updated LCCF results for renewable LAS from PKO are presented in response to comment 5 below.
3. Availability of the C10−C12 Fraction: This comment addresses the concern that increased production of renewable LAS utilizing CO and PKO may have impacts on existing food and oleochemical industry markets and should be modeled in the LAS life cycle carbon footprint (LCCF). Being a first of its kind study on renewable LAS, our approach encompassed an attributional rather than consequential scope in order to understand the relative importance of the various stages in the life cycle. However, we agree that a future extension of this study should be consequential in scope and should, as expressed in the comment, include effects on displacing both food and other biobased surfactants produced from CO and PKO.
4. Oil (triglycerides), Fatty Methyl Ester, or Fatty Acid Transformation in *n*-Paraffin: The transformation of CO and PKO to paraffin is envisioned as a catalytic hydroprocessing step involving a catalyst, hydrogen, natural gas for process heat, water, and electricity. This reaction step does not include the isomerization reaction that is mandatory for production of hydro-renewable diesel which adjusts cold flow properties, as described in reference 15. Yield of product paraffin based on input CO and PKO is close to 54% as shown by the mass allocation factors (MAF) in Table A6 in the Supporting

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Information accompanying the article. Hydrogen production was modeled in the study as steam reforming of natural gas with a greenhouse gas emission factor of 11.4 kg CO_2 equivalents/kg H_2. This emission factor is close to the ones used by others, such as the GREET model.

5. Extraction Process: This comment focuses on the oil extraction stage and the use of water at this stage, plus the need to treat mill wastewater to avoid harm to receiving waters in the environment. The literature sources for oil extraction were references 12 and 13 for the palm oil extraction mill and the palm kernel oil extraction mill process inputs and emissions, respectively. No information was provided in reference 13 on water effluent generated in the palm kernel oil extraction mill, but reference 12 provided details on the quantity of POME generated (1.86 t) per metric ton crude palm oil (CPO) produced on the treatment of POME to reduce COD from the range of 47,500−70,000 ppm in POME to approximately 5000−50 ppm for land application or discharge to rivers, as well as the amount of methane emitted from POME treatment (22.2 kg methane/metric ton CPO). These CPO inputs and emissions were input into the LCA software tool SimaPro in amounts allocated to palm kernel, and the LCCF of PKO LAS was repeated. The new results exhibit an increase in the cradle-to-gate LCCF for PKO LAS from 1.15 kg CO_2 eq/kg PKO LAS (see Table 5 in the article) to 1.47 and increased the cradle-to-grave LCCF for PKO LAS from 1.93 kg CO_2 eq/kg PKO LAS to 2.25. This increase in PKO LAS LCCF reduces the savings compared to petroleum LAS from 46.2% to 37.2%. The updated Figure 2 from the published article is shown in the figure below for the mass allocation case. The new figure

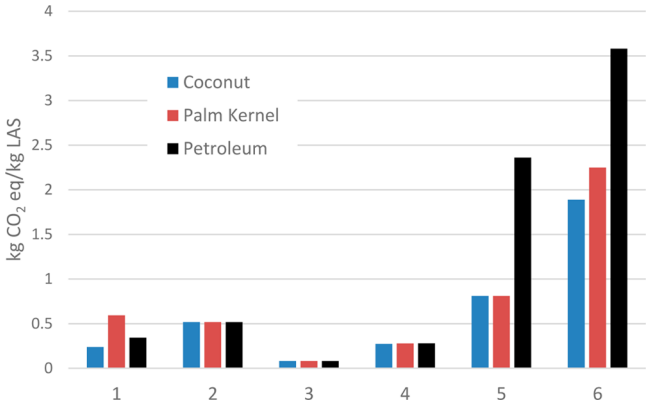

Figure 2. Stage-wise greenhouse gas contributions for the production of LAS from PKO-, coconut oil-, and petroleum-based paraffin sources assuming mass allocation: (1) paraffin production, (2) LAB production, (3) sulfonation, (4) neutralization, (5) EoL, and (6) total.

provided indicates that benefits of the EOL step remain the key differentiation between fossil and renewable LAS. The vast majority of the increase in GHG emissions from paraffin production, over 95% of the increase by our analysis, is due to methane emissions from POME treatment without capture and combustion of biogas. Therefore, if future production of renewable LAS from PKO were to be conducted with biogas capture and combustion from POME treatment, then the results from the original manuscript are valid. We repeat the recommendations from references 12 and 13 from the article that crude palm oil production should include biogas capture and combustion.

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Notes

The author declares no competing financial interest
Tom Kalnes is retired from UOP-Honeywell.

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