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Sustainability of Renewable Fuel Infrastructure: A Screening LCA Case Study of Anti-Corrosive, Graphene Oxide Epoxy Liners in Steel Tanks for Storage of Biodiesel and its Blends

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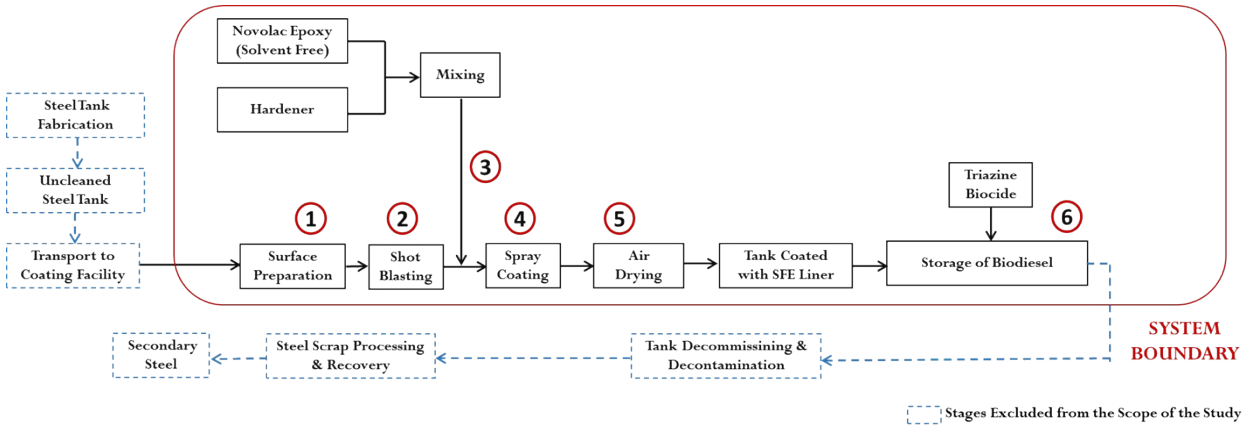

Figure S1. Block Diagram Showing Life Cycle Stages of Incumbent System (Coating of 400 µm DFT + Addition of 125 ppm of Triazine Biocide)

For the incumbent system, the internal surface of steel sheet is surface prepared and shot blasted prior to application of the solvent-free epoxy (SFE) coating. The SFE is then spray coated on the steel surface and dried in the air. The LCI data for the composition of the SFE coating is constructed using the commercial literature for the biodiesel tank liners.[1] The tank coated with the SFE liner is commissioned on an industrial site for storing biodiesel or its blends. The lifetime of the coating (20 years) is identical to the lifetime of the tank. Triazine (125 ppm) is added to biodiesel to prevent microbial growth and subsequent biofilm growth. The procedures for calculating the amount of SFE coating per functional unit (30 m^2) is given below.

S1.1 Amount of SFE coating solution required for the Incumbent system

- Theoretical Spread Rate (TSR) (m^2/L) = (Vol. Solids * 10)/(DFT)

  = (1000)/400 = 2.5 m^2/ L

- Practical Spread Rate (PSR) (m^2/L) = TSR* Transfer Efficency (Spray Coating)

  = 2.5 *0.68 = 1.7 m^2/ L

- Usage Rate (UR) (l/m^2) = 1/PSR = 0.588 L/m^2

- Amount of coating solution per functional unit (30 m^2) = 30*0.588 L = 17.64 L
- Density of the coating solution = 1.4 kg/ L
- Amount of coating solution (in kg) = 17.64 liters * 1.4 kg/ L = 24.7 kg
- Weight ratio of Resin: Hardener = 80:20
- Amount of Resin = 24.7*0.8 = 19.75 kg
- Amount of Hardener = 24.696*0.2 = 4.93 kg

S2. Inventory Data Calculations for GOE Liner

S2.1. Calculating Amount of GOE Solution per Functional Unit.

- Theoretical Spread Rate (TSR) (m^2/l) = (Vol. Solids * 10)/(DFT)

  = (600)/200 = 3 m^2/L
- Practical Spread Rate (PSR) (m^2/l) = TSR* Transfer Eff. (Spray Coating)

  = 3 *0.68 = 2.04 m^2/L
- Usage Rate (UR) (l/m^2) = 1/PSR = 0.49 L/m^2
- Amount of coating solution per functional unit (30 m^2) = 30*0.4901 L = 14.70 L
- Volume of NMP Solvent in Coating = 14.70*0.4 = 5.88 L
- Amount of NMP Solvent (kg) = 5.88 L *1.03 kg/ L (Density of NMP)

  = 6.076 kg
- 97% of the solvent is recovered and recycled back into the system. This amounts to 5.89 kg
- Amount of makeup solvent = 0.186 kg.
- 3% of solvent emitted as VOC = 0.186 kg.
- Volume of solids in coating solution = 8.82 liters
- Density of the solids = 1.17 kg/l
- Amount of solids in kg. = 8.82 liters * 1.17 kg/L = 10.31 kg

- Amount of Bisphenol A Resin in Solids = 70% = 10.31*0.7 = 7.22 kg.
- Amount of IPA = 10.31*0.29 = 2.989 kg.
- Amount of Hardener = 10.31*0.01 = 0.1031 kg.

S2.2. Power input for batch applications is calculated based on the following empirical formula developed by Feng.[2]

$$W_{input}\left(\frac{KWh}{l}\right) = \frac{Power\ of\ Sonotrode\ (W) * treatment\ time(seconds)}{3.6E+06\left(\frac{J}{KWh}\right) * volume\ of\ treated\ material\ (liters)}$$

Our study calculated the power requirements based on experimental conditions reported by Rajabi et al[3]. In this study, the authors used UIP 1000 hdT Ultrasonicator[4] with 70% amplitude which means the sonotrode power = 700 watts

The treatment time is 60 min. = 60 *60 = 3600 seconds

Volume of treated solution = 1 liters.

Thus the power is calculated as

$$W_{input}\left(\frac{KWh}{l}\right) = \frac{700 * 60 * 60}{3.6E+06\left(\frac{J}{KWh}\right) * 1\ liter} = 0.7\ KWh/l \quad (1)$$

A recent study conducted by Kashaba et al.[5] has reported the energy density for dispersing MWCNT in the epoxy resin using ultrasonication for 30 mins is 810 Watt-second/ml. This is equivalent to 0.45 KWh/L for 60 min. This value for the ultrasonication energy therefore matches with the 0.7 KWh/L estimated from Equation (1) in this study.

S3. LCI Data for Synthesis of Antifoulant and Antimicrobial Top Coats

S3.1. LCI Data for SGO-Silane Composite Coating Solution

It is assumed that the SGO with a dry film thickness (DFT) of 60 μm and 60% solids (v/v) is applied as a top coat on the GOE liner. Based on this assumption, the amount of coating solution required /functional unit (i.e. 30 m^2 of coating area) is 4.41 liters. The corresponding LCI data is shown in Table S1. The 1 wt% SGO-silane solution is prepared according to the experimental procedure described in literature.[6-8]

Table S1 LCI Data of SGO (1 wt%)-silane composite solution per functional unit

Inputs	Amount
Material Inputs	
Silane functionalized GO (SGO is 1% by weight in total solids)	8.82 g
Silane Solution	3.53 kg.
Deionized Water	617.5 g.
Acetic Acid	227 g
Isopropanol solvent (makeup 3%)	22.05 g
Solvent Recovery Burdens	706 g
Energy Inputs	
Energy Consumption for Mixing	3.08 KWh

S3.1. LCI Data of GO-PVK Coating Solution

It is assumed that the GO-PVK with DFT of 60 μm and 60% (v/v) is applied as a top coat on the GOE liner. Based on this assumption, the coating solution required per functional unit (i.e. 30 m^2 of the interior surface with the GOE liner) is 4.41 liters. The corresponding LCI data is shown in Table S2. The 1 wt% GO-PVK solution is prepared according to experimental procedure described in literature.[9-11]

Table S2 LCI Data of GO (1 wt%)-PVK composite solution per functional unit

Inputs	Amount
Material Inputs	
GO Dispersion in DI Water (1% by wt. in total solids)	31.75 g
Poly Vinyl Carbazole (PVK)	3.144 kg.
Tetrahydrofuran (THF) solvent (makeup3%)	48.51 g.

Solvent Recovery Burdens	1.521 kg
Energy Inputs	
Energy Consumption for Mixing & Ultrasonication	6.174 KWh

S4. Contribution Analysis of Preparation GOE Coating Solution per FU (i.e. to coat 30 m^2) of Steel Tank Interior

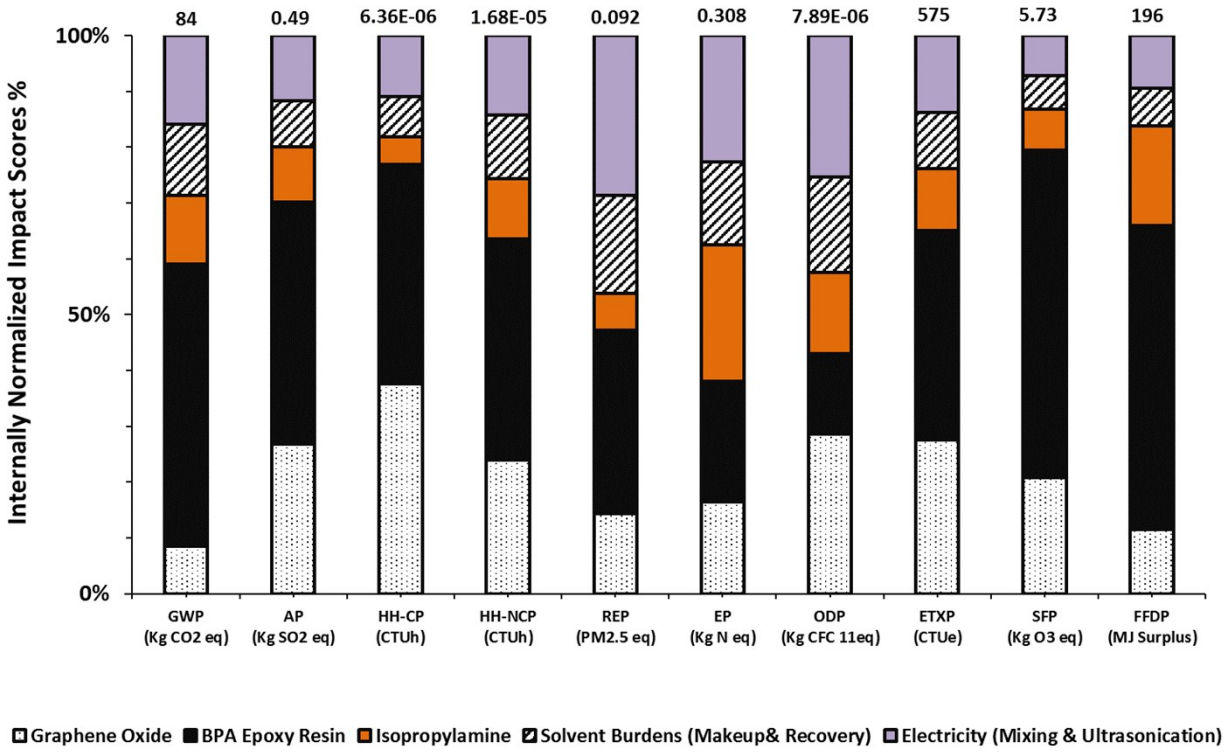

Figure S2.Contribution analysis of GOE coating solution required for 30 m^2 of steel tank interior

S5. Contribution Analysis of Incumbent System

- The incumbent system consists of 400 µm thick (DFT) solvent free novolac epoxy liner for corrosion protection and a maintenance dosage of 125 ppm (active ingredient concentration) of triazine biocide addition.
- For one year 2.5 kg of biocide needed for 10,000 liters of biodiesel storage. For 20 years, 50 kg is needed.

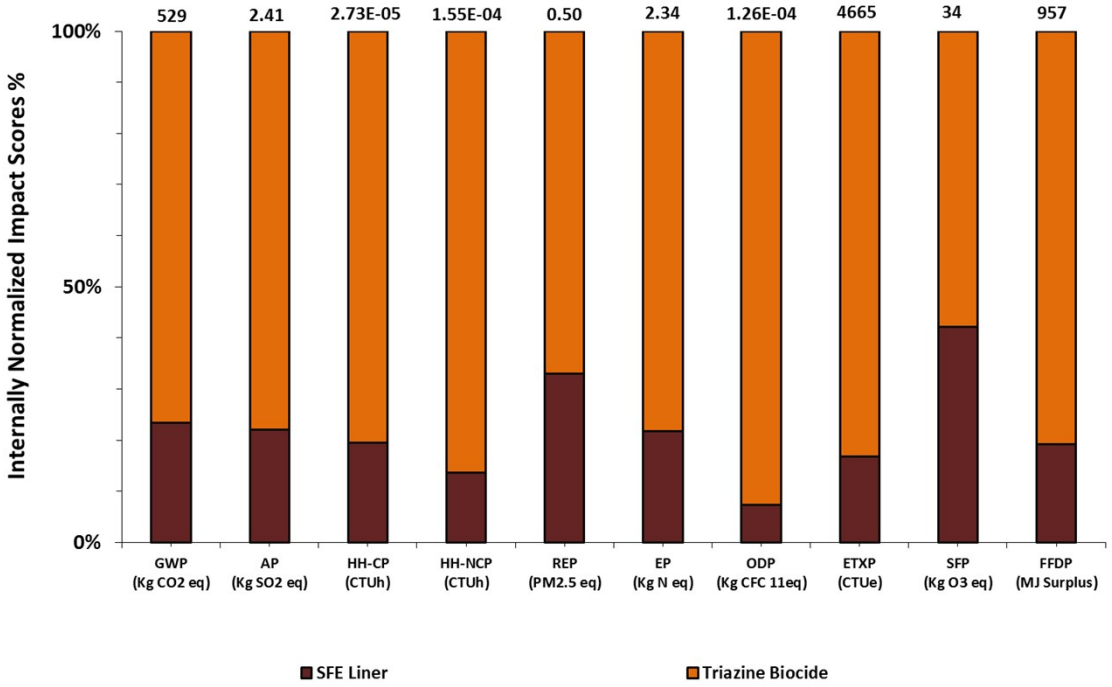

Figure S3.Contribution analysis of Incumbent System per Functional Unit

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