Carbon Footprint of Plastic and Sludge Waste Streams in Singapore

Xin He\textsuperscript{1,2}, Dingding Yao\textsuperscript{1,2}, and Chi-Hwa Wang\textsuperscript{*1,2}

\textsuperscript{1} Energy and Environmental Sustainability Solutions for Megacities (E2S2), Campus for Research Excellence and Technological Enterprise (CREATE), Singapore 138602.

\textsuperscript{2} NUS Environmental Research Institute, National University of Singapore, 1 Create Way, Create Tower #15-02, Singapore 138602

\textsuperscript{3} Department of Chemical and Biomolecular Engineering, National University of Singapore, 4 Engineering Drive 4, Singapore 117585

*Corresponding E-mail Address. Prof. Chi-Hwa Wang: chewch@nus.edu.sg
Introduction

- Rapid growths of urbanization and megacities challenge the urban waste management systems
- In Singapore, 5.88 million tonnes of waste were generated in 2020
  - The waste recycling rates of “Plastic” and “Ash & Sludge” are less than 10%
Carbon Footprint of Plastic Waste

- The COVID-19 pandemic has resulted in growing of plastic use due to the protective measures introduced to suppress the outbreak.
  - Personal protective equipment (PPE): mask, gloves, shield, fast test kit.
  
  - Food delivery during lockdown or movement restriction.
- The environmental consequences overshadowed by urgent health issue should be analyzed.

- Aluminum strip: ~0.5 g aluminum
- Filter: ~2 g Polypropylene (PP)
- Mask: ~9 g PP
- Rubber strap: ~0.5 g rubber

- Mask layer: ~1.3 g PP and ~0.7 g cellulosic fabric
- Nose wire: ~0.2 g High Density Polyethylene (HDPE)
- Ear loops: ~0.4 g Polyetherimide
Carbon Footprint of Plastic Waste

- Singapore general plastic waste consists of 40% polyethylene, 17% polyvinyl chloride, 12% polypropylene, 4% polystyrene, 4.8% polyethylene terephthalate and 22.2% other mixed compositions.
- In Singapore, the current plastic waste treatment is incineration, which considered as the Business-as-usual (BAU) scenario.
Carbon Footprint of Plastic Waste

- In this study, the pyrolysis approach is preferred for plastic waste management due to its lower energy intensity and higher overall yield of oil products.

- Different market options for oil products derived from plastic waste:
  - Fuel oil substitute (in this study).
  - Potential feedstock of oil refinery plants: refinery wax, naphtha, or oil substitute.
Carbon Footprint of Plastic Waste

- Life-cycle greenhouse gas (GHG) results based on different local electrical power
  - Functional Unit is 1 tonne of Singapore plastic waste.

**Singapore general electricity [0.419 CO₂eq/kWh]**

- **Leachate treatment**
- **Ash treatment**
- **Transportation**
- **Energy recovery**
- **Oil products**
- **Energy consumption**
- **Combustion emissions**
- **Net**

**Coal-fired electricity [1.211 CO₂eq/kWh]**

- **Leachate treatment**
- **Ash treatment**
- **Transportation**
- **Energy recovery**
- **Oil products**
- **Energy consumption**
- **Combustion emissions**
- **Net**
Carbon Footprint of Sewage Sludge

• Sewage sludge is the solid waste generated in wastewater reclamation plant
  – Residue of anaerobic digestion (AD) unit.
• In Singapore, the current sewage sludge treatment is incineration.

Diagram:
- Domestic Water
- Screw and Screening
- Sand and Grit Removal
- Primary Treatment
- Secondary Treatment
- Thickening Centrifuge
- Anaerobic Digester
- Combine Heat & Power Generation
- WRP Power Net
- Sludge/Digestate Dewatering
- WRP Process Heat
- Dewatered Sludge
- Final Discharge
Carbon Footprint of Sewage Sludge

- In this study, the anaerobic co-digestion of sewage sludge and food waste is proposed
  - The Singapore sewage sludge consists of 8.2% moisture, 50.8% volatile, 15.2% fixed carbon, and 25.8% ash.
  - The Singapore food waste consists of 84% organic fraction and 16% impurities.
Carbon Footprint of Sewage Sludge

- Life-cycle greenhouse gas (GHG) results based on different local electrical power.
  - Functional Unit is 1 tonne domestic sewage sludge and 1 tonne Singapore food waste.

![Graph showing GHG emissions for BAU and Proposed scenarios]

- Singapore general electricity [0.419 CO₂eq/kWh]
- Coal-fired electricity [1.211 CO₂eq/kWh]
Conclusions

• By diverting the plastic waste away from incineration, a reduction of 61% in GHG emission amount can be reached.
• The sewage sludge diverted from incineration is proposed to be co-digested with food waste at a 1:1 ratio.
• A reduction of 59% in GHG emission amount can be reached based on Singapore general electricity.
• The GHG emission of annual Singapore plastic waste and sewage sludge can be reduced from 1.82 million tonnes CO$_{2}$eq to 0.71 million tonnes CO$_{2}$eq.
Future Works

- Carbon footprints of all feasible waste management solutions in energy-water-food nexus.
Acknowledgement

• Campus for Research Excellence and Technological Enterprise (CREATE) program (R-706-001-102-281) under National Research Foundation of Singapore

*Corresponding Author Address:

Prof. Chi-Hwa Wang, National University of Singapore, 4 Engineering Drive 4,

Singapore 117585

E-mail: chewch@nus.edu.sg