Graphene Derived from Municipal Solid Waste

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Abstract

Landfilling has long been the most common method of disposal for municipal solid waste (MSW). However, many countries seek to implement different methods of MSW treatment due to the high global warming potential associated with landfilling. Other methods such as recycling and incineration are either limited to only a fraction of generated MSW or still produce large greenhouse gas emissions, thereby providing an unsustainable disposal method. Here, we report the production of graphene from treated MSW, which includes treated wood waste, using flash Joule heating. Results indicate an 81-89% reduction in global warming potential compared to traditional disposal methods at a net cost of -$304 per tonne of MSW, presuming the graphene is sold at just 5% of its current market value to offset the cost of the flash Joule heating process.

Keywords municipal solid waste; flash Joule heating; waste wood; global warming potential; sustainable

1. Introduction

Increased municipal solid waste (MSW) generation has long been attributed to population and urbanization growth.[1] As more MSW is generated, MSW management has become a major concern for many municipalities. In its most recent studies, the Environmental Protection Agency of the United States (EPA) estimated that out of the estimated 292 million tons of MSW produced by the United States in 2018, ~50% was managed through landfilling, suggesting landfilling to be the most common form of MSW management.[2] Though landfilling is typically the least expensive method of MSW disposal, it has been associated with significant land usage and volume uptake, but more concerningly toxic leachate release (**Figure 1**).[3-6] Landfill leachate is typically composed of components including diverse organics, inorganics including toxic heavy metals, and xenobiotics such as polychlorinated aromatic hydrocarbons.[4-6] Landfill leachate represents a significant pollution threat to waterways, and though various regulations have improved landfill construction to slow leachates from contaminating waterways, sustainable leachate management is difficult to achieve due to leachate compositions varying across landfills.[7-9] Landfilling also releases large amounts of methane (CH_4) and (CO_2).[10] Many countries are therefore implementing alternative strategies to landfilling.

Other common methods of mitigating MSW in developed countries include recycling and incineration. However, recycling is expensive, requires extensive sorting by humans, typically results in a downcycled product, and is limited to a fraction of MSW content.[2,11-14] Incineration of MSW has been shown to be an economically feasible option that allows for volume reduction while limiting CH_4 emissions when compared to landfilling. However, incineration has been known to emit greater amounts of CO_2, and it also emits nitride oxides, which have a larger global warming potential (GWP) than does CH_4. Dioxins and other organic pollutants with ranging toxicity are released upon incineration (**Figure 1**).[15-17] With global MSW production expected to increase by as much as 45% by 2050, it is imperative to find methods to both reduce the amount of landfilled MSW and to provide an alternative management method.[18]

Flash Joule heating (FJH) is a method that has previously been used to convert various carbon rich feedstocks into graphene.[19-21] By applying a high-voltage electrical discharge through a minimally conductive sample, heat is rapidly generated, facilitating rapid carbon bond dissociation. These carbon bonds reform to produce the thermodynamically most favored sp^2-hybridized graphene lattice. Rather than forming ordered, AB-stacked graphite, the rapid cooling rate results in rotationally disoriented graphene sheets that are referred to as turbostratic graphene, because the graphene sheets do not have sufficient time to orient themselves.[19] This is particularly desirable since the rotational disorientation of the sheets facilitates greater exfoliation efficiency rendering their more facile dispersion in composites.[19] Graphene has many demonstrated applications ranging from composite reinforcement to lubricant enhancement.[22,23] Since major components of MSW, including food waste and waste plastics, are typically carbon rich, FJH is a plausible method to convert MSW into graphene (**Figure 1**).[2] Here, we report the use of FJH to convert treated MSW (MSWT) into turbostratic graphene. Part of MSW is treated waste wood (WWT) which comes from construction waste and tree or plant trimmings. This WWT acts as a suitable conductive additive to decrease the electrical resistance in other MSW, rendering the mixed material suitable for FJH.

2. Results and Discussion

2.1 FJH Process

Since FJH reactions involve electric current, the reactant must be somewhat electrically conductive, but not too conductive such that there are no resistive hotspots and so that Joule heating can occur.[19] Using a mixture of MSW commercially pretreated at 316 °C (MSWT, 67%) along with commercially pretreated waste wood (WWT, 33%) as a conductive additive, a resistance of 620 Ω was achieved. These pretreatments are routine in many municipalities to lower the water content and the toxicity of MSW. The mixtures of MSWT and WWT were subjected to alternating current (AC) FJH resulting in a lowering of the resistance to 4-5 Ω, which is an optimal resistance for direct current (DC) FJH.[19] A 100 V discharge through the mixture resulted in a current measurement of 210 A with a corresponding maximum temperature of ~2550 °C (**Figures 2**a-b). Additional FJH reactions were required to produce sample homogeneity and optimal graphene conversion. 160 V and 235 V discharges resulted in currents of 670 A and 1450 A along with associated temperatures of 2750 °C and 1460 °C, respectively (Figures 2c-d). A final resistance of 0.10 Ω was recorded. Previous work indicates temperatures nearing 2800 °C are sufficient to convert amorphous carbon into turbostratically stacked graphene.[19] A mass yield of 45% was recorded; however, this is solely calculated from the total weight out divided by the total weight in. Many of the elements were non-carbon (H and O) in the starting materials, so the actual yield of graphene based solely on carbon was determined using elemental analysis and calculated to be 57%.

2.2.Characterization of Graphitic Product

The feedstocks and FJH reaction products were characterized using Raman spectroscopy. Average Raman spectra corresponding to WWT and MSWT show the presence of a D band occurring at 1350 cm^{-1} and a G band occurring at 1582 cm^{-1}. The D band only arises when defects are present in the lattice structure, whereas the G band arises through the vibration of sp^2 carbon atoms.[24,25] Based on the Raman spectra, the WWT and MSWT are amorphous carbon. In the average Raman spectrum of the MSWT/WWT graphene product, a small D band is observed along with the G band and the clear emergence of a 2D band at 2700 cm^{-1} (**Figure 3**a). The average D/G intensity ratio of 0.46 and average 2D/G intensity ratio of 0.97 suggests high quality graphene production, since the low intensity D band suggests there is little disorder in the MSWT/WWT graphene. The high-resolution Raman spectrum of the MSWT/WWT graphene shows the presence of TS_1 and TS_2 peaks occurring at 1875 cm^{-1} and 2025 cm^{-1} establishing the graphene to be turbostratic, and the missing M peak at 1750 cm^{-1} indicates no detectable AB-stacking (Figure 3b).[26]

Powder X-ray diffraction (XRD) analysis was used to study the bulk characteristics of the materials. The XRD spectrum of WWT is further evidence that WWT is amorphous carbon while the XRD spectrum of MSWT also indicates the presence of silicon carbides and silicon oxides. In the MSWT/WWT graphene, it is observed that many of the impurities are volatilized out of the sample (Figure 3c). The broadening of the (002) peak encountered on average at 26.1° can be traced to an average lattice spacing of 0.340 nm using Bragg's Law.[27] The rotational disorder results in the increased interlayer spacing from 0.335 nm that is observed in AB-stacked graphite to the observed 0.340 nm average lattice spacing in the turbostratic graphene product.

Elemental analysis and X-ray photoelectron spectroscopy (XPS) were conducted to determine elemental composition. Elemental analysis suggests the composition of WWT to be 83.4% C, and 0.2% H, while XPS survey scans indicate WWT to have 11.4% O. MSWT has a composition of 62.2% C and 6.77% H according to elemental analysis and an O content of 18.4%, Si content of

8.3%, and trace amounts of Ca, Zn, K, and Cl by XPS elemental scans. FJH of the MSWT/WWT mixture resulted in an increased C content of 87.7% and an overall H content of 1.8% while the O content decreased to 8.8% (**Figure 3**d).

XPS also confirms expulsion of impurities through FJH since a notable decrease in the intensity of the Si peak is observed in the graphene product when compared to MSWT (**Figure 3**e). Si presence decreased from an average of 8.3% in MSWT to an average of 0.41% in the MSWT/WWT graphene by XPS analysis. Si has a boiling point of 2355 °C, whereas carbon boiling would not occur until 4827 °C. XPS survey scans also indicate trace amounts of metals such as Ca, Zn, and K remain in the MSWT/WWT graphene but at <0.2%. High resolution scans of C*1s* suggest the presence of C-C bonding.

Thermogravimetric analysis (TGA) in air was used to further study the bulk character of the graphene product. MSWT displays signs of thermal degradation at 330 °C to 455 °C with ~10% inorganic content. WWT degrades at 465 °C to 550 °C with <3% inorganics. After undergoing FJH, the product graphene displays an increased thermal stability with gradual degradation at ~525 °C to 700 °C with ~18% inorganic content, assuredly some coming from inorganic oxide formation during the TGA analysis (**Figure 3**f). From XRD and XPS analyses of the residual TGA mass upon heating to 800 °C, the components that remain after heating to 800 °C are silicon carbides and silicon oxides (**Figure S1-S2**).

2.3 Electron Microscopy

Electron microscopy was employed to study morphological changes after FJH. Scanning electron microscopy (SEM) displayed the stacked morphology of the graphene that is shown at various magnifications in **Figure 4**a, in strong contrast to the dense structures encountered in WWT and MSWT (**Figures S3-4**). High resolution transmission electron microscopy (HR-TEM) micrographs depict lattice fringes indicating the high crystallinity of the graphene (**Figure 4**b-c). Fast Fourier transform of a selected region depict polycrystalline graphitic material while an interlayer spacing of 0.349 nm is observed, once again suggesting the graphene product to have an increased interlayer spacing compared to AB-stacking (**Figures S5-S6**).

2.4 Surface Area Analysis and Dispersion Testing

Brunauer-Emmett-Teller (BET) surface area analysis reveals WWT to have a surface area of 117 m^2/g, while MSWT has a much lower surface area of 1.8 m^2/g. Once the MSWT/WWT mixture undergoes FJH, the resulting surface area of the MSWT/WWT graphene is 5.6 m^2/g (**Figure 5**a). Pore size is significantly decreased by the FJH of the MSWT/WWT mixture when compared to WWT, yet the pore size is comparable to that encountered in MSWT (**Figure S7-S9**).

The dispersibility of the MSWT/WWT graphene was tested in 1% Pluronic-127, a surfactant, against flash graphene derived from metallurgical coke (MC-FG) (**Figure 5**b). At low concentrations, the MSWT/WWT graphene product displayed similar dispersibility to that of MC-FG, while at increased loadings, the dispersibility of MC-FG is greater. The lower dispersibility of the graphene product derived from MSWT/WWT could likely be attributed to the low surface area.

2.5 Gas Analysis of Volatiles Evolved During FJH Process

The volatile gases produced in the FJH of the MSWT/WWT mixture were captured and analyzed using gas chromatography (**Figures S10-S12** and **Tables S1-S3**). Volatiles evolved during the FJH process were determined to include hydrogen, carbon monoxide, and trace amounts of methane, carbon dioxide, and other hydrocarbons. The average ratio CO_2 to CO was calculated to be 0.66. Using this, the calculated CO_2 evolved during FJH would be 0.635 kg per tonne of reaction mixture assuming linear scaling. On average, hydrogen (H_2) content was found to be 28%

of the volatiles evolved and ~22% of available H_2 was recovered as H_2 . ~10 kg of H_2 could be produced by one tonne of reaction mixture. Recent work suggests the tunability of FJH to produce H_2 gas from waste plastic, indicating further work could provide even greater yields of H_2.[28] H_2 gas and CO production also provide a pathway to fuel production, thereby providing yet another attractive product from FJH MSW.

2.6 Life Cycle Assessment and Technoeconomic Analysis

A life cycle assessment (LCA, **Figure 6**) was used to determine the global warming potential (GWP) of the FJH process when compared to common methods of MSW management such as biogas capture with flaring, landfilling, and incineration (scope discussed on pp **S12-S15**). Recycling was not included since the range of items that can be recycled is significantly limited. Results indicate FJH lowers greenhouse gas emissions (**Figures S13-S15**). FJH can decrease GWP by up to 89 % when compared to landfilling with a gas capture and flare system (LF+GC) and decreased by 81% when compared to incineration. The net cost of FJH reacting one tonne of MSW would be -$304 presuming the sale of the graphene by-product at only 5% ($3,000/tonne) of the present market value of $60,000/tonne. Incineration, on the other hand, would result in a net cost of $48/tonne presuming the electricity generated is sold and the toxic ash by-product is treated. Incineration would result in disposal of ash into landfills whereas graphene, the byproduct of FJH, could be used in other applications such as composite reinforcement or lubrication enhancement.[22,23] Therefore, FJH provides a method that not only lowers GWP, but is both economically favorable and reduces materials destined for landfills.

3. Conclusion

We demonstrate the feasibility of using FJH to convert MSWT and WWT into turbostratic graphene, using two waste products that are normally sent to landfills. Through FJH we provide a potential alternative method to landfilling for MSW management. FJH provides not only a 87-89% GWP reduction but an overall net cost of -$304 per tonne of MSW, making it highly economically attractive.

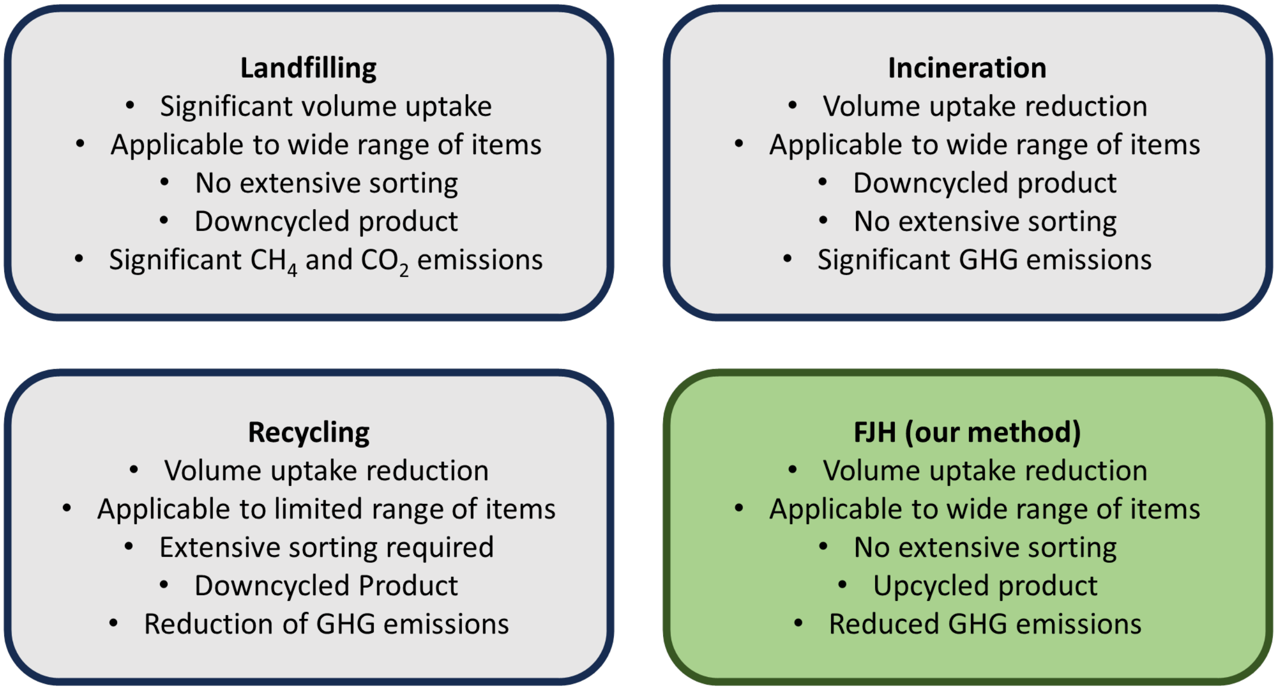

Figure 1. A scheme comparing common MSW management methods and FJH.

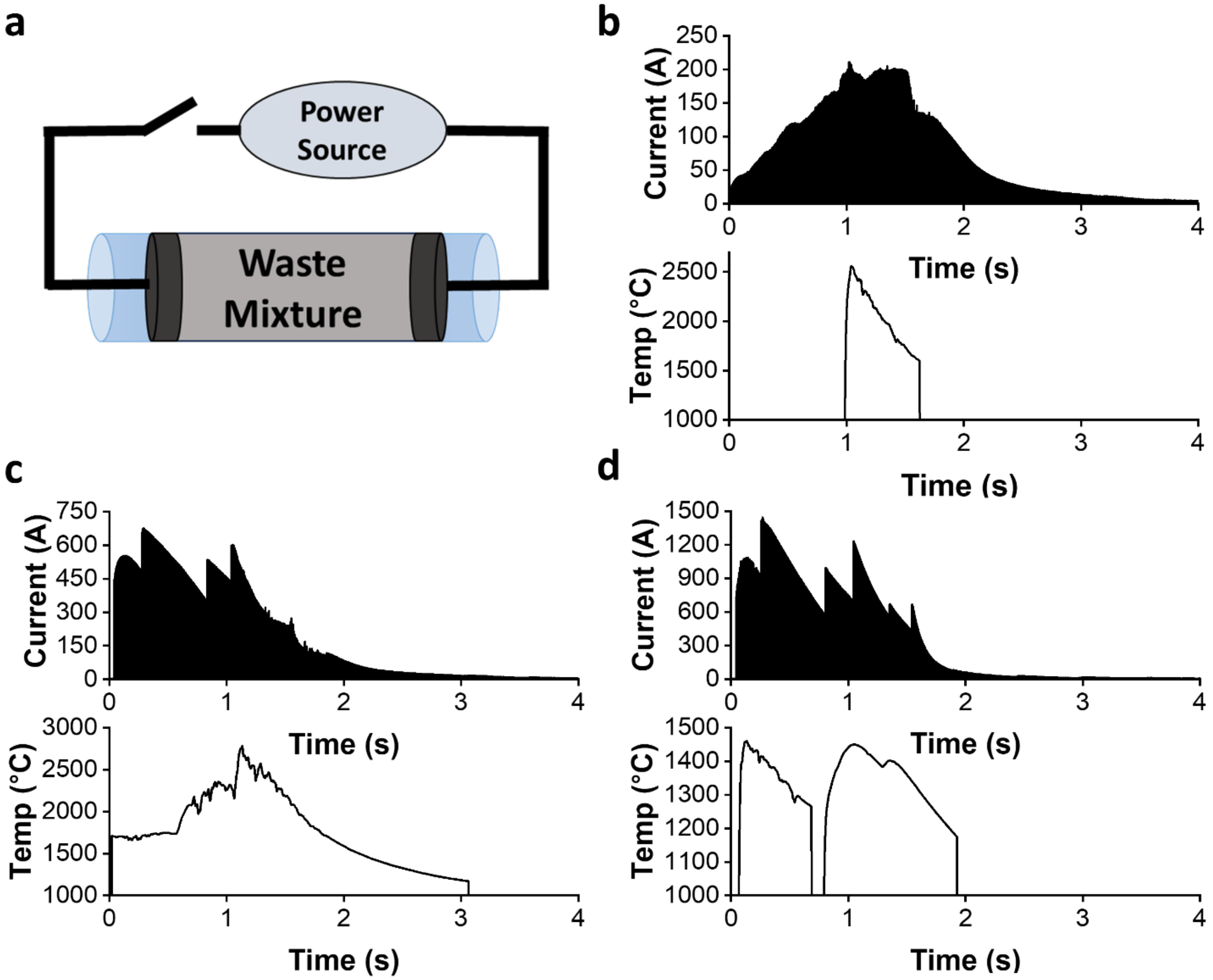

Figure 2. FJH schematic, current along with temperature profiles during various electrical discharges of the FJH of MSWT/WWT mixture a. FJH scheme **b-d.** Current measured during FJH with associated temperature measurements during the FJH of MSWT/WWT mixture at 100 V, 160V, and 235 V discharge, respectively. In Figure 2d, a rapid decrease in temperature is observed. This is attributed to the temporary misalignment of the pyrometer used to obtain temperature readings because of the vibrations of the system during F

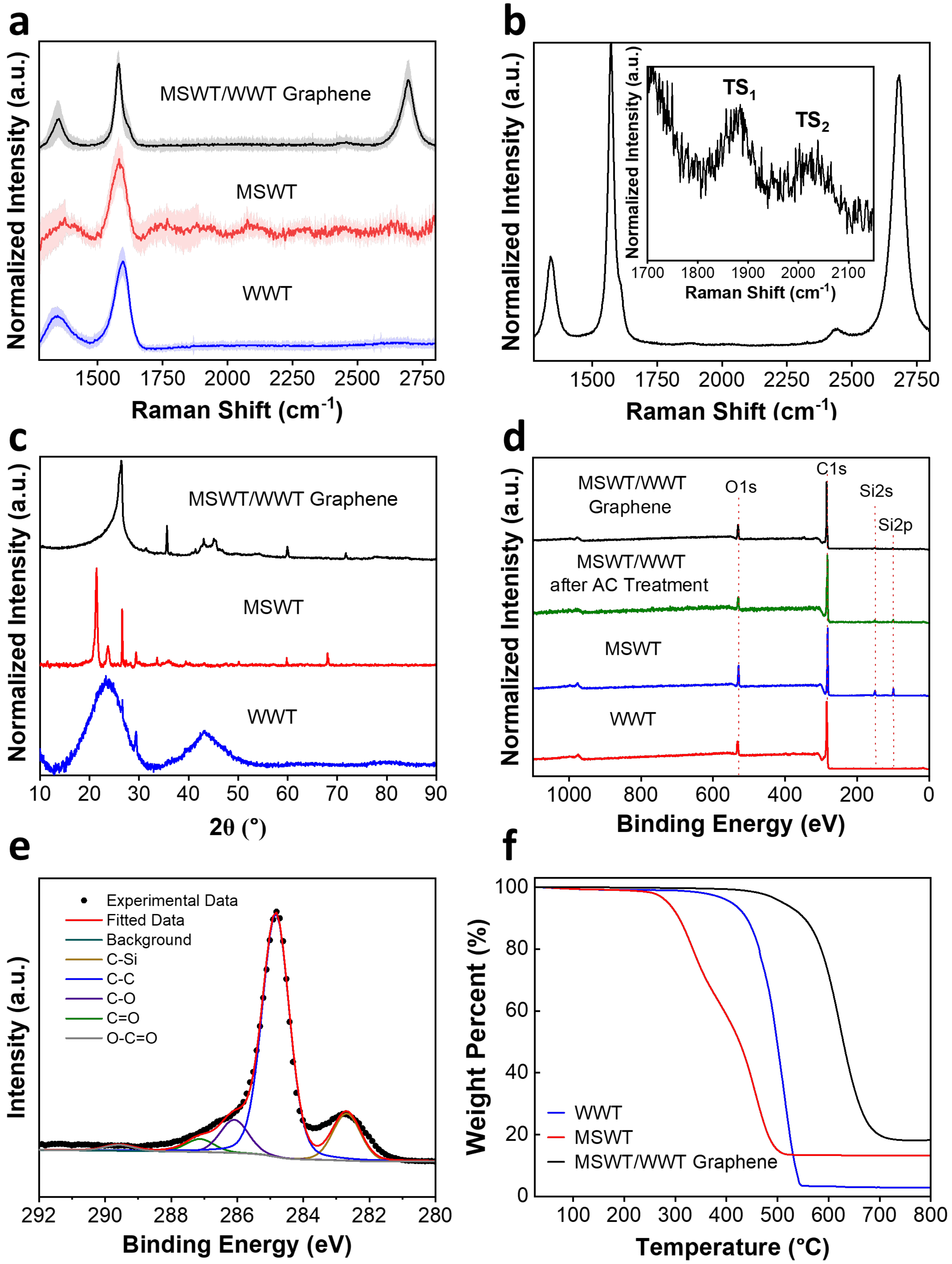
a
Normalized Intensity (a.u.)
MSWT/WWT Graphene
MSWT
WWT
1500
1750
2000
2250
2500
2750
Raman Shift (cm^{-1})
b
Normalized Intensity (a.u.)
Normalized Intensity (a.u.)
TS$_1$
TS$_2$
1700
1800
1900
2000
2100
Raman Shift (cm^{-1})
1500
1750
2000
2250
2500
2750
Raman Shift (cm^{-1})
c
Normalized Intensity (a.u.)
MSWT/WWT Graphene
MSWT
WWT
10
20
30
40
50
60
70
80
90
2θ (°)
d
Normalized Intenisity (a.u.)
MSWT/WWT Graphene
MSWT/WWT after AC Treatment
MSWT
WWT
O1s
C1s
Si2s
Si2p
1000
800
600
400
200
0
Binding Energy (eV)
e
Intensity (a.u.)
Experimental Data
Fitted Data
Background
C-Si
C-C
C-O
C=O
O-C=O
292
290
288
286
284
282
280
Binding Energy (eV)
f
Weight Percent (%)
100
80
60
40
20
0
WWT
MSWT
MSWT/WWT Graphene
100
200
300
400
500
600
700
800
Temperature (°C)

Figure 3. Characterization of starting materials and the graphene product. a. Average Raman spectra of starting MSWT, WWT, and MSWT/WWT-derived graphene. (200 individual spectra over a 1 mm^2 area for WWT and graphene and 200 spectra over a 0.5 mm^2 area for MSWT) with standard deviations represented by shaded regions. **b.** High resolution Raman spectra indicating the presence of TS_1 and TS_2 peaks from turbostratic stacking of MSWT/WWT graphene. **c.** Bulk XRD spectrums of starting materials and the MSWT/WWT-derived graphene. **d.** XPS survey scans of starting materials, MSWT/WWT mixture after one AC treatment, and the final graphene. **e.** High resolution scans of C*1s* of the graphene **f.** TGA (air, 11 °C/min) of starting materials and graphene suggesting increased thermal stability of the graphene compared to starting MSWT and WWT materials.

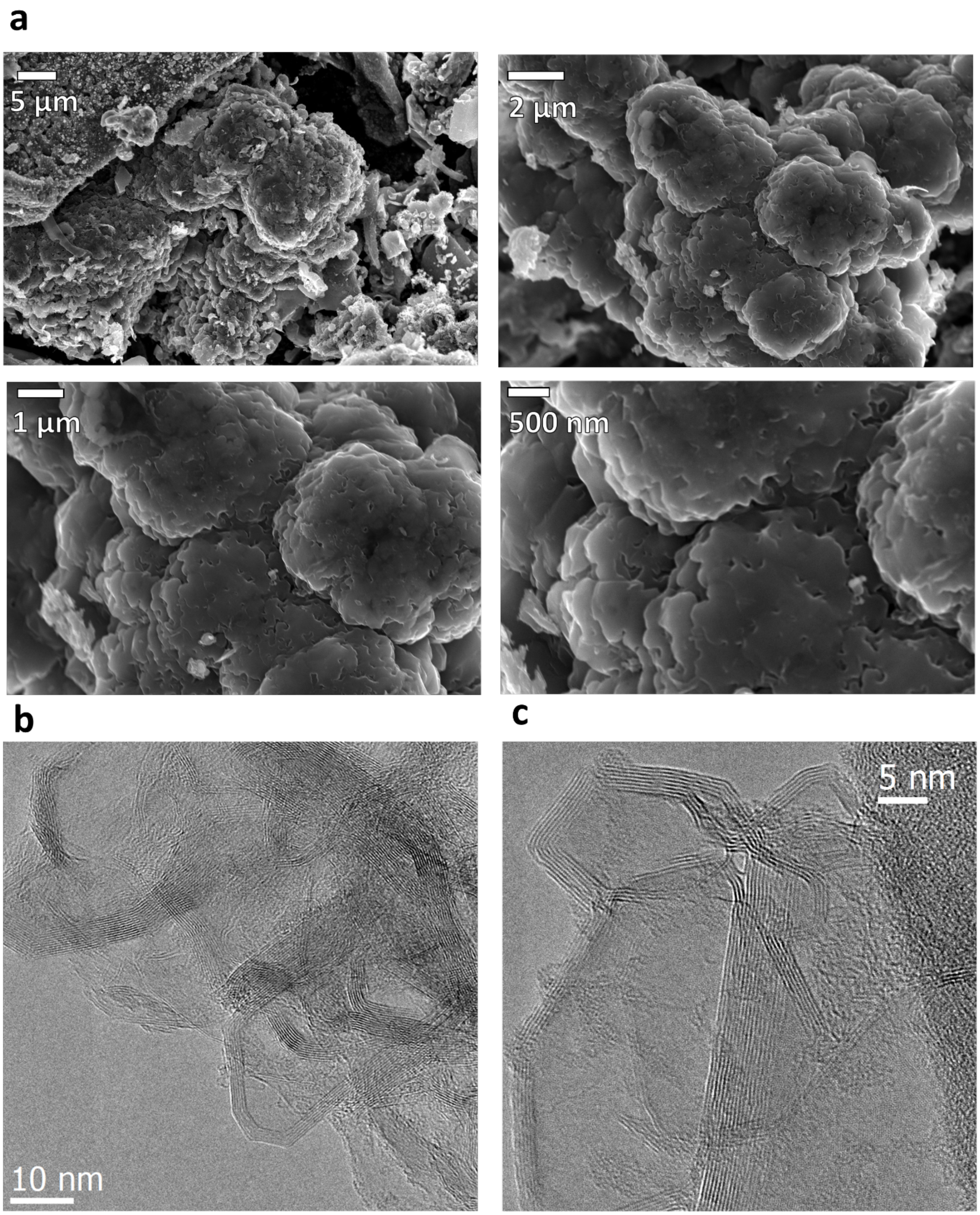

Figure 4. Electron microscopy of MSWT/WWT graphene. a. SEM images depicting sheet like morphology in MSWT/WWT graphene at various magnifications with associated scale bars. **b. and c.** TEM micrograph of MSWT/WWT graphene highlighting lattice fringes.

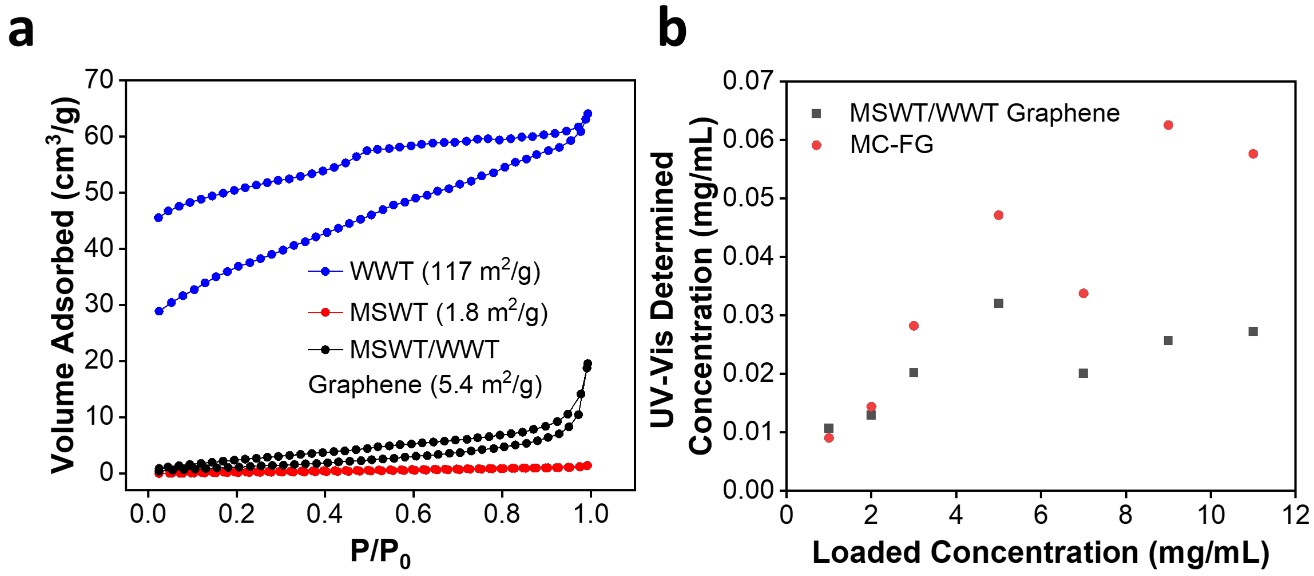

Figure 5. BET analysis and dispersion in 1% pluronic F-127 solution of MSWT/WWT-derived graphene and MC-FG. **a.** BET analysis of feedstocks and resulting graphene. **b.** Dispersion of MSWT/WWT graphene and MC-FG in pluronic F-127.

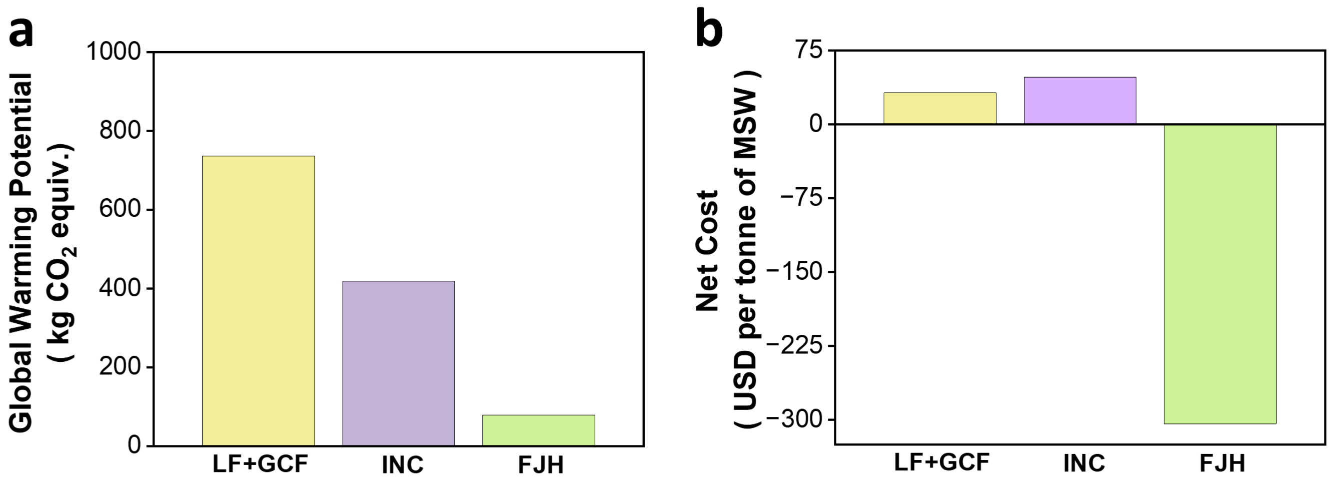

Figure 6. Life cycle assessment of common MSW management compared to FJH a. GWP associated with common MSW management methods such as landfilling with a gas capture and flare system (LF+GCF) and incineration (INC) compared to FJH **b.** Technoeconomic analysis impacts associated with landfilling with a LF+GCF and INC as compared to FJH, in US dollars (USD).

4. Methods

Feedstocks

MSW was provided by Midwest Custom Solutions, LLC which they dried at 120 °C for ~15 min followed by torrefaction at 316 °C for 90 min, a thermochemical process that decreases the water and volatiles content of the biomass, improving some of its fuel properties.[29] The waste was composed of 50% cardboard and paper and 50% food and plastic waste. The WWT was provided by Liberty Ashes, Inc., and its commercial treatment was not disclosed.[30]

FJH of MSWT/WWT mixture

Batches of MSWT (0.67 g) and WWT (0.33 g), total 1.00 g, were loaded between two pieces of copper woold rolled into cylinders, referred to as spacers, within quartz tubes (16 mm inner diameter).[19] Fritted graphite spacers were used as electrodes to facilitate outgassing. The samples were compressed until a resistivity of ~620 Ω was achieved and subjected to alternating current FJH (1-3 seconds) resulting in 4-5 Ω resistance. The sample was then subjected to FJH using direct current at a 10%, 20%, and 50% 1 kHz duty cycles at 1s, 0.5s, and 5s durations, respectively, with a rated capacity of 624 mF at 100 V, 160V, and 235 V discharges.[19]

Characterization

Feedstocks and FJH product were each ground using mortar and pestle and then characterized using Raman Spectroscopy (Renishaw inVia Raman microscope, 5 mW 532 nm laser, 50x objective lens), bulk-powder XRD (Rigaku SmartLab II, zero background holder, 7º/min with 0.05º step size), thermogravimetric analysis, (under air at a 11 °C/min heating rate), and BET surface area analysis (Quantachrome Autosorb-iQ3-MP/Kr BET, N analysis gas, with 6 h degas at 120°C under high vacuum). The morphology of the FJH MSWT/WWT product graphene product was studied through scanning electron microscopy (FEI Helios NanoLab 660 Dual Beam System, 15 keV) and that of the starting materials was also studied (FEI ESEM 15 keV, 1.5 keV). XPS analysis was carried out using a PHI Quantera SXM Scanning X-Ray Microprobe (5×10^{-9} Torr operating pressure, with 0.1 eV/140 eV step size and pass energy for survey scans, with 0.1 eV/26eV step size and pass energy for high resolution elemental scans). Dispersion analysis was carried out using ultraviolet-visible spectroscopy (Shimadzu UV-Vis 3600i Plus at 660 nm). Gases evolved during FJH were characterized using gas chromatography with an Agilent 8890 GC system equipped with an Agilent HP-5ms low-bleed column (30 m, 0.25 mm internal diameter, 0.25 μm film) with helium as the carrier gas for liquid and headspace sampling. A tandem Agilent 5977B mass selective detector was used for headspace gas analysis.

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Author Contributions

K.J.S designed the experiments and conducted the characterizations. K.M.W contributed to the experimental design and characterization. C.T., Y.C. and L.E. contributed to experimentation.

K.J.S and J.M.T. wrote and edited the manuscript. All aspects of the research were overseen by J.M.T. All authors discussed the results and commented on the manuscript.

Conflict of Interest

Rice University owns intellectual property on technologies here. That has been licensed to a company in which JMT is a shareholder, though not an officer, director, or employee. Conflicts of interest are managed through regular disclosures to the Office of Sponsored Programs and Research Compliance.

References

[1] A. Kumar, E. Singh, R. Mishra, S. L. Lo, S. Kumar, *Energy* **2023**, *275*, 127471.

[2] U.S. EPA, *National Overview: Facts and Figures on Materials, Wastes and Recycling*. https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials (accessed 21 Nov 2023)

[3] A. D. Read, P. Phillips, G. Robinson, *Resour. Conserv. Recycl.* **1997**, *20*, 183.

[4] R. Gonzalez-Valencia, F. Magana-Rodriguez, J. Cristóbal, F. Thalasso, *Waste Manag.* **2016**, *55*, 299.

[5] H. I. Abdel-Shafy, A. M. Ibrahim, A. M. Al-Sulaiman, R. A. Okasha, *Ain Sham. Eng. J.* **2023**, 102293.

[6] S. A. Al Raisi, *EJGEO* **2022**, *3*, 1.

[7] M. T. El-Saadony, A. M. Saad, N. A. El-Wafai, H. E. Abou-Aly, H. M. Salem, S. M. Soliman, T. A. Abd El-Mageed, A. S. Elrys, S. Selim, M. E. Abd El-Hack, S. Kappachery, K. A. El-Tarabily, S. F. AbuQamar, *Environ. Technol. Innov.* **2023**, *31*, 103150.

[8] E. R. Bandala, A. Liu, B. Wijesiri, A. B. Zeidman, A. Goonetilleke, Environ*.* *Pollut.* **2021**, *291*, 118133.

[9] M. A. Kamaruddin, M. S. Yusoff, H. A. Aziz, Y.-T. Hung, *Appl Water Sci.* **2015**, *5*, 113.

[10] K. Spokas, J. Bogner, J. P. Chanton, M. Morcet, C. Aran, C. Graff, Y. M.-L. Golvan, I. Hebe, *Waste Manage.* **2006**, *26*, 516–525.

[11] B.G. Mwanza, in *Recent Developments in Plastic Recycling. Composites Science and Technology*, (J. Parameswaranpillai, S. Mavinkere Rangappa, A. Gulihonnehalli Rajkumar, S. Siengchin, eds), Springer, Singapore. 1-13, 2021.

[12] J. P. Lange, *ACS Sustain. Chem. Eng.* **2021**, *9*, 15722.

[13] N. Kajiwara, H. Matsukami, G. Malarvannan, P. Chakraborty, A. Covaci, H. Takigami, *Chemosphere* **2022**, *289*, 133179.

[14] Y. Guo, X. Xia, J. Ruan, Y. Wang, J. Zhang, G. A. LeBlanc, L. An, *Sci. Total Environ.* **2022**, *838*, 156038.

[15.] Z. Fu, S. Lin, H. Tian, Y. Hao, B. Wu, S. Liu, L. Luo, X. Bai, Z. Guo, Y. Lv, *Sci. Total Environ.* **2022**, *826*, 154212.

[16] C. Li, L. Yang, J. Wu, Y. Yang, Y. Li, Q. Zhang, Y. Sun, D. Li, M. Shi, G. Liu, *J. Hazard. Mater* **2022**, *428*, 128220.

[17] B. Liu, Z. Han, X. Liang, *Atmos. Pollut. Res.* **2023**, *14* (8), 101842.

[18] A. Maalouf, A. Mavropoulos, *Waste Manag. Res* **2023**, *41* (4), 936–947.

[19] D. X. Luong, K. V. Bets, W. A. Algozeeb, M. G. Stanford, C. Kittrell, W. Chen, R. V. Salvatierra, M. Ren, E. A. McHugh, P. A. Advincula, Z. Wang, M. Bhatt, H. Guo, V. Mancevski, R. Shahsavari, B. I. Yakobson, J. M. Tour, *Nature* **2020**, *577* (7792), 647–651.

[20] P. A. Advincula, D. X. Luong, W. Chen, S. Raghuraman, R. Shahsavari, J. M. Tour, *Carbon* **2021**, *178*, 649–656.

[21] W. A. Algozeeb, P. E. Savas, D. X. Luong, W. Chen, C. Kittrell, M. Bhat, R.; Shahsavari, J. M. Tour, *ACS Nano* **2020**, *14*, 15595.

[22] P. A. Advincula, W. Meng, L. J. Eddy, J. L. Beckham, I. R. Siqueira, D. X. Luong, W. Chen, M. Pasquali, S. Nagarajaiah, J. M. Tour, *Macromol. Mater. Eng.* **2023**, *308*, 2200640.

[23] P. A. Advincula, V. Granja, K. M. Wyss, W. A. Algozeeb, W. Chen, J. L. Beckham, D. X. Luong, C. F. Higgs, J. M. Tour, *Carbon* **2023**, *203*, 87.

[24] M. J. Allen, V. C. Tung, R. B. Kaner, *Chem. Rev.* **2010**, *110*, 132.

[25] Z. Ni, Y. Wang, T. Yu, Z. Shen, *Nano Res.* **2008**, *1*, 273.

[26] R. Rao, R. Podila, R. Tsuchikawa, J. Katoch, D. Tishler, A. M. Rao, M. Ishigami, *ACS Nano* **2011**, *5*, 1594.

[27] C. G. Pope, *J. Chem. Educ.* **1997**, *74*, 129.

[28] K. M. Wyss, K. J. Silva, K. V. Bets, W. A. Algozeeb, C. Kittrell, C. H. Teng, C. H. Choi, W. Chen, J. L. Beckham, B. I. Yakobson, J. M. Tour, *Adv. Mater.* 2306763.

[29] Midwest Custom Solutions, http://www.midwestcustomsolutions.com/ (accessed 21 Nov 2023)

[30] Liberty Ashes Inc., https://libertyashes.com/contact (accessed 21 Nov 2023)

TOC Abstract: Using flash Joule heating, municipal solid waste is converted to graphene within 3 seconds. This method suggests a plausible pathway to achieve lower global warming potential when compared to traditional municipal solid waste disposal methods along economic viability.