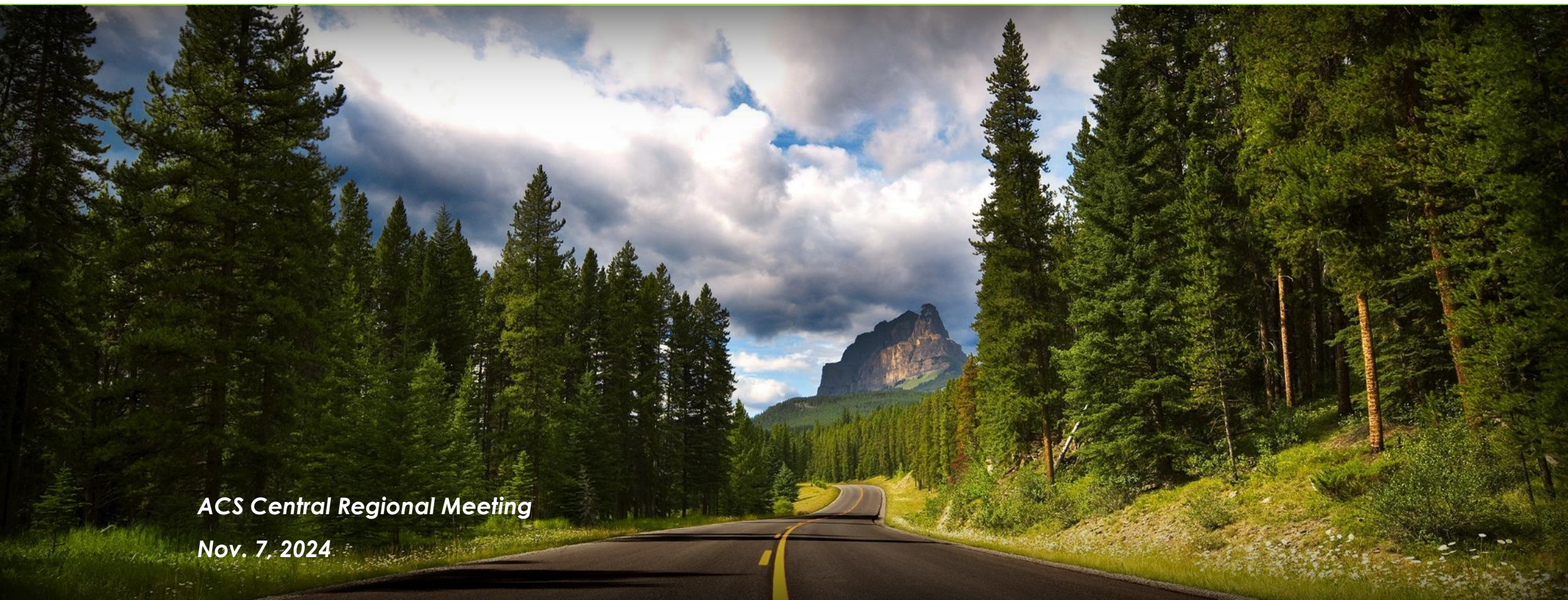


Upcycling Polyethylene Waste to Advanced Carbon Materials for Energy Storage Applications



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Research Engineer, NETL Support Contractor



ACS Central Regional Meeting

Nov. 7, 2024

Disclaimer



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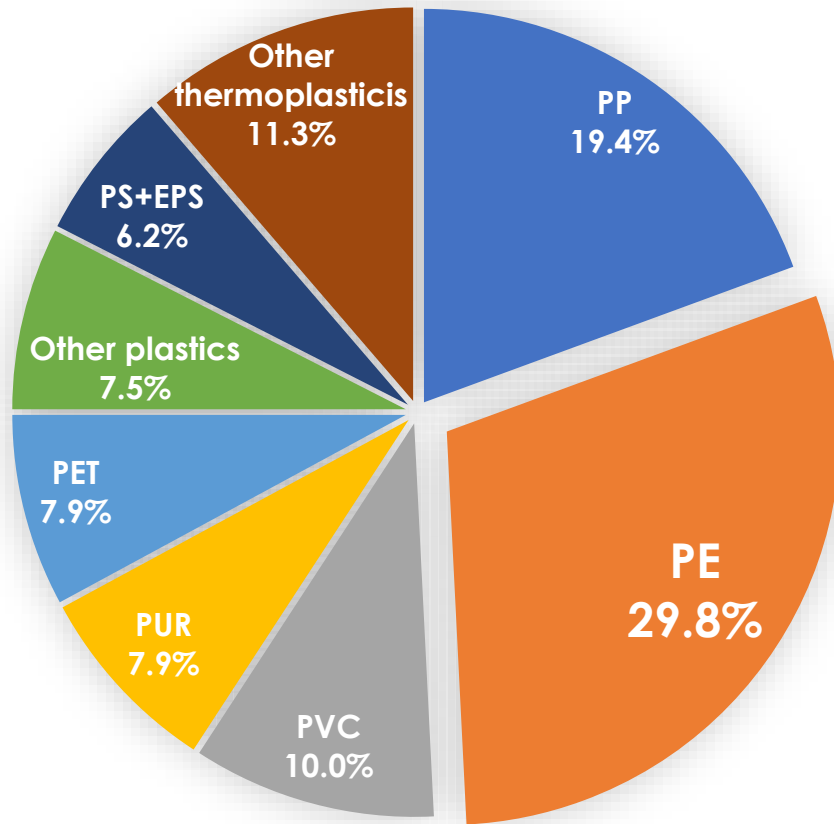
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Background-Plastic Recycling and Upcycling

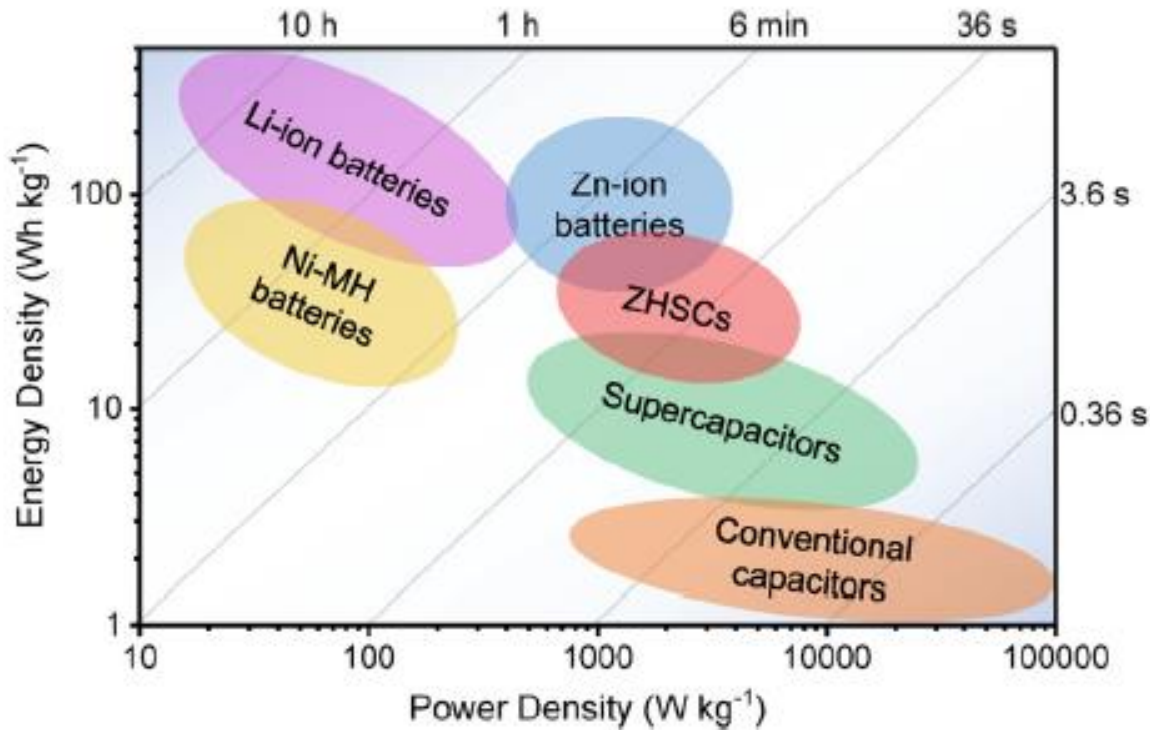


Distribution of global plastic production in 2019, by type.

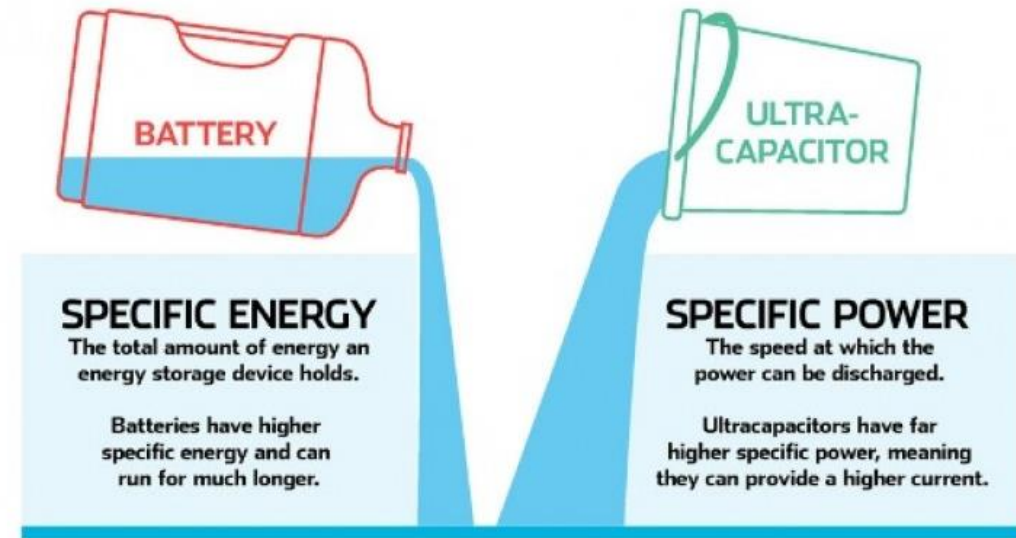
- 8 billion tons of plastic waste produced since 1950, but only 6-7% recycled.
- Current recycling downgrades technical and economic value of plastic, limiting utility.
- Polyethylene (PE) is difficult to recycle/reuse; decomposes during thermal processing.

Background-Energy Storage Devices

Various Electrochemical Storage Devices

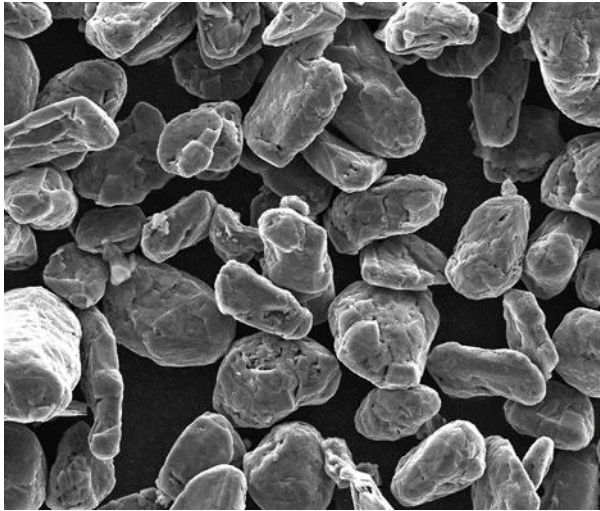


(Carbon Energy, 2020, 2, 521–539.)

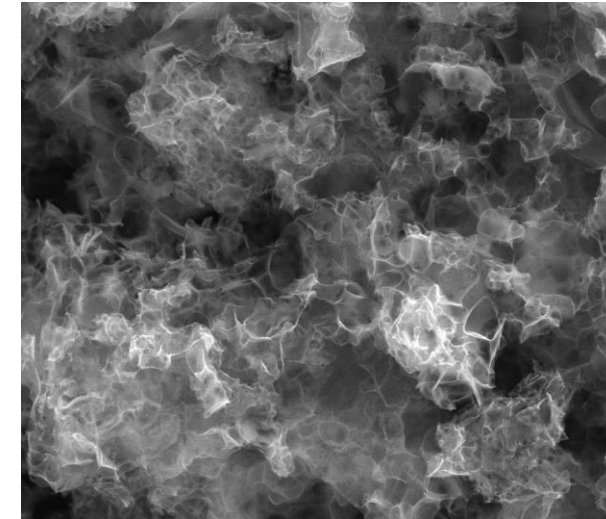


(<https://interestingengineering.com/science/could-ultracapacitors-replace-batteries-in-future-electric-vehicles>)

High-quality graphite for battery application



Porous graphene for supercapacitor application



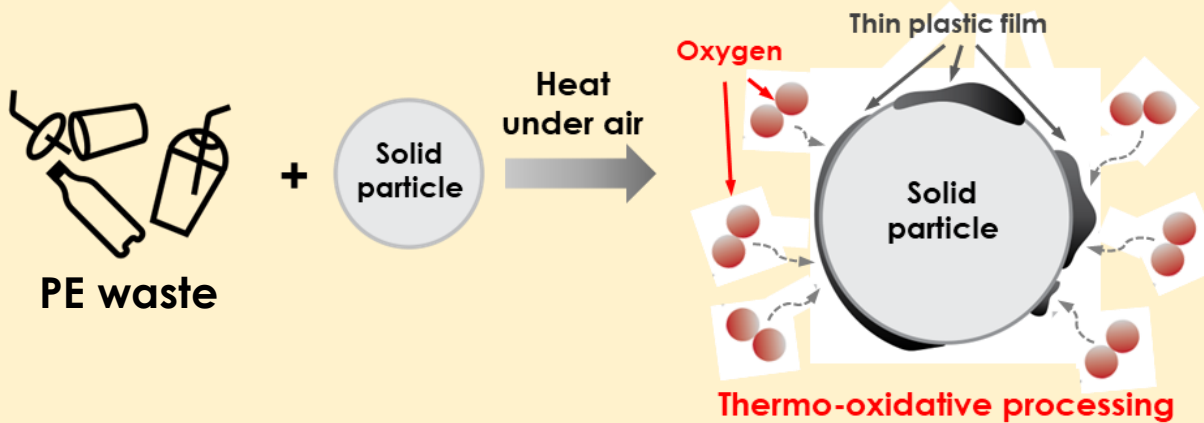
V. H. Pham et al., *Small Methods* 2024, 2301426.

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Synthesis Method of Polyethylene Upcycling

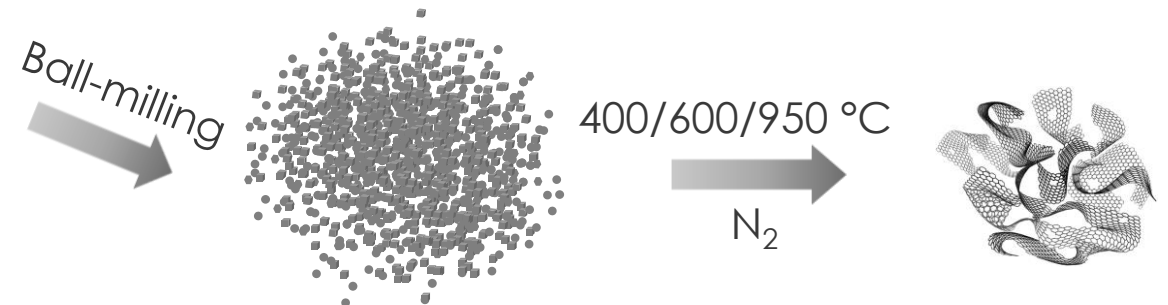
Plastic Stabilization



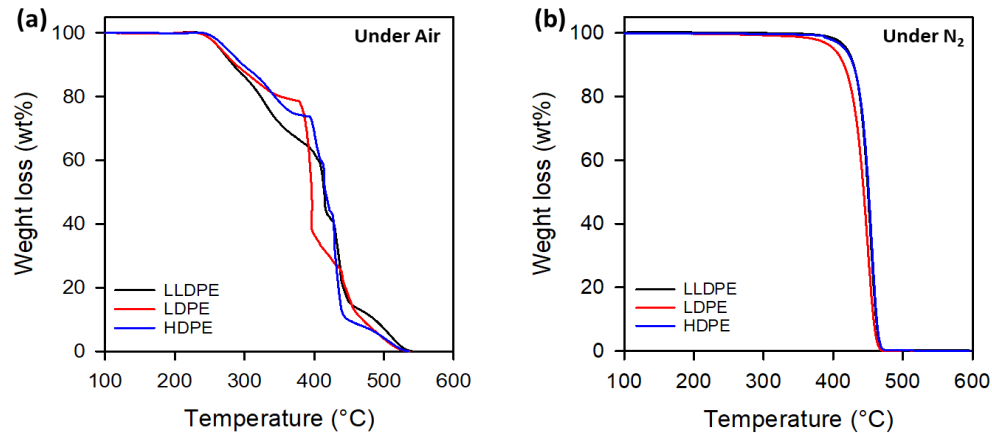
Catalytic Graphitization



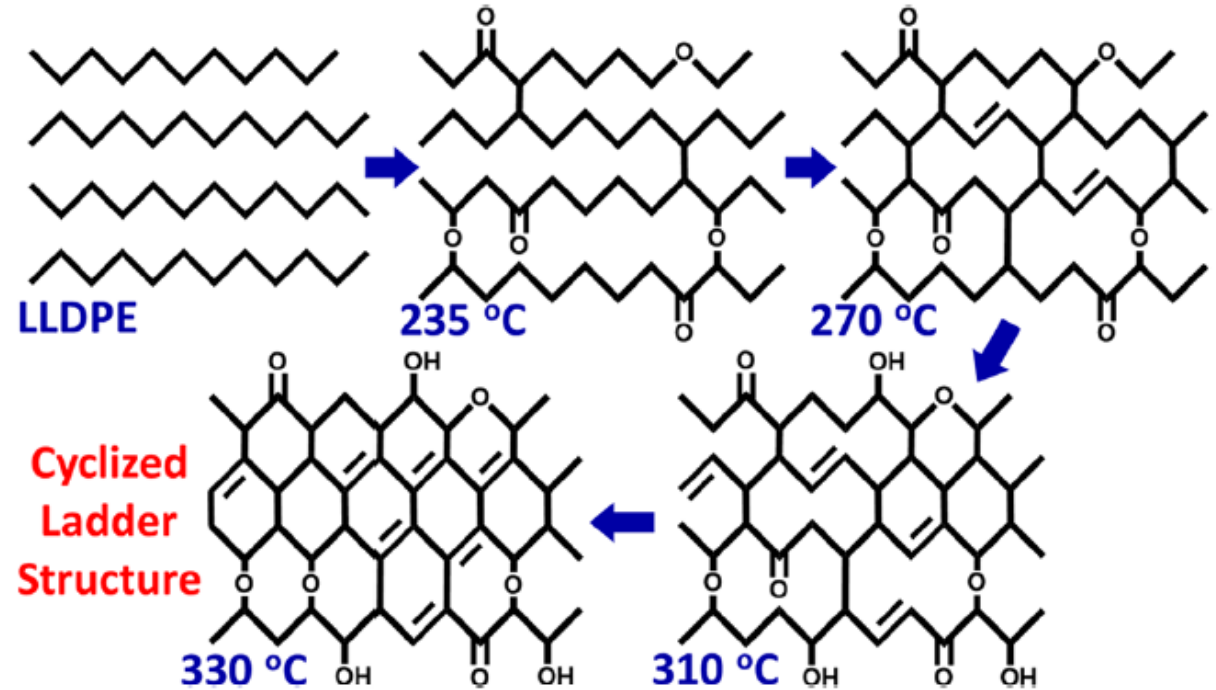
Catalytic Graphenization



Why Do We Need Stabilization as a Pretreatment?



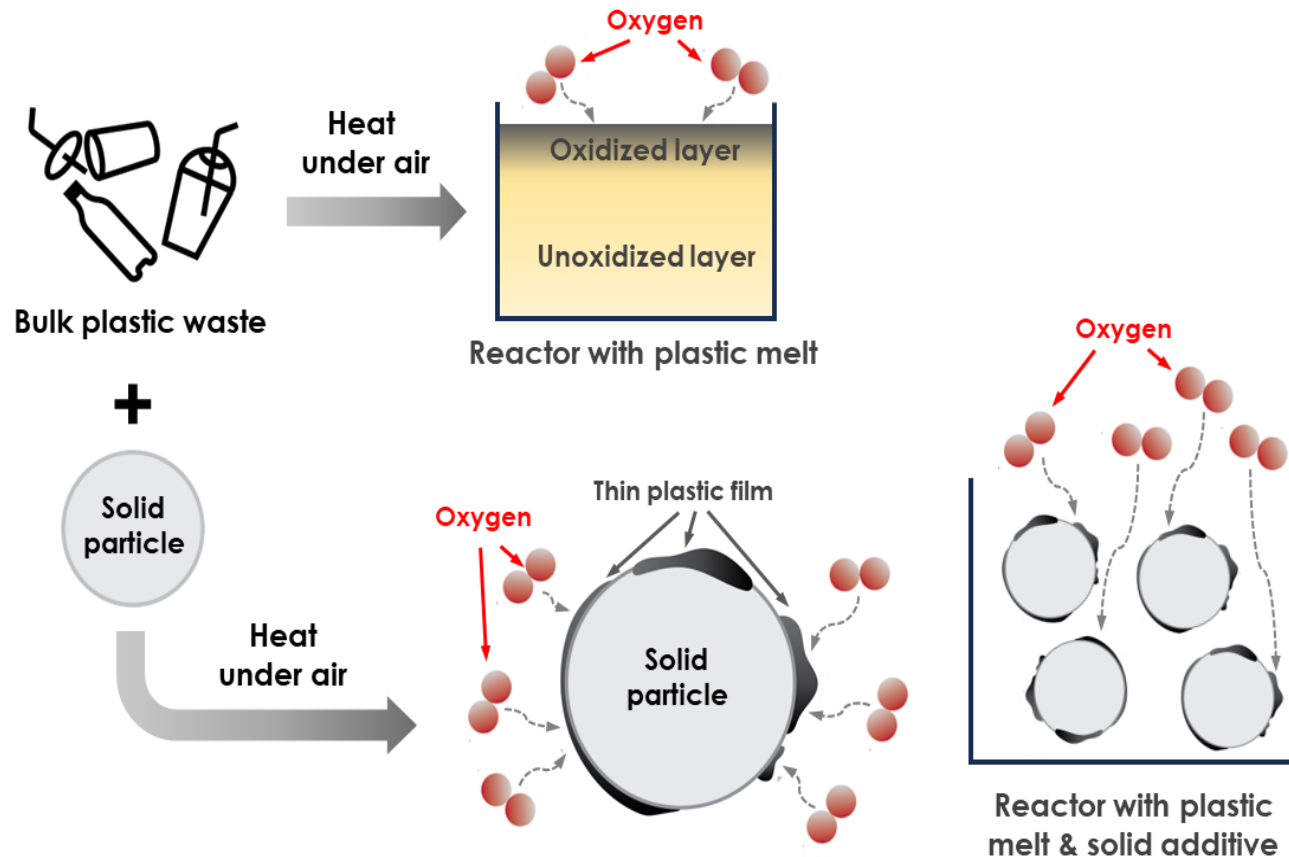
K. Kim. et al., ACS Sustainable Resource Management (in review).



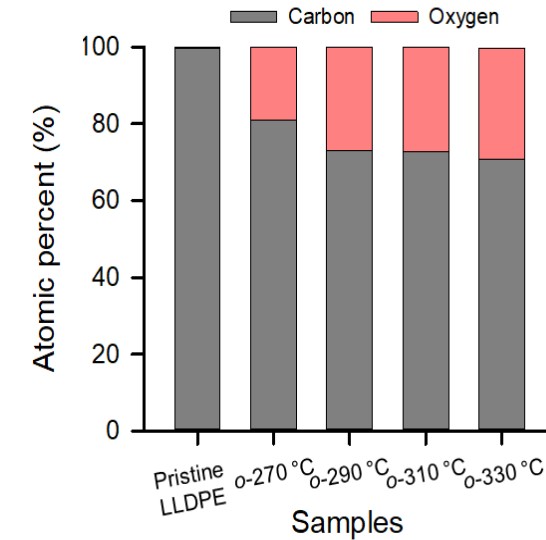
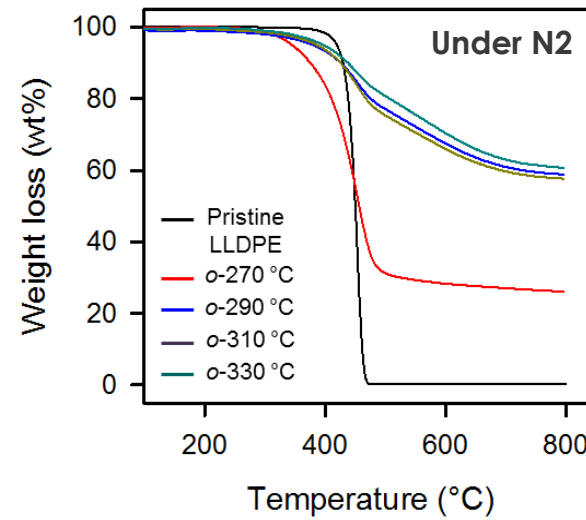
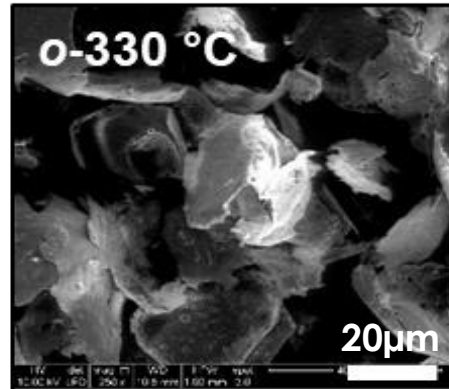
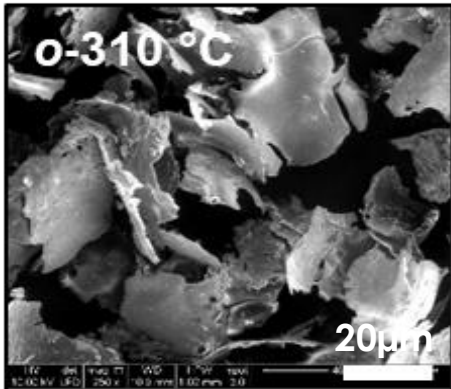
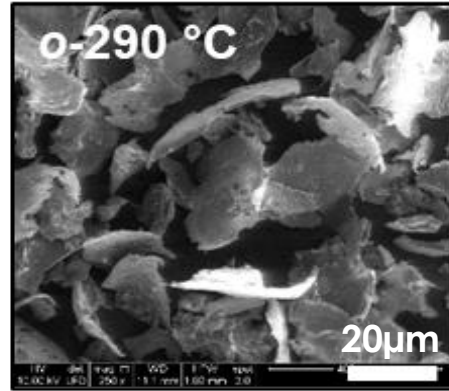
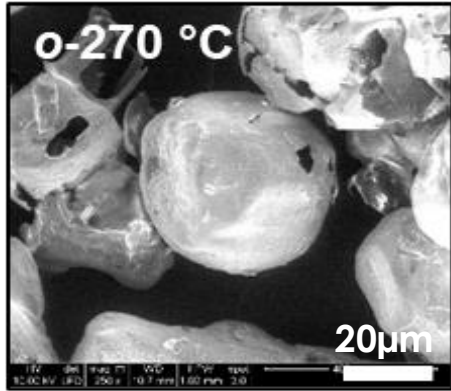
Mechanism from: Choi et. al., Chem. Mater. 2017, 29, p 9518–9527.

Stabilization occurs from thermal oxidation and formation of cyclized ladder structures which are more stable at high temperatures than original alkyl chain.

How Do We Do Stabilization in Bulk?



Oxidized Polyethylene



Pre-treating between 290-330 °C stabilizes PE for high temperature processing under N₂.

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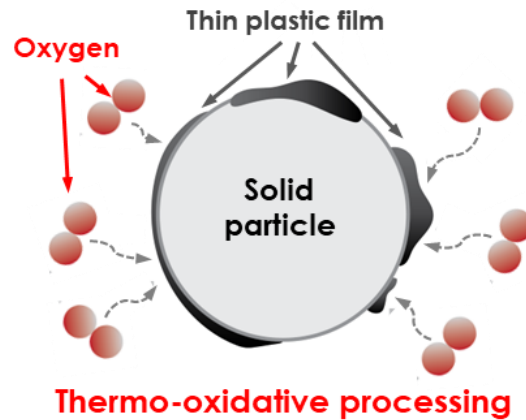
Plastic Stabilization



+



Heat
under air



Catalytic Graphitization

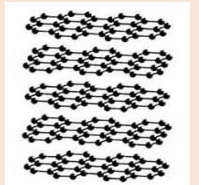
Remove
solid particle



Oxidized plastic

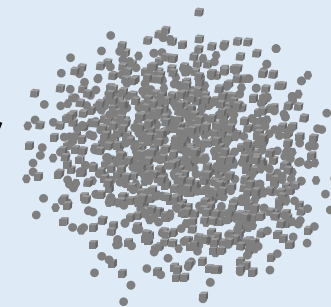
1500 °C for 3 Hours

Fe or Fe₂O₃



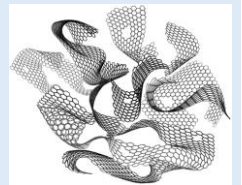
Catalytic Graphenization

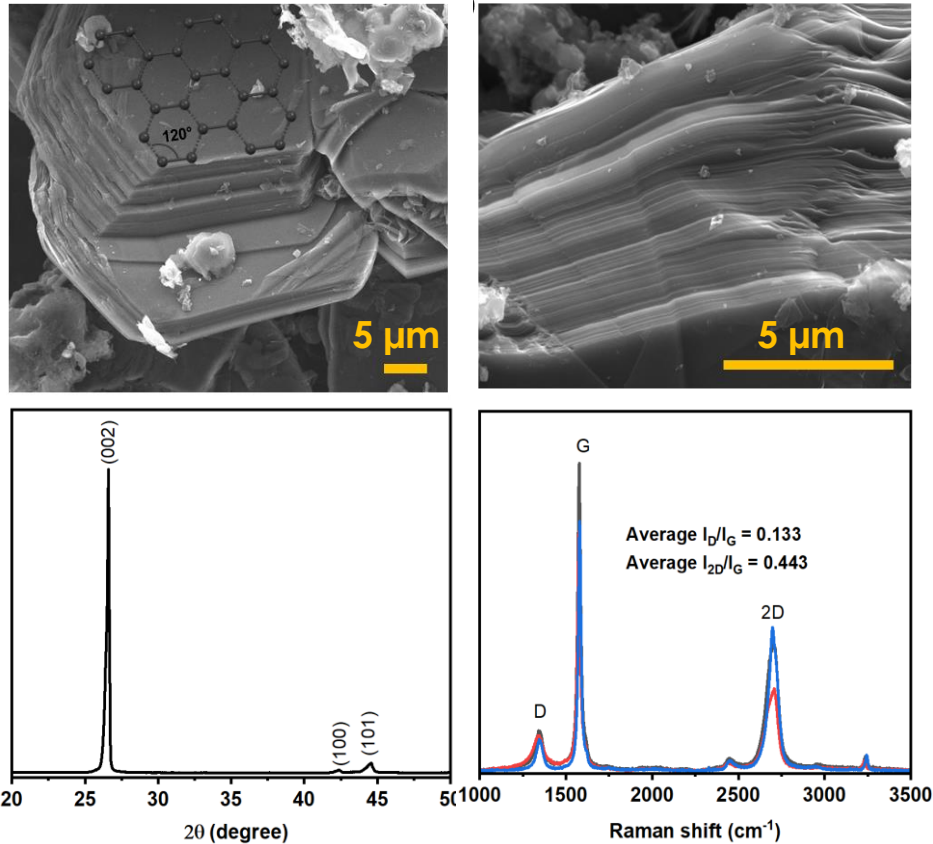
Ball-milling



400/600/950 °C

N₂



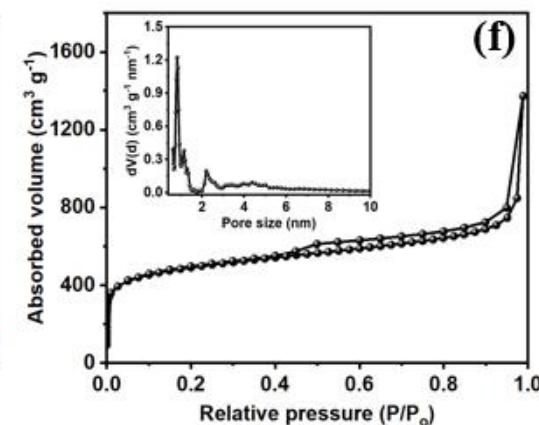
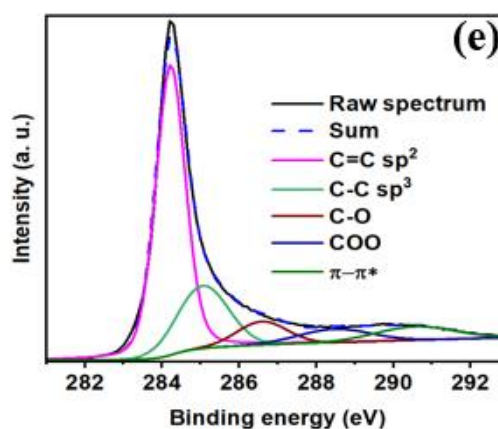
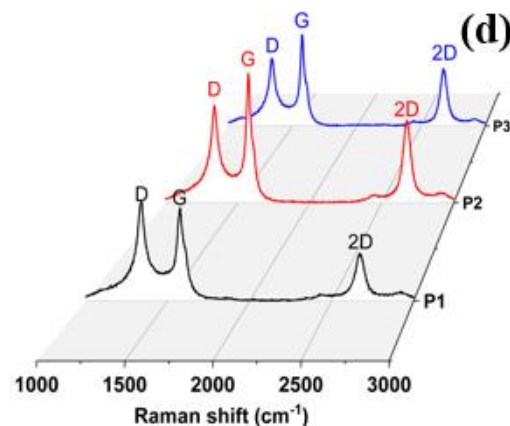
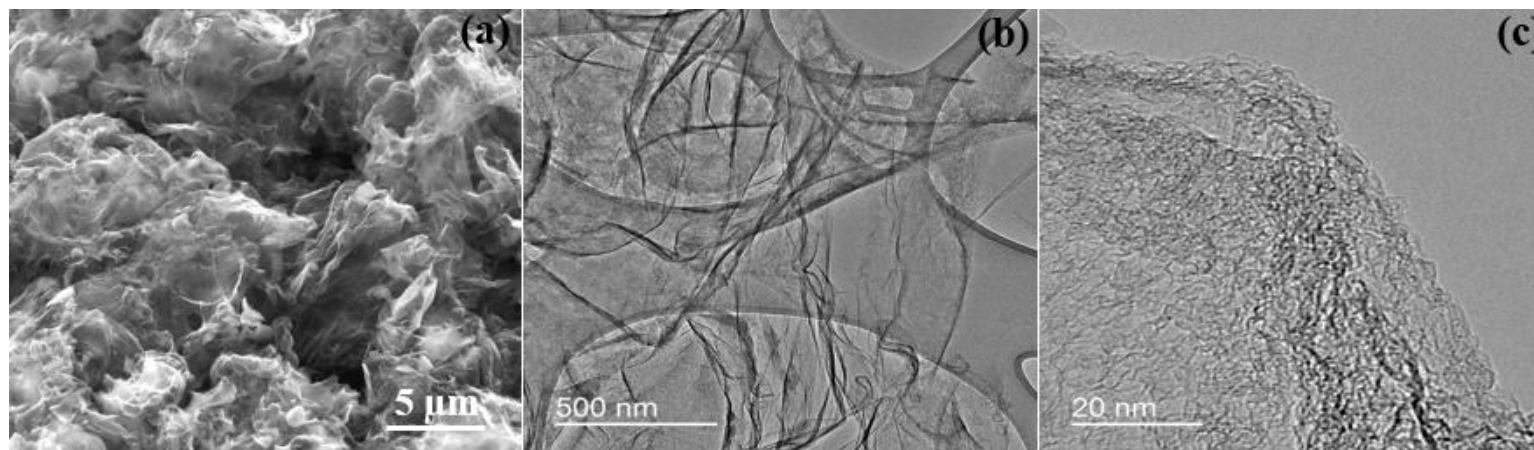


PE-Derived Graphite vs. Natural Graphite

Carbon Product	DG (%)	BET Surface Area (m ² g ⁻¹)	Residue (wt.%)	Graphite Yield from PE (wt.%)	Graphite Yield from o-PE (wt.%)
PE-Graphite	97	2.60	0.16	15	41
MSE natural graphite	95	2.26	0.07	Commercial graphite	

K. Kim, et al., ACS Sustainable Resource Management (in review).

PE-Derived Porous Graphene

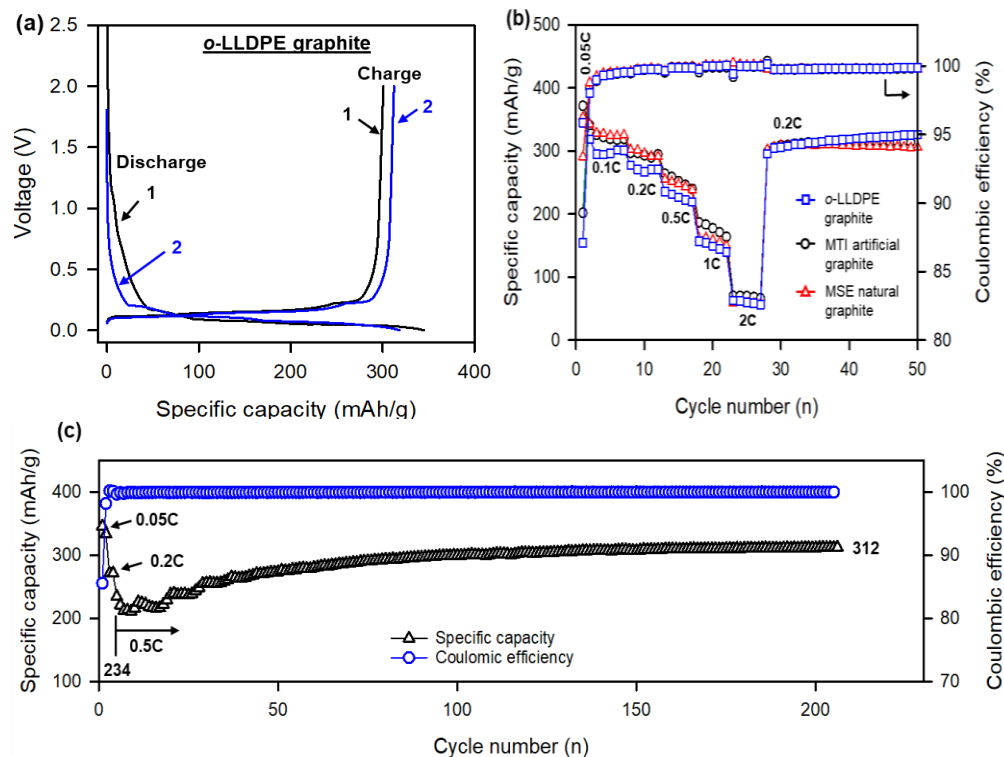


(Y. Gao et al., *Chemical Engineering Journal*, 2024, 498, 155873.)

Carbon Product	Yield	BET Surface Area (m ² g ⁻¹)	Raman I _d /I _g	Oxygen Content at%
PE-Graphene	7.5 wt.%	1,800	0.85	2

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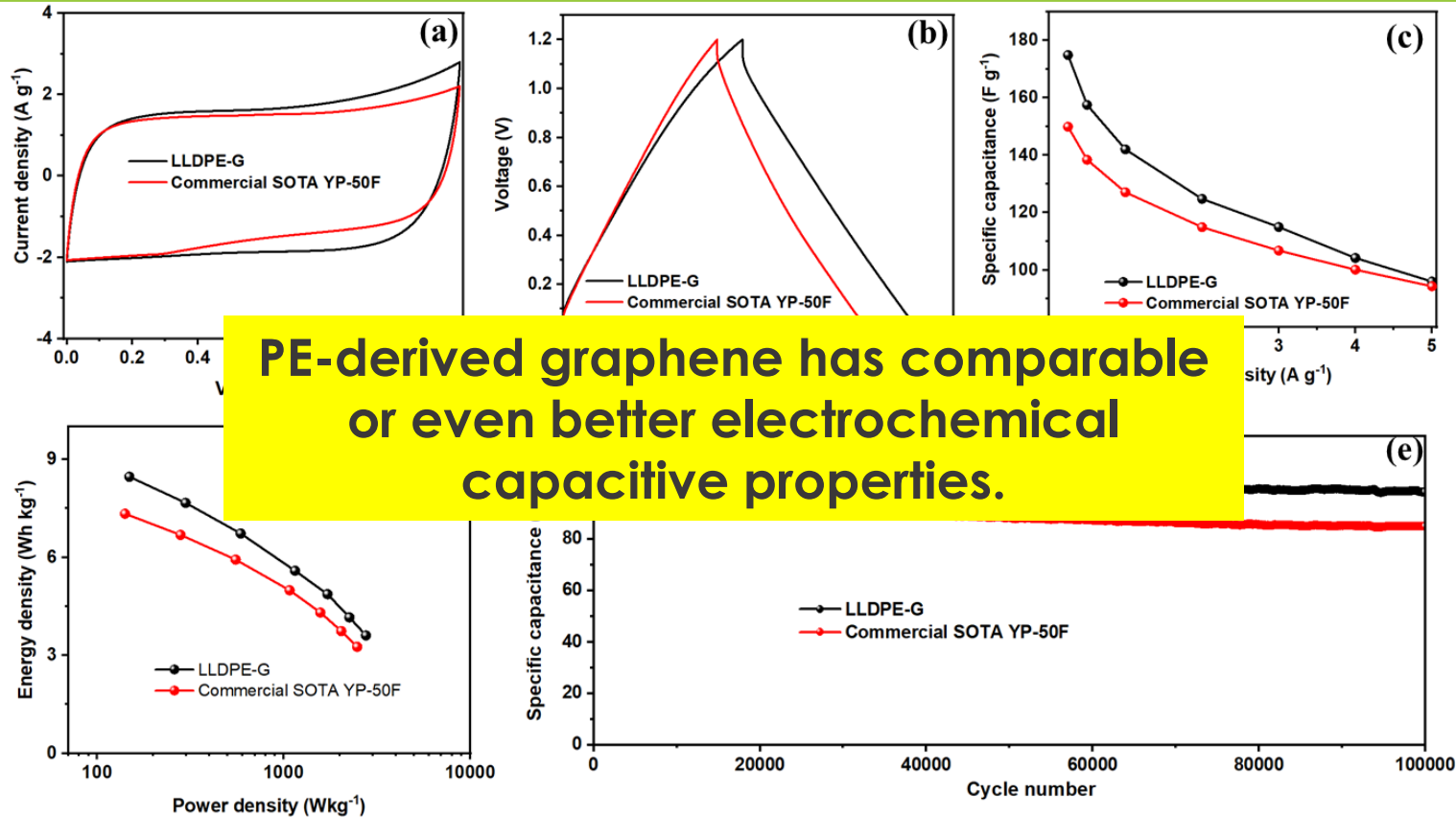


Battery Performance with Graphite Anode

Anode	1 st Discharge (mAh/g)	1 st Charge (mAh/g)	ICE (%)	2 nd Discharge (mAh/g)	2 nd Charge (mAh/g)	2 nd CE (%)
o-LLDPE Graphite	345	301	87	318	312	98 (99.9)
MSE Natural Graphite	354	330	94	342	338	99 (99.8)

PE-derived graphite has comparable battery performance compared to natural graphite.

Supercapacitor Test



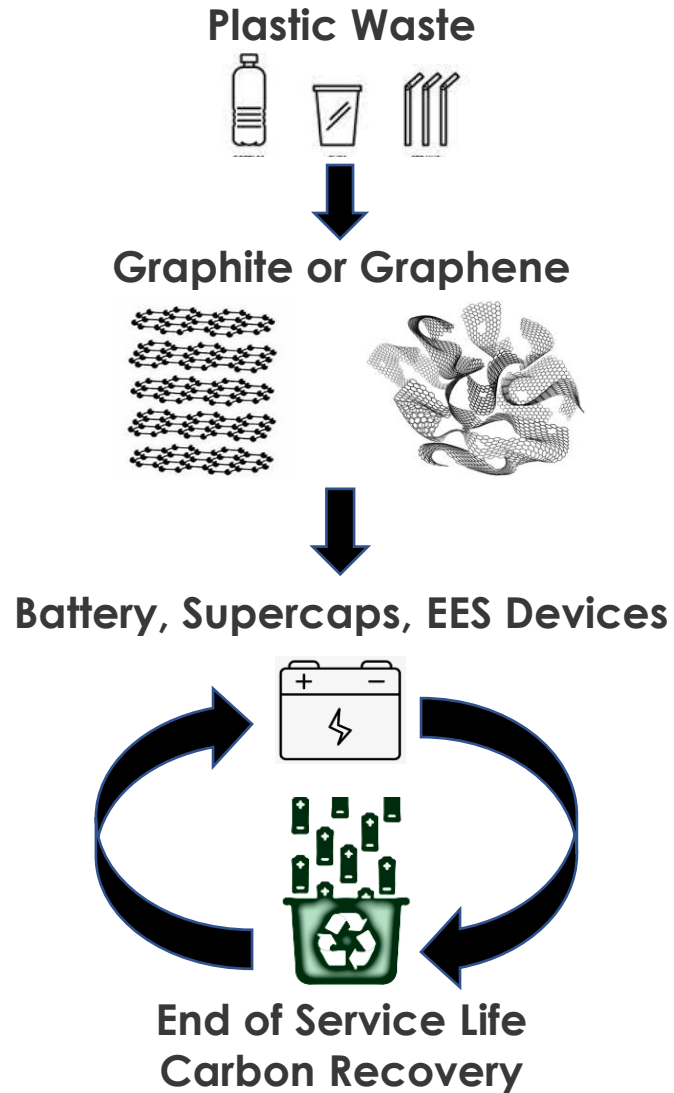
PE-derived graphene has comparable or even better electrochemical capacitive properties.

Electrode	BET Surface Area (m ² g ⁻¹)	Specific Capacity at 0.25 A/g (F g ⁻¹)	Energy Density at 150 W/kg (Wh kg ⁻¹)	Capacity Retention After 100,000 Cycles(%)
PE-Derived Graphene	1,800	175	8.47	95.8
Commercial SOTAYP-50F	1,760	150	7.33	88.5

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Conclusion



- Polyethylene is converted into high quality graphite or graphene with a facile and scalable bulk stabilization/oxidation method followed by catalytic graphenization or graphitization synthesis.
- The advanced carbon materials demonstrate excellent performance as battery or supercapacitor electrodes.
- The electrode is compared to conventional materials, which has comparable or outperforming performances.

Acknowledgments



This work was performed in support of the U.S. Department of Energy's (DOE) Laboratory Directed Research & Development (LDRD) and the Office of Fossil Energy and Carbon Management's Carbon Ore Processing Programs and executed through the National Energy Technology Laboratory (NETL) Research & Innovation Center consistent with the authorizing legislation and DOE LDRD Order 413.2C.

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