UNIVERSAL MATTER
ADVANCED MATERIALS

2022 Resource Sustainability Annual Project Review Meeting

Duy X Luong

October 2022

Department of Energy
FE0031988-FOA 2185
Award #: 13168441

Developing a Facile Technology for Converting Domestic US Coal into High-Value Graphene

Developing a Facile Technology for Converting Domestic US Coal into High-Value Graphene

Project Overview

- **Award #: 13168441**
  - Primary Recipient: Universal Matter Ltd
  - Sub-Recipient: University of Missouri

- **Project Objective:**
  - Enable the conversion of coal into turbostratic graphene via Flash Joule Heating at high yields of 70 - 90%
  - Validate the technical and economic benefits of production of graphene using different grades of coal as the feedstock for the FJH process.
  - Evaluate the performance benefits that can be realized by the incorporation of graphene-based modifiers into different end-use applications.
  - Complete a techno-economic analysis

- **Grant Period: April 1, 2021 – February 28, 2023**

Developing a Facile Technology for Converting Domestic US Coal into High-Value Graphene

Project Overview

- **Project Funding:**

	Year 1		Year 2		Total	
	DOE Funds	Cost Share	DOE Fund	Cost Share	DOE Funds	Cost Share
Universal Matter, Ltd. (Prime)	$213,740	$76,352	$151,260	$201,280	$365,000	$277,632
University of Missouri (Sub-recipient)	$0	$0	$150,000	$0	$150,000	$0
Total ($)	$213,740	$76,352	$301,260	$201,280	$515,000	$277,632
Percentage of costs (%)	74%	26%	60%	40%	65%	35%

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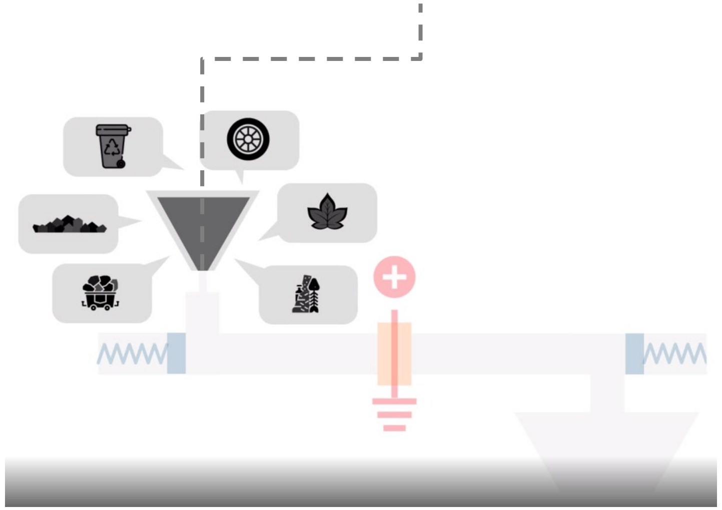
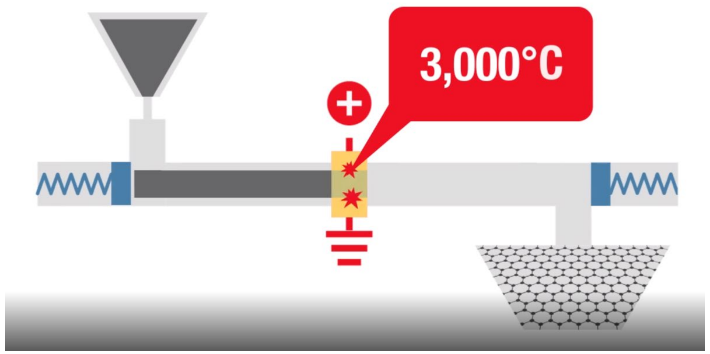
- **Business Lead: Dru Kefalos (druk@universalmatter.com or 512-667-4450)**

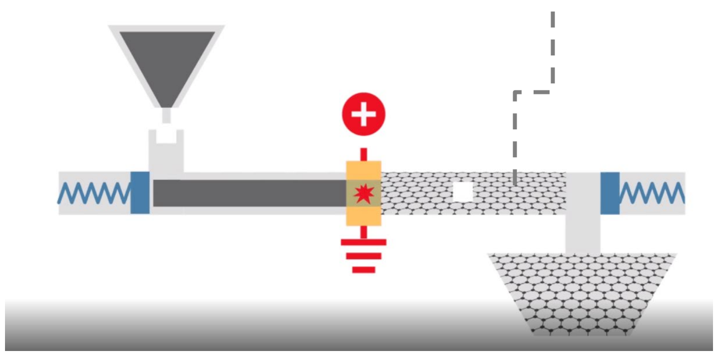
How We Make Graphene

Converting any carbon source, even plastic and food waste, into graphene

1 Proprietary Flash Joule Heating process can start with almost any carbon source placed between two electrodes	**2** Apply energy via a short electrical pulse to instantaneously heat temperature to 3,000 K, breaking every chemical bond in the material	**3** Non-carbon materials sublime out and remaining carbon elements reconstruct into turbostratic graphene
*Input carbon sources include **coal**, petroleum coke, **mixed plastic waste**, **rubber tires**, biomass, and **waste food***	*Environmentally-friendly process uses **no solvent** and **no chemical additives*** ***Tuneable** graphene morphologies*	*Reaction occurs in a **bright flash of light** in **less than one second**, so fast that the surrounding container does not even get hot*







How We Make Graphene

Work Plan

- Study of the process-structure-property relationships for different grades of coal used as feedstock in flash Joule heating process
- Acceleration of Process Optimization by Statistical Modeling
- Application Development for Coal-Derived High-Value Graphene Product
- Scale-up of the Quantity of Coal or Coal Derived Feedstock Amenable to Conversion to Graphene by Flash Joule Heating

Project Schedule

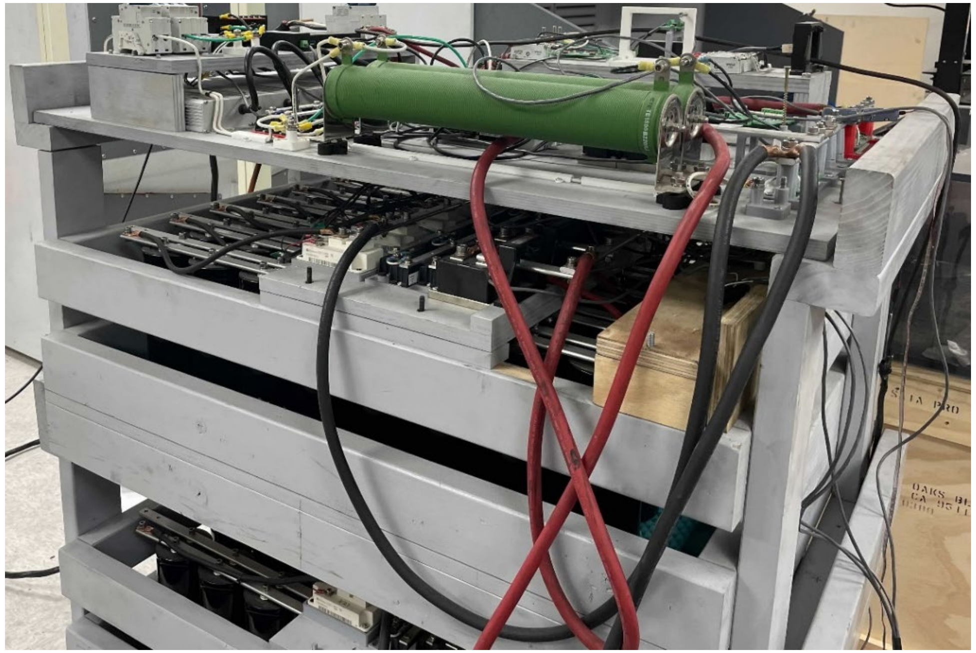
Task/ Subtask	Milestone Title & Description	Planned Completion Date	Verification method
1.1	Project Management Plan (PMP)	Update is due 30 days after award.	Submit to DOE/NETL project manager
1.2	Technology Maturation Plan (TMP)	Initial TMP is due 90 days after award. Final TMP is due at the end of the Period of Performance.	Submit to DOE/NETL project manager
2.1	In depth study on the effects of coal grade on properties of graphene produced in FJH process	End of year 1 (02/28/2022)	Report on conversion rate and quality of graphene produced from different grades of coal.
2.2	In depth study on the effects of processing parameters on properties of graphene produced in FJH process	End of year 1 (02/28/2022)	Report on the effects of processing parameters on the quality of graphene produced from different grades of coal.
3.1	Statistic model of FJH parameters for coke	End of year 2 (02/28/2023)	Statistic model of flashing parameters to predict graphene quality
4.1	Application development for coal-derived sheet-like graphene morphologies	End of year 2 (02/28/2023)	Report on applications, data and publications provided.
4.2	Application developments for coal-derived polyhedral graphene morphologies	End of year 2 (02/28/2023)	Report on applications, data and publications provided.
5.1	Convert a 100 g Batch of Coal Flash Graphene Using Flash Joule Heating (FJH)	End of year 1 (02/28/2022)	Report on flashing 100 g batch
5.2	Convert a >1 kg Batch of Coal or Coal Derived Feedstock to Flash Graphene Using FJH	End of year 2 (02/28/2023)	Report on flashing >1 kg batch
5.3	Semi-automation demo for lab scale-up flash at 1 kg/h throughput	End of year 2 (02/28/2023)	Report on semi-automation flashing system with 1 kg/h throughput
6.0	Technoeconomic Analysis (TEA) and Technology Gap Analysis (TGA), as outlined in SOPO	End of year 2 (02/28/2023)	Submit to DOE/NETL project manager

Project Progress

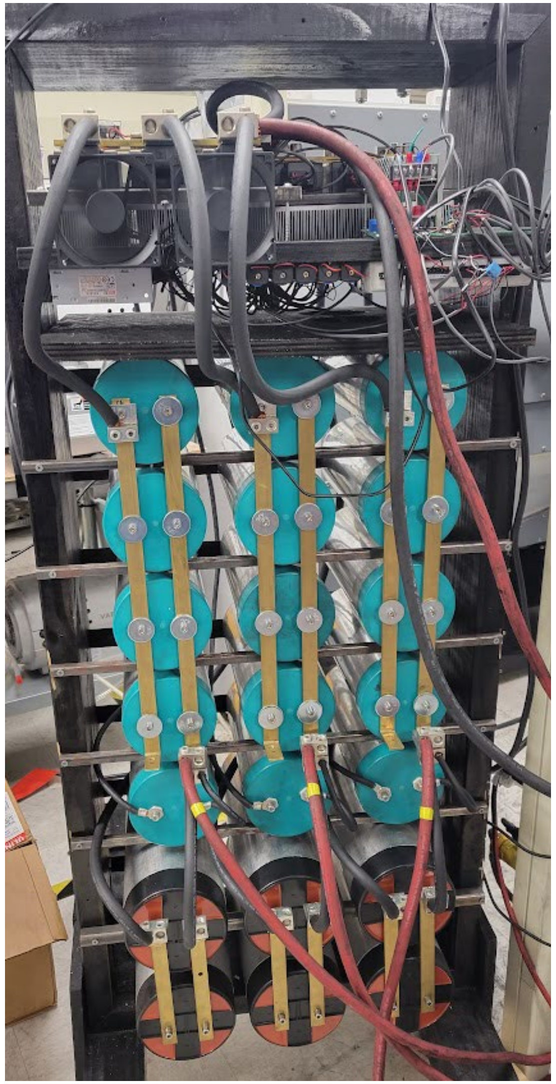
- Studied the conversion of different grade of coal into flash graphene.
- Studied the morphology and structure of these flash graphene.
- Developed the chemical assisted exfoliation method to efficiently disperse the graphene from coal to solvent.
- Built and optimize the flashing system that increase the conversion batch size from 5 g to 100 g. Recently achieved >1kg/batch as demonstrated in the attached video.
- Investigated emission from the FJH process for environmental control.
- Built the database system to record parameters from downstream to upstream of the process.
- Demonstrated application of coal derived flash graphene in epoxy.
- Demonstrated application of coal derived flash graphene in asphalt.

Customized Flash Joule Heating System

- Universal Matter had built several version of the customized flash Joule heating system using the DOE funding.



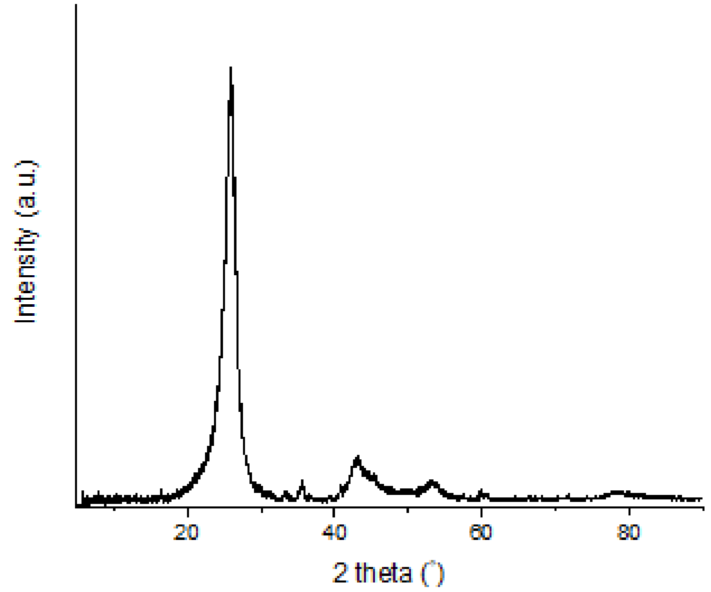
Unit 1 cost ~ $X. Capability: 20g

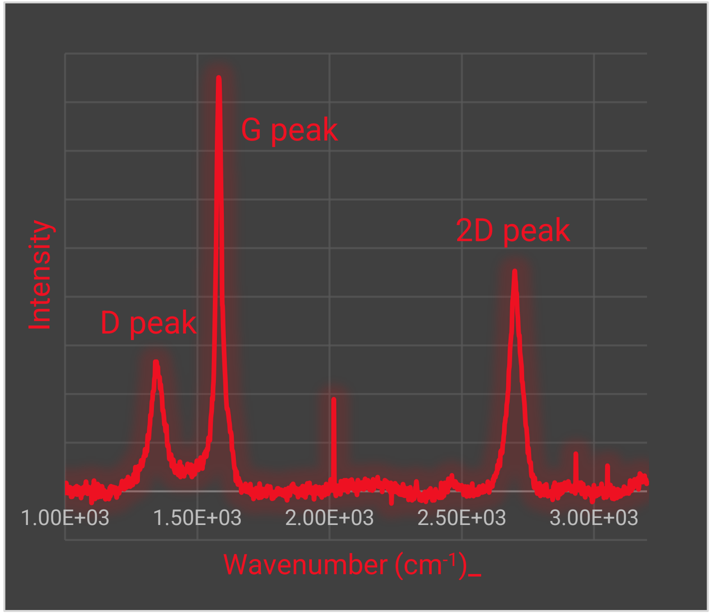


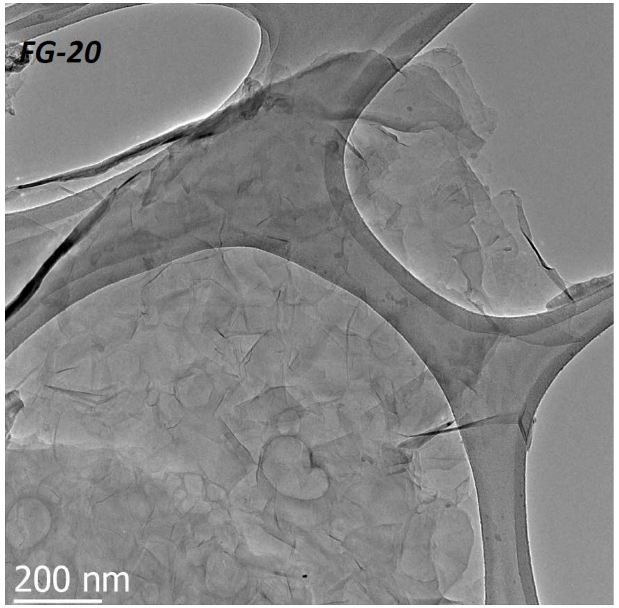
Unit 3 cost ~ $1/3X. Capability: 200g

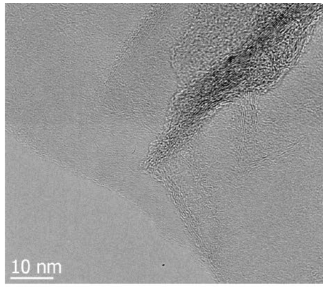
Conversion of Coal into Flash Graphene

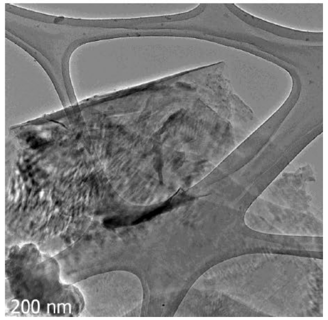
- Metallurgy coke has been converted to high quality graphene.
- Anthracite coal can be converted to graphene but with lower graphene quality.
- Bituminous coal cannot be converted into graphene due to high volatile concentration.
- Emission test showed two main volatiles are carbon monoxide and sulfur dioxide. The combustible concentration is well below the explosive limit.





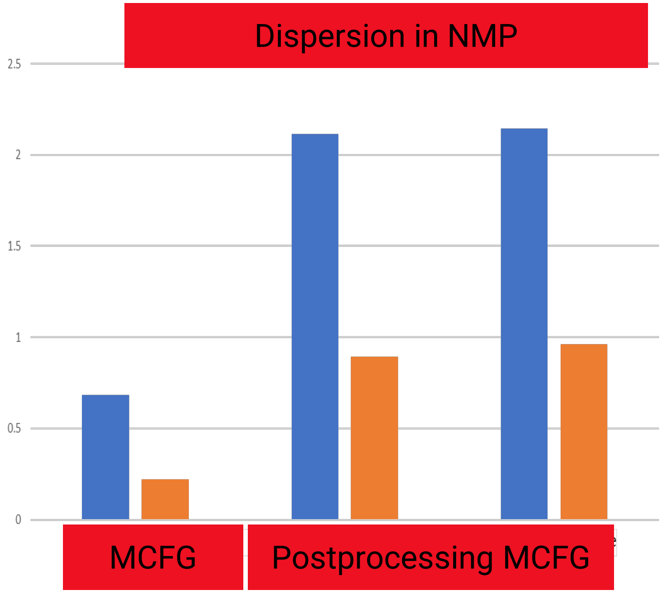


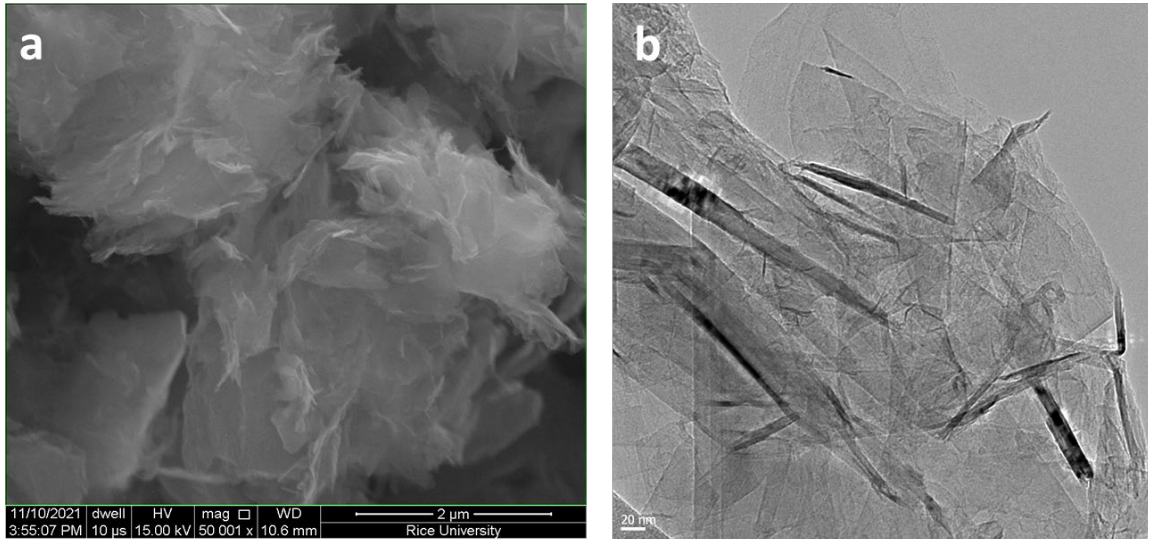


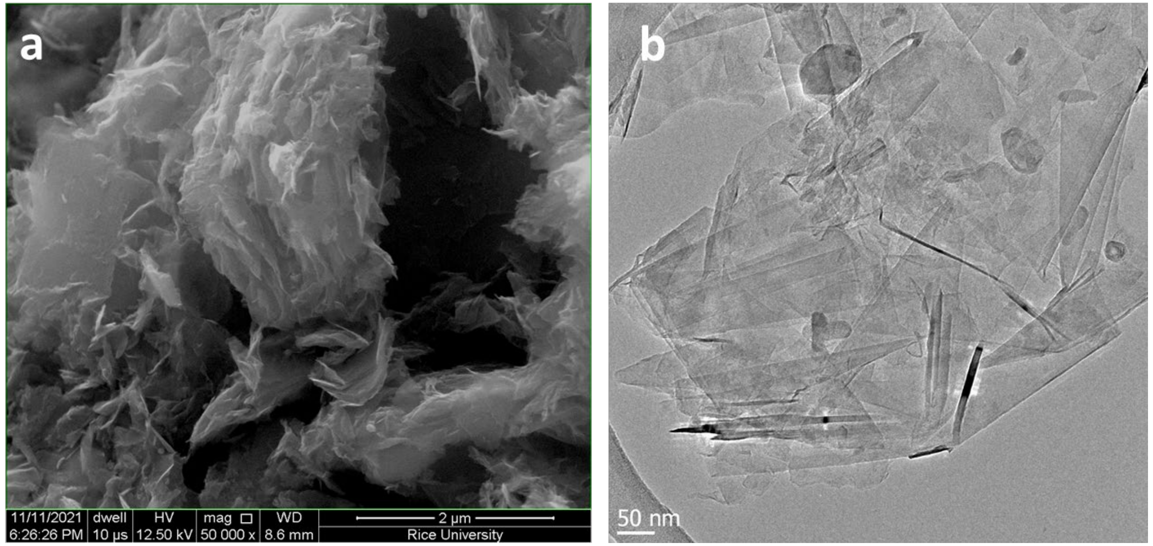


Conversion of Coal into Flash Graphene

- MCFG has turbostratic structure but need some post-processing process to improve the exfoliation.
- Further postprocessing using chemical assisted exfoliation reduce the thickness. Thus, increase the dispersibility.

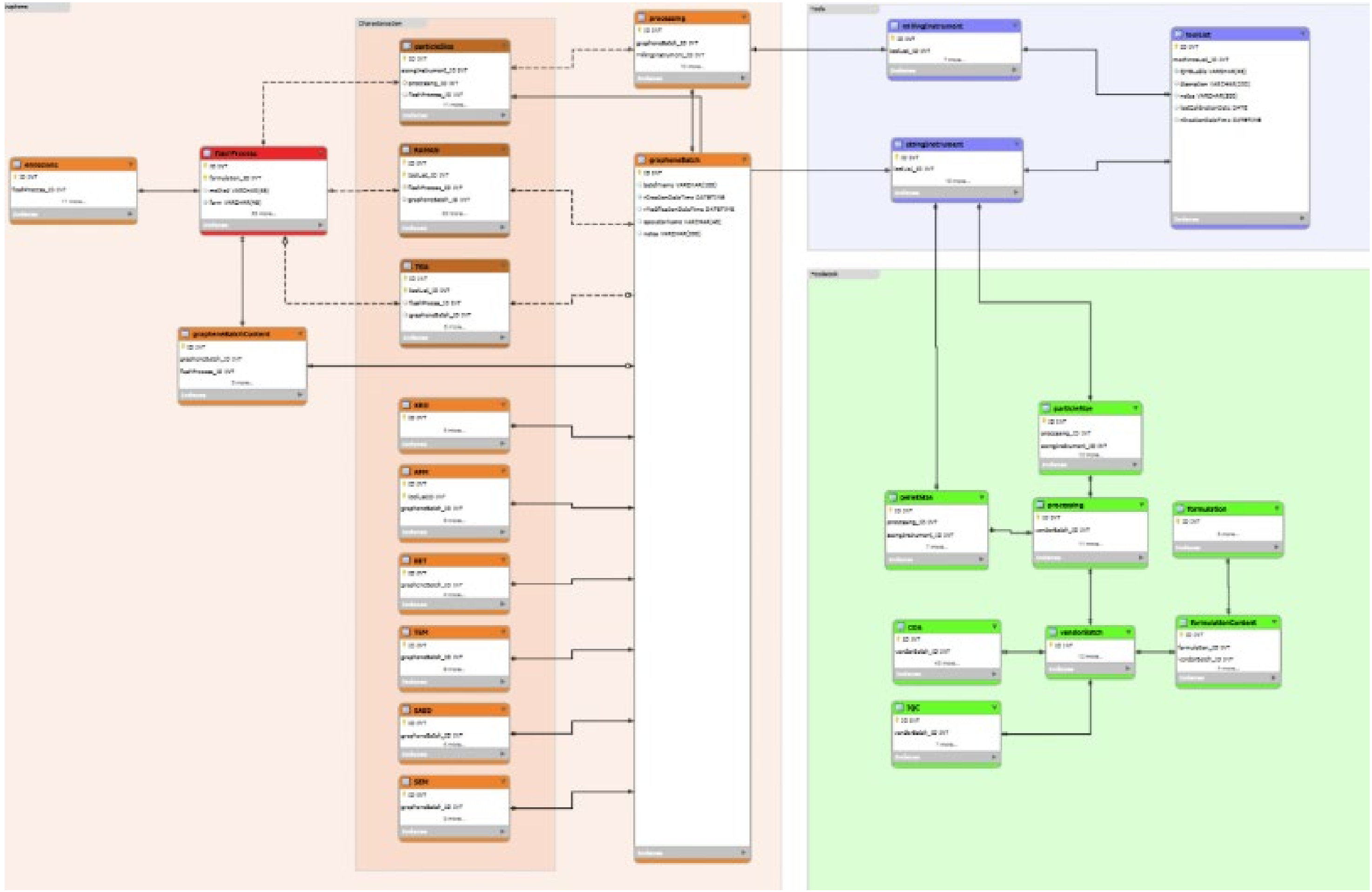






Database System

- Database built in collaboration with Dr. Jian “Javen” Lin and Yunchao Xie from the University of Missouri
- Model learning phase based on FJH process scale-up for developing graphene from metallurgical coke
- Goal to connect effect of feedstock composition and electrical parameters through the application phase and into performance results

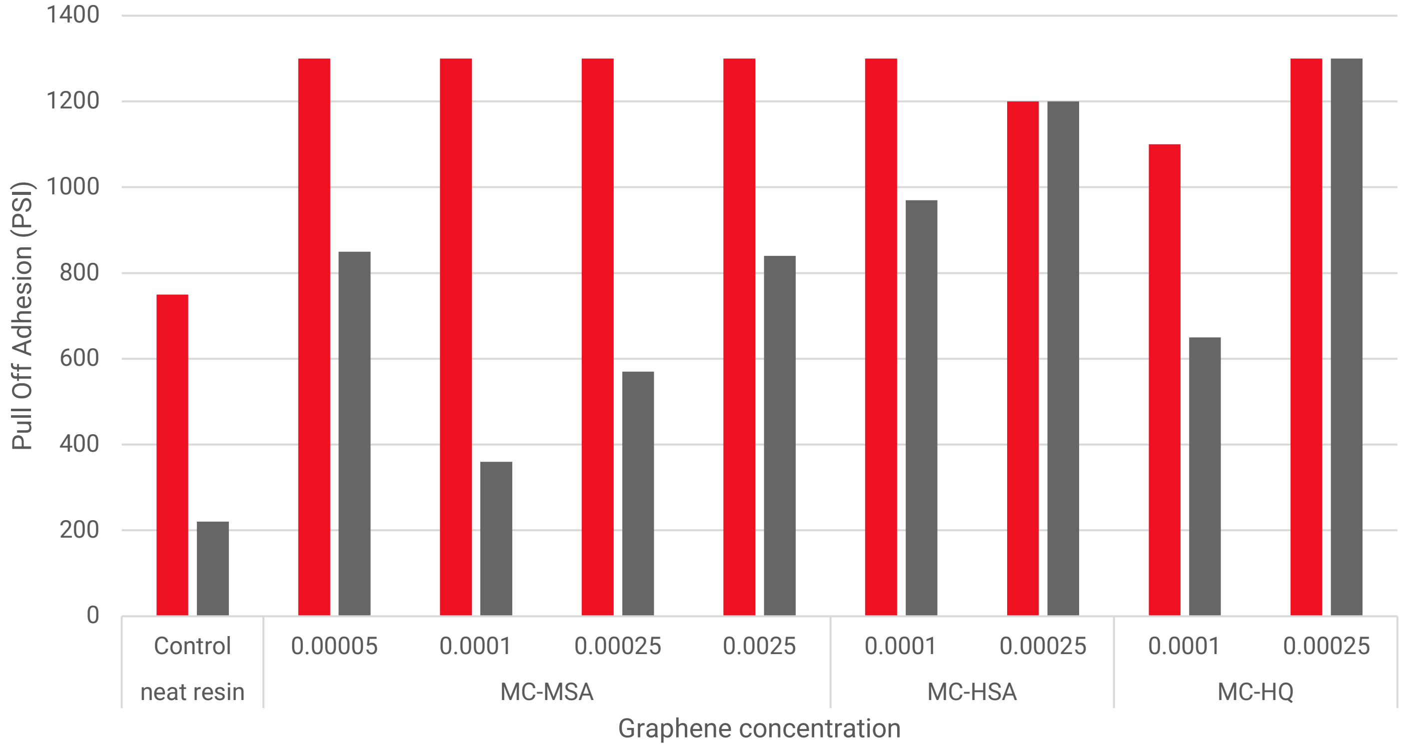


Pictured: early view of SQL database connections

College of Engineering
University of Missouri

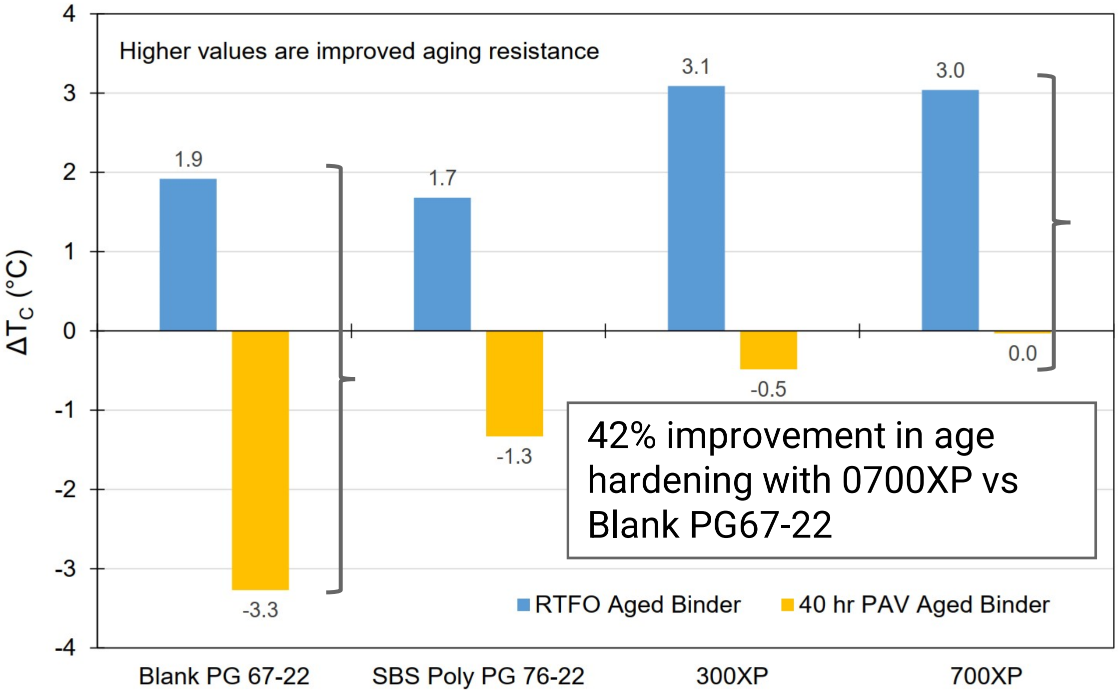
Epoxy Application

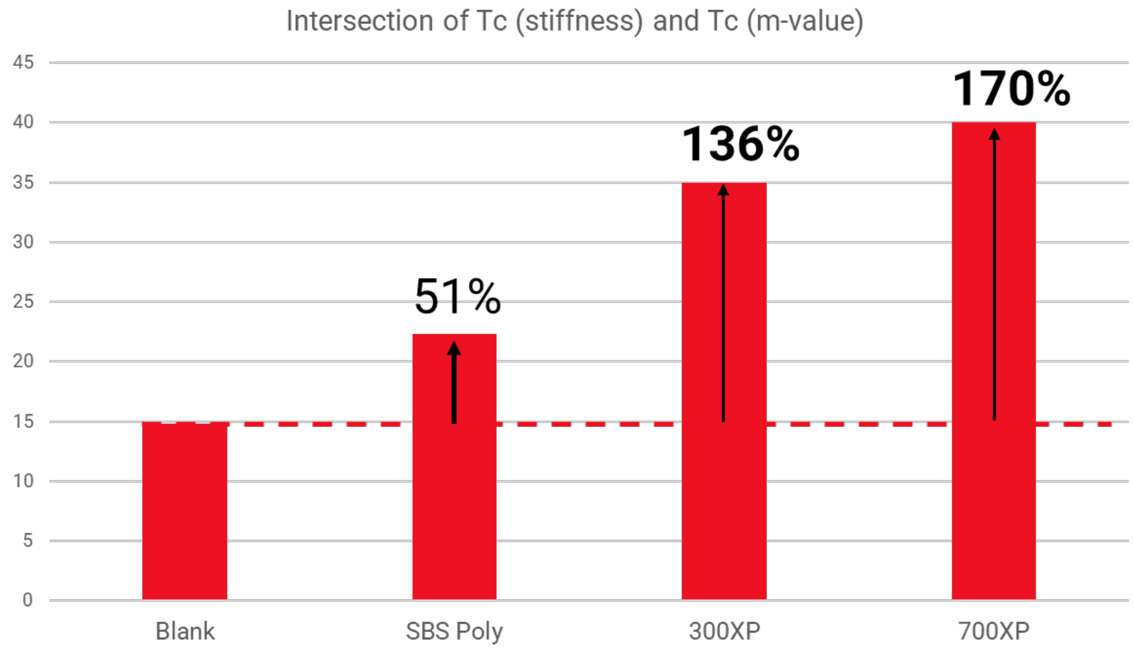
- Collaboration with ChemQuest, a leading independent industry research laboratory to test MC derived FG in epoxy application
- Initial result showed that the MC derived FG has improved the anticorrosion property of epoxy. Below graph show the water permeability for epoxy/MCFG vs control.



Asphalt Application

- Collaboration with Army Corps of Engineers - ERDC to test MC derived FG in asphalt application
- Initial result showed that the MC derived FG has improved the aging performance of asphalt. Below graph show the ΔTc, a parameter that indicate asphalt durability, increase with our MCFG additive; the result show aging improvement in asphalt.





Future Plans

- Build the semi-automation system that is capable of 1kg/h production of graphene from metallurgy coke.
- Complete the database system and build the statistical model for flashing parameters.
- Get more data on the application of the MCFG in epoxy and asphalt.

Next applying DOE project:

- Investigate more on difference approach for FG exfoliation.
- Investigate the functionalization of the FG.
- Improve application of modified MCFG in epoxy and asphalt.

Outreach and Workforce Development Efforts or Achievements

- Workforce Development:
  - Increased our Houston based technology team headcount from 4 to 7 since commencement of this project in April 2021. Two of the additions are recent mechanical engineering/material science graduates.
  - Substantial experience gained by all team members in substantially scaling up an early-stage process to convert carbon-based feedstocks to high performing turbostratic graphene (from Rice University lab to platform for Demonstration Plant).
  - Application Development team gained experience confirming graphene performance benefits with industry/research leading collaborators
  - Maintained project schedule and grew organization throughout COVID environment

Summary

- Successfully converted metallurgy coke and anthracite coal into higher quality graphene using the flash Joule heating method.
- Scaled-up the batch size in two order of magnitude with customized flash Joule heating system build.
- Demonstrated the application of the coal derived graphene in epoxy and asphalt applications.
- Demonstration Plant under construction and expected to commence operation in 2^{nd} quarter 2023 with capability of 1 ton/day throughput.

Note: Rice University has granted a worldwide exclusive license to Universal Matter Inc. relating to certain of Rice's intellectual property rights including patents (2) directed to subject matter within the field of graphene synthesis by flash joule heating.

Thank You!
Q&A

Organization Chart

- Vladimir Mancevski PhD – VP Engineering
  - John Williams – Engineering Technician
- Duy Luong PhD – Research Scientist
  - Taylor Martin – Engineering Technician
- Tyler Cooksey PhD – Sr Process Engineer
- Jerry Zhong PhD – Sr. Application Development Engineer
  - Nick Goodwin – Engineer I
- Dru Kefalos – Chief Marketing Officer

Gantt Chart