InnovationXLab CarbonX Summit

Carbon Fibers and Materials

Wednesday, October 21, 2020

Moderator & Panelist
Dr. Christopher Matranga

Research Scientist, Materials Engineering and Manufacturing Division
National Energy Technology Laboratory

Panelist
Dr. Merlin Theodore

Director, Carbon Fiber Technology Facility
Oak Ridge National Laboratory

Panelist
Alex Walk

Vice President of Sales – Carbon Fiber
Zoltek, Inc.

Panelist
Charles Atkins

Director of Development
Ramaco Carbon, LLC

InnovationXLab CarbonX Summit

Carbon Fibers and Materials

Moderator & Panelist

Dr. Christopher Matranga

Research Scientist, Materials Engineering and Manufacturing Division

National Energy Technology Laboratory

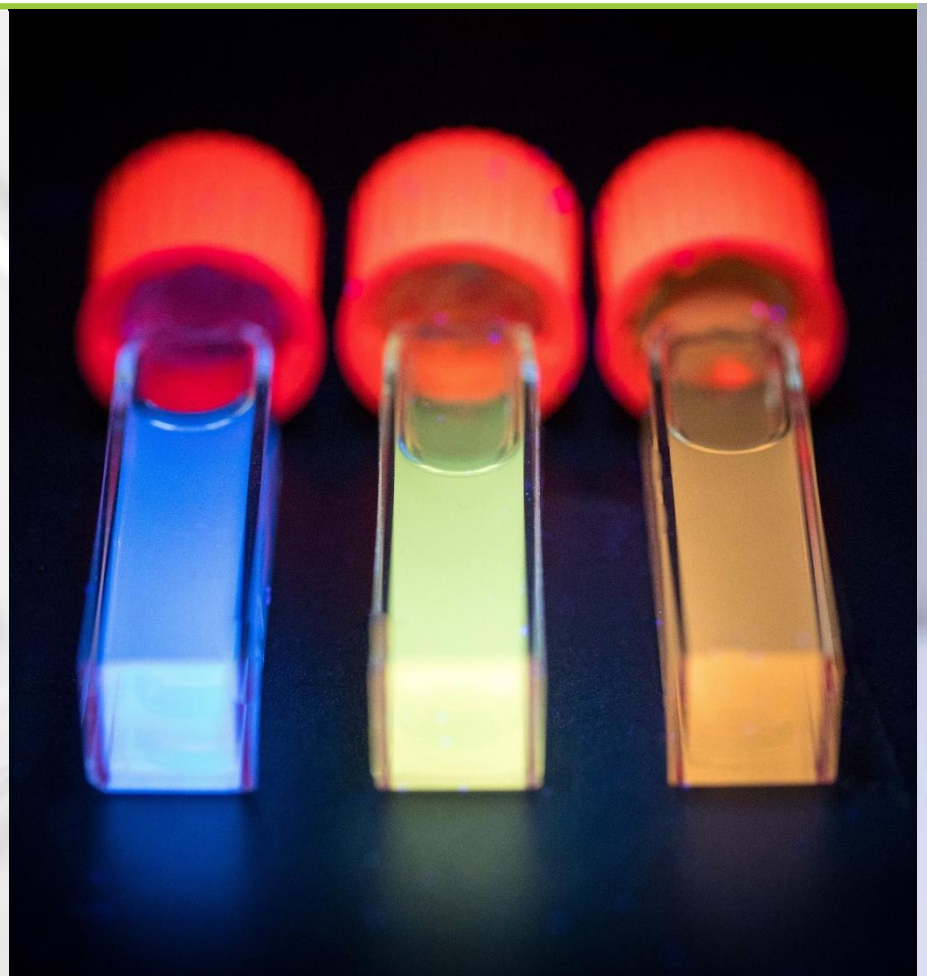
Carbon Materials & Fibers

Christopher Matranga

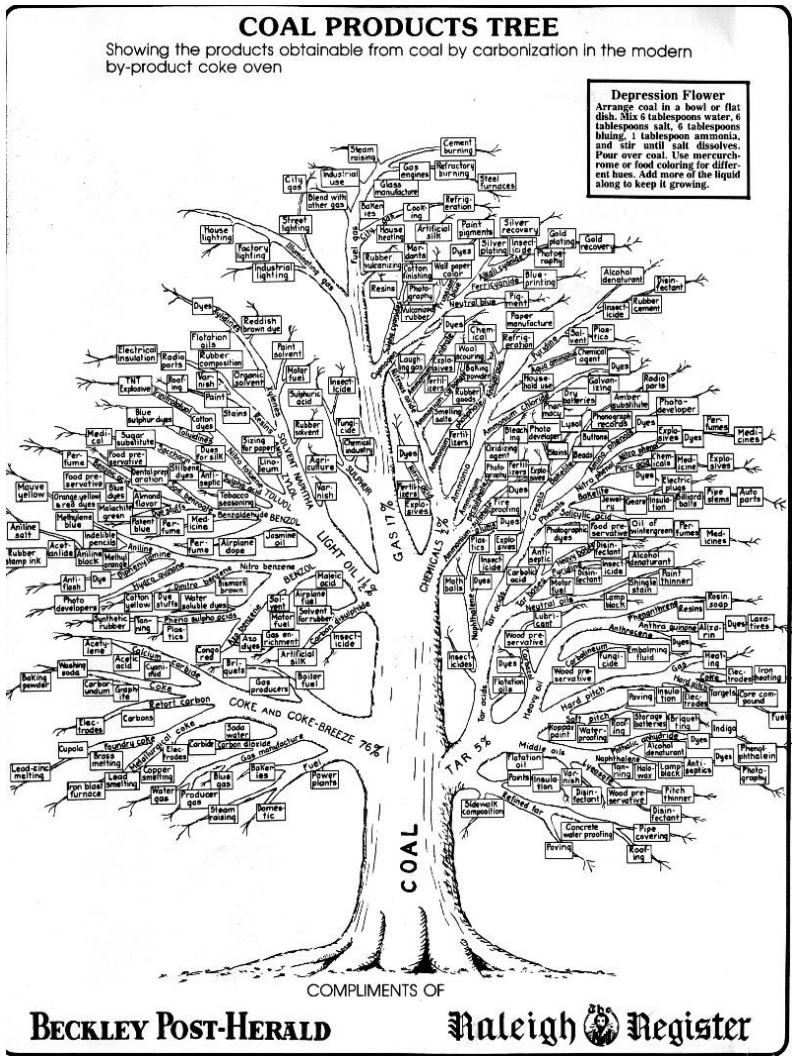
Materials Engineering & Manufacturing Division
NETL

2020 DOE CarbonX Summit | Energizing Innovations for Industry

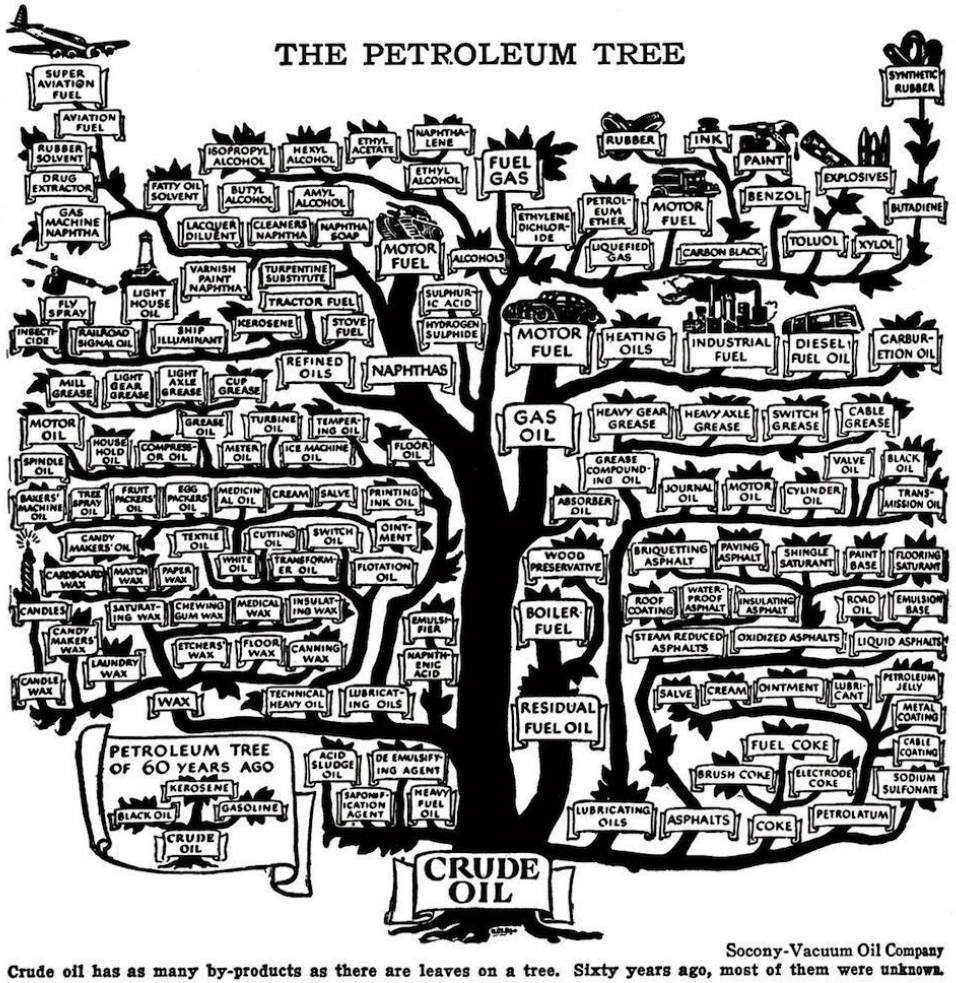
NATIONAL ENERGY TECHNOLOGY LABORATORY



Carbon Products Trees (Historical)



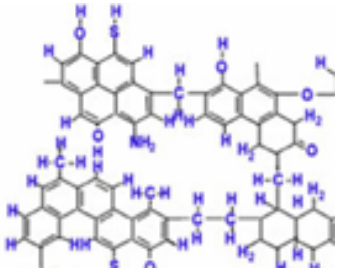
www.williamsonlibrary.lib.wv.us



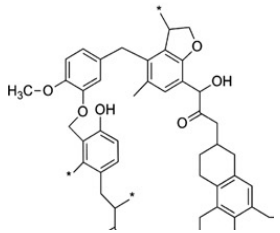
The Book of Trees: Visualizing Branches of Knowledge
Manuel Lima (2014) ; & **Socony-Vacuum Oil Company** (1957)

Carbon & Hydrogen Ores

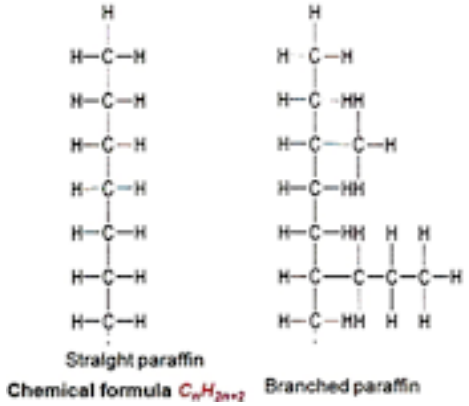
Anthracite

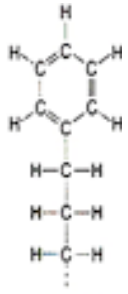


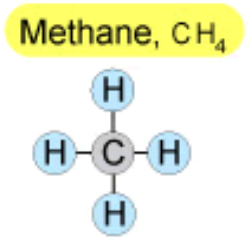
Bituminous

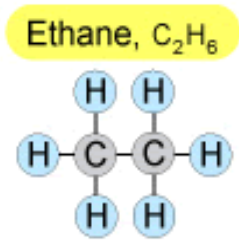


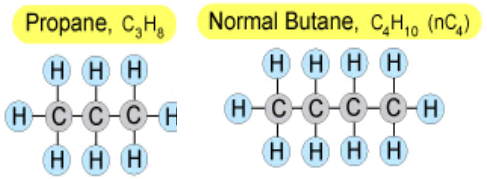
Lignite

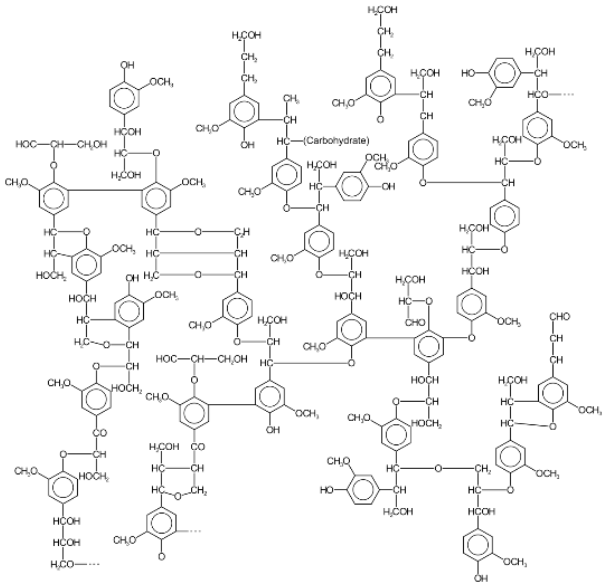


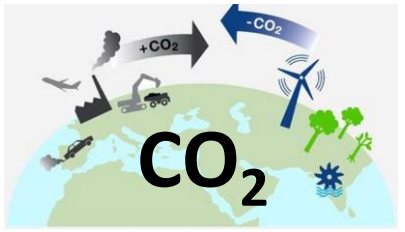






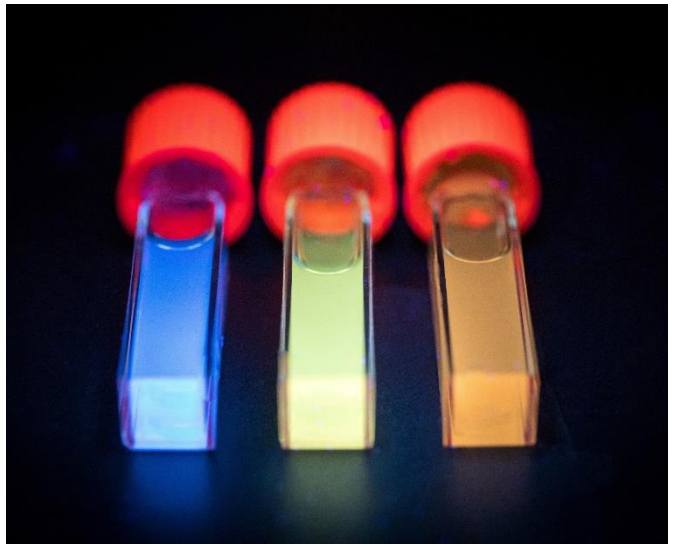






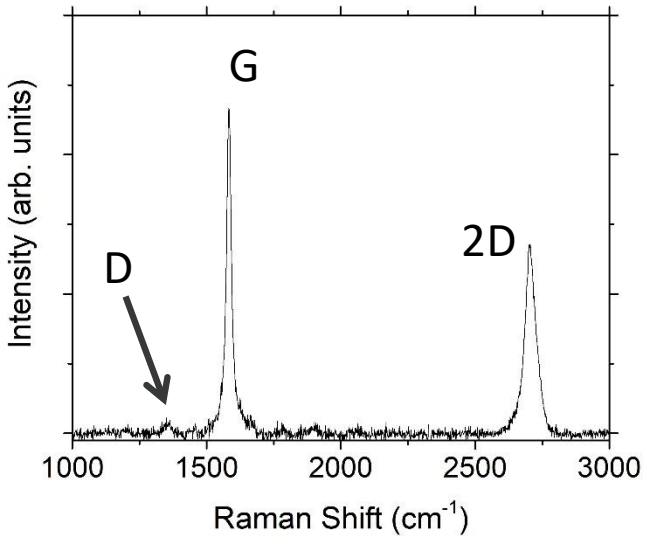
Biosensing & Medical Diagnostics

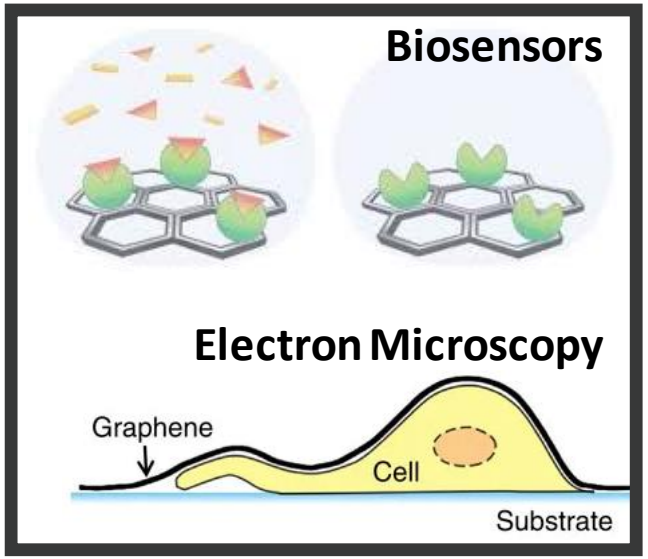
Optical Tags



- Graphene quantum dots (luminescent)
- Used as optical tags for imaging applications

Biosensors & Microscopy





- 3-6 layer, low defect, graphene from coal CVD
- Used for biosensor & electron microscopy applications

Cell image: Nat. Commun. vol. **6**, article No: 7384 (2015).

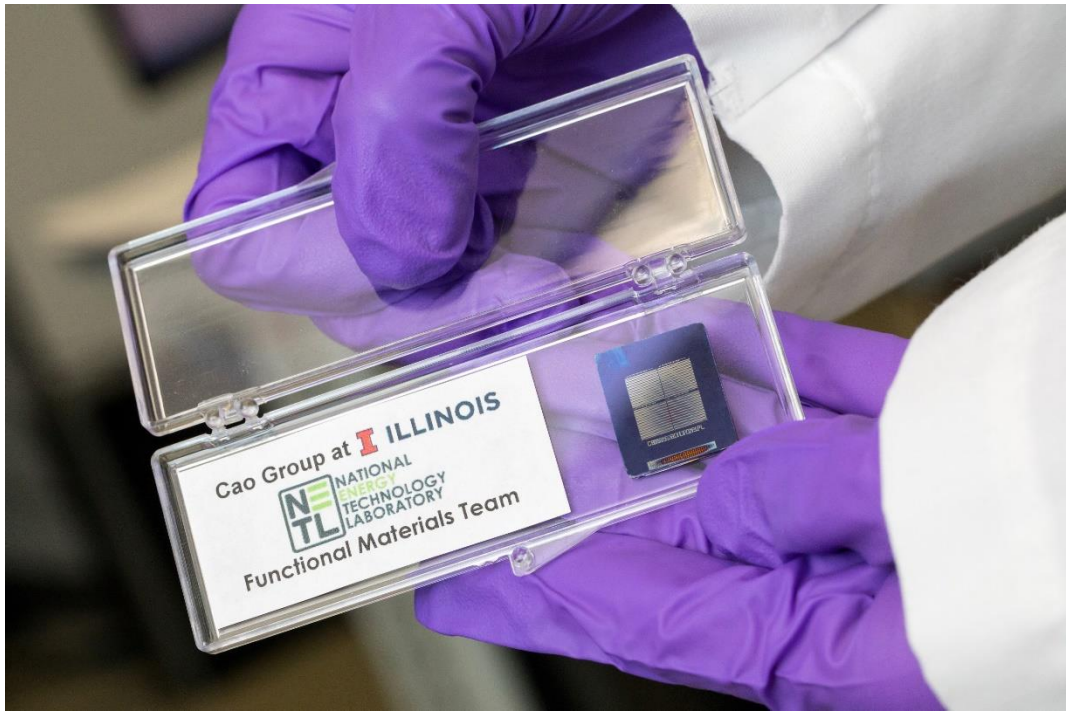
RAMACO CARBON

UIC UNIVERSITY OF ILLINOIS AT CHICAGO

NETL's C2G Process

2020 R&D 100 WINNER

Microelectronics: Memristor Computer Memory Devices



ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

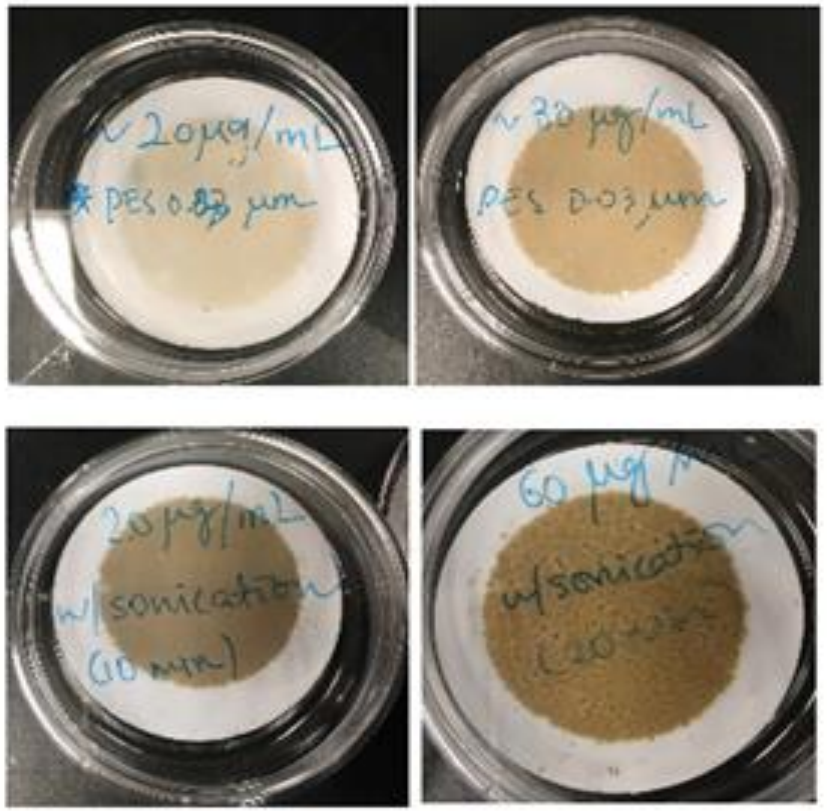
Cao Group, Materials Science

Functional Materials Team

- **Memristor computer memory devices:**
  - Emerging memory technology
  - Energy efficient (<pJ/operation)
  - High speed (10 ns)
  - Easily miniaturized (10 X 10 nm)
  - Integrable on logic chip
- **Coal carbons outperform other carbons and metal oxides:**
  - Dielectric switching media
  - Lower cost fabrication method
  - Improved device-to-device reproducibility
  - Better long-term device stability

Filtration Materials & Separation Membranes

Solid carbon membranes from coal & other carbon feedstocks



MIT preliminary results showing four different membranes obtained using coal-derived graphene quantum dots

- Solid carbon membranes with controlled porosity & chemical functionalization
- MIT will fabricate/test membranes, MIT & NETL will fabricate carbons. ORNL will provide adv. nanomat. characterization

Massachusetts Institute of Technology
Grossman Lab
Materials Science

Functional Materials Team

OAK RIDGE National Laboratory

Thank You!

InnovationXLab CarbonX Summit

Carbon Fibers and Materials

Panelist

Dr. Merlin Theodore

Director, Carbon Fiber Technology Facility
Oak Ridge National Laboratory

OAK RIDGE National Laboratory

Advance Fiber & Composite Strategy

"Precursor-to-parts"

Dr. Merlin Theodore
Oak Ridge National Laboratory
Director of Carbon Fiber Technology Facility
Advance Fibers Group Lead

DOE InnovationXLab CarbonX Virtual Summit
October 21 – 22, 2020

ORNL is managed by UT-Battelle, LLC for the US Department of Energy

U.S. DEPARTMENT OF ENERGY

Mission Statement

Enable an advanced fiber composite industry for high volume energy applications

- The Carbon Fiber Technology Facility at Oak Ridge National Laboratory is an AMO/VTO Consortia focused on leveraging National Lab capabilities to accelerate the development and adoption of advanced fibers and composites manufacturing technologies in collaboration with industrial partners.
- Bridge from R&D to deployment and commercialization of advance fibers.
- Demonstrate advance fiber production using lower-cost precursors, and/or advanced conversion processing methods.
- Produce relevant quantities of advance fiber for evaluation, and composites market development.
- Enable development of domestic commercial sources for production.
- Serve as a national resource to assist industry in overcoming the barriers of advance fiber cost, technology scaling, intermediate formation, and composite product and market development.
- Formulate a Workforce Development program for carbon fiber and advance composites workforce.

The Carbon Fiber Technology Facility (CFTF)

Only Open Access State-of-the-Art Facility in the U.S

Advance Fiber & Composites Pillars

Integrated Advance Fiber and Composites Strategy that delivers significant ENERGY and PROSPERITY impacts to the United States.

Integrated Fiber, Recycling & Composites Equipment, ORNL

Precursor Spinning Processing

Carbon/Advance Fiber Processing

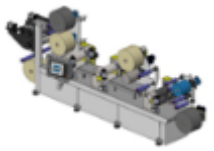
Fiber Chopper

Textile Carbon Fiber Winder

Thermoplastics

D-LFT Plasticator

RocTool induction heating



Tow-preg line

Characterization

DSC/TGA

Twin Screw Compounder

Fourier Transform Infrared

Rheometer

Automation and Molding

Injection over-molding

Automation

Ovens

500-ton fast acting press

Additive Manufacturing

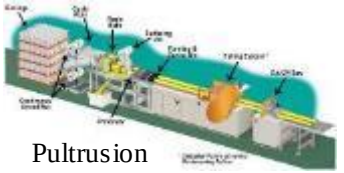
Big Area Additive Manufacturing (Thermoplastics)

Reactive Additive Manufacturing (Thermosets)

Out of Plane Deposition

Thermosets

Sheet Molding Compounding



Pultrusion

Garmut Booth

Filament winder

Recycling & Recovery

OMAX 60120 Waterjet Cutter

ZSE 27 MAX Twin-Screw Extruder

MR40120 Shredder

T5070 Granulator

Strategic Path From Precursor-to-Part from Lab Scale-to-Application

Strategic Drivers

- Cost of carbon fiber and composites manufacturing
- Insufficient U.S. owned production capacity
- Potential opportunities in new applications
- Growth rate in emerging markets
- Focus on Mass Market Opportunities
- Economic Opportunities

Capacity at each Scale

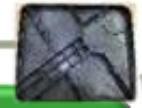
- 1 - 2 tows
- 20k – 80k filaments

- 1-ton capacity
- 1-5 tows
- 5k -80k filaments
- Preferred tow size ≥ 3k

- 25 ton/yr capacity
- Designed for 3k – 80k tows
- Instrumented research Capacity for additional conversion

- Readiness level varies depending on material or unit operations



Material Identification
- Conversion Yield
- Availability
- Cost
- Carbon Content
- Quality

Alternative Precursor
- Spinnability
- Melt Spinning Processability
- Characterization & Analysis
- Precursor Chemistry

Fiber Evaluation
- Feasibility Study
- Batch process recipe & conditions
- 1g material req.

Pilot Scale
- Short term cont. processing
- Dev. proc. cond.
- Ideal Material selection
- 100 g – 1Kg material req.

Scale-up
- Dev. multi-tow cont. processing
- Produce volume for market dev.
- Enable dev. of domestic commercial sources.
- >100 Kg material req.

Carbon Fiber Intermediate
- Development of usable for factor technology and processes
- Investigate carbon fiber intermediate forms and technical

Carbon Fiber Composite
- Fiber and intermediate form factor evaluation
- Coupon Level Testing
- Prototypes
- Recycling

Market Performance & Evaluation
- Performance, or Property Evaluation
- Product Development

ORNL –CF & Composite -Group | **ORNL/CFTF** | **ORNL/MDF - UT** | **Industry**

Manufacturing Demonstrating Facility (MDF)
University of Tennessee (UT)
Carbon Fiber (CF)

- Identify high potential, low cost alternative precursors
- Identify and develop advance conversion processes
- **Integrated Multi-scale approach to develop to reduce Technical uncertainties associated with scaling**
- Investigate carbon fiber intermediates forms and challenges in composites applications
- Develop a data analytic framework using in-process measurements, sensors and control methods to correlate process data with product characteristics
- Provide quantities to industrial partners for testing based on DOE approval
- Address feedback from industrial partners
- Improve carbon fiber manufacturing cost metrics
- Commercialization

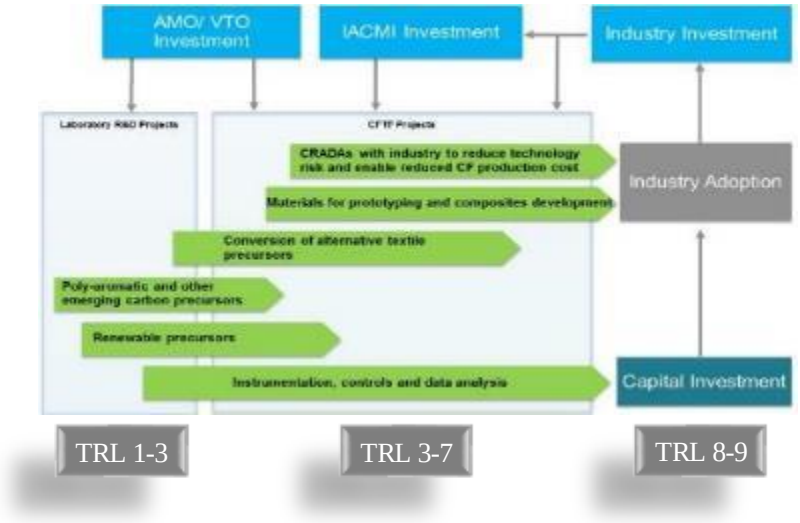
Transition to Partners

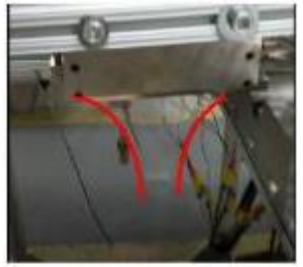
Carbon Fiber Industry Collaboration

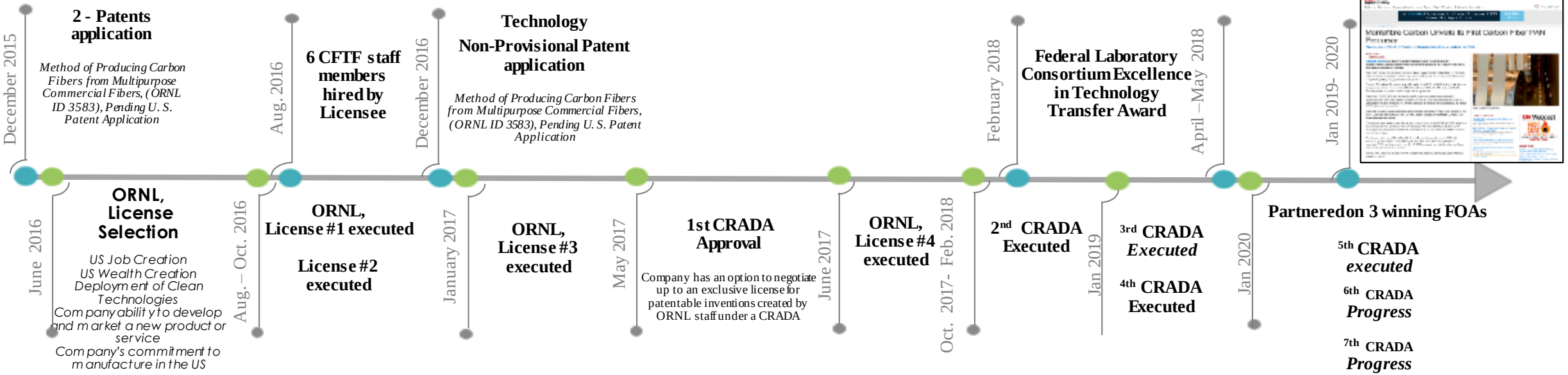
- *Over 26 Technical Collaborations*
- *4 Licensees for Textile precursor to CF*
- *4 CRADAs for textile carbon fiber*
- *CFTF Tech Interns to Licensee employees*
- *Mission and Capabilities*
  - *Industries can adopt new opportunities using CF*
  - *Enhance their processes and capabilities, thus expand their market growth.*

2019 – 2020

- *1 CRADA executed for pitch fiber material*
- *2 CRADAs for pitch fiber in progress*
- *14 Publication/Presentations/Announcements*



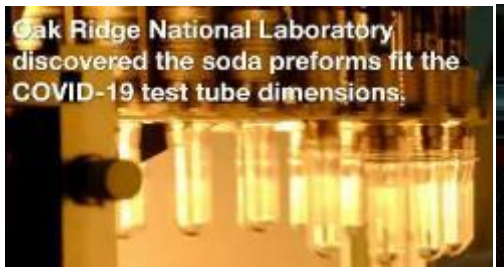




OAK RIDGE National Laboratory

Field Work Proposal (Fossil Energy)
Coal-to-Pitch Fibers

Transition to Industry Partners – COVID-19 Initiatives



ORNL is leading a 16-lab manufacturing consortium in the fight against COVID-19. In partnership with the U.S. Department of Defense Industrial Base Analysis and Sustainment Program (IBAS) from the Office of Industrial Policy and the US Department of Health and Human Services, ORNL has mobilized advanced manufacturing researchers at the MDF to develop tooling such as molds that will enable the production of face masks, shields and test collection tubes in quantities estimated from hundreds of thousands to millions. **The MDF and CFTF work in sync to convert CFTF melt-blowing capability into a filter media production line aiding in production of Filter Media for N95, Medical level II and III. Peter Tsai, inventor of the core technology used in the N95 mask, also works along side the ORNL team. In addition, ORNL are working with companies to deploy the technology.** The Carbon Fiber Technology Faculty supplies material to other National Labs (BNL, LNNL, LANL, ANL, Brookhaven, Sandia, PNNL, and NETL)for COVID-19 Research and Development.

4/01/20

Approval for Dr. Tsai to be onsite at ORNL – 1st Trials

https://www.nature.com/articles/d41586-020-02550-8

Filtration

4/08/20

1st virtual meeting with Industry Partner

4/28/20

Achieve N95 Target(s)

https://www.washingtonpost.com/lifestyle/2020/07/07/peter-tsai-n95-mask-covid/

5/19/20

Designed and built Corona Charging Device

5/26/20

5 weeks - Transfer Knowledge/Technology to Cummins Filtration ***Produce filter media for 1 Million masks per day*** Expanding capacity

https://www.cummins.com/news/releases/2020/08/31/cummins-inc-and-oak-ridge-national-laboratory-collaboration-enables

ionic

DemeTECH

Printforia

Industry Partner is now producing ***3 million surgical masks and a ½ million N95 masks per day.*** The N95 face masks have met the requirements of Title 42, Code of Federal Regulations, Part 84 (42 CFR 84).

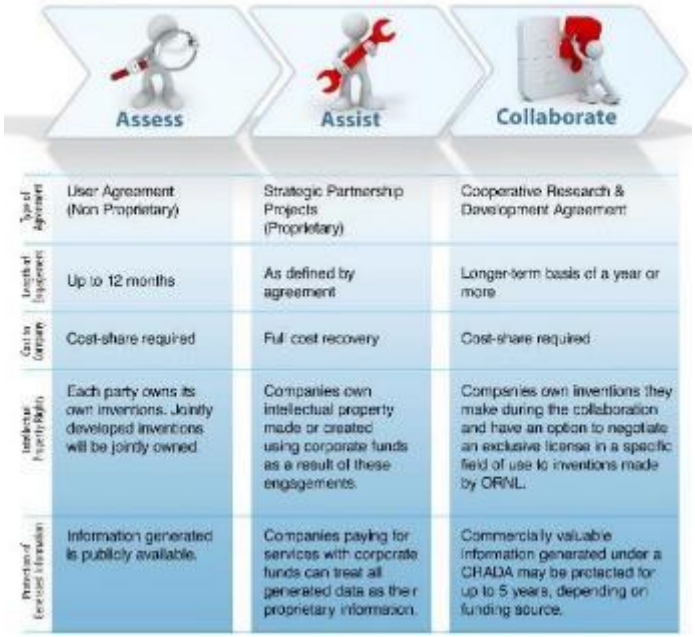
"The strength of collaboration and the willingness to work together towards purposeful innovation is a rewarding and positive outcome during challenging times like this," said Pushpa Manukonda, director of the John Deere Technology Innovation Center.

OAK RIDGE National Laboratory

For more information: https://www.ornl.gov/news/advanced-manufacturing-innovation-helps-industry-covid-19-fight.

ORNL Advance Fibers Operations and Working Mechanism

Users	FY 20
Academia	2
Government Agencies National Labs	11
Industry	10
Consortium	1



- Export Control Regulated Facility
- Scale-up research shall work in parallel with project started at bench scale.

Collaboration Ever Growing Partnerships: Integrating the AM Supply Chain

FY 21 ORNL User Facility Rate Approval Form

User Facility Name	**Carbon Fiber Technology Facility**
User Facility Director/Mgr	**Merlin Theodore**

Rate Summary – Unburdened*

Rate Title	FY 21 Rate
Full Conversion Line (Oxidation, Carbonization, Surface Treatment, Sizing, Winding)	$980.69
Oxidation	$366.38
Carbonization	$244.27
Surface Treatment	$126.37
Sizing	$126.37
Winding	$117.30
Melt Spinner	$257.55
Lab Testing	$194.07
Chopping	$194.07

InnovationXLab CarbonX Summit

Carbon Fibers and Materials

Panelist

Alex Walk

Vice President of Sales – Carbon Fiber

Zoltek, Inc.

ZOLTEK

Carbon Fiber and the DOE

ZOLTEK

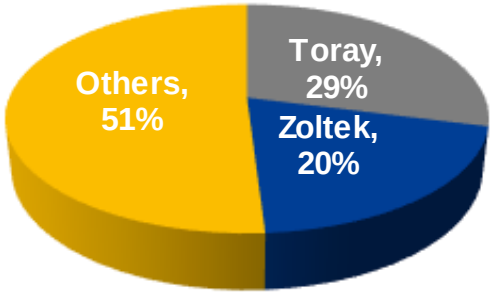
Toray Group

ZOLTEK OVERVIEW

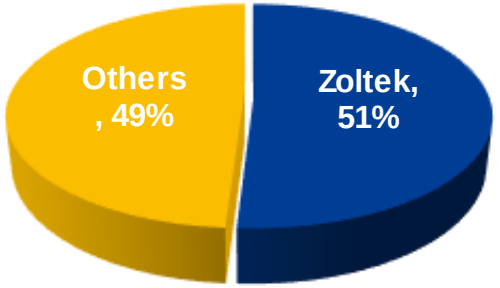
- Company Name: Zoltek Companies, Inc.
- Founded: 1975
- Acquired by Toray 2014
- Headquarters: St. Louis, MO, United States
- Representative: Nobuya Ando (CEO, COO & President)
- Employees: 2,600
- Carbon Fiber Production = 25,000 ton and growing

Toray / Zoltek – World Leader in Carbon Fiber Supply

Total Global Carbon Fiber Supply



Large Tow Carbon Fiber (Demand <30K)



ZOLTEK
Toray Group

Raising the Bar for Low-Cost Carbon Fiber

The Zoltek Advantage

- Proven Low-Cost Production
- Sustainable Cost Structure allows for Capacity Expansion
- Stable Pricing Structure
- Dedicated Continuous Improvement yielding Improved Quality / Cost
  - Optimized Throughput per Capital Expense
  - Reduced Fuzz
  - Lower Variability
  - Increased Mechanical Performance
- Cost / Performance Leader
- Value Added Intermediate Products
  - Experienced Technology Team developing Market-Driven Material Solutions
  - World renowned production of carbon fiber pultruded structures
  - Full Line of Carbon Fiber based products from Ox Fiber to Carbon Fibers to Short Fibers and Fabrics

Market Penetration = Enhanced through DOE Assistance

DOE Funding = Collaboration

- DOE projects require industry / academic / national lab involvement
- Connecting the supply chain is critical for expanding the science and use of carbon fiber.
- Raw Material to End User participants bringing expertise combined with academic and national lab research

Relationships built through DOE investment leads to sustainable industry and science growth

DOE Resources = Filling the Gap

- DOE maintains state-of-the-art facilities and people
- Carbon Fiber research held by very few private entities but ORNL holds best-in-world resources open to all
- Carbon Fiber market growth depends on non-traditional carbon fiber end users access to science and corporate experts

Science expands access to carbon fiber technology growing into new applications

Funding and Science combine for sustainable applications

OAK RIDGE National Laboratory

Industry / Academic Partnership
CARBON FIBER Consortium

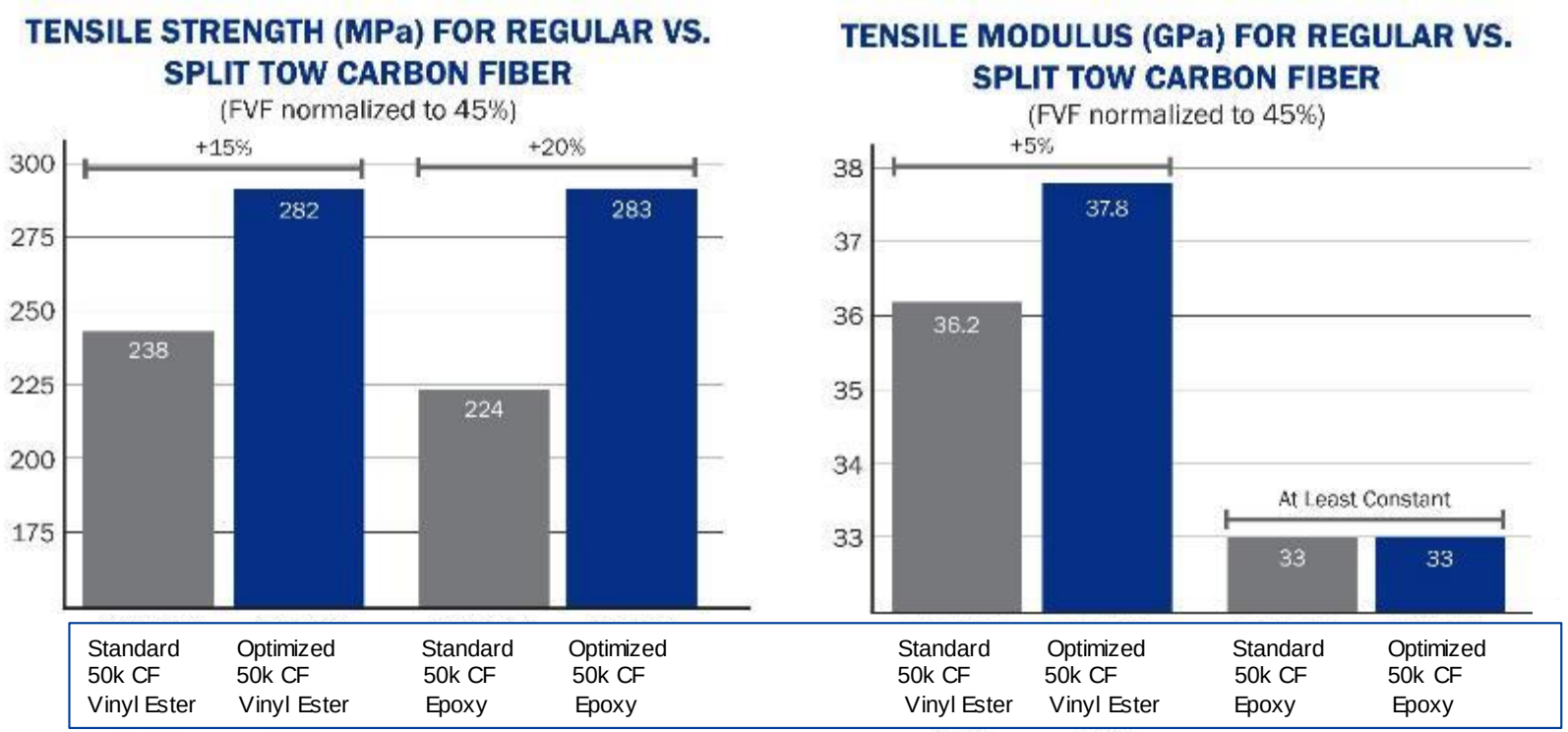
The Institute for iacmi Advanced Composites Manufacturing Innovation

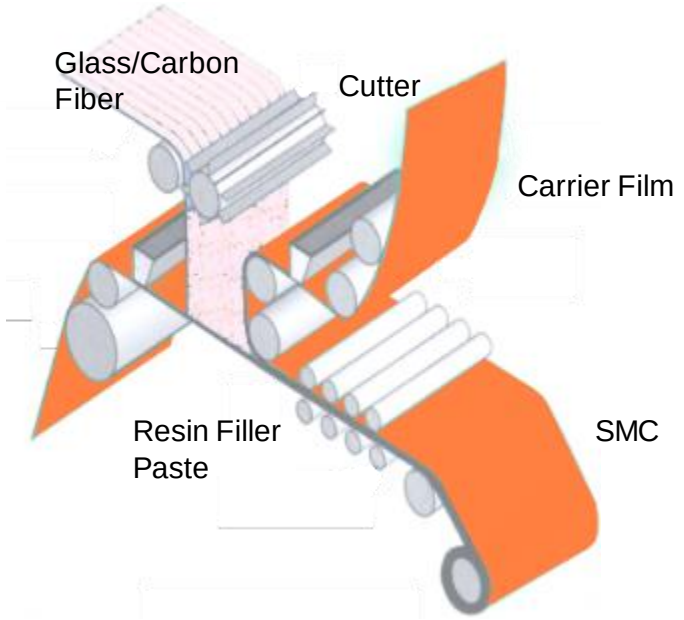
- Low Cost Carbon Fiber
  - Non-PAN based
  - Optimized Processing
- More Efficient Mfg Techniques
  - SMC – Direct Fiber to Part
  - Thermoplastics
- New Applications
  - Automotive Focus
  - Energy Focus
  - New Entrants
- Environment
  - Recycling

ZOLTEK Toray Group

Funding Leads to Collaboration – Example – Magna / Zoltek

Optimizing Tow Presentation and Sizing to meet market needs

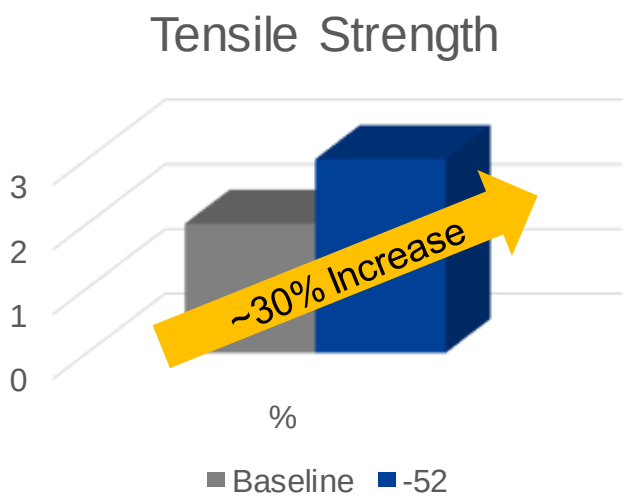


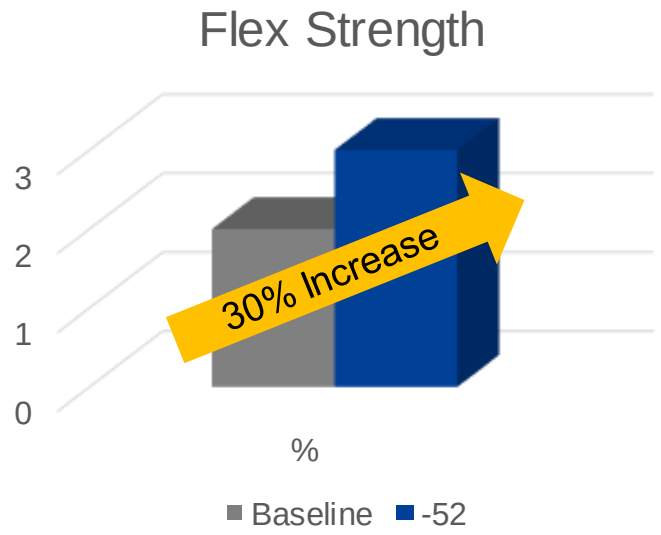


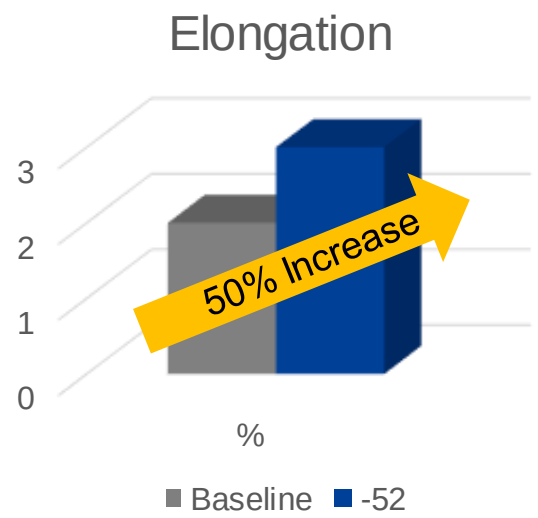
Properties shown are typical results: Zoltek Optimized PX35 Tow for SMC has reached values greater than 325 MPa Tensile Strength and 40 GPa Tensile Modulus

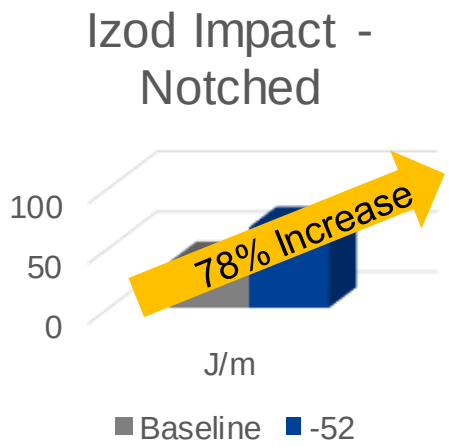
Science Leads to New Products and End Users – PP Example

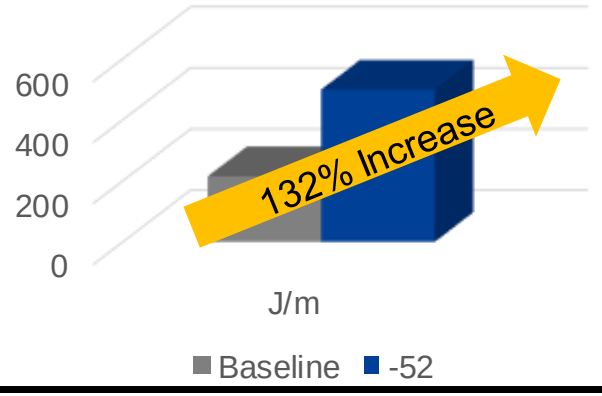
Creating Market Solutions for Polypropylene Applications – Matrix-specific Sizing











Effect of DOE on Carbon Fiber Industry Growth

1. Funding
2. Resources – Facilities and People
3. Building Industry / Academic Relationships
4. Sustainable Carbon Fiber Industry Growth – All Markets

ZOLTEK Toray Group

InnovationXLab CarbonX Summit

Carbon Fibers and Materials

Panelist

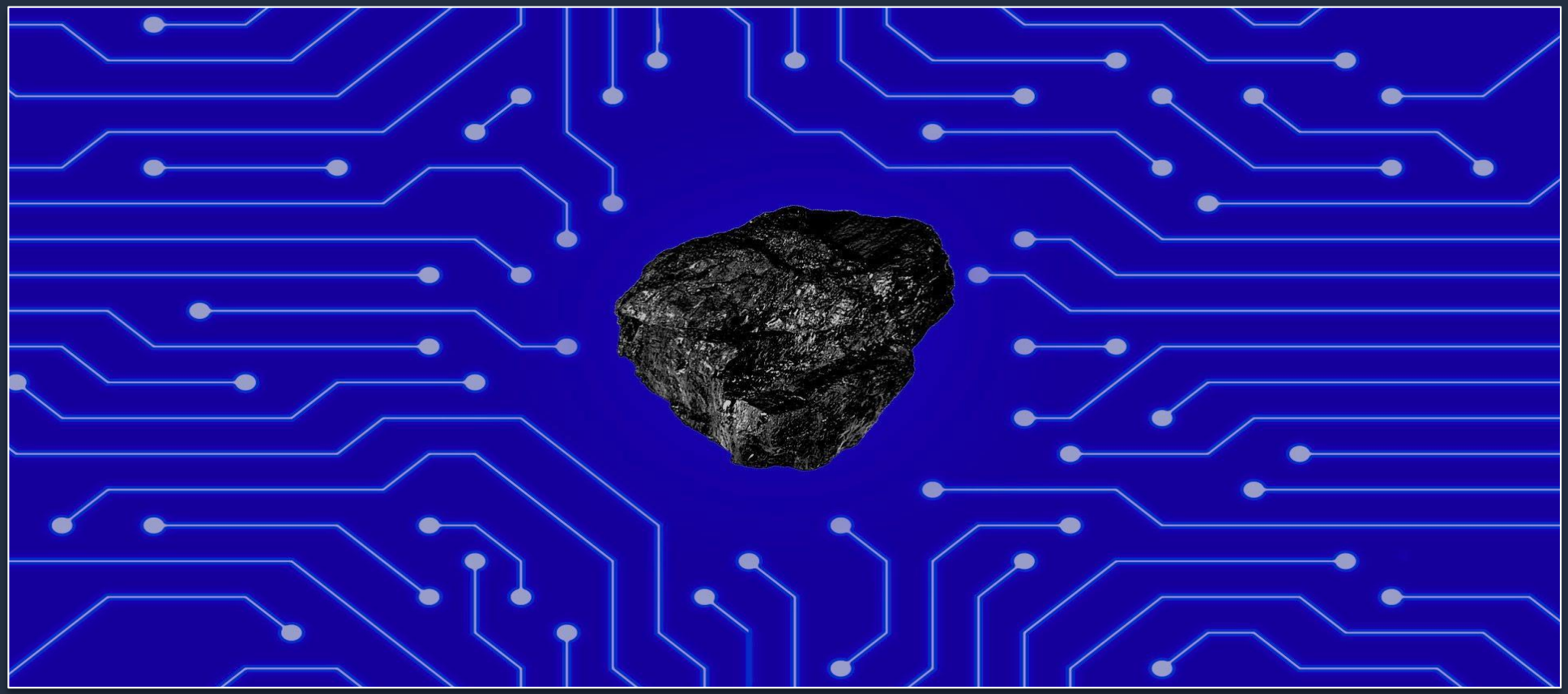
Charles Atkins

Director of Development

Ramaco Carbon, LLC

Partnerships for a New Carbon Age

"Coal to Products"



InnovationXLab CarbonX Summit

Charlie Atkins – Director of Development, Ramaco Carbon

Who We Are

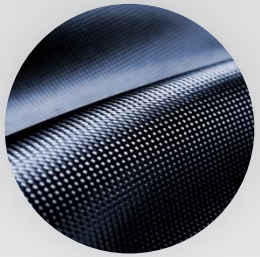
Ramaco Coal, founded in 2011, is a coal-based conglomerate with operations in five states. It consists of two main operating companies:

RAMACO RESOURCES

A publicly traded met coal producer (METC-Nasdaq) with low cost, high quality production in West Virginia, Virginia and Pennsylvania.

Headquartered in Lexington, Kentucky.

www.ramacoresources.com



RAMACO CARBON

The first vertically integrated Resource, Research and Manufacturing Coal Technology platform focused on creating "Coal to Products".

Headquartered in Sheridan, Wyoming.

www.ramacocarbon.com

A Coal Tech Company

COAL RESERVES

Ramaco Carbon owns the Brook Mine in Wyoming, a 1.1 billion ton privately owned coal resource.

Ramaco Coal also owns 250+ million tons of metallurgical coal reserves mostly in West Virginia.

RESEARCH PARK

The iCAM in Wyoming will be completed in November. An additional lab was opened in West Virginia this Spring.

These labs will incubate carbon research to commercialize coal-based carbon products, from bench thru pilot stage.

INDUSTRIAL PARK

The iPark is a contiguous 100+ acre "coal to products" mine-mouth manufacturing park, next to the Brook Mine.

Companies will use coal from the Brook Mine to manufacture advanced carbon products and materials.

With Unique Partners and Partnerships

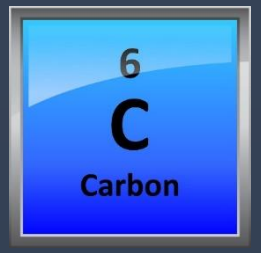
- **Ramaco Carbon** is privileged to be working with the DOE, top U.S. National Labs, research institutes and leading research universities, who form our core research and development network.
- Ramaco Carbon has received **four awards from the DOE for projects** to produce low cost carbon fiber from coal.
- Ramaco Carbon has Cooperative Research and Development Agreements (CRADAs) with both the NETL and ORNL on developing a variety of coal processes, carbon products, REEs and advanced material technologies.
- Ramaco Carbon is also licensing key technology from NETL so that it can commercialize several innovative carbon conversion processes and products.

Partners include:

- National Energy Technology Laboratory
- Oak Ridge National Laboratory
- MIT- The Grossman Materials Group
- Fluor Corporation
- TerraPower, LLC
- HTI-Axens
- West Virginia Univ.
- Univ. of Illinois-Chicago
- Western Research Institute
- Southern Research Institute

Where Are We Headed?

RAMACO CARBON



Carbon (from Coal)…

- Carbon is becoming the dominant "***advanced material***" of the 21st Century — think carbon fiber, graphene, graphite and carbon resins.

- We're entering a **Carbon Age**.

- The United States could lead in a wave of innovation by making carbon products and materials from **coal instead of petroleum**. This could create **significant growth in both coal demand and production**, as well as manufacturing opportunities for mining communities.

- Cheaper materials made from coal could enhance or replace both key metals (i.e. steel, aluminum), as well as basic building products (i.e. asphalt, rebar, roof shingles). Carbon also has applications in chemicals, resins and even life sciences.

- These are fast-growing, game changing uses requiring huge volumes of coal.

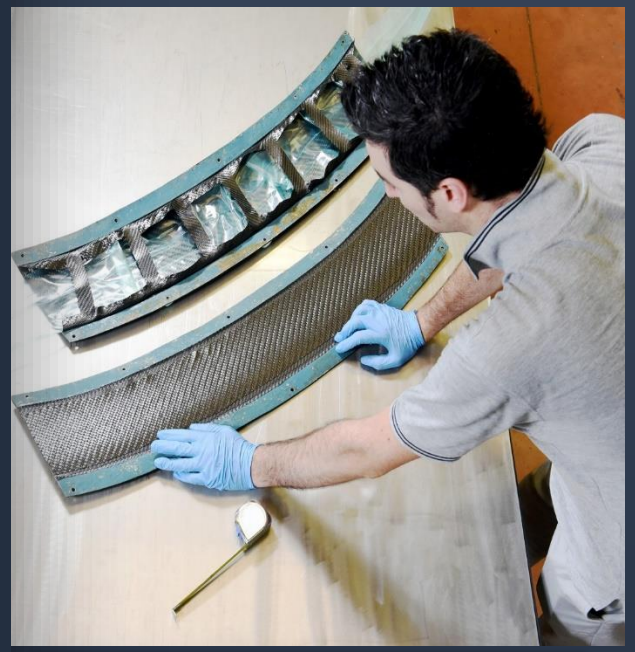
- Like the internet, this could enable disruption in manufacturing by lowering cost on a massive scale. Just a few new large scale uses could create a demand inflection point for the entire US coal industry..

Coal (Carbon Fiber) to Cars

RAMACO CARBON

- CF is 4x lighter than steel and 2x as strong. It is 2x lighter than aluminum and 4x as strong.
- The barrier is its high cost. CF now made from petroleum is 8x more expensive than steel.
- CF costs could drop well below $5. Ripe for market disruption.
- We are in our 3rd year of a DOE award with many national partners nicknamed **"Coal to Cars."** The focus is using coal to make low cost carbon fiber for vehicles.
- And we are entering the second year on three other DOE awards, on two of which we are the recipient:

- Coal to Carbon Fiber – Novel Supercritical CO2 Solvated Process. DE-FE-0031800
- Experimental Validation and Continuous Testing of an On-Purpose High-Yield Pitch Synthesis Process for Producing Carbon Fiber from Coal DE-FE-00310801



Carbon Fiber Value Proposition

Raw Coal
$0.03/kg

Metallurgical Coal
$0.15/kg

Coke
$0.25/kg

Coal Tar
$0.40/kg

Coal Tar Pitch
$0.70/kg

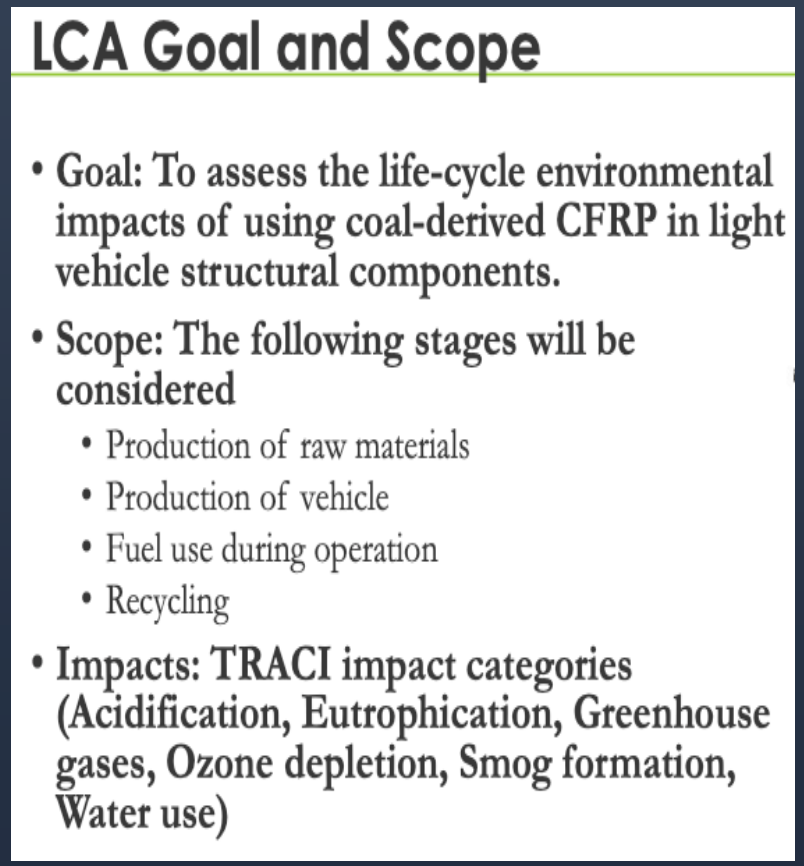
Mesophase Coal Tar Pitch Precursor
$3.30/kg

Pitch Carbon Fiber
$11.00/kg

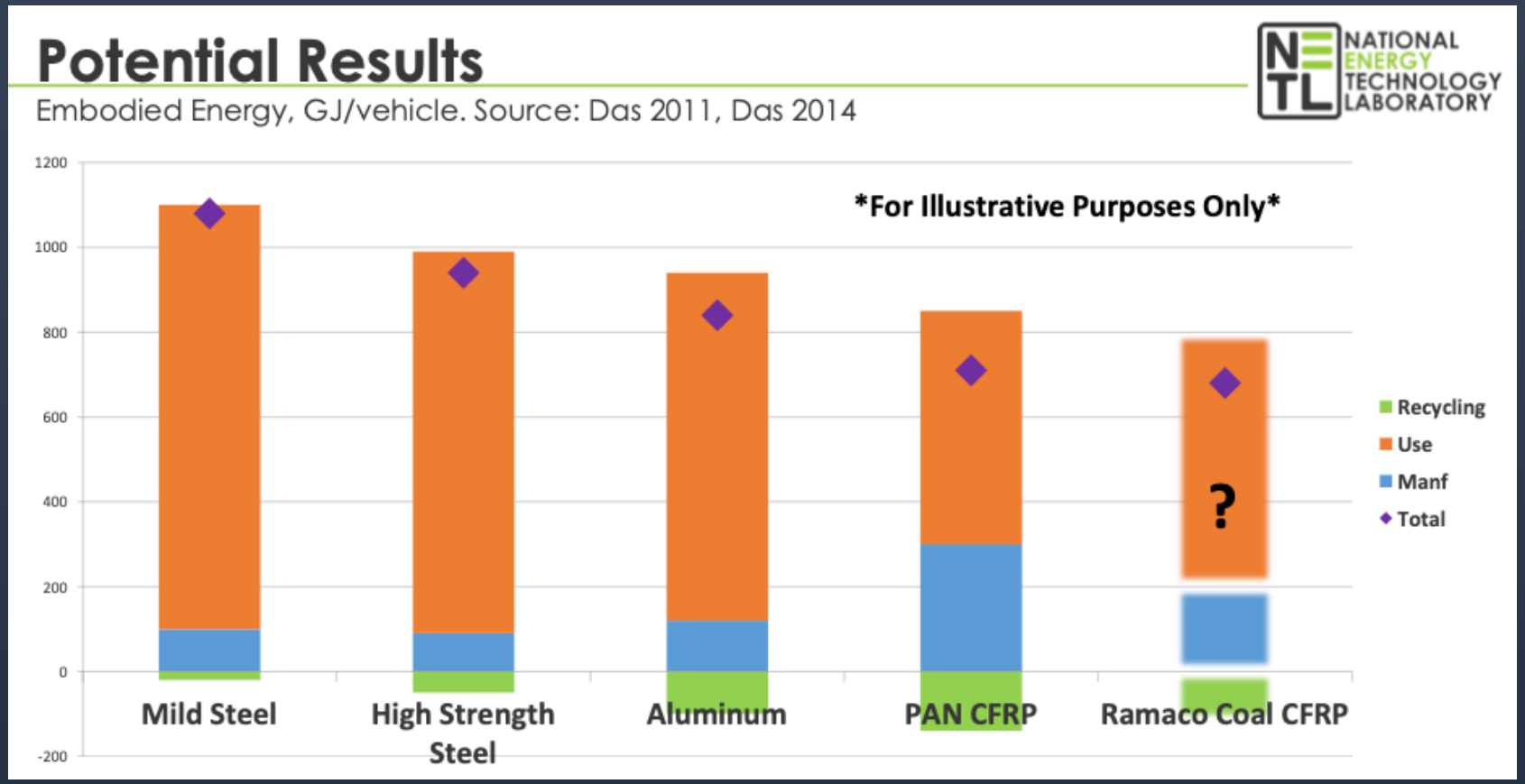
A huge value creation from $.03/kg for raw coal to over $11.00/kg for Pitch based carbon fiber

LCA Analysis of Coal Based Products

- Through its partnership with NETL, Ramaco is involved in a ground-breaking environmental "Life Cycle Analysis" (LCA) to assess the carbon impacts of various coal-based advanced products and materials from extraction to disposal.
- The first LCA analysis involves the use of coal based CF and CFRP to make lighter weight vehicles.
- Coal based CF uses different production techniques to lower carbon footprint.
- The same environmental advantages that coal based advanced material brings to CF can also be applied across other products and materials.
- Basically we are converting coal to a recyclable form of carbon sink as opposed to combusting it and creating GHG emissions.



LCA Analysis Potential



- A 10% direct weigh reduction in vehicle weight by using pitch based CF and CFRP composites can result in a 2-8% fuel reduction.
- Secondary weight reductions (parts and drivetrains) can result in even great savings.

RAMACO
CARBON

www.ramacocarbon.com

Disclaimer

Ramaco Carbon, LLC its licensors, licensees and business partners maintain an extensive portfolio of intellectual property rights including but not limited to patents, patents pending, preliminary patent applications, trademarks, copyrights and trade secrets. We vigorously assert and defend out intellectual property rights and nothing in this presentation should be construed as a waiver of those rights or a public disclosure of proprietary information.

An affiliate of **Ramaco Carbon, LLC**, named **Ramaco Resources, Inc**., trades publicly on the NASDAQ under the symbol "**METC**" and has filed a registration statement (including a prospectus) with the SEC for the offering of securities. Before you invest, you should read the prospectus in that registration statement and other documents the issuer has filed with the SEC for more complete information about the issuer and this offering. This presentation shall not constitute an offer to sell or the solicitation of an offer to buy any securities, nor shall there be any sale of these securities in any state or jurisdiction in which such offer, solicitation or sale would be unlawful prior to registration or qualification under the securities laws of any such state or jurisdiction. Any such offering of securities will only be made by means of the registration statement (including the prospectus) filed with the SEC, after such registration statement becomes effective. You may get these documents for free by visiting EDGAR on the SEC Web site at **www.sec.gov**.

All forward-looking statements, expressed or implied, included in this presentation are expressly qualified in their entirety by this cautionary statement. This cautionary statement should also be considered in connection with any subsequent written or oral forward-looking statements that we or persons acting on our behalf may issue.

Except as otherwise required by applicable law, we disclaim any duty to update any forward-looking statements, all of which are expressly qualified by the statements in this section, to reflect events or circumstances after the date of this presentation.

InnovationXLab CarbonX Summit

Carbon Fibers and Materials

THANK YOU!

Please submit your questions in the Zoom Q&A function!

Looking for additional conversation and networking?

Join us in the Peer Connections Lounge after the next panel!