www.iacmi.org

February 2020

Realizing Mass Markets for Coal-Derived Carbon Fiber Composites

A National Strategy for Revitalizing Rural Coal Communities Through Advanced Manufacturing

IACMI-The Composites Institute

Proceedings of the Workshop Hosted by IACMI – The Composites Institute | 1400 Rosa Parks Blvd, Detroit, MI 48216

Table of Contents

Table of Contents 2
Introduction 3
The Motivation 3
The Opportunity 3
The Strategy 4
Workshop Process Overview 6
Partnerships & Funding Mechanisms 7
Process Technology Development 8
Coal Refinement and Chemical Production 8
Mesophase Pitch and Carbon Fiber Production 9
Composites Manufacturing and Application Trials 10
Rigorous Analyses & Impact Assessments 12
Workforce Development 14
Scale-Up Production 15
Appendix A: About this Report 16
Appendix B: Workshop Agenda 17
Appendix C: List of Contributors 18
Appendix D: Slide Deck Presentations of Speakers 19

Introduction

The **Institute for Advanced Composites Manufacturing Innovation (IACMI)** is pursuing opportunities to create **new mass markets for low-cost, high-modulus carbon fibers derived from coal (i.e., coal-to-carbon fiber [C2CF]).** Such composites may offer significant cost savings for composites designed for applications that benefit from high stiffness and low-to-moderate ultimate strength and strain capacity, including high-volume applications in vehicles, infrastructure, and electronics.

IACMI – The Composites Institute is a community of industry, academia, and government agencies leading innovation and workforce development initiatives to drive the adoption of advanced composites to grow U.S. manufacturing and support national security. To reach this goal, IACMI pursues innovative materials and processes that can support the advanced composites industry, such as through realizing mass markets for coal-derived carbon fiber composites.

The Motivation

Coal-derived carbon fiber composites could meet the needs of high-volume, cost-sensitive industries, thus impacting the nation's energy and environmental security, and generating high-quality U.S. manufacturing jobs. **The confluence of two trends makes this a unique moment in American History**:

1. **After 100 years as the predominant source of fuel for electricity generation, the use of coal in the power sector is declining.** Devastating job and tax revenue losses have occurred in coal-mining communities—a trend that is expected to continue unless new coal-derived products and markets are developed.
2. **A personal mobility revolution (autonomous, electrified vehicles and shared mobility business models) is driving unprecedented changes in the automotive industry.** Automakers are investing in radical innovations in vehicle architecture and manufacturing processes. Carbon fiber composites—which offer automakers significant performance, energy efficiency, and pollutant emissions advantages—could be part of the solution, but high material costs and existing metals-based production capacity have prevented widespread adoption.

The Opportunity

Coal-derived carbon fiber composites offer a solution pathway for the coal industry, the automotive industry, and beyond. The carbon source used to make carbon fibers contributes about 50% of the current cost of carbon fibers. **Using coal as the source of carbon fibers has the potential to dramatically lower cost while also delivering superior performance for targeted applications.** In turn, this would:

- Increase the combined annual market value of domestic coal and coal-derived products
- Be part of the environmental solution by lowering emissions in the transportation sector
- Enable other significant product markets for coal across the United States, such as aerospace, marine, and infrastructure

Coal is an attractive carbon source for carbon fiber composites:

- Coal is an **abundant, affordable, domestic natural resource** with existing production and transportation infrastructure.
- Coal's **chemical composition enables the production of mesophase pitch-based carbon fibers** with offers desirable attributes such as high stiffness and low cost valued in automotive applications.

- Coal-derived carbon fiber composites are produced today; **technical feasibility is proven**—Japanese producers currently make coal-derived carbon fibers, but at costs 10-100x higher than needed to gain widespread use.
- Coal-derived carbon fiber composites has a **significantly lower greenhouse gas intensity** than combusting coal for power generation
- Extending the coal market value chain beyond electric power generation to encompass carbon fiber production **can contribute to the creation of manufacturing jobs and economic prosperity**—especially in states affected by the downturn in U.S. coal demand.

The initial target market is discontinuous fiber-reinforced, non-primary structures in automotive applications starting with injection molding and migrating into other discontinuous fiber molding processes. Other significant potential markets include infrastructure and electronics.

Coal-derived carbon fiber production can also lead the way to **other high value-added, coal-derived products** such as:

- Activated carbon
- Mesoporous carbon
- Plastics
- Chemicals
- Graphene
- Graphite
- Electronic devices including photovoltaics
- Electrodes for lithium-ion batteries and supercapacitors
- Building and construction materials
- Thermal insulators and conductors

Bold, urgent action is needed to capture this opportunity; **IACMI has a plan and is ready to act now**. **IACMI leads a world-class industrial research network established by once-in-a-generation investments** that provide the Nation's only open-access, industrial carbon fiber and composites technology development infrastructure and partner network capable of the scale needed to achieve national impact.

The Strategy

Carbon fiber cost and performance **improvements are possible through a focused technology development and scale-up program** that aligns public and private efforts and interests. IACMI's established industrial community, partnership models, supply chain-based collaboration, and research facilities at various scales of validation make it the ideal partner for government investment that can achieve national-scale impact. Working with government, industry, national laboratory, and university partners, IACMI has a plan for a nationally integrated, urgently executed effort to deliver cost and performance breakthroughs needed to capture this once-in-a-century opportunity:

- **Phase 1 (0-3 years)**: Secure funding commitments from government and industry, assess market demand, conduct technology development and scale-up programs, quantify cost advantages and environmental benefits, and initiate workforce development programs.
- **Phase 2 (2-5 years)**: Build the first-of-its-kind commercial-scale facility to achieve cost, performance, and reliability targets with funding commitments from both industry and government.
- **Phase 3 (5+ years)**: Pursue full commercial deployment with industry-driven funding to capture commercial opportunities.

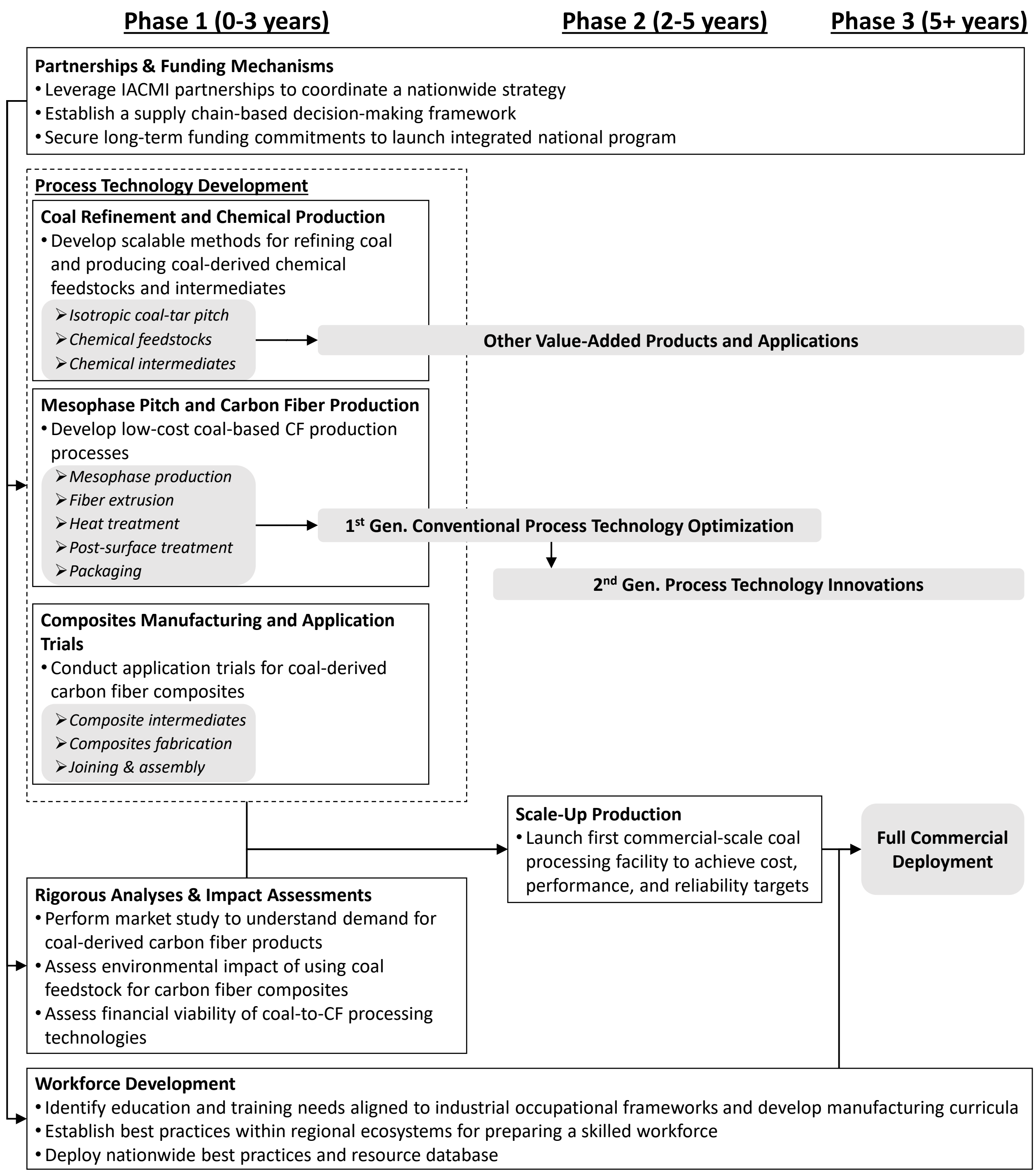


Figure 1: IACMI's strategy to launch a national technology development and scale-up program

Workshop Process Overview

On October 16th, 2019, IACMI hosted a one-day workshop titled *Realizing Mass Markets for Coal-Derived Carbon Fiber Composites* at Michigan State University's Scale-Up Research Facility (SURF) in the Corktown district of Detroit, MI to articulate a national program to develop and commercialize coal-derived carbon fiber composites with an unprecedented cost-performance profile that will meet the needs of high-volume, cost-sensitive industries. More than 50 IACMI members and subject matter experts attended the workshop including OEMs, all levels of the supply chain, investment and economic development communities, and state and federal government agencies to investigate key technology adoption drivers, investment requirements for stakeholders, and supply chain business models needed to facilitate C2CF composites adoption and growth for high-value applications in key industrial sectors.

Workshop attendees participated in multiple facilitated exercises across three parallel breakout groups to **develop a set of detailed, actionable initiatives for a national technology development and scale-up program to realize coal-derived carbon fiber reinforced polymer (CFRP) composites** including time-based milestones, investment requirements, potentials sponsors, and key stakeholder roles. This report presents a summary of those action plans developed by workshop attendees during the October 2019 workshop.

Partnerships & Funding Mechanisms

Coal-based precursors could significantly reduce the cost of carbon fibers and deliver economic and environmental benefits for coal-producing states. Capturing this opportunity will require long-term committed investments from both public and private entities. The technical feasibility of the approach has been proven, but the cost of coal-derived carbon fiber remains too high for commercial-scale adoption; targeted investments are needed to scale-up advanced carbon fiber production manufacturing technologies and deliver the cost and performance breakthroughs needed to become attractive to mass markets in automotive, infrastructure, electronics, and beyond.

To secure long-term investments, IACMI will coordinate across the supply chain to define stakeholder roles and responsibilities, determine appropriate studies and technology assessments to quantify long-term impacts, identify technology development pathways and barriers to innovation, and prepare a well-trained and knowledgeable workforce. Public-private investments will create manufacturing jobs and economic prosperity for coal-producing states and expand the coal market value chain beyond electric power generation.

Table 1: Actionable steps to realize coal-derived CFRPs: Partnerships & Funding Mechanisms

Actions	**Leverage IACMI partnerships to coordinate a nationwide strategy; Establish a supply chain-based decision-making framework, and; Secure long-term funding commitments to launch integrated national program**
Key Tasks	➢ Identify and convene stakeholders including coal processing technology companies and industry trade groups to identify key technology development challenges at critical points across supply chain ➢ Develop a strategic roadmap that defines stakeholder roles, responsibilities, accountabilities, and authorities (est. time required: 0-12 months) ➢ Identify suitable funding agencies and sponsors based on specific technology development needs ➢ Develop a consortia funding call for each critical R&D focus area along the supply chain (est. time required: 12-18 months)
Funding Requirements	➢ [**Phase 1**] $300K–$500K: Convene series of ~6 workshops, develop strategic guidance document, and release a consortia funding call from sponsoring groups/agencies
Roles	➢ **IACMI**: Coordinate and integrate stakeholder engagement and program planning ➢ **Industry**: Define technical objectives and demonstration program requirements; contribute funding, capital expenditure investments in infrastructure, facilities, equipment ➢ **Government**: Co-funding from state economic development agencies and Federal agencies; gather relevant economic data ➢ **NGOs**: Convene stakeholder groups and partnerships, and secure funding commitments; examine regulatory and policy barriers

Potential Sponsors	➢ OEMs, material suppliers, equipment vendors
	➢ Private investors
	➢ Department of Energy (DOE):
	  o Office of Energy Efficiency and Renewable Energy (EERE): Advanced Manufacturing Office (AMO), Bioenergy Technologies Office (BETO), Building Technologies Office (BTO), Vehicle Technologies Office (VTO)
	  o Office of Fossil Energy (FE)
	➢ Department of Defense (DoD)
	➢ Department of Commerce (DOC)/National Institute of Standards and Technology (NIST)
	➢ National Science Foundation (NSF)

Process Technology Development

While the technical feasibility of producing mesophase pitch from coal has been demonstrated, further process development work is needed to discover the most cost-effective technology pathways from available options. Process economics will depend on several factors, such as the feedstock coal type, carbon fiber form, and process scale-up parameters. Developing scalable production methods is an essential part of this national initiative.

Coal Refinement and Chemical Production

The first process technology development stream involves the refinement of coal into isotropic coal-tar pitch: a key prerequisite for the downstream production of low-cost carbon fibers. Stakeholder groups will work to optimize and scale-up suitable coal processing technologies for carbon fiber production while demonstrating a range of feedstocks for use in other coal-derived product markets.

Table 2: Actionable steps to realize coal-derived CFRPs: Process technology development for coal refinement and chemical production

Action	**Develop scalable methods for refining coal and producing coal-derived chemical feedstocks and intermediates**
Key Tasks	➢ Investigate solvent extraction and modified pyrolysis processing approaches including alternative non-coking-based production methods ➢ Characterize pitch sources from various coal types (est. time required: 6-12 months) ➢ Demonstrate use and optimization of range of feedstocks for use in manufacturing various coal-derived products ➢ Optimize isotropic pitch for downstream production of mesophase pitch ➢ Optimize production steps to work with multiple coal varieties ➢ Select most effective coal processing approaches for scale-up
Funding Requirements	<u>Capital expenditures</u>: ➢ [**Phase 1**] $80M: Coal conversion processing equipment <u>Coal tar pitch conversion technologies</u>: ➢ [**Phase 1**] $20M: Bench-scale production ➢ [**Phase 1**] $20M: Pilot-scale and prototyping ➢ [**Phase 1**] $300K: Develop specifications for 3 sources of pitch ➢ [**Phase 1**] $300K: Develop specifications of process parameters to produce precursors (e.g., isotropic coal-tar pitch) for the synthesis of mesophase pitch
Roles	➢ **IACMI, Research Institutes**: Coordinate demonstration projects; facilitate communication across stakeholder groups ➢ **Industry/Academia/Tier Suppliers**: Participate in technology demonstration and scale-up efforts ➢ **OEMs**: Measure progress with researchers and Tier suppliers; Characterize pitch precursor sources and processing technologies ➢ **National Labs**: Characterize pitch precursor sources and processing technologies ➢ **Government/DOE**: Lead interagency effort to help define strategic program requirements; Assess project impacts and policy implications; Review and approve construction of coal tar pitch plant(s)
Potential Sponsors	➢ State governments ➢ DOC, DoD ➢ DOE-EERE: BTO, VTO; DOE-FE ➢ Industry

Mesophase Pitch and Carbon Fiber Production

The second process technology development stream addresses the production scale-up of mesophase pitch precursors through the extrusion, heat treatment, post-surface treatment, and packaging of predominantly non-woven carbon fiber product forms. Initially, these carbon fiber processing technologies will be based on the use and optimization of existing or conventional processing approaches, which will transition into a second generation of technology development and emergence of innovative carbon fiber processing methods, such as field-assisted heat treatment technologies.

Table 3: Actionable steps to realize coal-derived CFRPs: Process technology development for production of mesophase pitch and carbon fibers

Action	Develop low-cost coal-based CF production processes
Key Tasks	➢ Investigate production methods for development and scale-up: o Mesophase pitch production o Fiber extrusion o Heat treatment o Post-surface treatment (optimized for non-woven product forms) o Packaging (optimized for non-woven product forms) ➢ Characterize process methods; Evaluate mesophase robustness, spinnability and temperature stability; Optimize steps for several types of coal (est. time required: 12 months) ➢ Characterize tensile modulus properties of coal-derived CF (est. time required: 12 months)
Funding Reqs.	Capital expenditures: ➢ [**Phase 1**] $3M: Mesophase production technologies ➢ [**Phase 1**] $3M: Fiber formation production technologies ➢ [**Phase 1**] $2M: Heat treatment process technologies Conversion technologies to convert coal tar pitch to mesophase pitch precursors: ➢ [**Phase 1**] $5M: Bench-scale production ➢ [**Phase 1**] $10M-50M: Pilot-scale and prototyping Fiber formation and heat treatment production technologies: ➢ [**Phase 1**] $6M: Bench-scale production ➢ [**Phase 1**] $10M-50M: Pilot-scale and prototyping ➢ [**Phase 1**] $300K: Characterize mechanical properties of coal-derived carbon fibers
Roles	➢ **IACMI, Research Institutes**: Coordinate demonstration projects; facilitate communication across stakeholder groups ➢ **Industry/Academia/Tier Suppliers**: Participate in technology demonstration and scale-up efforts ➢ **OEMs**: Measure progress with researchers and Tier suppliers; Develop and characterize processing technologies for coal-derived CF forms ➢ **National Labs**: Develop and characterize processing technologies for coal-derived CF forms ➢ **Federal Government/DOE**: Lead interagency effort to help define strategic program requirements; Assess project impacts and policy implications; Review and approve construction of mesophase pitch pilot units ➢ **State Government**: Expedite processing for siting and permitting pilot manufacturing facilities; Assess project impacts and policy implications
Potential Sponsors	➢ State governments ➢ Department of Homeland Security (DHS), DOC, DoD, Department of Transportation (DOT), ➢ DOE-EERE; DOE-FE ➢ Industry: carbon fiber manufacturers, coal refining companies, etc.

Composites Manufacturing and Application Trials

Using a range of composite manufacturing techniques, coal-derived carbon fiber composites will be validated for use in various automotive and infrastructural applications; those with a sound business case will undergo a formal materials qualification process. The gradual decline in the cost of coal-derived carbon fibers will lead the way to additional high value-added products beyond automotive and infrastructural applications.

Table 4: Actionable steps to realize coal-derived CFRPs: Process technology development for composites manufacturing and application trials

Action	Conduct application trials for coal-derived carbon fiber composites

Key Tasks	➢ Identify equipment and facility requirements for manufacturing composites from coal-derived mesophase pitch precursors
	➢ Demonstrate the use of the coal-derived carbon fibers in different manufacturing processes including injection molding, sheet molding, and other relevant composites fabrication processes
	➢ Evaluate and qualify coal-derived carbon fibers in key applications:
	  o <u>Automotive</u>: Semi-structural components, under-the-hood components, and Class A appearance/surface components (e.g., exterior body panel)
	  o <u>Infrastructure</u>: Architectural components
	➢ Develop surface treatment techniques for one thermoplastic application and one thermoset application (est. time required: 24 months)
	➢ Employ design optimization strategies to reduce manufacturing costs:
	  o Develop software to design and test digital parts
	  o Develop ASTM-type standards for broader penetration of composite parts
	  o Develop cost models to improve process efficiencies and success rates (est. time required: 12-48 months)

Funding Requirements	<u>Qualification and application trials</u>: ➢ [**Phase 1**] $5-10M: Cost/performance validation activities ➢ [**Phase 1**] $10M: Qualify materials for automotive applications ($500K-1M per application) ➢ [**Phase 1**] $10M: Qualify materials for infrastructural applications ($500K-1M per application) <u>Design optimization activities</u>: ➢ [**Phase 1**] $500K: Form partnership with materials suppliers, OEMs, equipment, and software companies to develop design software ➢ [**Phase 1**] $500K: Define properties properties/functions for standardization ➢ [**Phase 1**] $2M: Develop cost models, database population, and code development
Roles	➢ **IACMI, Research Institutes**: Coordinate demonstration projects; facilitate communication across stakeholder groups ➢ **Industry/Tier Suppliers**: Identify key applications for demonstrating coal-based CF; participate in technology demonstration and scale-up efforts; Performance testing and database population with participation from: CF manufacturers; resin/sizing makers; thermoplastic manufacturers; weavers and tape makers; process equipment manufacturers; design engineering and software companies; OEMs ➢ **OEMs**: Measure progress with researchers and Tier suppliers ➢ **Academia**: Participate in technology demonstration and scale-up efforts; develop cost models in collaboration with software companies ➢ **National Labs**: Develop and characterize CF composite applications and production technologies; support with standards development

Action	Conduct application trials for coal-derived carbon fiber composites
	➢ **Government/DOE**: Lead interagency effort to help define strategic program requirements; Assess project impacts and policy implications; Review and approve construction of coal-derived CF composites pilot-scale demonstration facility
Potential Sponsors	➢ Industry; Large-scale OEMs including automotive manufacturers ➢ State governments ➢ DHS, DOC, DoD, DOT ➢ DOE-FE; DOE-EERE: AMO, BETO, BTO, Fuel Cell Technologies Office (FCTO), VTO

Rigorous Analyses & Impact Assessments

Coal-derived carbon fibers and composites hold promise for many applications. A rigorous analysis of potential markets, product cost and performance targets needed to succeed in those markets, market size, potential market uptake, and other factors can provide investors information needed to estimate return-on-investment analyses. Such market studies can also provide insights into which market segments and applications to target first and which may require longer product development and qualification cycles before widespread commercial adoption.

Table 5: Actionable steps to realize coal-derived CFRPs: Comprehensive study of potential market opportunities

Action	**Perform market study to understand demand for coal-derived carbon fiber products**
Key Tasks	➢ Identify opportunities for mass market applications of coal-derived carbon fiber composites; Examine interim non-automotive markets for coal-derived carbon fiber composites (est. time required: 3-6 months) ➢ Evaluate demand curve to understand price-quantity relationship (est. time required: 6-9 months) ➢ Develop a comprehensive return on investment (ROI) analysis (est. time required: 3-12 months) ➢ Establish business case for R&D funding
Funding Requirements	➢ [**Phase 1**] $300K: Market study of high-volume and/or high-value applications
Roles	➢ **Industry**: Provide data to assess market demand ➢ **NGOs**: Conduct market study ➢ **IACMI**: Implement the results of the market analysis study ➢ **Academia/National Labs/Industry**: Provide information on probable production costs and scales
Potential Sponsors	➢ State governments ➢ DOE-EERE: AMO, BTO, VTO

Implicit in the argument for pursuing coal-derived products like carbon fiber composites is the assumption that the pathway offers environmental benefits associated with the greater use of lightweight carbon fiber composites. Further, coal-derived products may carry unexpected public perception concerns. Careful assessments of the environmental benefits and possible public perception of the coal-to-composites supply chain are needed to provide the needed evidence and messaging for ensuring public support of this initiative.

Table 6: Actionable steps to realize coal-derived CFRPs: Rigorous assessment of environmental benefits of coal-derived CF production

Action	**Assess environmental impact of using coal feedstock for carbon fiber composites**
Key Tasks	➢ Conduct public perception studies to understand objections to coal-derived CF production technologies and inform focus of technology scale-up programs (est. time required: ~2 years) ➢ Conduct rigorous LCA study of coal-to-carbon fiber (C2CF) composites to quantify emissions reduction potential ➢ Launch a targeted public relations campaign to address perception issues regarding production facilities; focus on locations envisioned for production plants)
Funding Requirements	➢ [**Phase 1**] $250K: Public perception study ➢ [**Phase 1**] $250K: LCA assessment

Action	Assess environmental impact of using coal feedstock for carbon fiber composites
	➢ [**Phase 1**] $1-2M: Public relations campaign
Roles	➢ **Industry**: Provide data for LCA providers; fund public relations campaign ➢ **IACMI**: Coordinate and direct LCA study ➢ **Research community**: Provide LCA data: input materials, energy levels, energy sources, outputs, chemical yields, etc. ➢ **NGOs**: Coal industry association to fund public perception study; conduct LCA work ➢ **Government**: Inform LCA work (e.g., DOE-FE)
Potential Sponsors	➢ State governments ➢ Coal industry associations ➢ DOE-EERE: AMO; DOE-FE

In addition to market, environmental, and public perception studies, the partnership requires a rigorous technoeconomic analysis (TEA) of the various technology pathways for processing coal into mesophase pitch. Such a thorough TEA will provide important direction for selecting processing methods, supply chain structures, and other critical inputs to the costly process development and scale-up activities, eventually leading to the first-of-its-kind, full-scale commercial facility.

Table 7: Actionable steps to realize coal-derived CFRPs: Robust technoeconomic assessment of process technology development scenarios

Action	Assess financial viability of coal-to-CF processing technologies
Key Tasks	➢ Articulate a vision and mission statement for a proof-of-concept pilot coal processing facility (CPF) ➢ Identify equipment and facility requirements to convert coal-derived feedstocks into carbon fibers ➢ Conduct technoeconomic analyses to determine the financial viability of coal-to-CF processing technologies
Funding Requirements	➢ [**Phase 1**] $5M: Technoeconomic study of CPF
Roles	➢ **Government**: Appropriate funding ➢ **NGOs**: Social impact funding ➢ **IACMI**: Collaborate across stakeholder groups to articulate a lead response ➢ **Research community**: Provide R&D inputs on equipment and process; capex, labor, energy, and other cost elements
Potential Sponsors	➢ DOE-EERE: BTO, VTO; DOE-FE ➢ State governments, legislatures (WY, UT, KY, WV, MT)

Workforce Development

Building mass markets for widespread use of carbon fiber composites will require a much larger workforce with education, training, and experience working with those materials. Expanding education, training, and worker-retraining programs to build greater understanding and skill in working with coal processing, carbon fibers, and composites will ensure that as mass market uptake of low-cost composites occurs the workforce is ready.

Table 8: Actionable steps to realize coal-derived CFRPs: Preparing a skilled workforce in coal-to-carbon fiber technology development

Actions	Identify education and training needs aligned to industrial occupational frameworks and develop manufacturing curricula; Establish best practices within regional ecosystems for preparing a skilled workforce; Deploy nationwide best practices and resource database
Key Tasks	➢ Identify education and training needs aligned to industrial occupational frameworks and develop manufacturing curricula o Develop state-level model curriculum in partnership with industry, academia, and government organizations o Certify model curriculum at state level with participation from multiple state government agencies and academic institutions ➢ Establish best practices within regional ecosystems for preparing a skilled workforce o Develop a database to track potential funding sources and record best practices for successful projects, procedures, and processes ➢ Deploy nationwide best practices and resource database o Share information on curricula, successful projects, procedures, and processes to stimulate industry participation and demonstration efforts o Adopt and certify model curriculum in other states
Funding Requirements	➢ [**Phase 1**] $50K-$100K: Develop shared resources database of funding resources and best practices ➢ [**Phase 1**] $500K-$1M: Develop model curriculum in first state ➢ [**Phase 1**] $250K: Certification of model curriculum at state level ➢ [**Phase 2**] Under $500K: Adoption of model curriculum in other states ➢ [**Phase 2**] $250K: Certification of model curriculum in other states
Roles	➢ **Academia**: Engage industry partners to inform the development of curricula; certify model curricula ➢ **Federal/State Governments**: Assist with certification of curricula; Provide funding ➢ **Industry**: Provide inputs to model curriculum and participate in content reviews to ensure alignment ➢ **Academia**: Conduct training and workforce development; Implement curricula ➢ **IACMI**: Coordinate workforce training opportunities at model processing facilities; House database of best practices and potential funding sources; Develop training modules
Potential Sponsors	➢ **Federal government**: Department of Labor (DOL), DOE, DoD, DOC/NIST, Department of Education ➢ **State governments** ➢ **Industry**: Trade organizations, individual companies ➢ **Foundations**: National, state, regional, local ➢ **Academia**: Major research universities, community and technical colleges

Scale-Up Production

The most promising coal-to-CF process technologies will proceed to scale-up and demonstration at a commercial-scale production facility to make further progress toward cost, performance, and reliability targets. Composites manufacturing stakeholders will work in parallel to validate and qualify coal-derived carbon fiber technologies to determine their ability to meet the requirements for specific market applications.

Table 9: Actionable steps to realize coal-derived CFRPs: Scale-up and demonstration of coal-to-CF processing technologies

Action	Launch first commercial-scale coal processing facility to achieve cost, performance, and reliability targets
Key Tasks	➢ Demonstrate cost, performance, and reliability targets of pilot-scale technologies: o Coal refinement facility o Carbon fiber production facility ➢ Use market analysis results to identify production-scale requirements of the coal refinery and CF production factories
Funding Requirements	➢ [**Phase 2**] [TBD]: Commercial-scale coal refinery; primarily funded by industry ➢ [**Phase 2**] $100M-200M: Commercial-scale carbon fiber factory
Roles	➢ **IACMI, Research Institutes**: Integrate the results of rigorous analyses, market studies, and impact assessments; coordinate demonstration projects; facilitate communication across stakeholder groups ➢ **Industry/Tier Suppliers**: Identify key applications for demonstrating coal-based CF; participate in technology demonstration and scale-up efforts ➢ **OEMs**: Measure progress with researchers and Tier suppliers; Characterize scaled-up pitch sources, CF forms, and processing technologies ➢ **National Labs**: Characterize scaled-up pitch sources, CF forms, and processing technologies ➢ **Government/DOE**: Lead interagency effort to help define strategic program requirements; Assess project impacts and policy implications
Potential Sponsors	➢ State governments ➢ DOC, DoD ➢ DOE-EERE: AMO ➢ Industry

Appendix A: About this Report

On October 16th, 2019, IACMI hosted a one-day workshop titled *Realizing Mass Markets for Coal-Derived Carbon Fiber Composites* at Michigan State University's Scale-Up Research Facility (SURF) in the Corktown district of Detroit, MI to articulate a national program to develop and commercialize coal-derived carbon fiber composites with an unprecedented cost-performance profile that will meet the needs of high-volume, cost-sensitive industries. More than 50 IACMI members and subject matter experts attended the workshop including OEMs, all levels of the supply chain, investment and economic development communities, and state and federal government agencies to investigate:

- **key technology adoption drivers** including incentives and strategies to reduce the risk associated with financial investments in support of C2CF composite production factors;
- **investment requirements for stakeholders** across the composites manufacturing supply chain, and;
- **supply chain business models** needed to facilitate carbon fiber adoption and growth in the automotive sector and other high-volume industries such as infrastructure and electronics.

Following opening remarks from John Hopkins (CEO, IACMI), IACMI invited three guest speakers to present an overview of recent research and developments efforts and analysis of market opportunities to enable coal-derived carbon fiber composites. (Each presentation is appended to this document.)

For the remainder of the day, workshop attendees participated in multiple roadmapping-style exercises across three parallel breakout groups to: **1) identify the major technical, business, and economic challenges** preventing large-scale investments for the development and commercialization of coal-derived carbon fiber production technologies, and; **2) develop a set of detailed, actionable initiatives for a national technology development and scale-up program to realize coal-derived carbon fiber reinforced polymer (CFRP) composites** including time-based milestones, investment requirements, potentials sponsors, and key stakeholder roles.

During the final exercise, the workshop leveraged an open layout that gave participants the opportunity to freely interact and weigh in on all workshop outputs. The workshop concluded with a large group discussion in which participants offered the following final remarks about the workshop outcomes and overall effort:

- The technical feasibility to produce C2CF composites is challenging, but the price-performance target is achievable.
- Achieving commercial scale will be a significant challenge; success will require significant collaboration and participation from multiple public-private partnerships.
- The overall program timescale and timing of investments is questionable; efforts to prove technoeconomic feasibility must begin immediately.
- It is unclear which stakeholders would possess the intellectual property (IP) rights resulting from technology development, though there may be a solution that involves share IP among supply chain partners to help control costs.
- The coal production workforce is in significant decline, and there is uncertainty about the ability to achieve sufficient participation of skilled workers.
- Although the automotive industry is the appropriate initial market for C2CF composites, involving other industry sectors at an early stage may diversify risk for program investors.

Appendix B: Workshop Agenda

Table 10: Workshop agenda

Tuesday, October 16, 2019	
Time	**Agenda**
8:00	**Arrive: 1400 Rosa Parks Blvd, Detroit MI 48216**
8:30 – 8:50	**Opening Remarks** • John Hopkins, CEO, IACMI
8:50 – 9:00	**Workshop Purpose & Objectives**
9:00 – 9:25	**DOE's Coal-to-Products R&D Program** • John Rockey, Technology Manager, NETL
9:25 – 9:50	**Development of Market Opportunities for Coal-Based Carbon Fiber Composites** • Patrick Blanchard, Technical Leader, Advanced Polymer Systems, Ford
9:50 – 10:15	**Low-Cost, High-Modulus Carbon Fibers** • Dale Leftwich, Business Development Leader, JR Automation
10:15 – 10:30	**BREAK**
10:30 – 12:00	**[Breakout Groups] Identify and Prioritize Key Technical and Business Challenges for C2CF Composites** • What major technical, business, and economic challenges are preventing large-scale investments to develop and commercialize coal-derived carbon fiber production technologies?
12:00 – 1:00	**LUNCH**
1:00 – 1:15	**Review Top Challenges**
1:15 – 2:45	**[Breakout Groups] Develop Action Plans to Address Challenges: Part I**
2:45 – 3:00	**BREAK**
3:00 – 4:30	**[Breakout Groups] Develop Action Plans to Address Challenges: Part II**
4:30 – 5:00	**Final Comments/Remarks**
5:00	**ADJOURN**

Appendix C: List of Contributors

Table 11: List of workshop contributors

Name	Affiliation
Scott Anair	JR Automation
Rodney Andrews	Center for Applied Energy Research
Randall Atkins	Ramaco Carbon
Dan Beattie	Polaris Strategies
Patrick Blanchard	Ford Motor Company
Craig Blue	Oak Ridge National Laboratory
Raymond Boeman	Michigan State University
Albert Chan	Solvay
Mark Cieslinski	BASF
Girish Deshpande	Cytec Carbon Fibers, LLC, subsidiary of Solvay
Jim Dietz	TwoPoint Solutions, Inc.
Larry Drzal	Michigan State University
Craig Eatough	Ekomatter
Thomas Ebeling	Lyondellbasell Engineering Composites
Cliff Eberle	IACMI - The Composites Institute
Jeff Edwards	Utah Advanced Materials and Manufacturing Initiative
Paul Elwell	Harper International
James Ferguson	U.S. Department of Energy, NETL
Alan Franc	Techmer PM
John Hopkins	IACMI - The Composites Institute
Jennifer Johnson	Bighorn Public Affairs Group
Moe Khaleel	Oak Ridge National Laboratory
Jeff Klipstein	AOC Alaincys
Brian Knouff	Oak Ridge National Laboratory
Tyler Krutzfeldt	Mont Vista Capital
Edgar Lara-Curzio	Oak Ridge National Laboratory
Dale Leftwich	JR Automation
Terri Lester	IACMI - The Composites Institute
Tianna Lutz	JR Automation
Christopher Matranga	U.S. Department of Energy, NETL
Richard Moore	Plasan Carbon Composites
Gina Oliver	American Chemistry Council
Soydan Ozcan	Oak Ridge National Laboratory
Rick Pauer	Polynt Composite
George Racine	ExxonMobil
John Rockey	U.S. Department of Energy, NETL
Chad Schell	U.S. Department of Energy
Khaled Shahwan	Fiat Chrysler Automobiles (FCA)
Mike Siwajek	Continental Structural Plastic
Merlin Theodore	Oak Ridge National Laboratory
John Unser	IACMI - The Composites Institute
Uday Vaidya	IACMI; University of Tennessee, Knoxville
Alan Vaughan	ExxonMobil
Matthew Weisenberger	UK CAER
Cyrus Western	Wyoming State Legislature

Appendix D: Slide Deck Presentations of Speakers

This section contains the following appended slide decks from the speakers who gave presentations during the October 16th, 2019 workshop:

Table 12: List of speakers' slide deck presentations

The Composites Institute: Drivers for Coal-Derived Carbon Fiber Composites • John A. Hopkins, CEO, IACMI–The Composites Institute
DOE's Coal-to-Products R&D Program • John Rockey, Technology Manager, NETL
Development of Market Opportunities for Coal-Based Carbon Fiber Composites • Patrick Blanchard, Technical Leader, Advanced Polymer Systems, Ford
Low-Cost, High-Modulus Carbon Fibers • Dale Leftwich, Business Development Leader, JR Automation

The Composites Institute

Drivers for Coal-Derived Carbon Fiber Composites

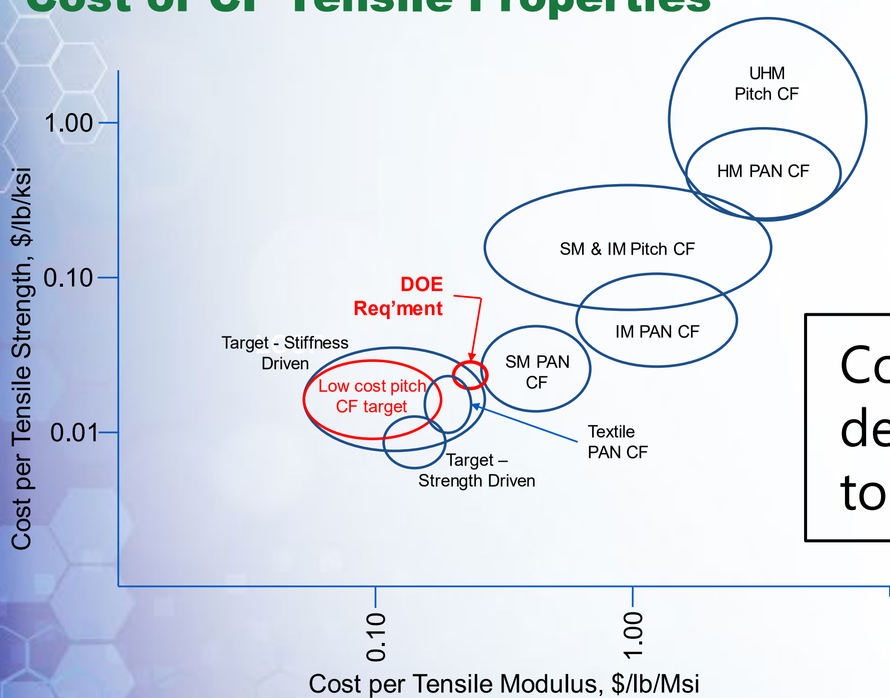
John A. Hopkins

CEO, IACMI-The Composites Institute, managed by Collaborative Composite Solutions Corporation

Presented at
Workshop on Realizing Mass Markets For Coal-Derived Carbon Fiber Composites
Detroit, MI 16 October 2019

Coal-Derived Carbon Fiber Value Proposition

Cost of CF Tensile Properties



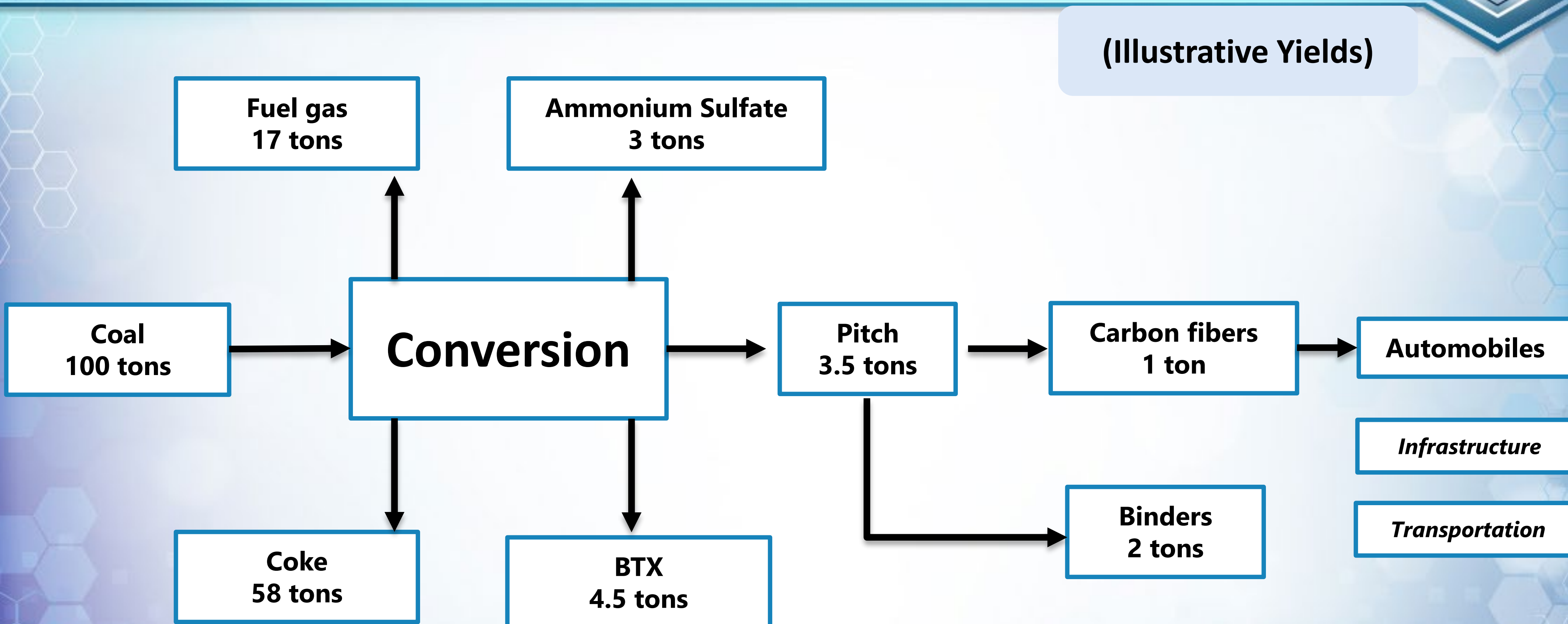
Design Driver	Best Value Fiber	Likely application
Strength	Glass	Industrial
Strength + Stiffness	PAN-based carbon	Aerospace
Stiffness	Pitch-based carbon	Industrial, esp. auto

Coal-derived

Coal-derived, pitch-based carbon fibers potentially deliver 3X higher stiffness per dollar than any of today's commercially available carbon fibers

Carbon fiber value is realized optimally in composites

Coal-to-Products Value Map



Path Forward

- Validate the market opportunity for coal-derived carbon fibers and composites across value chain
- Establish targets required for technoeconomic validation and scale-up investment
- Identify most likely applications for early adoption
- Identify key supply chain challenges and provide ROM estimates of required production capacities/investment

Key Workshop Deliverables

- Description (scope, budget, timeline, metrics, deliverables) of a program to develop and commercially deploy coal-derived carbon fiber composites for mass markets
- Identification of the key program stakeholders
  - Innovators
  - Investors and commercial producers throughout the supply chain
  - OEM’s, customers and end users
  - Impacted communities
- Articulation of anticipated program impacts

Questions?

jhopkins@iacmi.org

www.iacmi.org

Coal Beneficiation

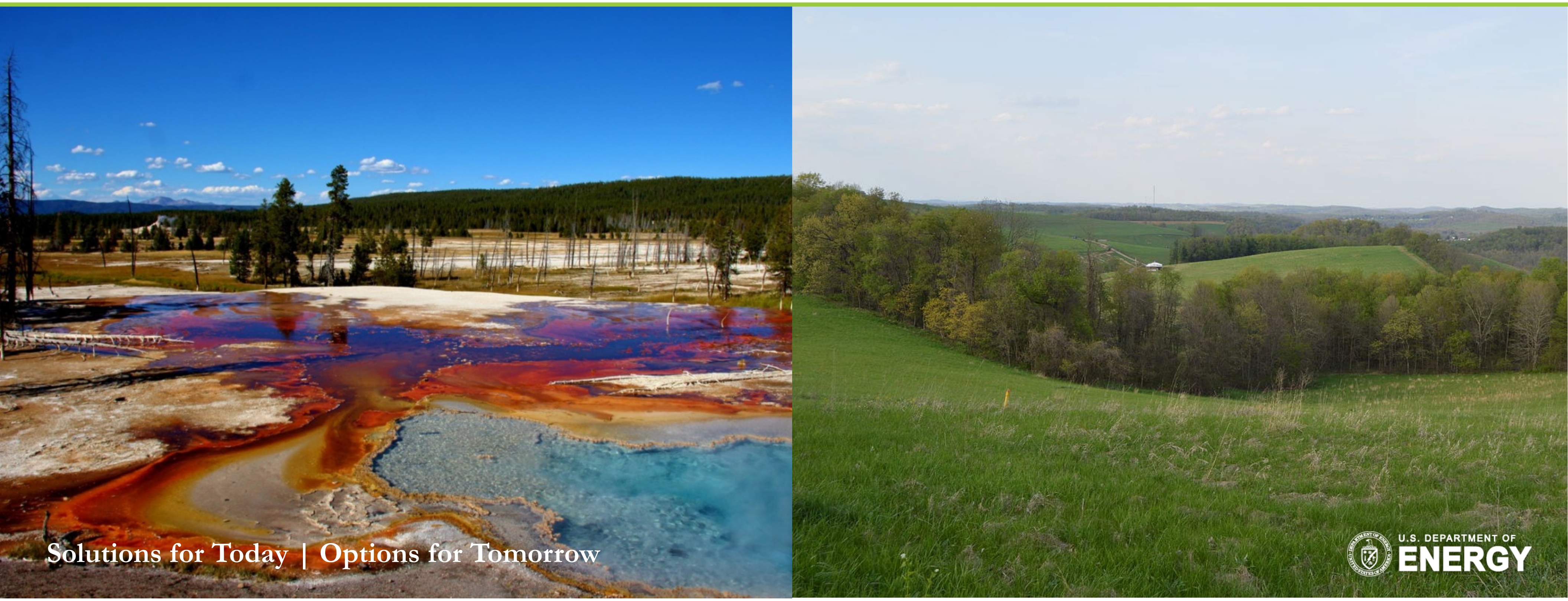
DOE's R&D Program

Workshop on Realizing Markets for Coal-Derived Carbon Fiber Composites

NATIONAL ENERGY TECHNOLOGY LABORATORY

John Rockey – Technology Manager

October 16, 2019

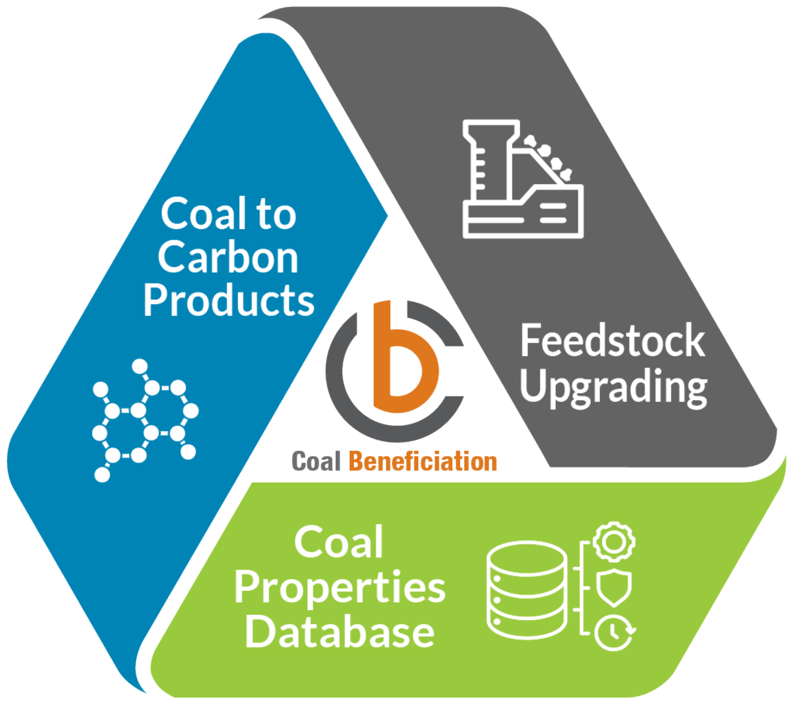


Coal Beneficiation

Program Goals

Program Initiated May 2018

NATIONAL ENERGY TECHNOLOGY LABORATORY



Coal Beneficiation

Collaborations and Partnerships

NATIONAL ENERGY TECHNOLOGY LABORATORY

Coal-based Manufacturing Technologies

- Oak Ridge National Laboratory
- University of Kentucky Center for Applied Energy Research
- Ramaco Carbon
- The Institute for iacmi Advanced Composites Manufacturing Innovation — The Composites Institute

Materials Discovery & Design

- NETL
- Massachusetts Institute of Technology
- Illinois — University of Illinois at Urbana-Champaign
- Russell County, VA Industrial Development Authority
- Pitt
- Ramaco Carbon
- Western Research Institute

Systems Engineering & Analysis

- NETL
- Oak Ridge National Laboratory

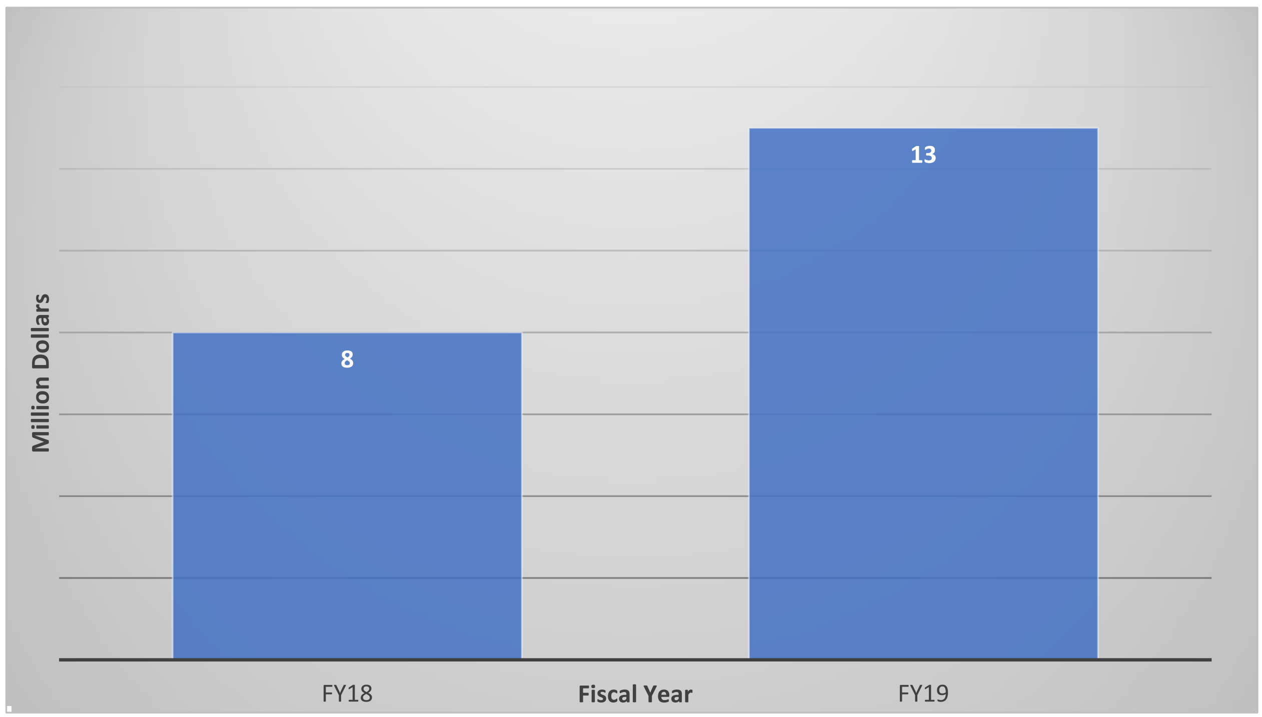
Coal Beneficiation

Carbon Products Show Exceptional Promise

NATIONAL ENERGY TECHNOLOGY LABORATORY

Carbon Product	Potential U.S. Coal Industry Requirements - 2050		U.S. Product Value -2050 (Million $)	Employment-2050 (Mfg.)	Type of Coal Used	
	Coal Production (mmt)	Coal Mining Employment			Today	2050
Activated Carbon	22.0	2,641	15,979	32,437	Bituminous	TBD by R&D
Carbon Anodes	25.0	3,005	2,254	4,576	**Tar/Pitch Derived from Coking Coal** (largely in China); R&D examines additional ways to make pitch, which could include multiple types of coal	
Carbon Black	14.1	1,692	5,077	10,306		
Graphite Electrodes/Needle Coke	12.5	1,502	41,315	83,869		
Carbon Fiber (incl. cement additive)	47.5	5,705	21,393	43,427		
Carbon Nanomaterials (incl. cement additive)	1.5	180	3,000	6,090	R&D examining multiple coal types	
Conductive Inks	**TBD EY19/20**					
Roofing Tile						
Composites						
Foams						
Bottom Line	**122.6**	**14,725**	**89,018**	**180,705**		

Budget History



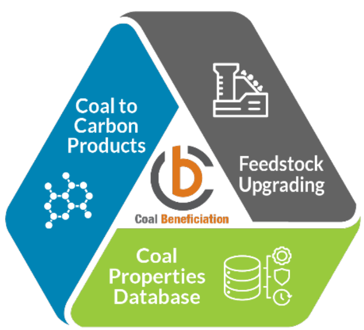
Coal Beneficiation

Current R&D Portfolio

NATIONAL ENERGY TECHNOLOGY LABORATORY

Feedstock Upgrading
- CarbonFuels
- Minerals Refining Co

Coal Properties Database
- NETL RIC



Building Materials
- Semplastics
- Ohio U
- Battelle Memorial Inst
- NETL RIC

Conductive Inks
- Minus 100

3-D Printable Polymers
- H Quest Vanguard

Carbon Fibers
- Ramaco Carbon
- U. of KY Research Fdn
- Ramaco Carbon
- Oak Ridge National Lab
- NETL RIC

Silicon Carbide Foam
- Touchstone Research

Nanomaterials
- University of Illinois
- Rice U
- Massachusetts Institute of Technology
- NETL RIC

Electrodes
- George Washington U
- Physical Sciences

Building Materials

Coal to Carbon Products

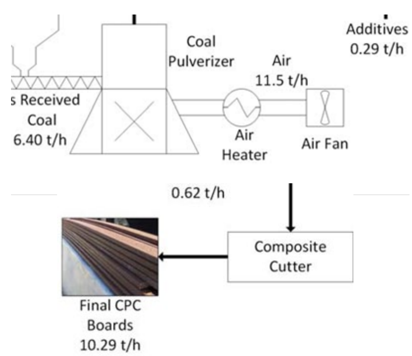
Semplastics
SBIR Grant
Phase 1 – 2018
Phase 2 – 2019

Coal-core composite (CCC) for roofing tiles and other products

[redacted]

Ohio U
Awarded Sept. 2019

Coal plastic composite (CPC) for decking boards and other products



Battelle Memorial Inst
Awarded Sept. 2019

Coal to polyurethane (PU) foam (solid) products

NETL - RIC
Awarded Sept. 2019

Coal-derived graphene used as an additive in ordinary Portland cement

Coal Beneficiation

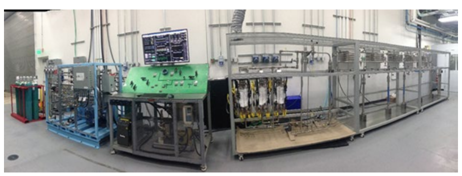
Carbon Fibers

Coal to Carbon Products

NATIONAL ENERGY TECHNOLOGY LABORATORY

Ramaco Carbon
Awarded Sept. 2019

Raw coal feedstocks into pitch and carbon fibers

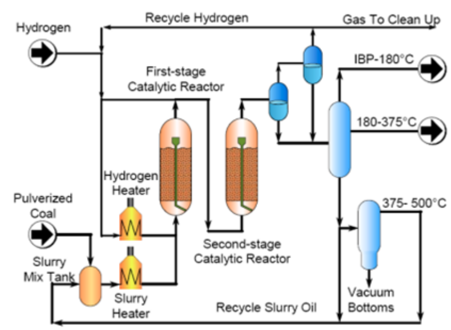


U. of KY Research Fdn
Awarded Sept. 2019

Melt spinning coal-derived pitch into fiber, then thermal conversion to carbon fiber

Ramaco Carbon
Awarded Sept. 2019

High-quality carbon fiber precursor material



Oak Ridge National Lab and University of KY
Awarded Sept. 2019

Coal-derived Carbon Fiber for Thermo-Structural Applications

Coal Beneficiation

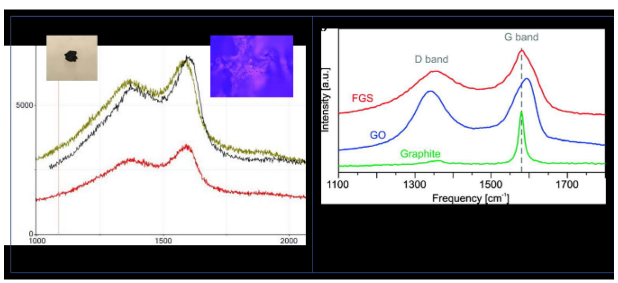
Nanomaterials

Coal to Carbon Products

NATIONAL ENERGY TECHNOLOGY LABORATORY

University of Illinois
Awarded – Sept. 2019

High-value carbon nanomaterials and carbon sorbents

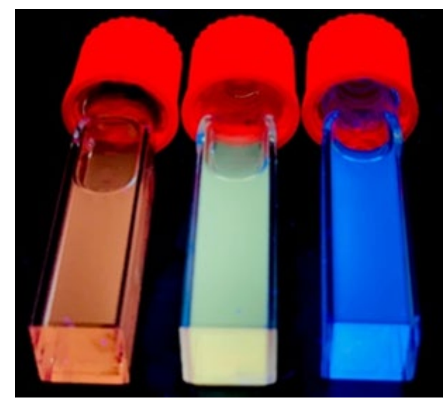


Rice U
Awarded – Sept. 2019

High-quality graphene

NETL - RIC
Initiated 2018

Coal-based Carbon Nanomaterials



Electrodes

Coal to Carbon Products

George Washington U

Awarded – Sept. 2019

High value (Li-ion grade) "potato" graphite

Physical Sciences

SBIR Grant

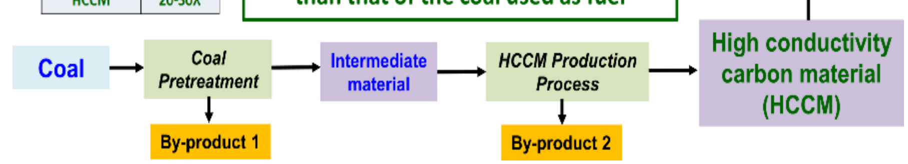
Phase 1 – 2018

Phase 2 – 2019

High-conductivity carbon material (HCCM) for electrochemical applications

Stream	Rel. Price
Coal	1X
By-product 1	1X
By-product 2	3-10X
HCCM	20-30X

PSI process produces a high conductivity carbon product for electrochemical applications with 20 -30X higher value than that of the coal used as fuel



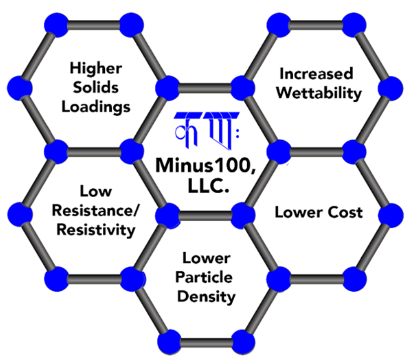
PSI's Innovative Process

Other Products

Minus 100

SBIR Grant
Phase 1 – 2018
Phase 2 – 2019

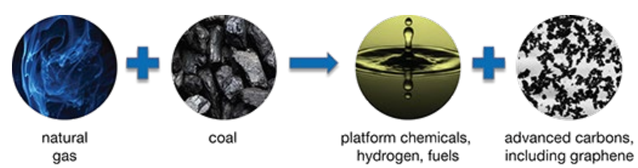
New methods of manufacturing highly conductive ink pigments



H Quest Vanguard

Awarded – Sept. 2019

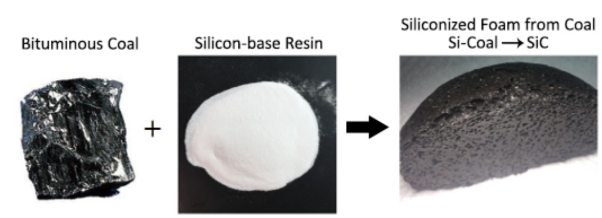
Carbon and graphitic materials for industrial electrode applications and advanced 3-D printable carbon polymer composites



Touchstone Research Lab

SBIR Grant
Phase 1 – 2018
Phase 2 – 2019

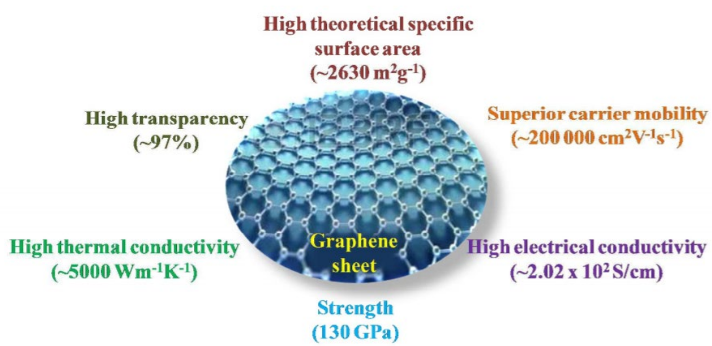
New silicon carbon (SiC) foam utilizing coal feedstock for s-CO_2 turbine operation

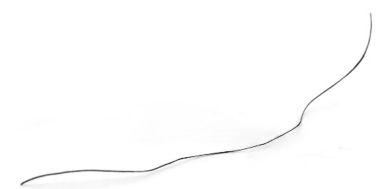


Coal Beneficiation

Graphene

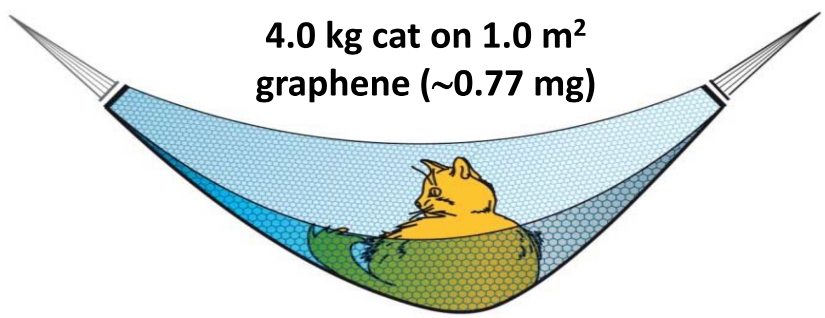
Superior Fundamental Properties of Graphene





One strand of human hair

4.0 kg cat on 1.0 m^2 graphene (~0.77 mg)



Scientific Background on the Nobel Prize in Physics 2010; Nanoscale **10**, 9427-9440 (2018)
https://cmp.callawaygolf.com/2018/07/graphene-incorporating-the-worlds-strongest-known-material-in-chrome-softs-core/

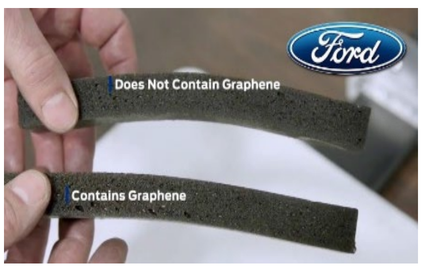
https://media.ford.com/content/fordmedia/fna/us/en/news/2018/10/09/ford-innovates-with-miracle-material-powerful-graphene-for-vehicle-parts.html

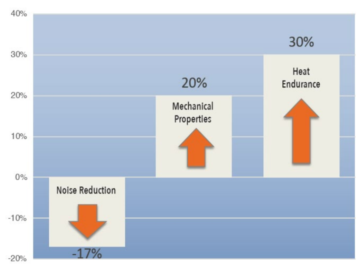
Coal Beneficiation

Graphene

NATIONAL ENERGY TECHNOLOGY LABORATORY

Graphene-polyurethane Composite Appears in Every Ford F150 and Mustang, Starting in 2019





Graphene Composites in Cores of Callaway Golf Balls

Outperforms competitors

- ✓ Graphene improves durability & performance of cores
- ✓ Allows larger, softer core w/stiffer graphene composite shell

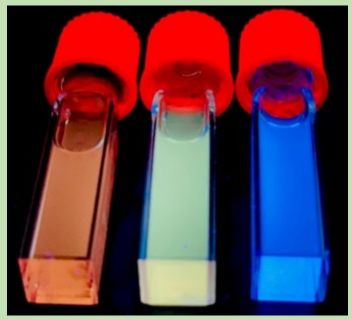
Coal Beneficiation

Coal-based Carbon Nanomaterials at NETL

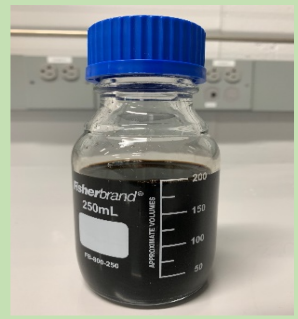
NATIONAL ENERGY TECHNOLOGY LABORATORY

DOMESTIC COAL

GRAPHENE QUANTUM DOTS



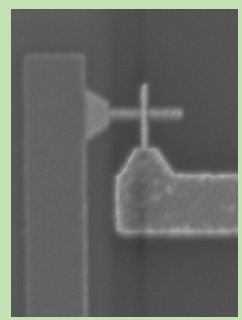
LOW COST GRAPHENE INKS/FLUIDS



GRAPHENE-ENHANCED CEMENT

FILTRATION SORBENTS/MEMBRANES (w/J. Grossman, MIT)

CARBON ELECTRONICS (w/Q. Cao, UIUC)



HYDROPHOBIC COATINGS (w/P. Leu, PITT)

Coal Beneficiation

Takeaways

NATIONAL ENERGY TECHNOLOGY LABORATORY

- Exciting opportunities exist to expand the coal value chain
- New program – less than two years old
- Lab scale through pilot scale projects getting underway
- All projects have industry involvement

Stakeholder involvement essential for transition of technologies to industry

Coal Beneficiation

Contacts

https://www.netl.doe.gov/Coal_Beneficiation

NATIONAL ENERGY TECHNOLOGY LABORATORY

John Rockey
Technology Manager
304-285-4711
John.Rockey@NETL.DOE.GOV

Regis Conrad
HQ Division Director
301-903-2827
Regis.Conrad@HQ.DOE.GOV

Coal Beneficiation

Projects

NATIONAL ENERGY TECHNOLOGY LABORATORY

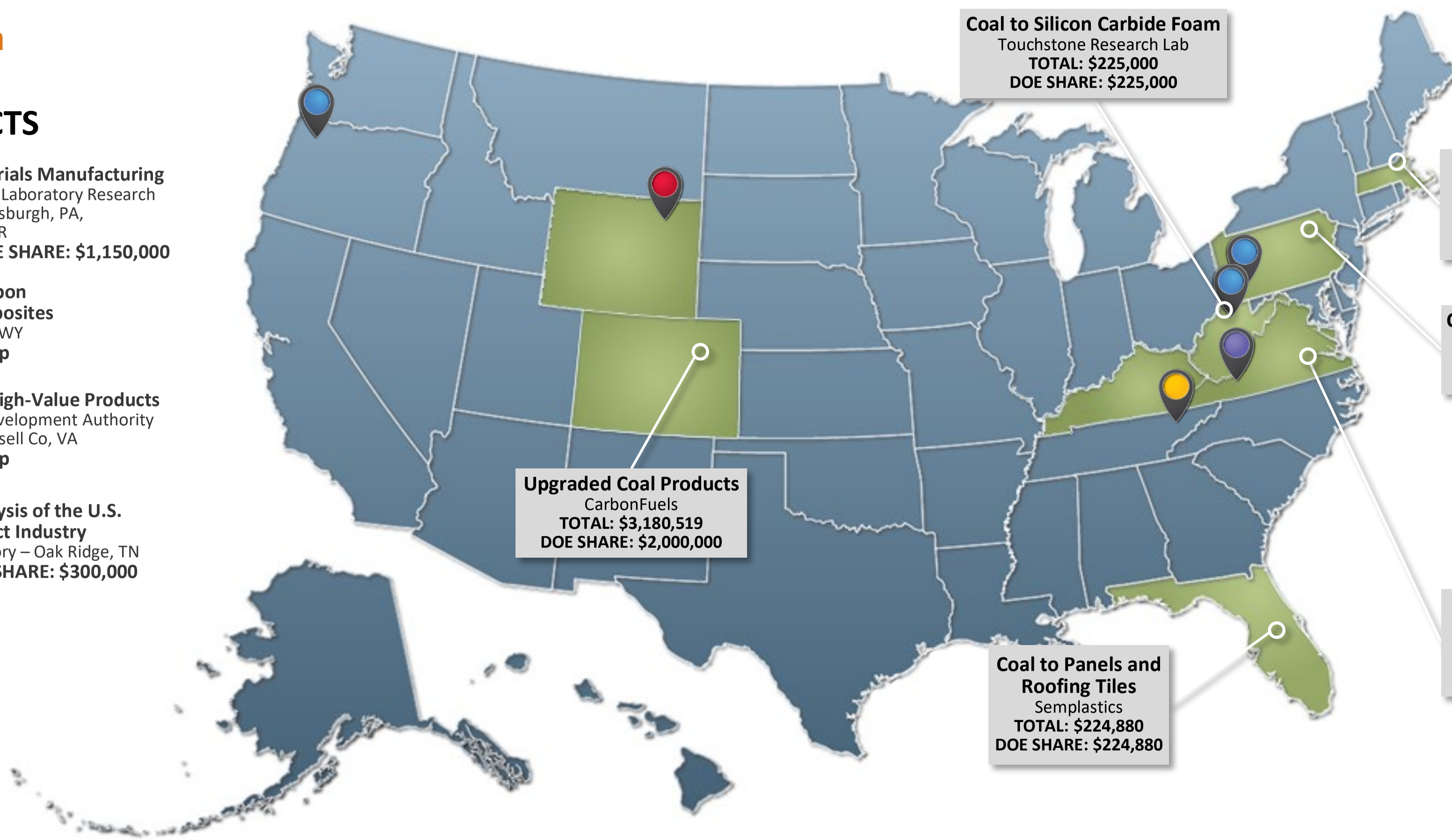
NETL RIC PROJECTS

Coal-Based Carbon Materials Manufacturing
National Energy Technology Laboratory Research and Innovation Center – Pittsburgh, PA, Morgantown WV, Albany, OR
TOTAL: $1,150,000 • DOE SHARE: $1,150,000

Converting Coal into Carbon Nanomaterials and Composites
Ramaco Carbon – Sheridan, WY
Public-private partnership

Transforming Coal into High-Value Products
Russell County Industrial Development Authority and Virginia Carbonite – Russell Co, VA
Public-private partnership

Technical Economic Analysis of the U.S. Value-Added Coal Product Industry
Oak Ridge National Laboratory – Oak Ridge, TN
TOTAL: $300,000 • DOE SHARE: $300,000



Coal Beneficiation

Projects

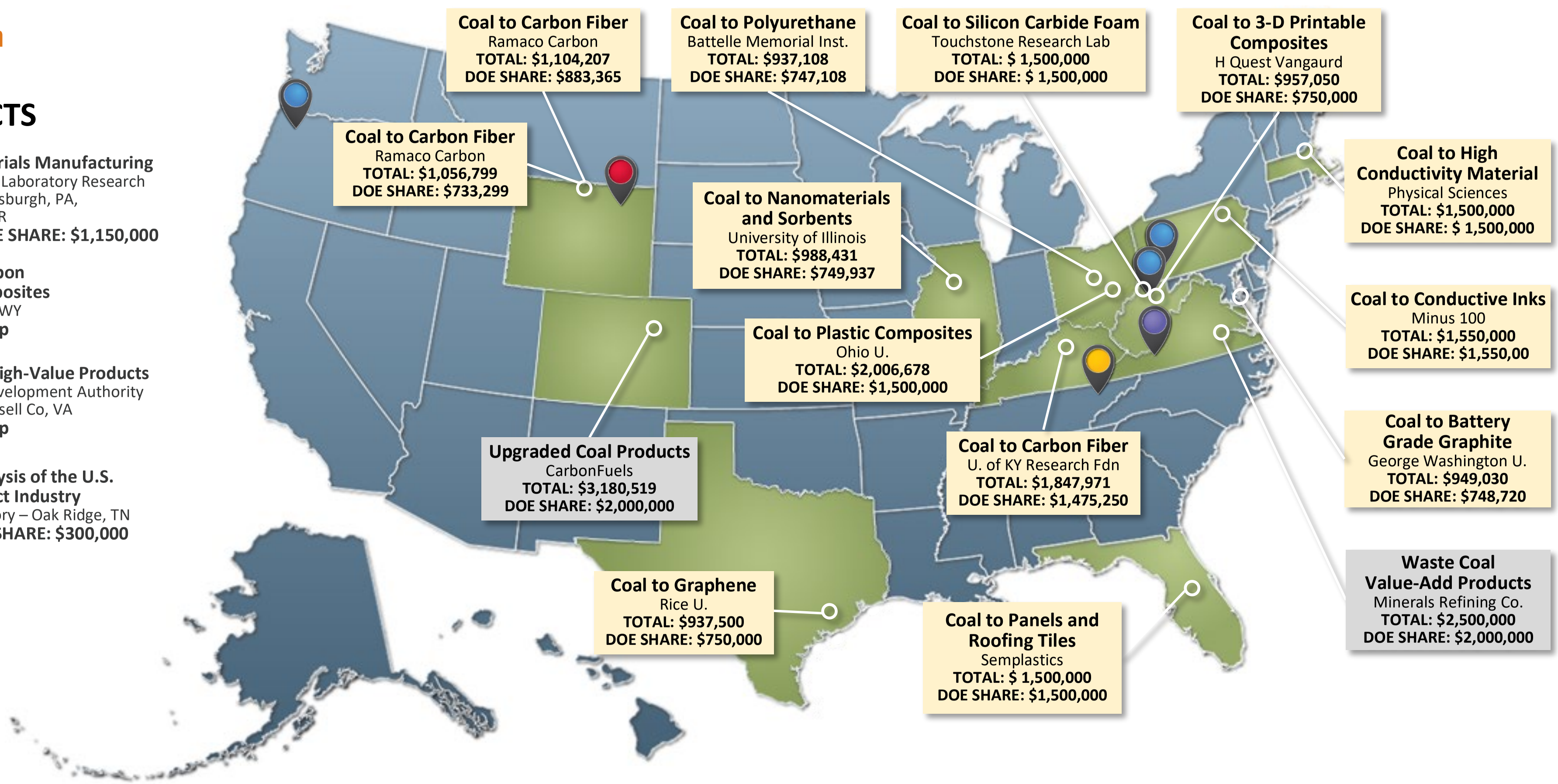
NETL RIC PROJECTS

Coal-Based Carbon Materials Manufacturing
National Energy Technology Laboratory Research and Innovation Center – Pittsburgh, PA, Morgantown WV, Albany, OR
TOTAL: $1,150,000 • DOE SHARE: $1,150,000

Converting Coal into Carbon Nanomaterials and Composites
Ramaco Carbon – Sheridan, WY
Public-private partnership

Transforming Coal into High-Value Products
Russell County Industrial Development Authority and Virginia Carbonite – Russell Co, VA
Public-private partnership

Technical Economic Analysis of the U.S. Value-Added Coal Product Industry
Oak Ridge National Laboratory – Oak Ridge, TN
TOTAL: $300,000 • DOE SHARE: $300,000



Go Further

Development of Market Opportunities for Coal Based Carbon Fiber Composites

Patrick Blanchard
Technical Leader – Advanced Polymer Systems
Ford Research and Advanced Engineering

October 16th, 2019

10 Top Reasons Why People Buy Specific Cars

1. Expected Reliability
2. Exterior Styling
3. Previous Experience with Brand/Model
4. Reputation/Reviews
5. Ride & Handling
6. Price/Payment
7. Safety
8. Fuel Economy
9. Quality of Workmanship
10. 4WD/AWD

Material selection influences many vehicle attributes but is not considered by most as a primary vehicle characteristic

Source: 2016 J.D. Power Annual Survey

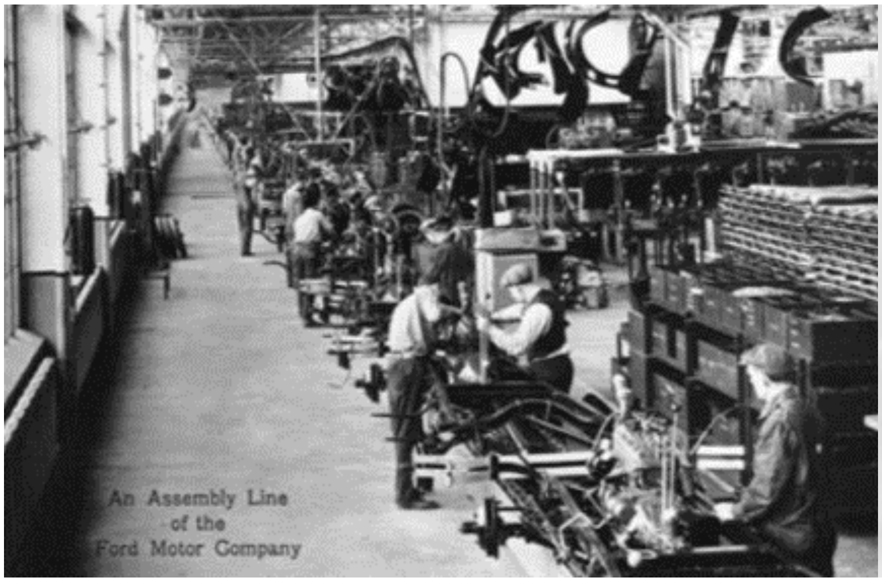
Overview

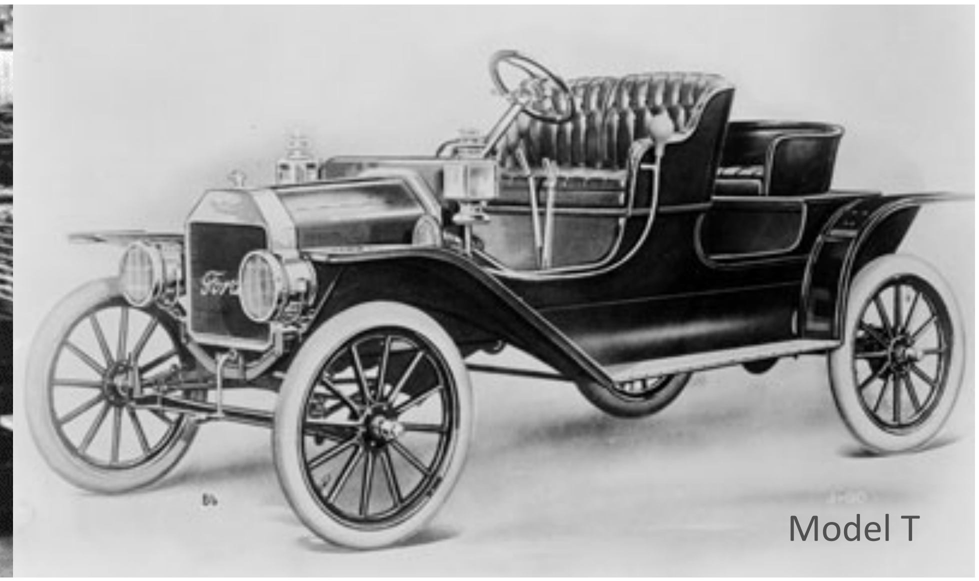
Go Further

- Automotive history and legacy infrastructure
- The current role of polymer composites
- Disruption in the automotive market
- New customer use cases
- Historical challenges to broad adoption of CF composites
- New opportunities for coal based carbon fiber

Henry Ford Invents The Moving Assembly Line

Go Further





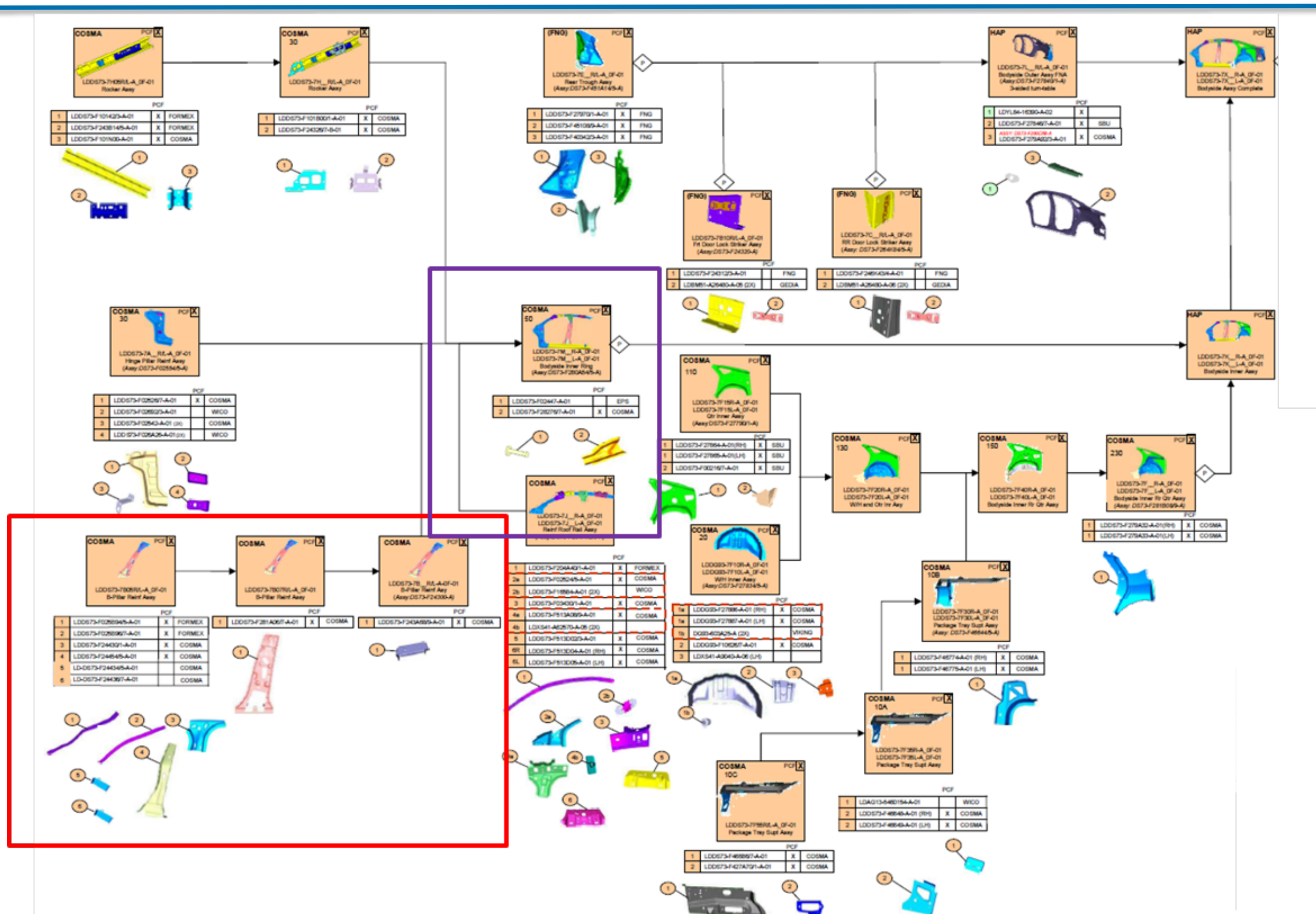
Model T

- Ford Motor Company incorporated in 1903. Opened the Piquette Plant in 1908.
- In 1913 Ford's Highland Park becomes the first auto plant to feature a moving assembly line.
- Vehicles are conveyed to the worker as opposed to the worker roaming from station to station.
- Reduced assembly time for Model T chassis from 12.5 to 1.5 hours.
- Increased throughput reduced overhead cost and enabled Henry Ford to lower the price of the vehicle. Cars become affordable to the general population.
- Ford sold 15 million Model Ts before ceasing production in May 1927.

Modern Day Assembly Plant

- Moving assembly line breaks down complex operations into simple steps of <30s.
- Typical assembly plant throughput 60 - 100 vehicles per hour.
- This innovation in assembly methodology has been replicated by all Auto OEMs and now supports a global automotive business that produces 90MM vehicles per year.

Bill Of Process For High Volume Manufacturing

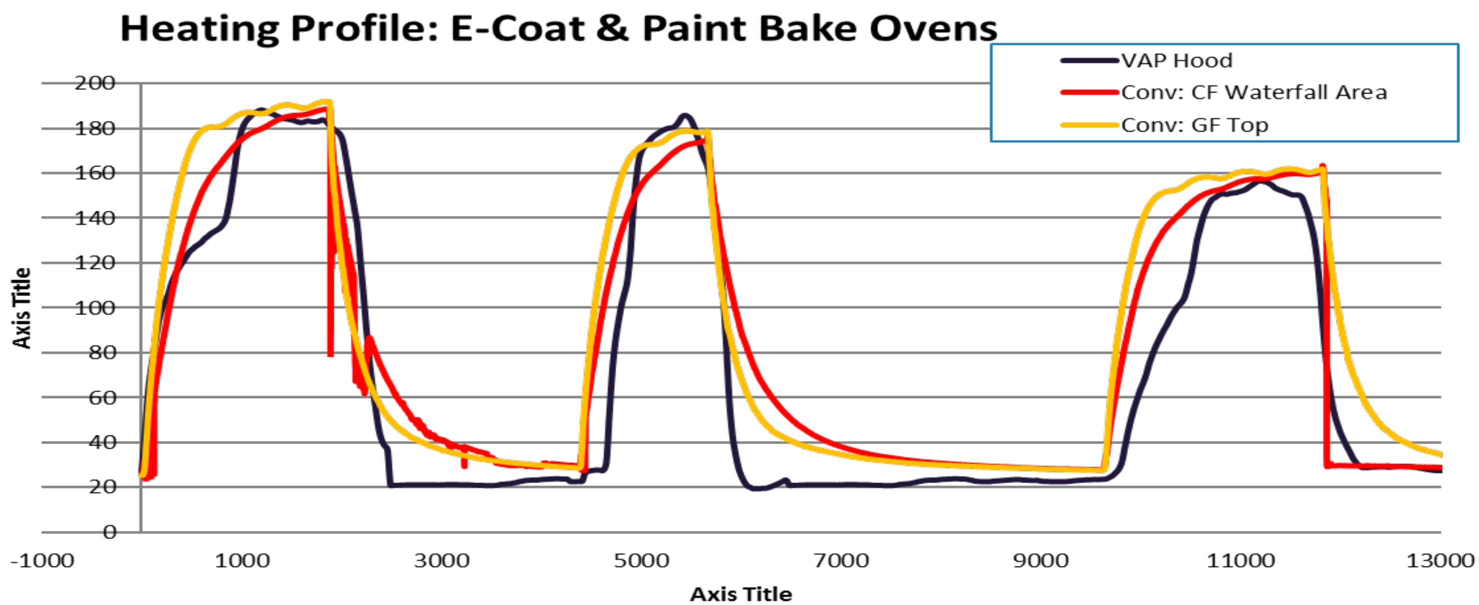


Quality operating systems and joining and assembly methods developed to maximize throughput for a given plant size

E-Coat & Paint Bake Thermal Cycle

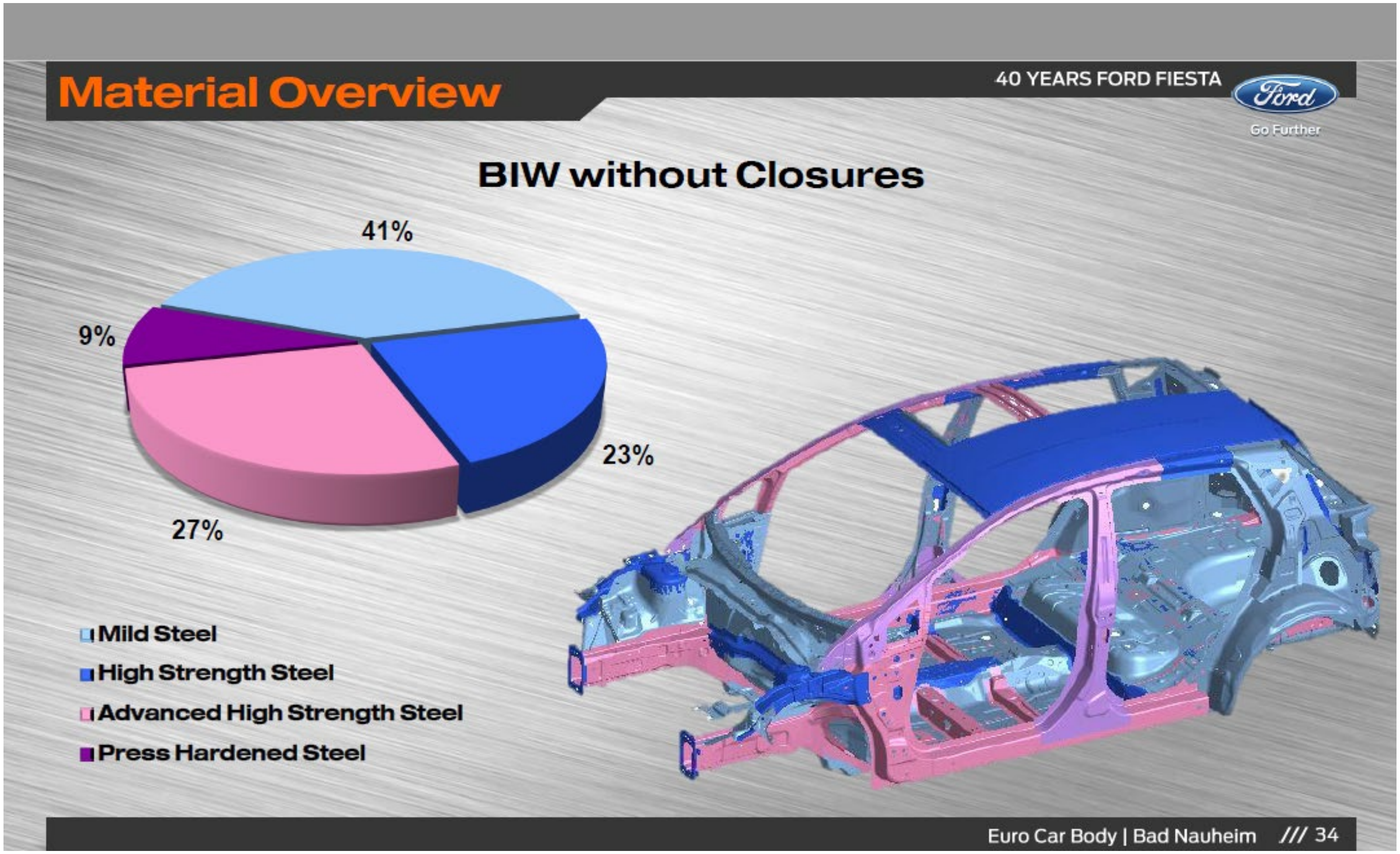
Go Further

Thermal Cycles: 190°C for 30min
180°C for 20min
160°C for 35min



Dictates minimum thermal requirements for all body shop installed parts

Typical BIW Material Content



So where have polymer composites played a role?

Front End Modules / GORs

Go Further

Edge Underbody Aero Shields

Edge Front End Bolster

Explorer Front End Bolster

Class A Body Panels

Go Further

LINCOLN

Navigator Hood

Raptor

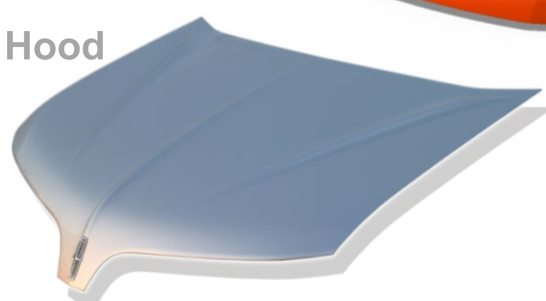
Fenders & Hood

LINCOLN

MKS Decklid

LINCOLN

MKS Hood



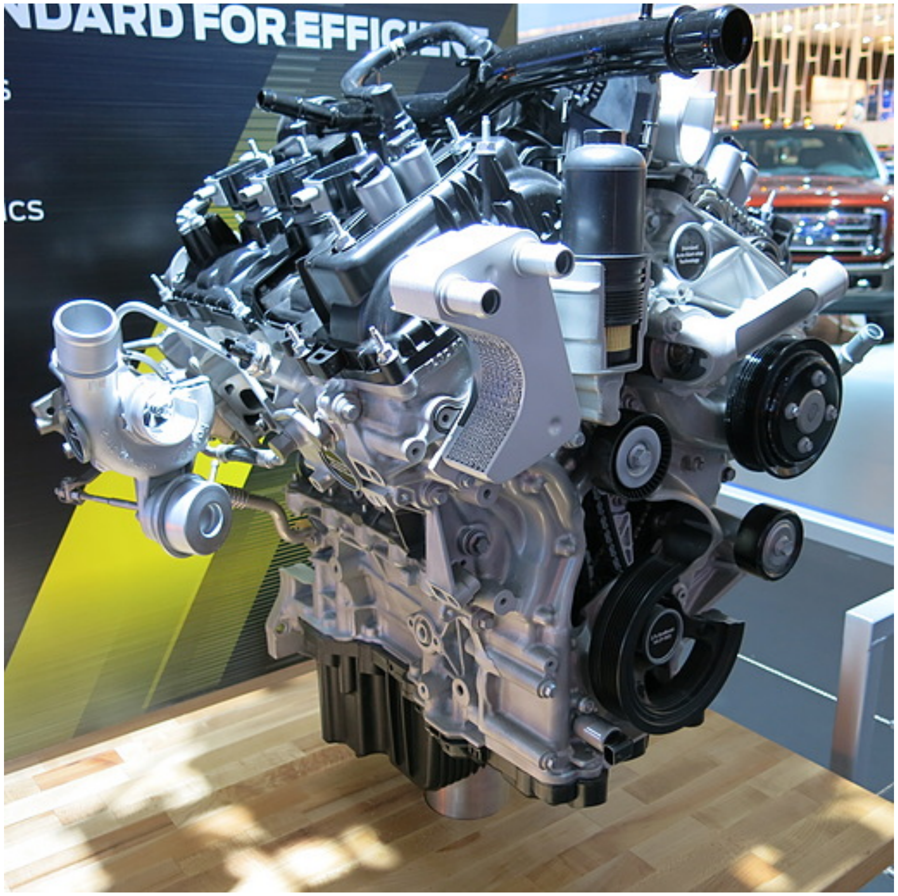
Interior Components

Go Further

Ford C-Max Composite Cross Car Beam

Ford Mustang
Second Row Seat Back

Powertrain Components

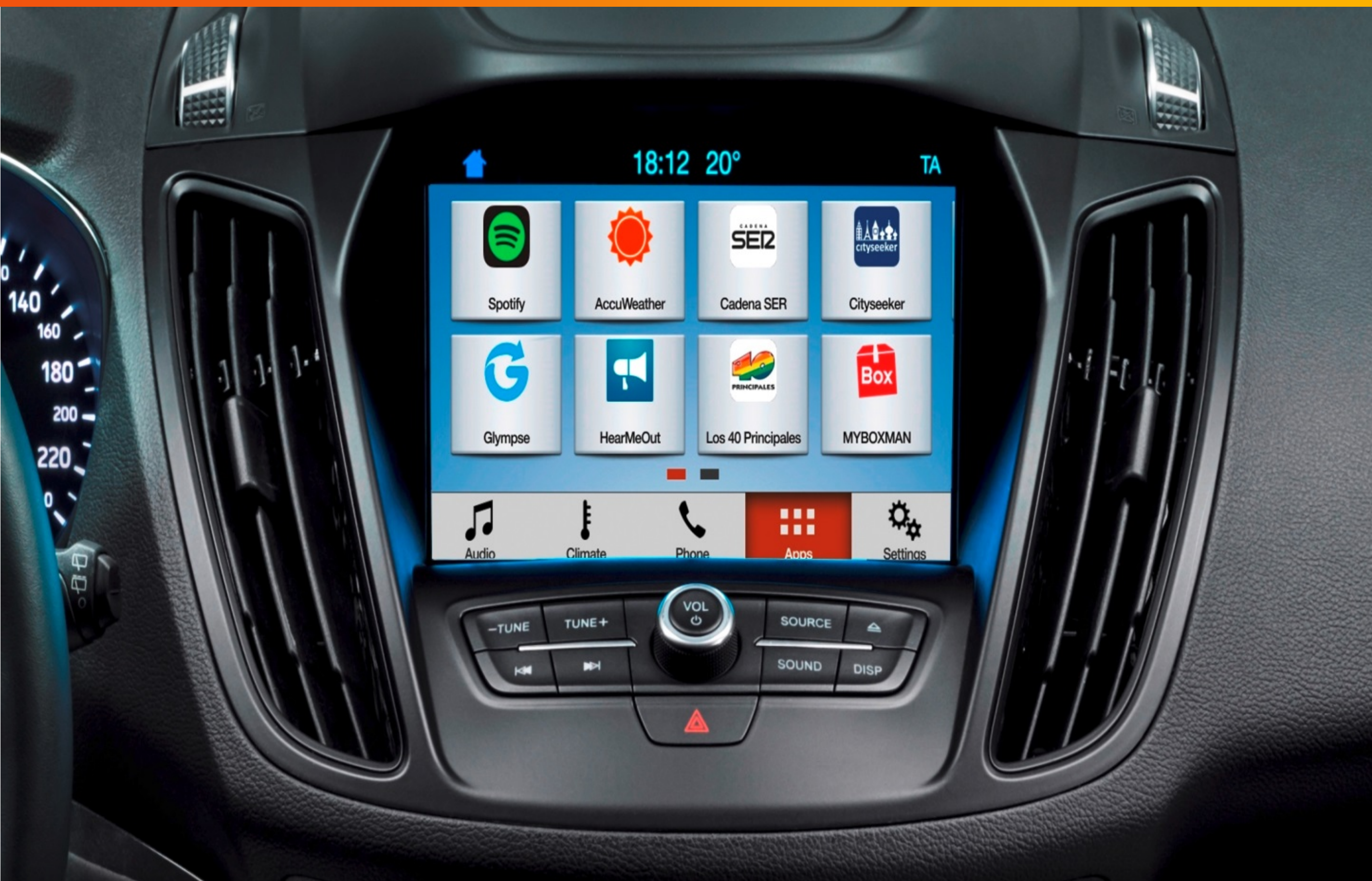


2015 Ford 2.7-L EcoBoost V6

MMLV Oil Pan & Front Cover Concepts

CONNECTIVITY

FORD SMART MOBILITY



SYNC®

2007: Launched on 12 Ford vehicles

2016: More than 15 million SYNC-equipped vehicles on the road globally

2020: Expected deployment reaching 30 million vehicles globally

Democratization of New Technologies

TECHNOLOGY TRENDS

Go Further

Revolution in Computing & Software

Data/Analytics Artificial Intelligence & Visualization

Biology & Brain Machine Interface

Connectivity Networking / Internet of Everything

Advanced Materials & Manufacturing

New Mobility & Autonomy

Clean Energy & De-carbonation

So What’s The Impact On New Vehicle Design?

Go Further

New Use Cases And Ownership Models

- Personal / Shared ownership
- Ride Share – UBER/LYFT/AV
- Delivery services
- Evolution of new EV based vehicles

Re-definition of vehicle use cases presents a unique opportunity to re-invent the primary vehicle architecture to meet the need for future functionality

New Opportunities For Composite Materials

Redefining The Occupant Space

- Reconfigurable seating (forward/rear facing and articulating seat systems)
- Interior cabin experience
  - Most contact surfaces for the occupant are produced from polymer composites
  - Smart surfaces and integrated sensors
- NVH enhancements for BEV platforms
- Composites as an enabler for sensor integration (internally/externally facing)
- Closed loop recycling of sustainable materials
- Weight management with increased vehicle content.

To accommodate a transformational shift in vehicle use cases, driving modes and powertrains, legacy bill of materials/processes will need to be updated.

Material Selection Through The Perspective Of An Automotive Engineer

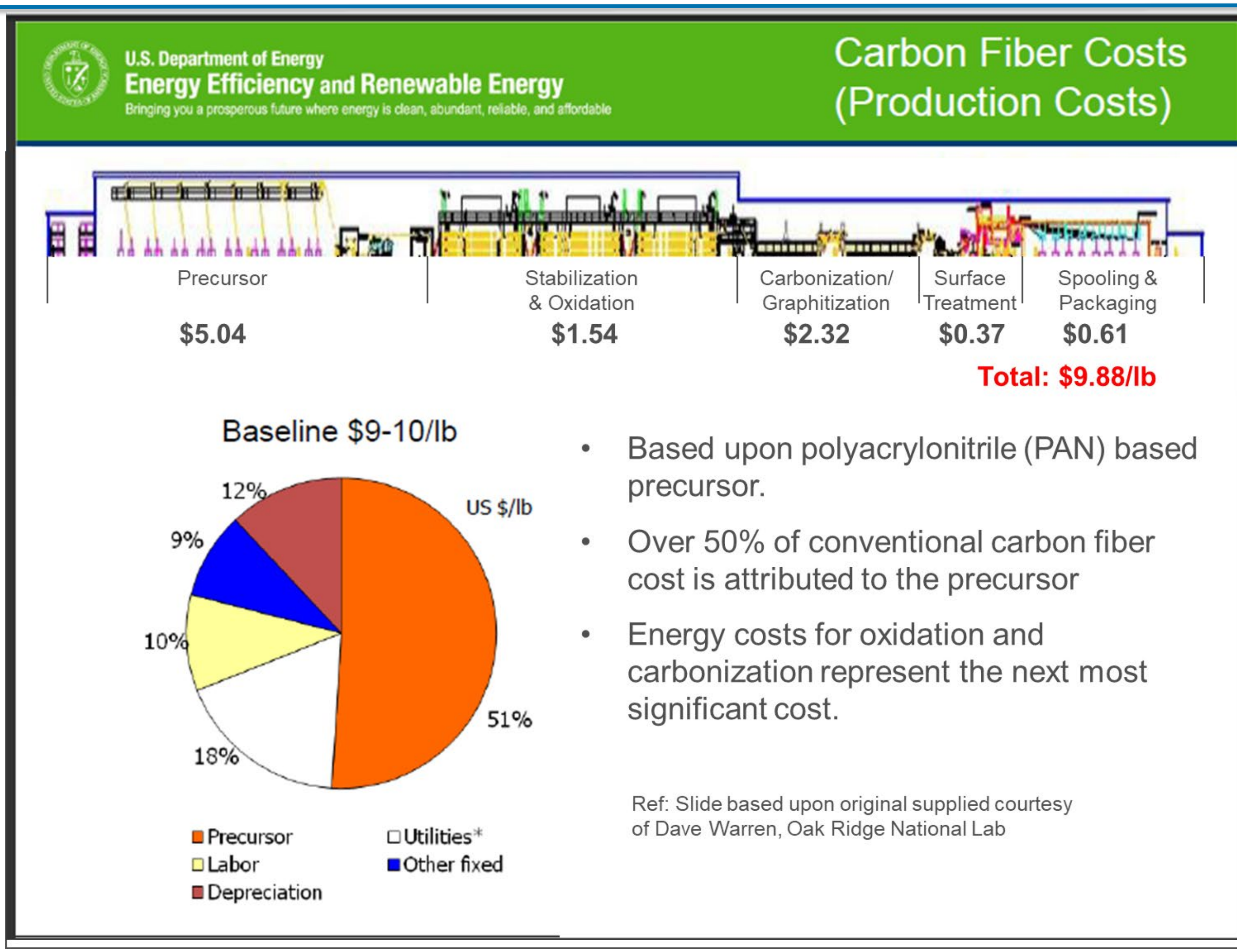
Go Further

1. Piece cost & tooling investment
2. Mass reduction
3. Package envelope
4. Intrinsic properties (e.g. stiffness / strength)
5. Design lead time and simulation capabilities
6. Testing and prototyping requirements
7. *Functional integration*
8. *Styling/Design flexibility*
9. *Impact on "Bill of Process"*
10. *Sub-system joining and assembly methods*

Performance projections for higher modulus coal based carbon fiber creates the potential to compete directly with metallic based alternatives

Cost Breakdown of PAN Based Carbon Fiber Process

Go Further



Source: ORNL

Impact of Material Cost When Transitioning From Low to High Volume

Implications of Current Fiber Pricing

Mustang GT500 Hood

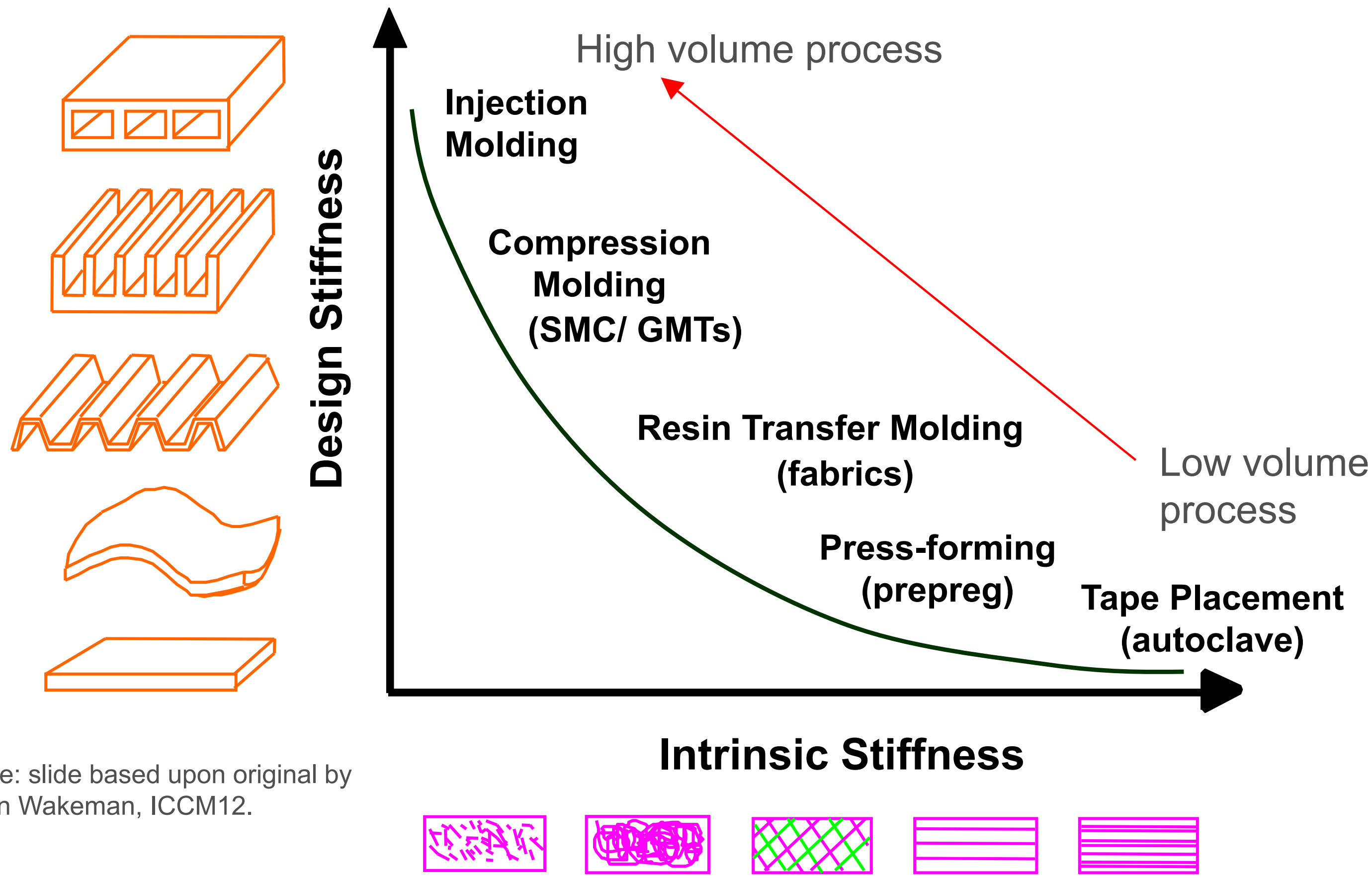
	Wt. (lbs)	Piece Price	Total Cost @10K	Total Cost @200K	$/lb Wt. Save
Steel	42	1	1.8	1	-
Glass SMC	36	1.4	1	1.2	3.3
Aluminum	28	1.25	2.2	1.2	1
Carbon Fiber	25	3.8	2.4	3.3	10.6

Low Volume (Total Cost @10K)

High Volume (Total Cost @200K, $/lb Wt. Save)

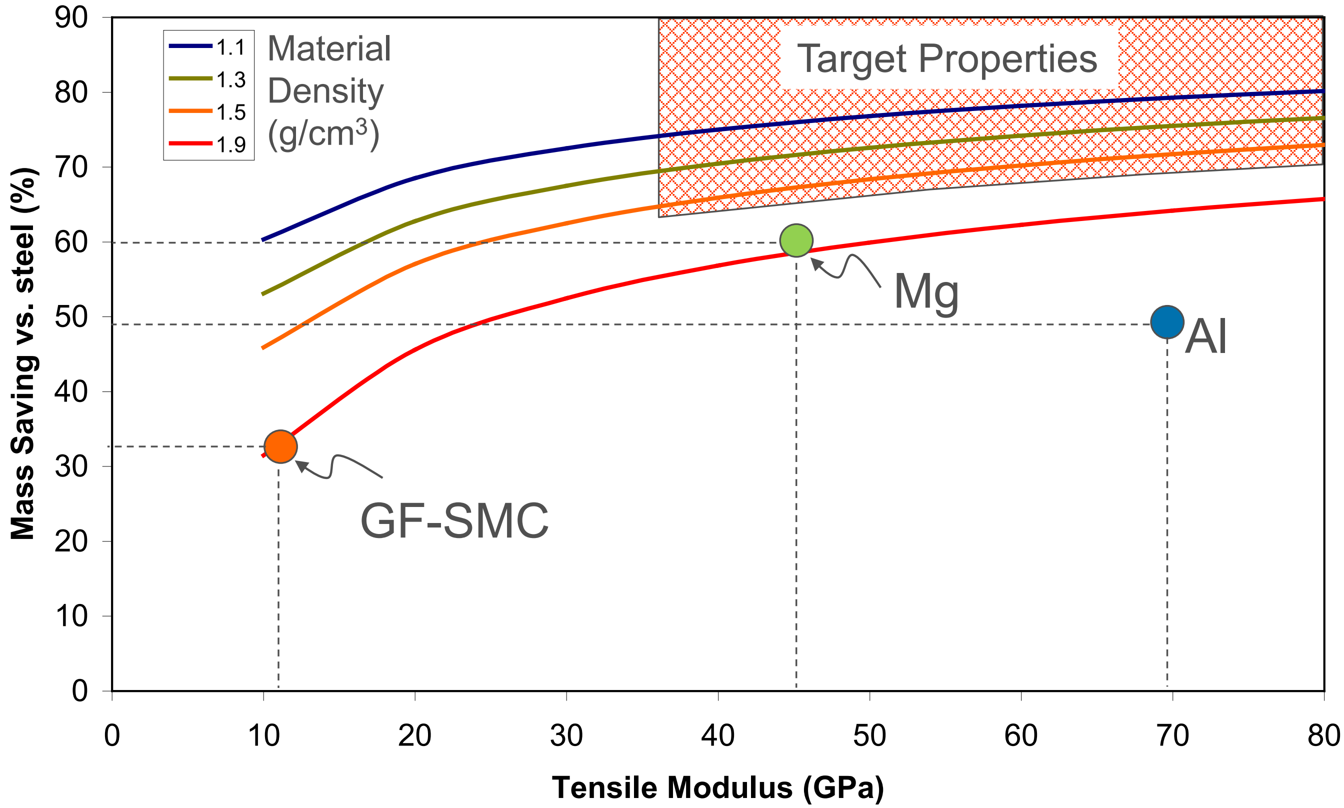
- Tooling amortization has a major impact on the business case depending on the production volume.
- At 10k units/yr, carbon fiber can be a competitive weight buy compared to alternate materials.
- At 200k/yr, Al is the arguably the best option for weight savings at $1/lb cost premium.
- Hence, lower cost/higher performing carbon fiber are required for high volume applications to be cost effective.

Design vs Intrinsic Stiffness



Source: slide based upon original by Martyn Wakeman, ICCM12.

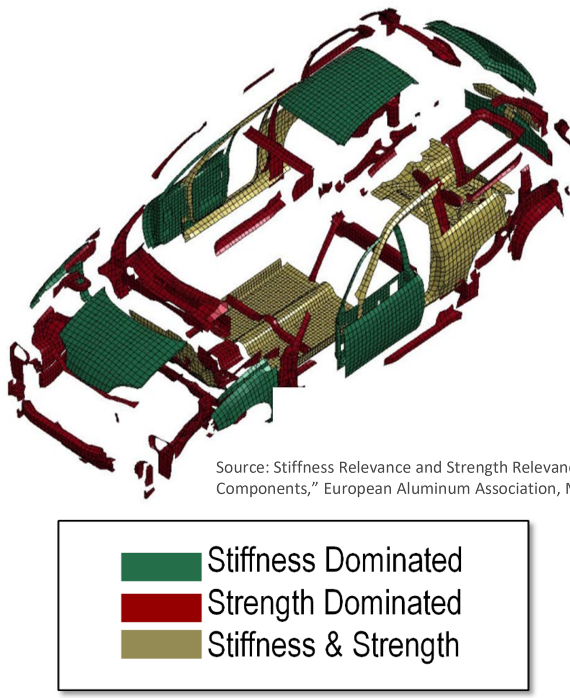
Mass Savings Over Steel Based Upon Equivalent Plate Bending Stiffness



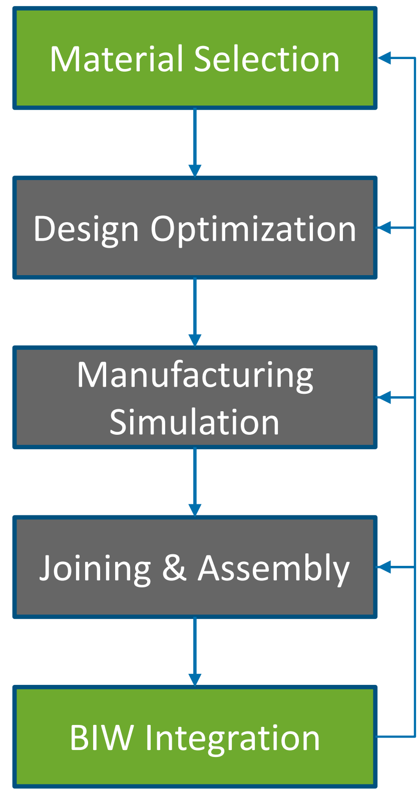
Recent successes already reported in development of CF-SMC products

Vehicle Development Process

Go Further



Source: Stiffness Relevance and Strength Relevance in Crash of Car Body Components," European Aluminum Association, May 2010



Coal based CF analysis capabilities will need to be developed in order to compete with time to market to alternate metallic solutions.

Proposed Market Space For Coal Based CF In Automotive

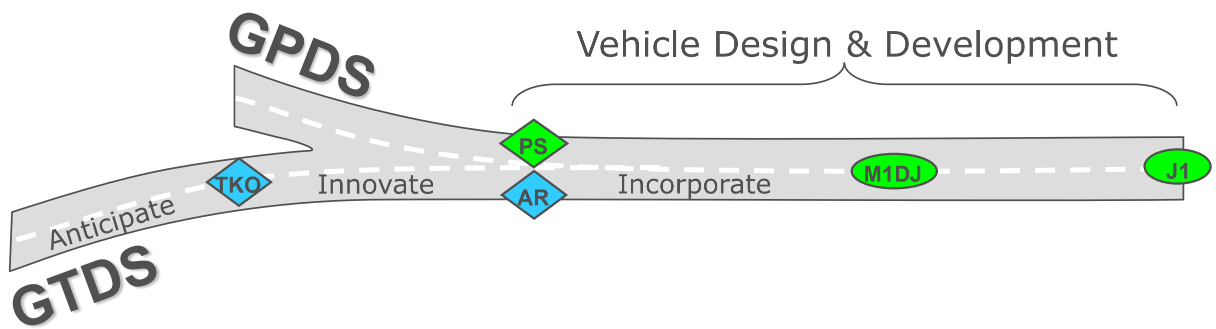
Go Further

1. Development of discontinuous chopped products as opposed to fabric (textile) broad goods
2. Displacement of PAN based carbon fiber in injection and compression molded derivatives

Benefits of this approach include:

- Takes advantage of improved cost per modulus for coal based CF, becoming competitive with glass based composites
- 3x stiffness over glass fiber based systems
- Conforms to existing capital infrastructure
- 100% material utilization
- Ability to conform to the same design package as metallic solutions
- Thermoplastic solutions facilitate end of life recycling

Closing Remarks



- The invention of the modern day assembly line and subsequent legacy infrastructure has been an impediment to broad scale adoption of polymer composites in primary body structure
- However, re-definition of the automobile in the context of future mobility creates a unique opportunity to re-define material solution for future bill of process.
- New coal based carbon fiber has the promise to provide an economic pathway to higher modulus composites that can compete with alternative light metal solutions
- Support from the supply base will be needed to develop analytical tools capability for both material performance and manufacturing simulation.

Go Further

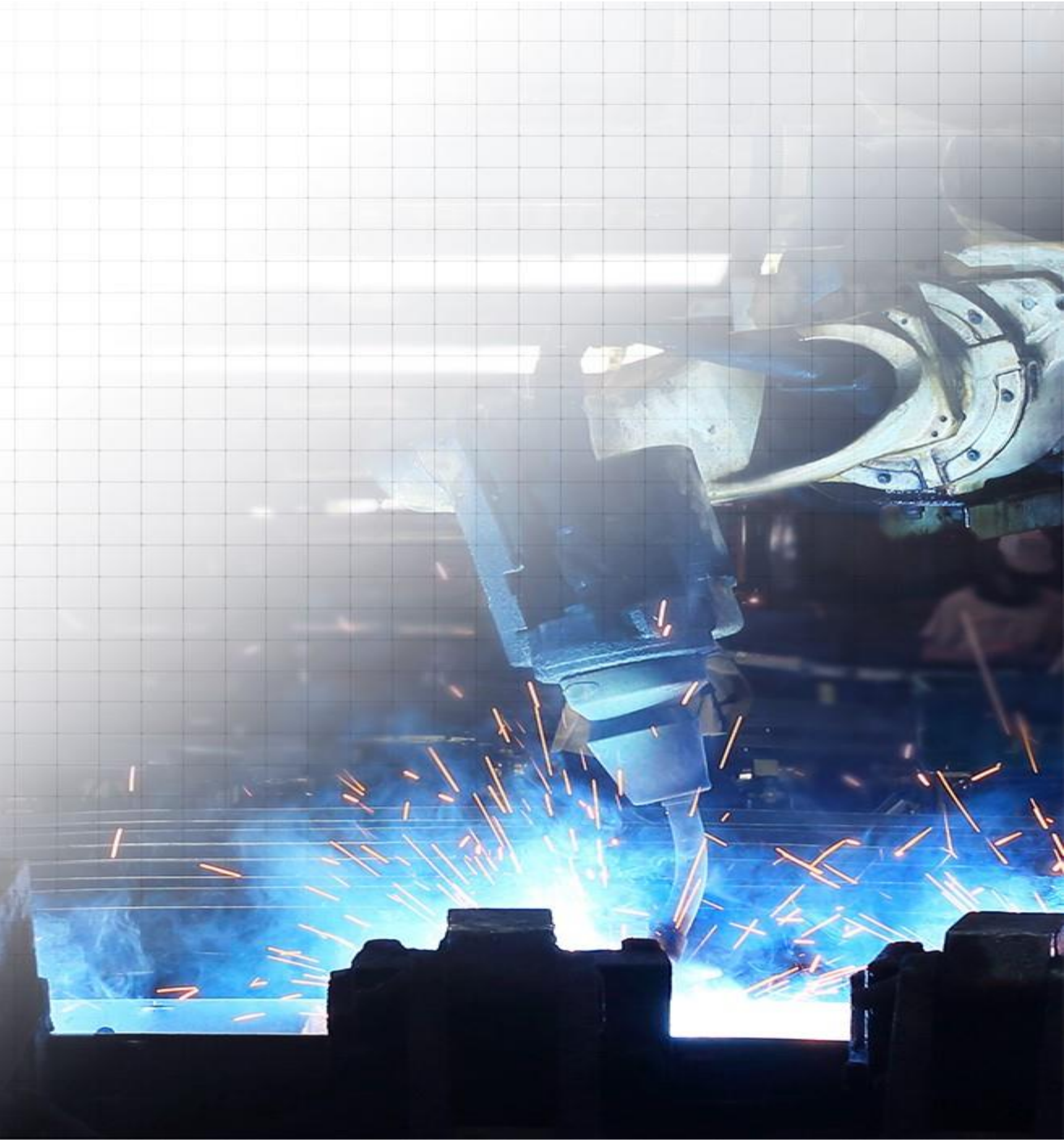
QUESTIONS ?

JR AUTOMATION™

October 16, 2019

LOW COST HIGH-MODULUS CARBON FIBER

DALE LEFTWICH
BUSINESS DEVELOPMENT MANAGER
DLEFTWICH@JRAUTOMATION.COM
615.308.2014



JR AUTOMATION™

JR Automation: At a Glance

Year Established: 1980
Annual Sales: $600,000,000+
Facilities: 1,200,000+ sq. ft. across 23 locations in North America, Europe, and Asia
Employees: 2,000+

- Multi-discipline expertise
- Cross-industry experience
- Over 30% of employees work in engineering functions
- ISO 9001 Registered
- Authorized FANUC System Integrator
- Authorized ABB Integrator
- RIA Certified Robot Integrator
- ITAR Certified Facilities

ISO | FANUC Authorized System Integrator | ROBOTICS VALUE PROVIDER ABB | ria CERTIFIED Robot Integrator | ITAR International Traffic in Arms Regulations

JR AUTOMATION™

LOCATIONS

HQ: Holland, MI, USA (7 facilities)
Stevensville, MI, USA
Auburn Hills, MI, USA (2 facilities)
Nashville, TN, USA
Liberty, SC, USA
Greenville, SC, USA
Ogden, UT, USA (5 facilities)

Besançon, France
Valence, France

Cluj-Napoca, Romania

Singapore

Beijing, China

Global Footprint

With our recent acquisitions, JR Automation now has 23 facilities spread throughout North America, Europe, and Asia.

JR AUTOMATION™

40+ Years of Experience in Fibers

JR Automation offers advanced fiber solutions for many applications. We aim at enabling our customers to implement their proprietary processes and manufacturing technologies from concept to start-up while maintaining complete confidentiality.

Industries Served

- PAN & Carbon Fiber Lines
- Pitch Conversion Systems
- Coating & Laminating
- Nonwovens
- Composites / Pre-pregs
- Glass Fibers
- Web Handling
- Advanced Fibers
- Staple & Filament Lines
- Fiber Optics

JR AUTOMATION

Conoco Cevolution - 1995

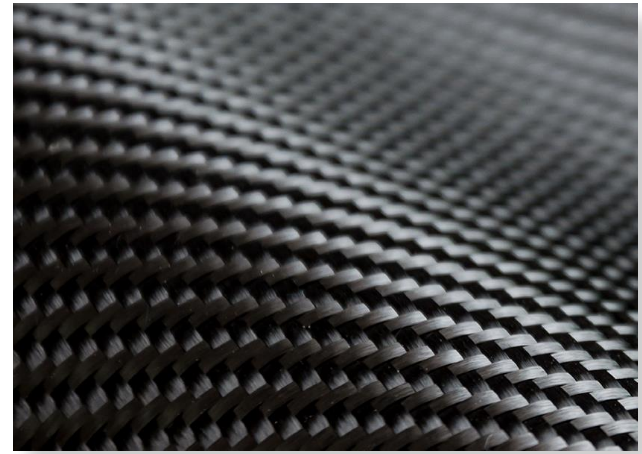
- Technical Specification
  - Tensile Modulus of 200 GPa (30 Msi)
  - Tensile Strength of 1.7 GPa (200 ksi)
- Plant Capacity – 25K tpy
  - With future additional lines planned
- Target Cost - $6.60/kg ($3.00/lb) in 2000
- Largest Target Markets
  - Automotive
    - Body Panels, Brakes, & Batteries
  - Reinforcement Markets
    - Structural Concrete Panels & Pipes
    - Highways and Roads
  - Performance Markets
    - Cell Phones, Laptops, Business Machine
- Conoco's estimated market potential was over 1 Billion Pounds Annually

JR AUTOMATION™

Pitch Carbon Fiber Attributes

- Low Cost
- High Carbon Yield
- Low Shrinkage
- Stretching not needed to obtain mechanical properties
- Inexpensive Feedstock
- Melt Spinnable
- Low Effluent hazards vs. PAN
- Can be Spun and Heat Treated in Web Form

Target Goals to Achieve Success



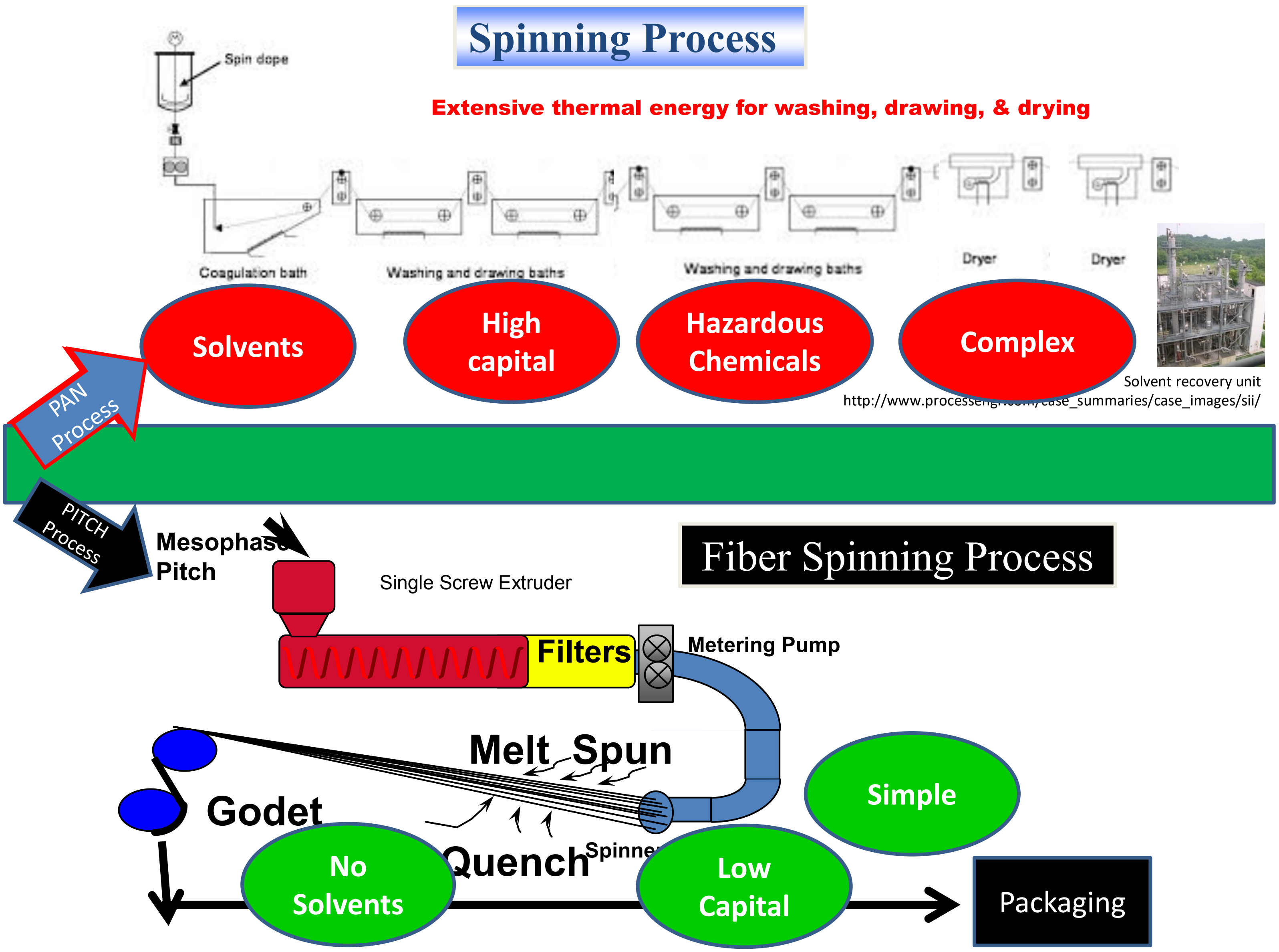
- Duplicate Solvay P55 technical spec
  (Twice the stiffness and modulus of Conoco target)
  - Tensile Modulus of 400 GPa (60 msi)
  - Tensile Strength of 1.9 GPa (275 ksi)
  - Density of 2.0 g/cc
- Convert raw material source from petroleum to coal
- Build pitch conversion system to supply CFTF spinning system for development trials
  - CFTF has the technical capability in current furnace to achieve the needed higher temperatures for this process
- Build a production line capable of 10,000 tpy or higher
- Achieve price point of $10 / KG or less

JR AUTOMATION

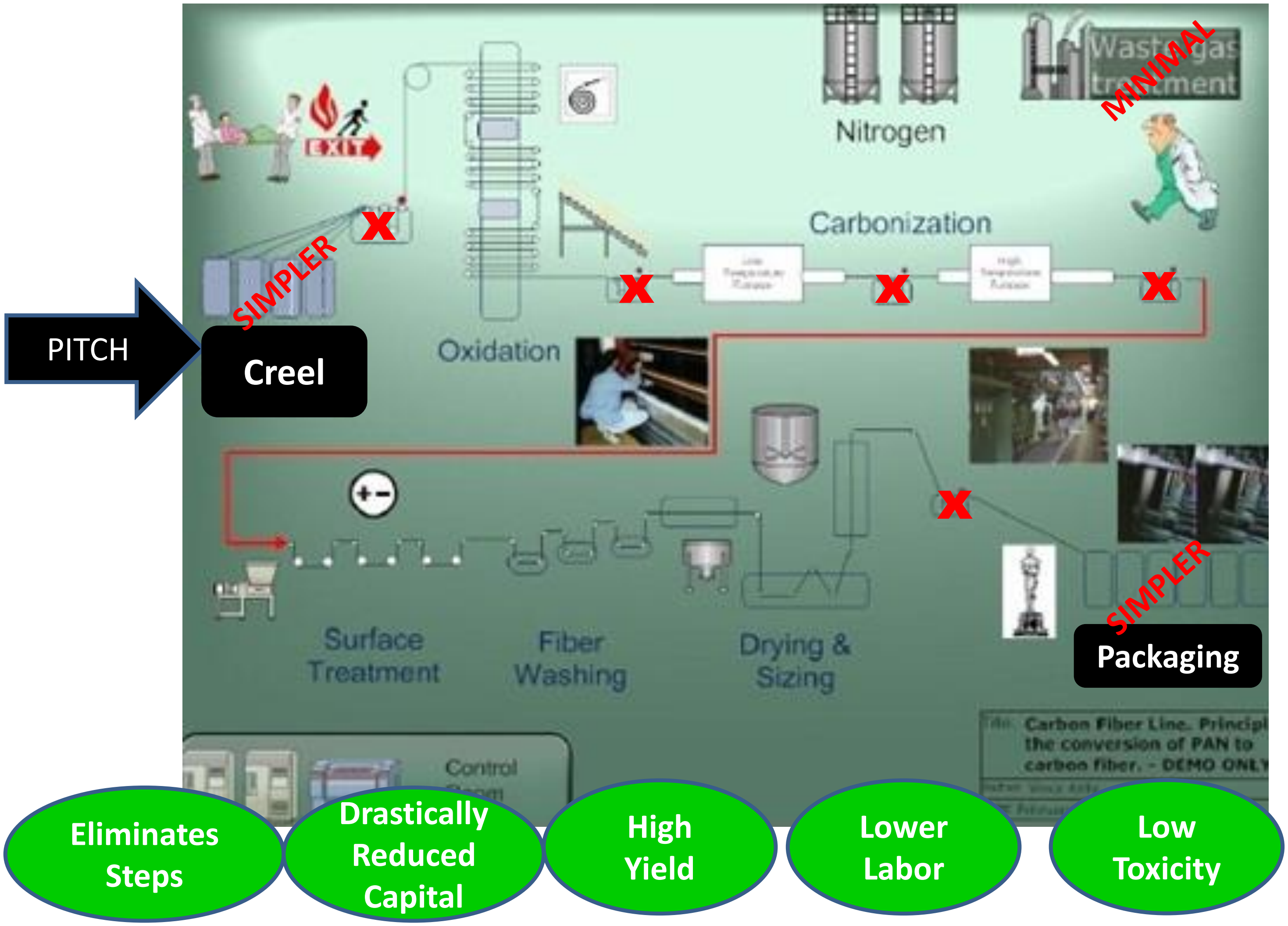
Industrial Grade Reinforcement Fiber Comparison

Value parameter	Tensile modulus	Density	Approx. Price	Stiffness / price	Specific stiffness / price
Reinforcement type	GPa	g/cc	USD 2019	GPa/$/kg	GPa/$/liter
E-glass	70	2.5	$ 1.50	47	19
Industrial grade PAN CF	240	1.8	$ 18	13	7
Recycled CF	240	1.8	$ 8	30	17
Textile PAN CF	270	1.8	$ 13*	21	12
Industrial grade Pitch CF	400	2.0	$ 10*	40	20

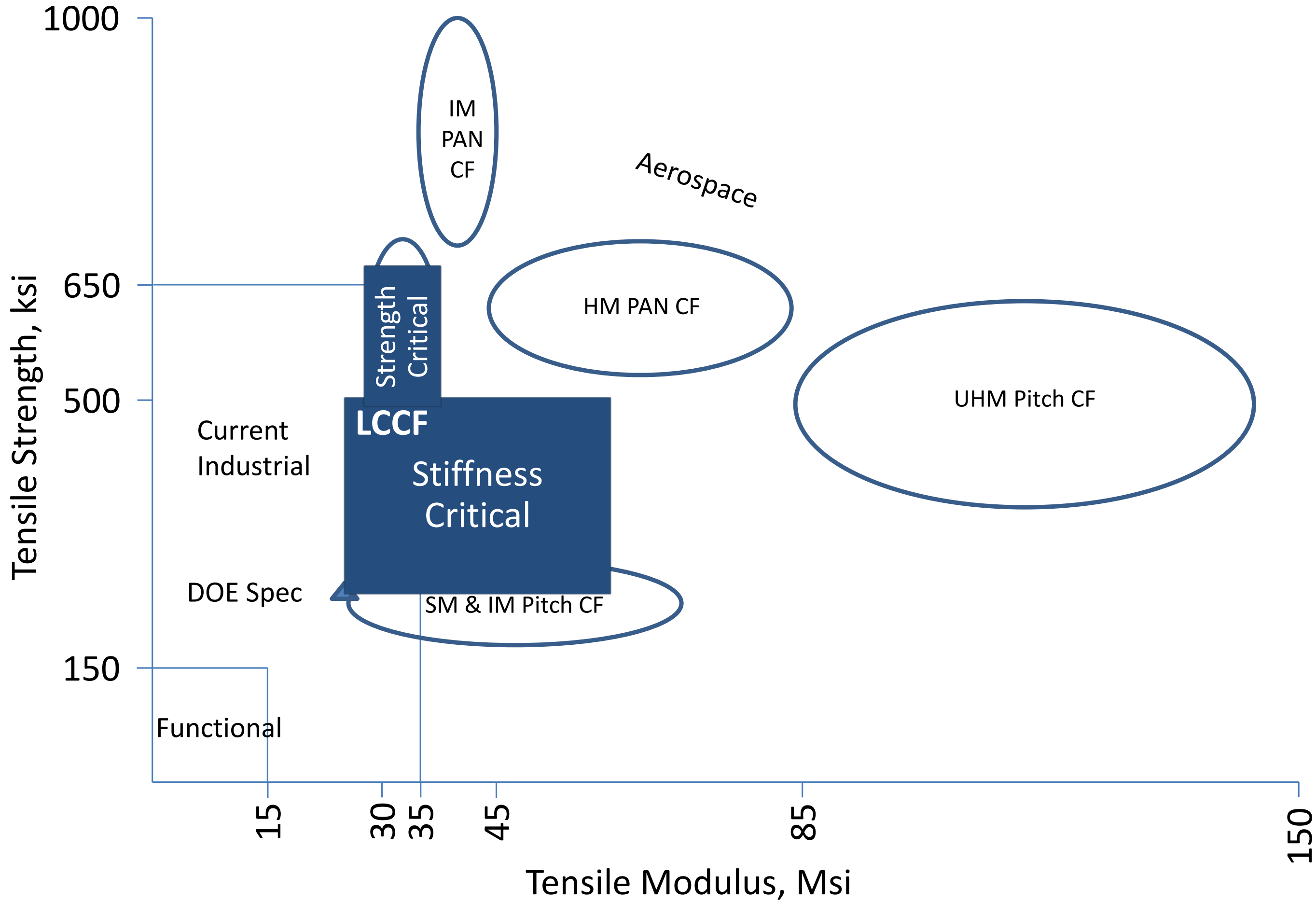
* Estimated textile Pan and Pitch CF prices assume that technical targets are satisfied and commercial scale production occurs in supply-demand balanced market with typical operating overheads and profit margins


Spinning Process
Extensive thermal energy for washing, drawing, & drying
Spin dope
Coagulation bath
Washing and drawing baths
Washing and drawing baths
Dryer
Dryer
Solvents
High capital
Hazardous Chemicals
Complex
Solvent recovery unit
http://www.processeng...case_summaries/case_images/sii/
PAN Process
PITCH Process
Mesophase Pitch
Single Screw Extruder
Fiber Spinning Process
Filters
Metering Pump
Melt Spun
Godet
Quench
Spinner
Simple
No Solvents
Low Capital
Packaging

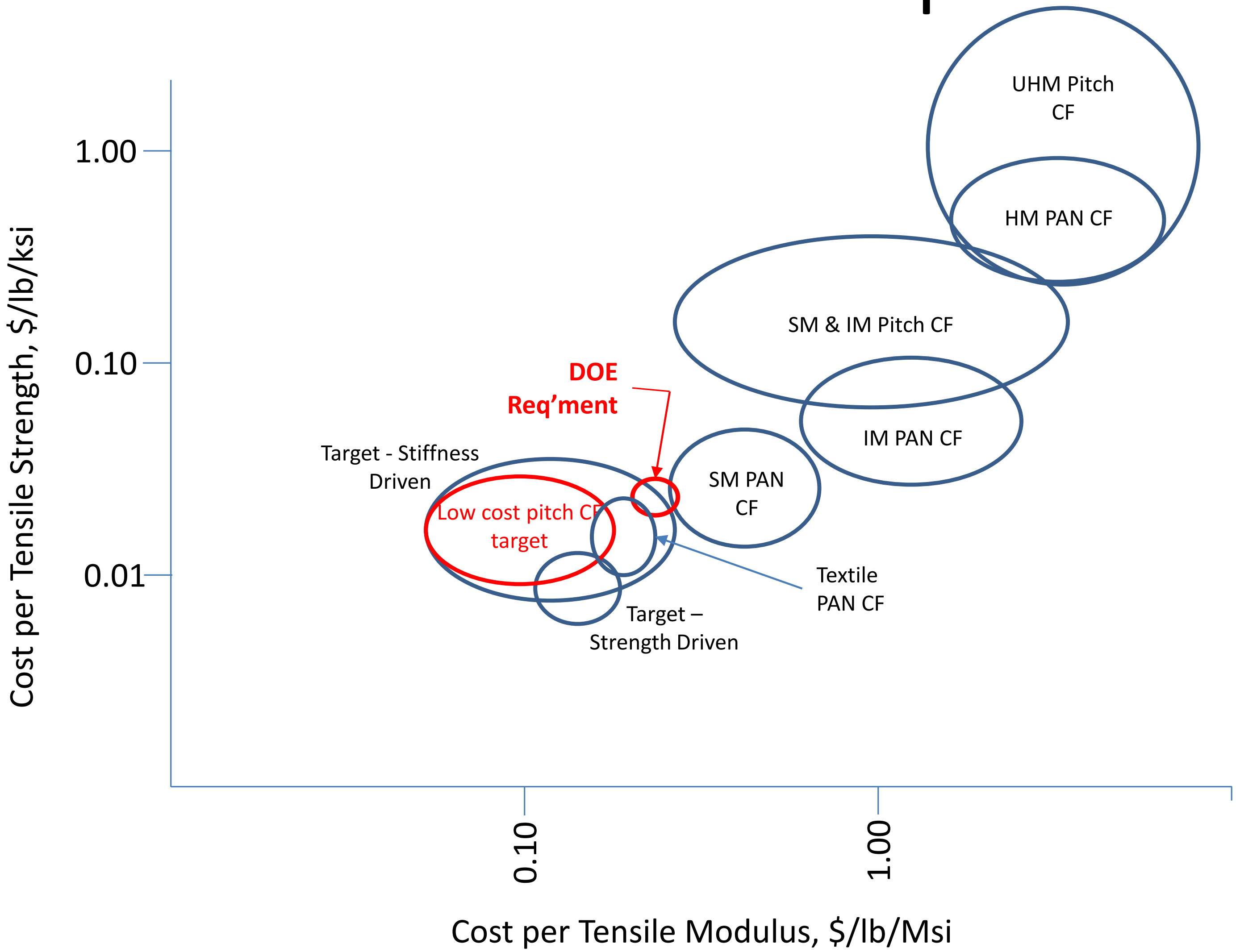
Thermal Conversion Process for Fibers



Classes of Commercial Carbon Fibers



Cost of CF Tensile Properties



Summation

- IACMI and Stakeholders have all the technical and material resources available to meet our goals.
- Our lessons learned to date combined with the capability of ORNL, CFTF, and our industry experts give us a very high probability of success
- Based on JRA’s experience with pitch based systems, we feel the technical and cost targets for this program are achievable
- The Time is Now!... This is a generational opportunity that will affect our familes, the USA, and our competivieness in the world for years to come…

Thank You…

JR AUTOMATION™

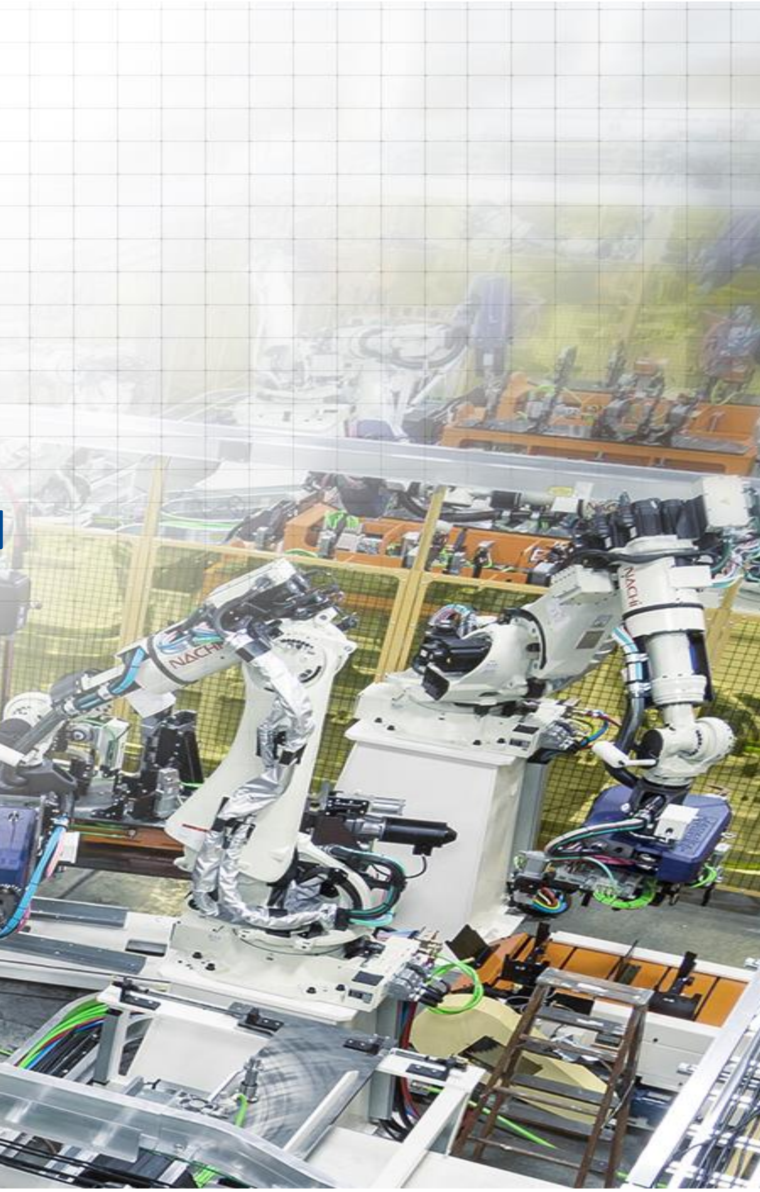
ACKNOWLEDGEMENTS

CHRIS LEVAN, CARBON FIBER SOLUTIONS

IACMI TEAM

ORNL TEAM

TIANNA LUTZ & PROCESS TEAM, JR AUTOMATION



JR AUTOMATION™