TESTIMONY OF RANDALL W. ATKINS

CHAIRMAN AND CHIEF EXECUTIVE OF RAMACO COAL APPEARING BEFORE THE UNITED STATES SENATE COMMITTEE ON ENERGY AND NATURAL RESOURCES

"The New Carbon Age"

Chairman Manchin, Ranking Member Barrasso and other Senators of the Committee, it is an honor to appear before you.

I am particularly honored that the two ranking members of this Committee are from West Virginia and Wyoming, both States that I proudly call home, as well as where our companies have their operations.

Coal today is basically thought of as a cheap, controversial, environmentally challenged fuel combusted in power plants. What if we looked at the use of the commodity thru an entirely different lens and assumed that "***coal is too valuable to burn***". It therefore does not become an emitter of greenhouse gas.

Today, I would like to discuss a fundamentally new, environmentally positive use for carbon derived from coal. Our approach is to use the commodity as a low-cost carbon feedstock to make high-value advanced carbon products and materials that we call "**coal to products**". We have coined the phrase "**carbon ore**" to refer to coal used in this manner.

As an overview, I would first refer the Committee to the White Paper I chaired to then Secretary of Energy Perry in 2019 from the National Coal

Council entitled "Coal in the New Carbon Age". https://www.nationalcoalcouncil.org/studies/2019/NCC-COAL-IN-A-NEW-CARBON-AGE.pdf

Our advances for the use of coal for chemical and material purposes, borrow from developments in the U.S. from the early parts of the 20th century,… before coal was supplanted by petroleum for use as a basic chemical feedstock. Today most carbon products are made from petroleum feedstocks which are almost 40 x more expensive than the same carbon equivalent from coal.

We are also substantially behind China in pursing this path. The IEA estimates that China annually now uses roughly 400 million tons of coal to produce chemicals, fuels and fertilizers. Their new 5-year plant calls for construction of 370 new coal to product plants (or one new plant a week). By 2024, they will annually consume a billion tons of coal. In comparison, the U.S. will produce this year only about 580 million tons.

We originally embarked on our effort eight years ago, encouraged by new technology developments in advanced materials and manufacturing. We have worked on grants for innovative carbon research with the Department of Energy (**DOE**). We also have had an unparalleled partnership with the National Labs, especially NETL in both Pittsburg and Albany, Oregon, as well as Oak Ridge National Lab in Tennessee.

Carbon is becoming the dominant "advanced material" of the 21st century - think carbon fiber, graphite, graphene, porous carbons and even bio-medical uses.

If we could make these carbon materials for less cost using coal, it would have a dramatic positive disruption on the cost structure of many industries, as well as improve the environmental and qualitative aspects of many products.

So what product and material areas are we currently pursuing? I refer to my appendix for a more complete description, but a partial list is:

- ***Porous activated carbons*** for fuel cells, catalytic supports and direct carbon capture,
- ***Graphene*** ranging from both high-volume applications like paint and cement additives… to also exceedingly high margin but lower volume products such as electronics and life science applications like medical diagnostics and bio-sensors,
- ***Carbon fiber*** for stronger and lighter planes, electric vehicles, missile technologies,
- ***Building products*** for new forms of commercial and residential carbon structures, basic products like rebar, fiber insulation and for rebuilding aging infrastructure
- ***Synthetic graphite*** anodes used in EV batteries, and
- ***Rare earth elements*** for electronics, magnets and strategic defense products.

We recommend vastly more funding for carbon research and implementation of the "**Coal Tecc**" provisions of the Energy Bill of 2020. We also encourage the funding of pilot facilities to implement these new

carbon technologies. Indeed, this summer will open the first "iCAM" research center prototype in Wyoming pictured in the attached materials.

As a second recommendation, I would encourage the development of what I call "**Carbon Camps**". 100 years ago, my grandfather ran small company stores in southern West Virginia, at what used to be called "Coal Camps", which I know Senator Manchin is very familiar with. The 21st century version of CAMP stands for "**Carbon Advanced Materials and Product" centers**.

These CAMPs can repurpose older and existing mining areas across the country into new mine-mouth, higher tech, net zero emission manufacturing hubs. NETL has estimated this might create as many as almost 500,000 new jobs.

In conclusion, the United States possesses the world's largest and cheapest ***carbon*** reserves. It needs to capitalize on that advantage and develop its own form of a "Carbon Valley" to unlock that full potential.

I deeply thank you for your time.

Appended Material

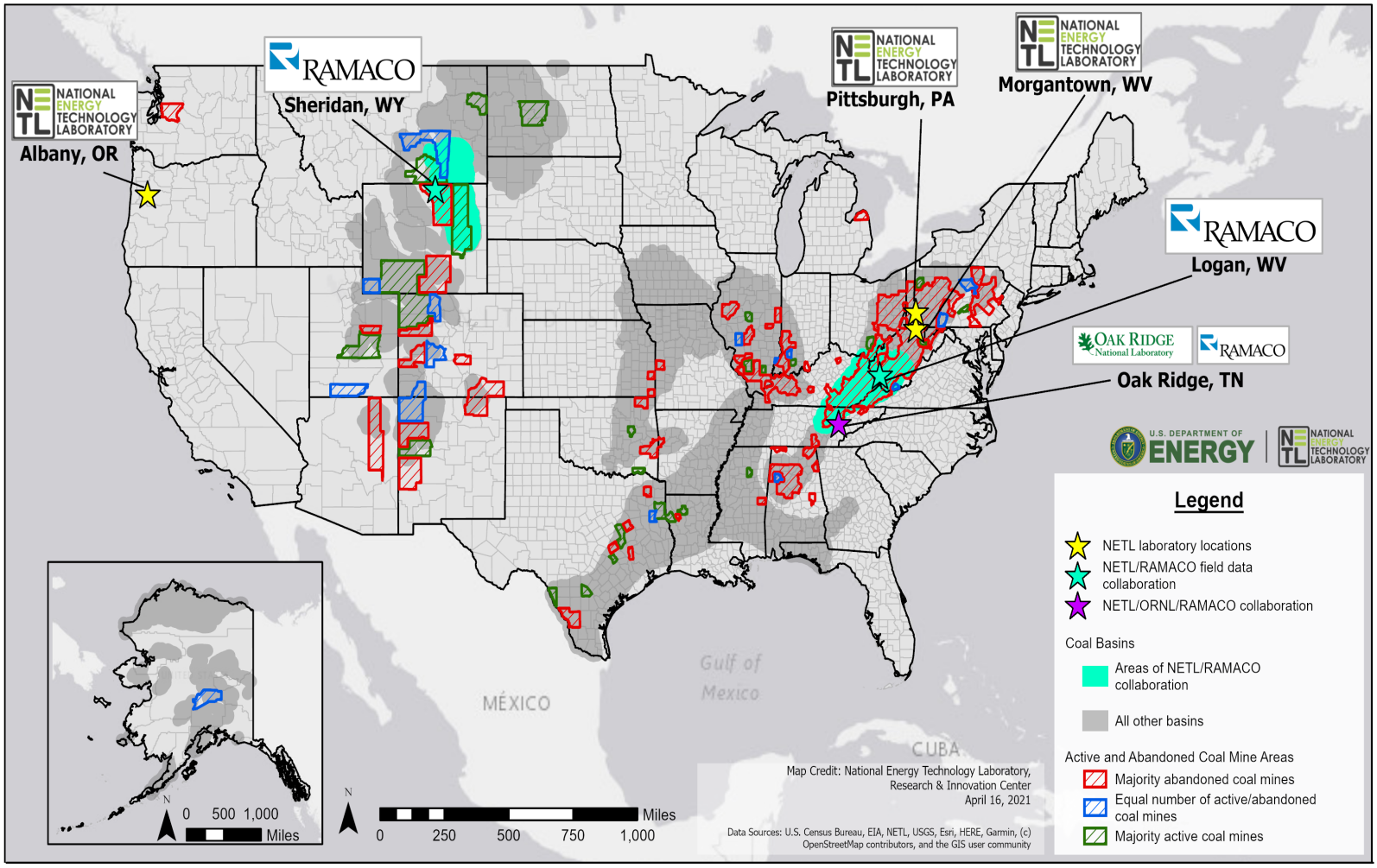
The Introductory Video Clip:

https://www.dropbox.com/s/tsho25mssjuj8x1/Ramaco%20Carbon%20Intro%20copy.mp4?dl=0

The new iCAM (Carbon Advanced Material Innovation Center) research and pilot facility near Sheridan, Wyoming:


iCAM

Map of US Coal Basins, Ramaco Operations and Related Partner operations with National Energy Technology Laboratory (NETL) and Oak Ridge National Laboratory (ORNL):

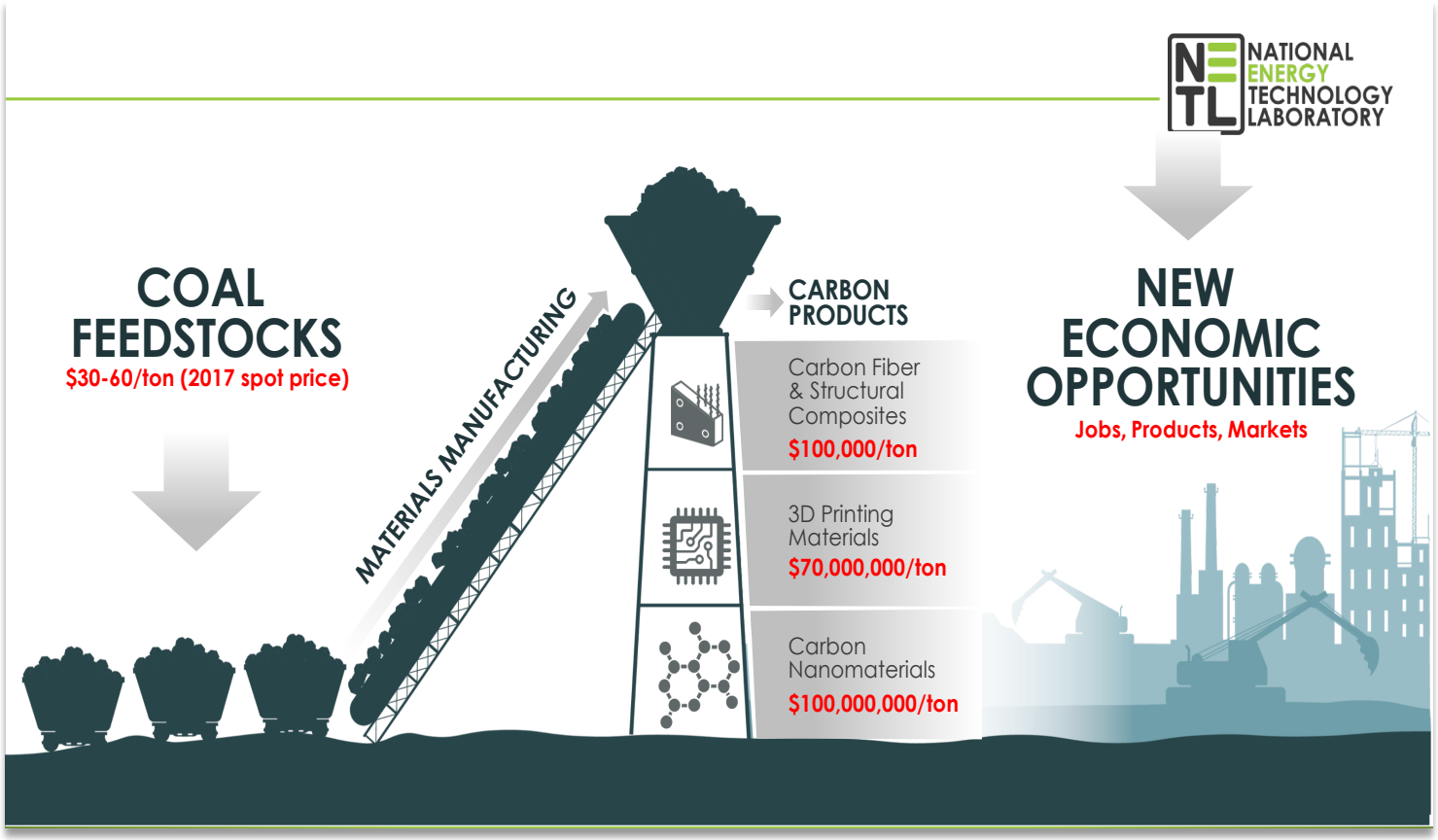


Estimate by NETL of Job Creation and Coal Usage from Development of Advanced Carbon Products and Materials:

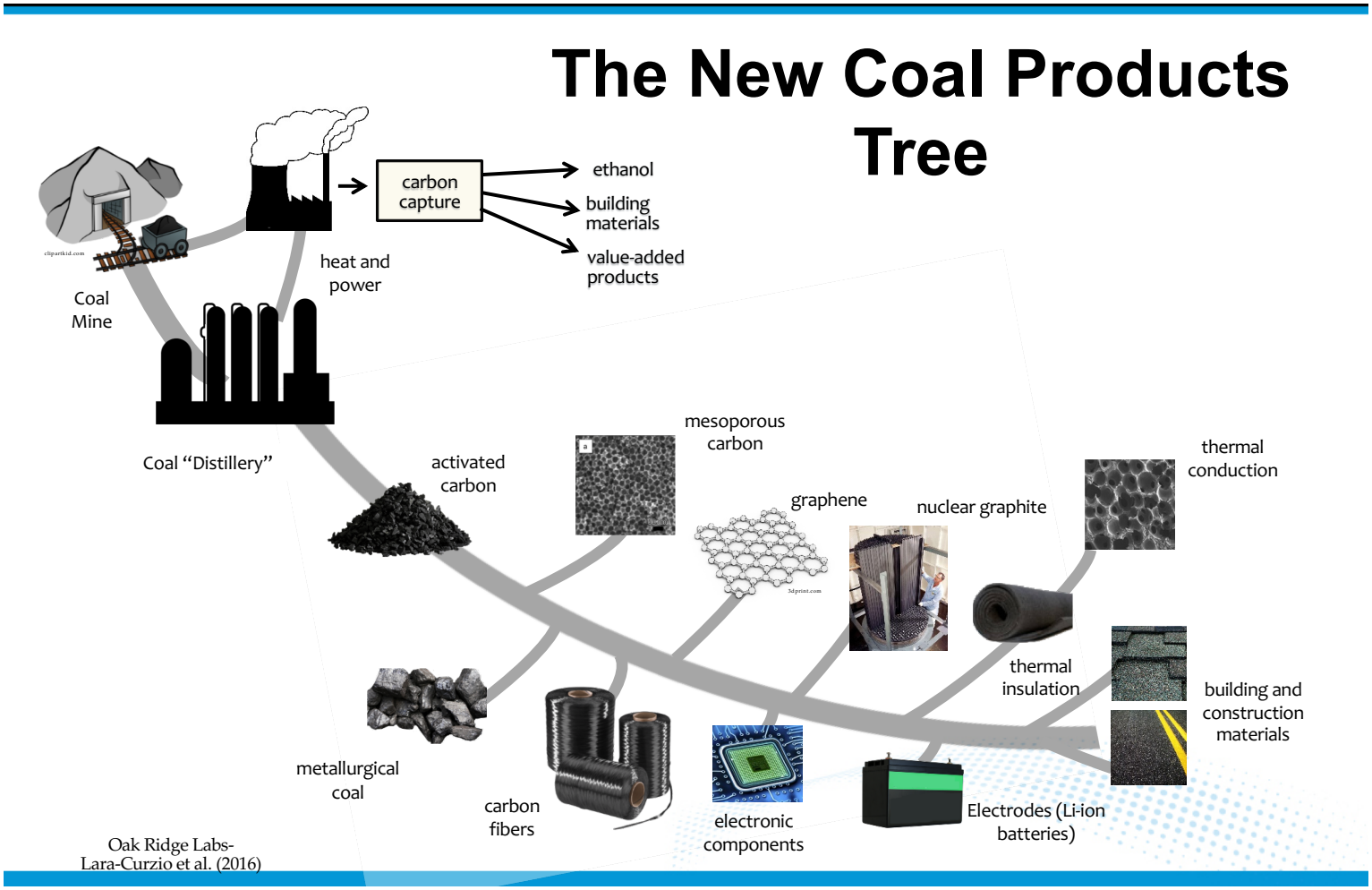
Carbon Product	Potential U.S. Coal Industry Requirements - 2050*		U.S. Product Value -2050 (Million $) *	Employment-2050 (Mfg.)*
	Coal Production (mmt)*	Coal Mining Employment*		
Activated Carbon	22	2,641	15,979	32,437
Carbon Anodes (incl. Aluminum, Li-Ion Battery Anodes)	35	4,257	31,289	63,476
Carbon Black	14.1	1,692	5,077	10,306
Graphite Electrodes/Needle Coke	12.5	1,502	41,315	83,869
Carbon Fiber (incl. CFRP, C-C composites, cement)	47.6	5,713	24,701	50,127
Carbon Nanomaterials (incl. cement)	12.1	1,457	14,125	28,300
Conductive Inks	0.001	1	264	500
Roofing Tile	2	243	7,192	14,500
Aggregate**	**100+**	**15,000+**	**TBD**	**100,000+**
Foam - Building Mat**	**100+**	**15,000+**	**TBD**	**100,000+**
Total Carbon Products	**145 to 345+**	**17,500 to 47,500+**	**139,000 +**	**280,000 to 480,000+**

* Values reported in 2050 represent a high coal penetration scenario in which carbon-based products made from coal penetrate 80 percent of the overall product market. Additionally, several products (e.g., anodes/electrodes, CF & graphene) represent high demand growth scenarios.
** Data from project estimates with technology developers for large commodity markets

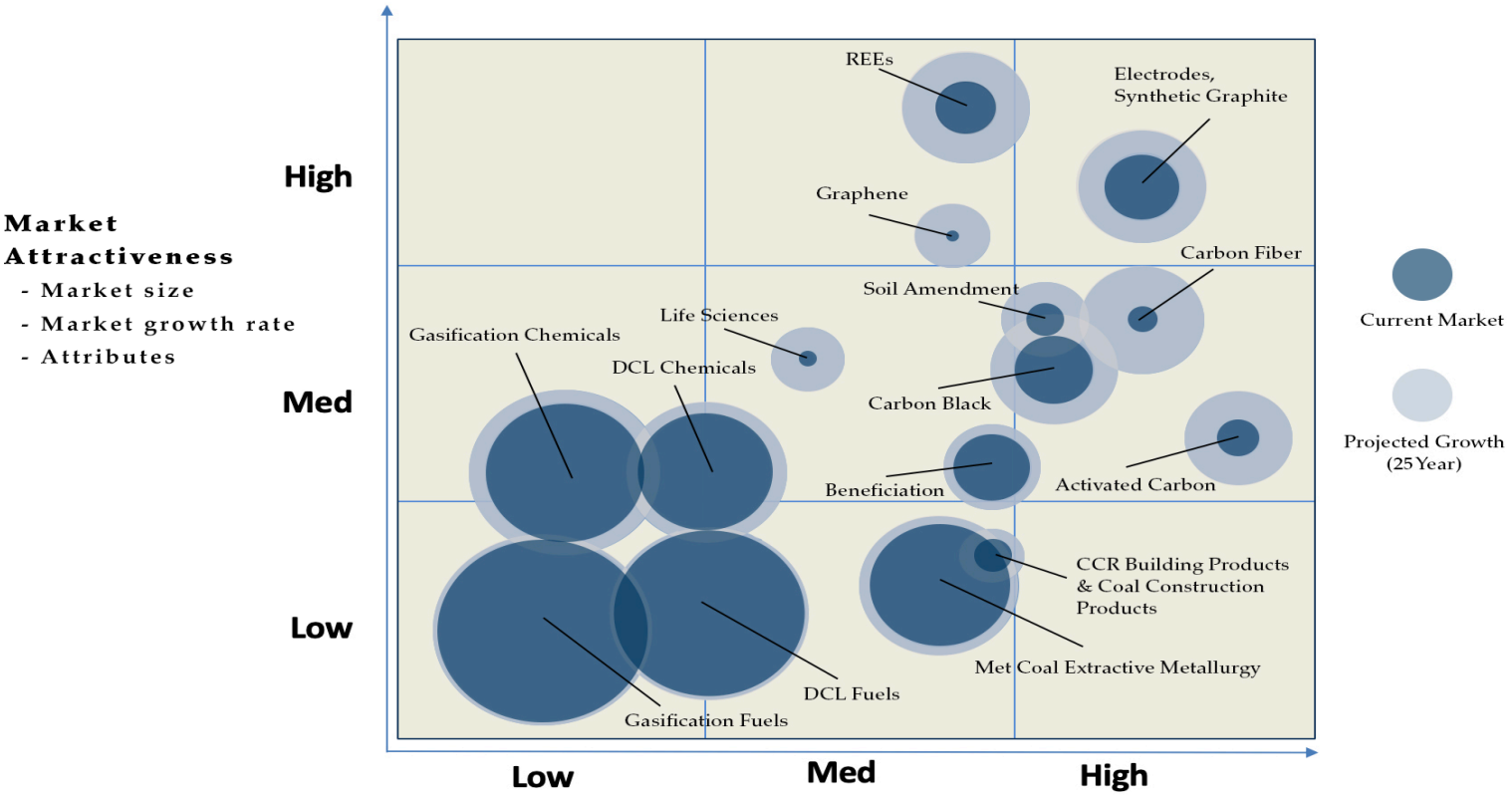
Estimate by NETL of Value Proposition from Coal Usage for Development of Advanced Carbon Products and Materials:



New Forms of Advanced Products & Materials from Coal Based Carbon- "The New Coal Products Tree":



National Coal Council Estimate of Market Attractiveness and Competitive Strength of various Advanced Carbon Products & Materials:



Preliminary Life Cycle Analysis by NETL of use of Ramaco Coal to make Carbon Fibers used in Vehicles:

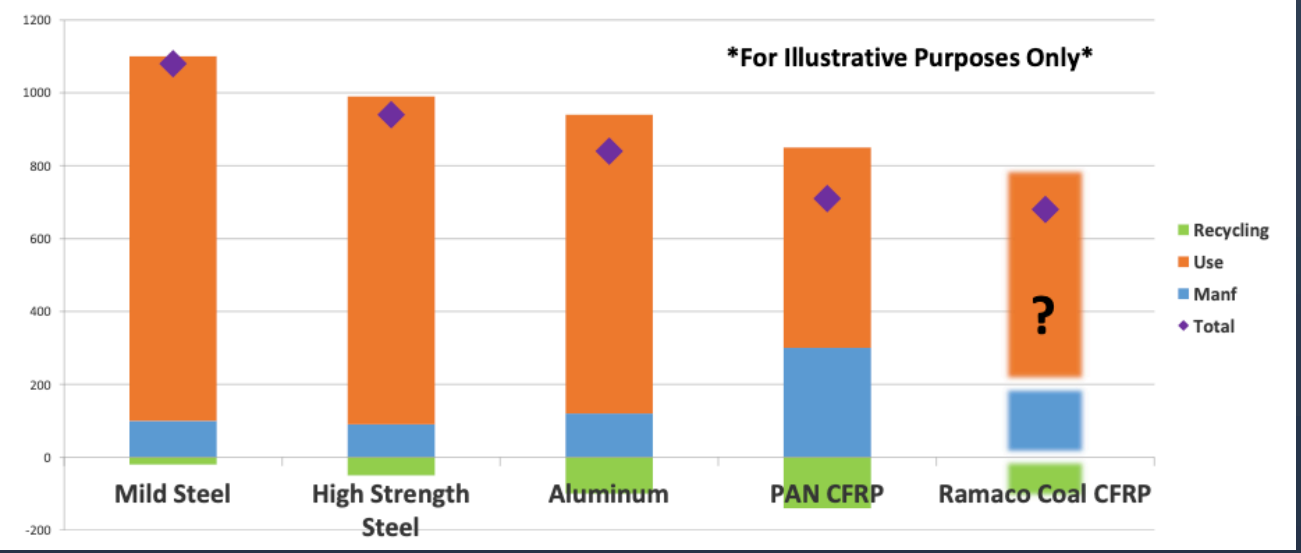
LCA Analysis Potential

RAMACO CARBON

Potential Results

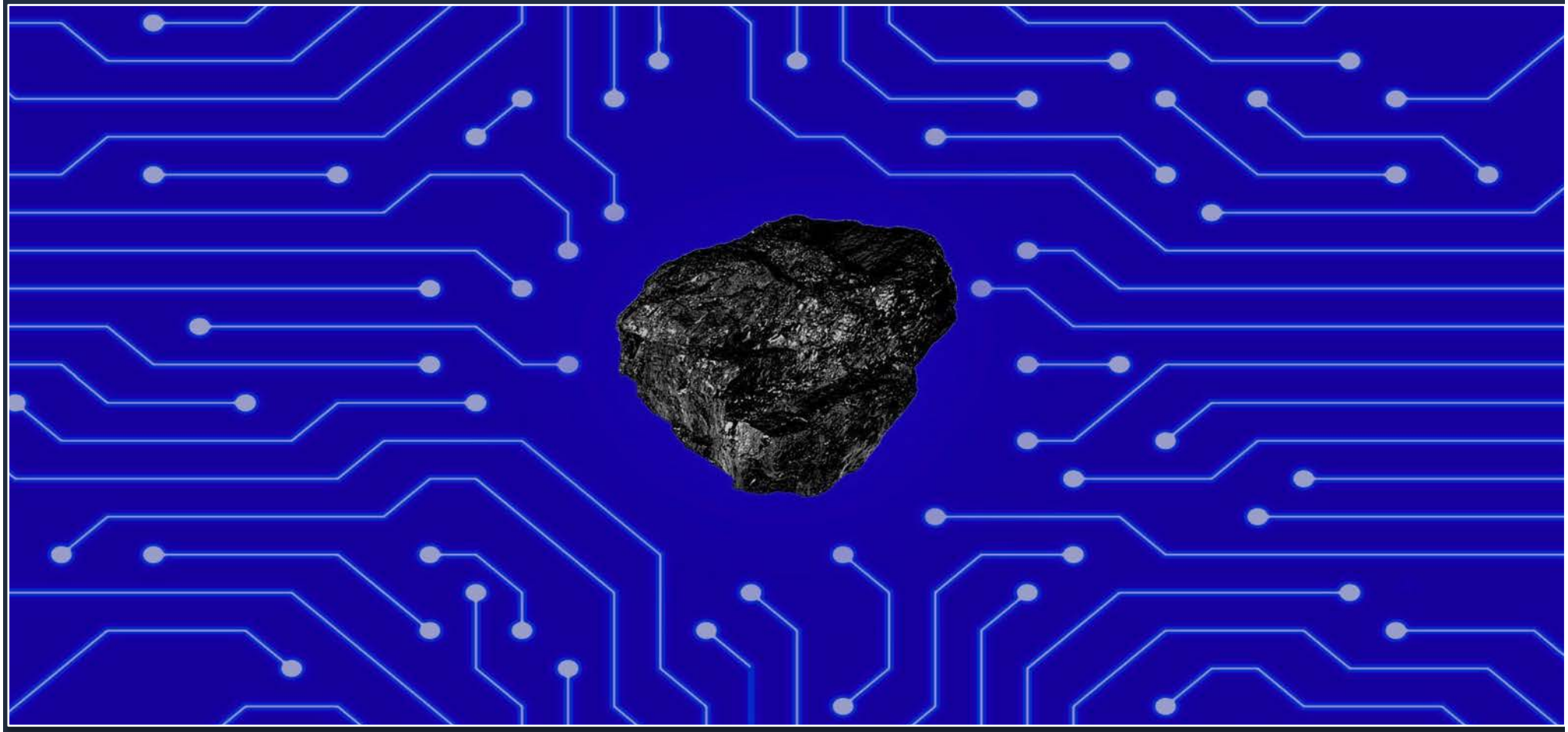
NATIONAL ENERGY TECHNOLOGY LABORATORY

Embodied Energy, GJ/vehicle. Source: Das 2011, Das 2014



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

The New Carbon Age



Senate Energy and Natural Resources Committee
April 2021

Randall W. Atkins– Chairman & CEO, Ramaco Coal

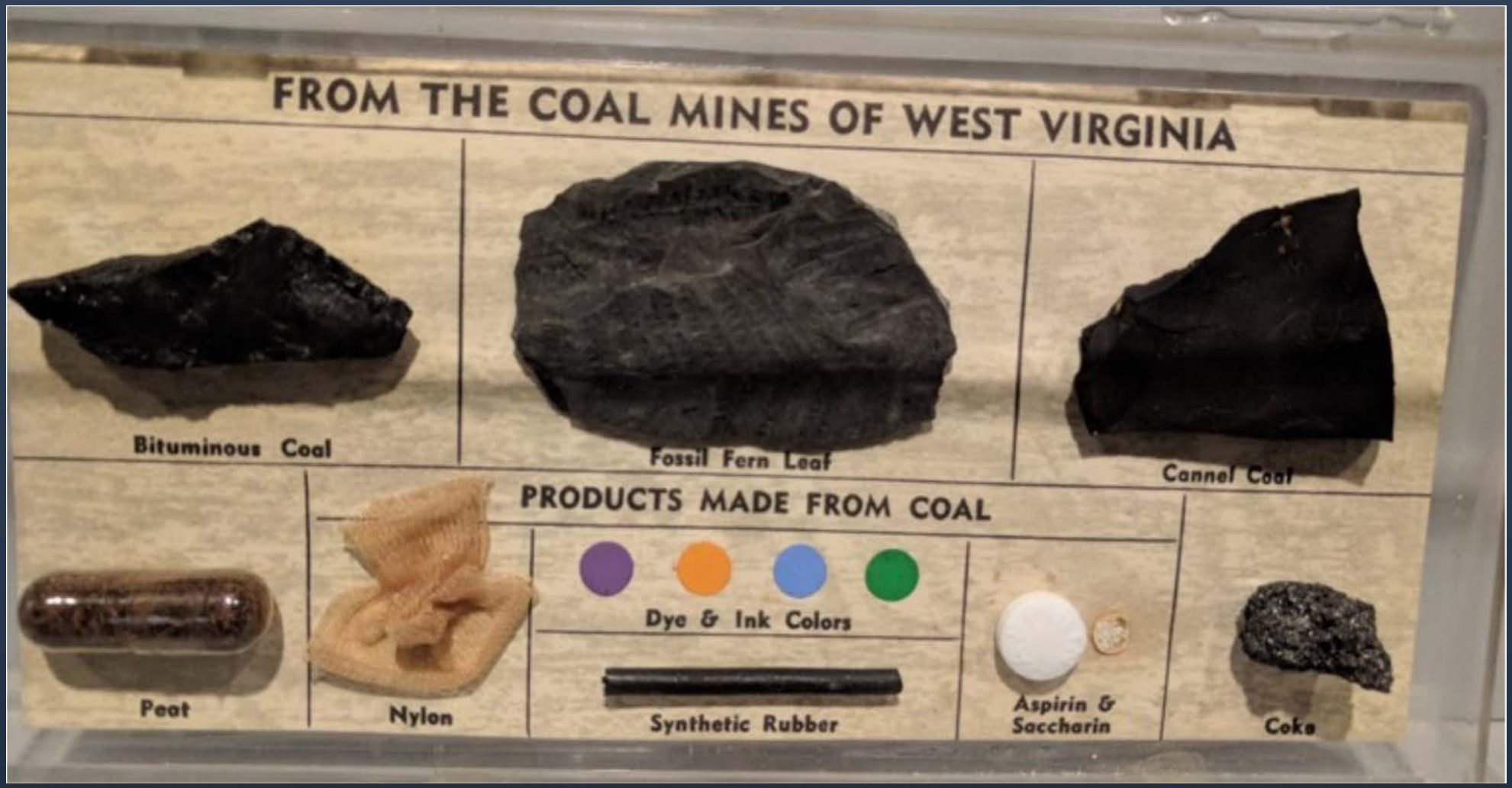
Does Coal Have a Future?

- Since 2017, our industry has seen a dozen major bankruptcies or restructurings announced by both thermal and met coal producers in CAPP, ILB and PRB.
- Both political parties are looking for long-term solutions to this industrial, strategic and socio-economic crisis in an environmentally responsible manner.
- Since 2013, we have embarked on an unconventional, technology-focused approach to fundamentally change how we perceive and use coal.
- **Our Mantra**: **"Make coal too valuable to burn"**
- **Our Focus:** Create positive disruption by using coal as a precursor for high-value advanced carbon products and materials. This is called "**Coal to Products**" (C_2P).
- The National Coal Council's May 2019 report to the Secretary of Energy — entitled "**Coal in a New Carbon Age**" — provides a blueprint.

Our Goals

- To transform the coal industry into a provider of non-combustion carbon feedstock for advanced carbon products and materials.
- We no longer live in the world of Dickens. Don't think Coal. Think "Carbon Ore."
- By manufacturing high-value products and materials from coal, we could create a vastly higher economic value for it than combustion, and importantly a lower environmental footprint.
- We start by borrowing existing CTL conversion technologies from the 1970s-80s and combine them with new advancements in carbon and material research, as well as new forms of manufacturing like 3D printing.
- Thermal coal can have a vastly more valuable end use than power. Even metallurgical coal can have a higher value than coking for steel. As the price of coal rises, it could create a virtuous cycle… currently stranded, higher-cost coals become economic to mine.

We knew even 50 years ago there was a different path



A souvenir made for then-Senator John F. Kennedy by 6th graders in Huntington, West Virginia *Credit: JFK Presidential Library & Museum*

Our Socio-Economic Plan: Carbon CAMPs

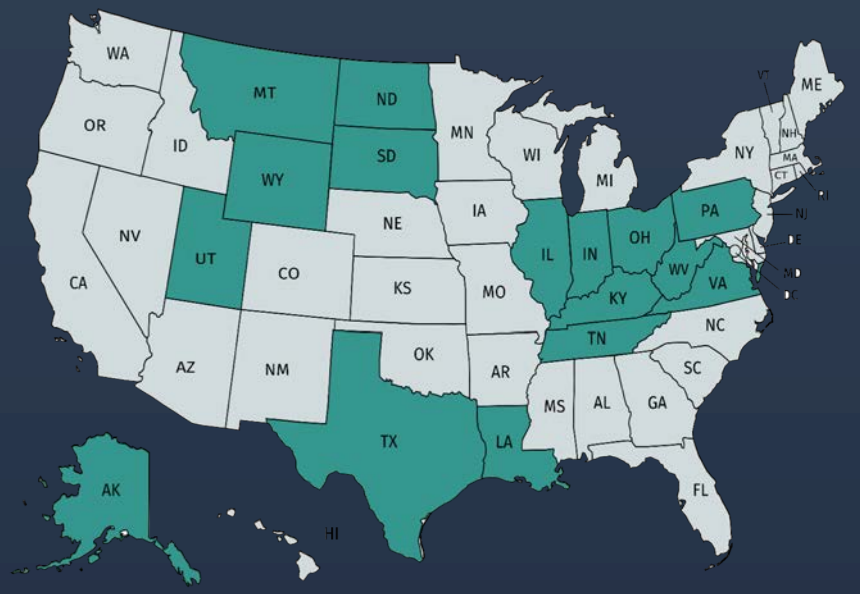
RAMACO CARBON

- **Create an ecosystem of net-zero emission manufacturing hubs** around the country, producing carbon products from coal.
- These are called **Carbon CAMP centers**, for "Carbon Advanced Materials, Manufacturing and Production.
- Locate CAMP centers in coal-producing areas where mine-mouth logistical advantages and access to smart, skilled coal mining talent can be accentuated.
- We "repurpose" older mining communities into advanced manufacturing hubs.
- Focus on the manufacture of environmental carbon products and materials with high value margins, *and* which require the use of coal as the basic carbon feedstock.
- **Build an innovative, higher tech future for the coal industry** independent of power trends and environmental concerns.

CAMP Centers in Coal States

RAMACO CARBON

- With Federal and State support, construction could start almost immediately.
- The Federal Government can fund a public/private pilot center and pre-commercial facilities per Coal Tecc legislation already passed.
- We plan to invest in center in coal states with our existing production like West Virginia, Wyoming, Pennsylvania, Virginia, Kentucky, and more.
- Creating CAMP centers near mines creates synergies with huge logistical cost advantages.
- Even non-coal coastal states have significant economic and political interests in advanced carbon materials and life sciences.



New Job Creation and Production Potential

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** Data from project estimates with technology developers for large commodity markets

Carbon Derived from Coal

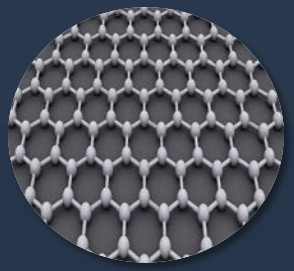
- Carbon is becoming the dominant "**advanced material**" of the 21st Century — think carbon fiber, graphene, graphite and carbon resins.
- We're entering a **Carbon Age**.
- The United States could lead a wave of innovation by making carbon products and materials from **coal instead of petroleum**. This would generate significant 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.
- 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..

Displacement Potential of Carbon from Coal

- Coal's potential is to make advanced carbon materials **that are stronger, lighter, and most importantly cheaper.**
- The key to coal's advantage is cost. It is far cheaper than petroleum, the typical precursor for advanced carbon materials .
- Materials that can be made from coal instead of petroleum include:

Carbon Fiber

Carbon fiber is 50% the weight of aluminum but 4X as strong. It is 25% the weight of steel but 2X as strong.



Graphene

Used to conduct heat and electricity, this material is thinner than paper and can be harder than a diamond.

Graphite

Used to make brake linings, lubricants, and molds in foundries, as well as in the production of steel.

Cost Comparison: Carbon from Coal vs. Oil

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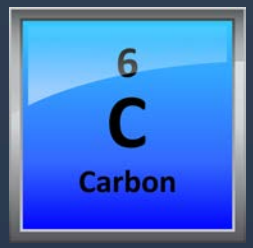
There is the same amount of carbon in a ton of coal and a ton of petroleum, but coal has over a 35x cost advantage.

1 Ton of PRB Coal

=

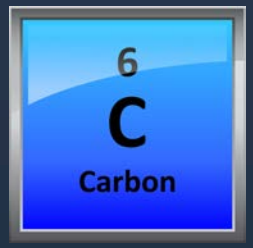


1400 lbs. of Carbon

= **$12 per ton**

1 Ton of Petroleum =
7 Barrels of Crude Oil

=

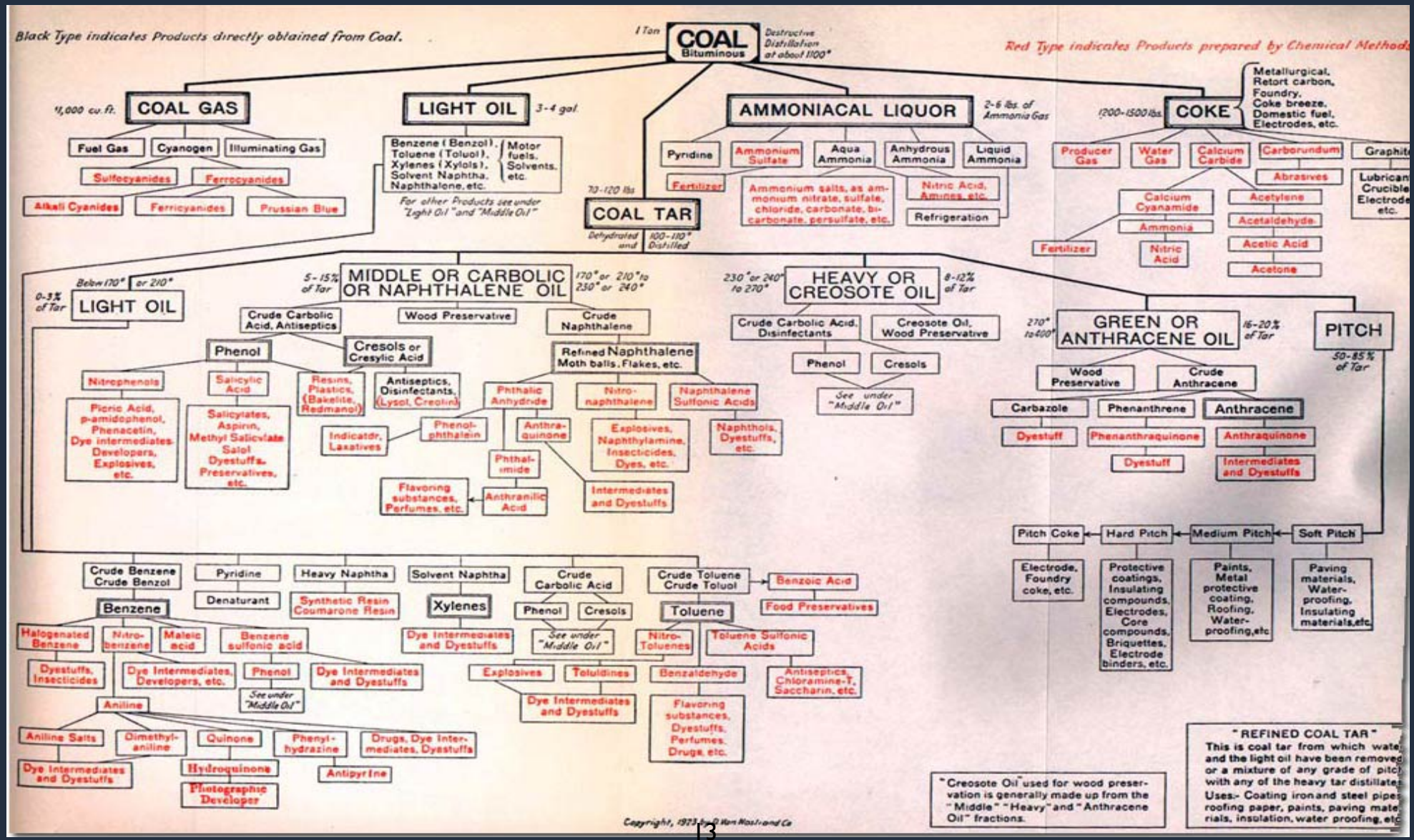


1400 lbs. of Carbon

= **$420 @ $60 per barrel**

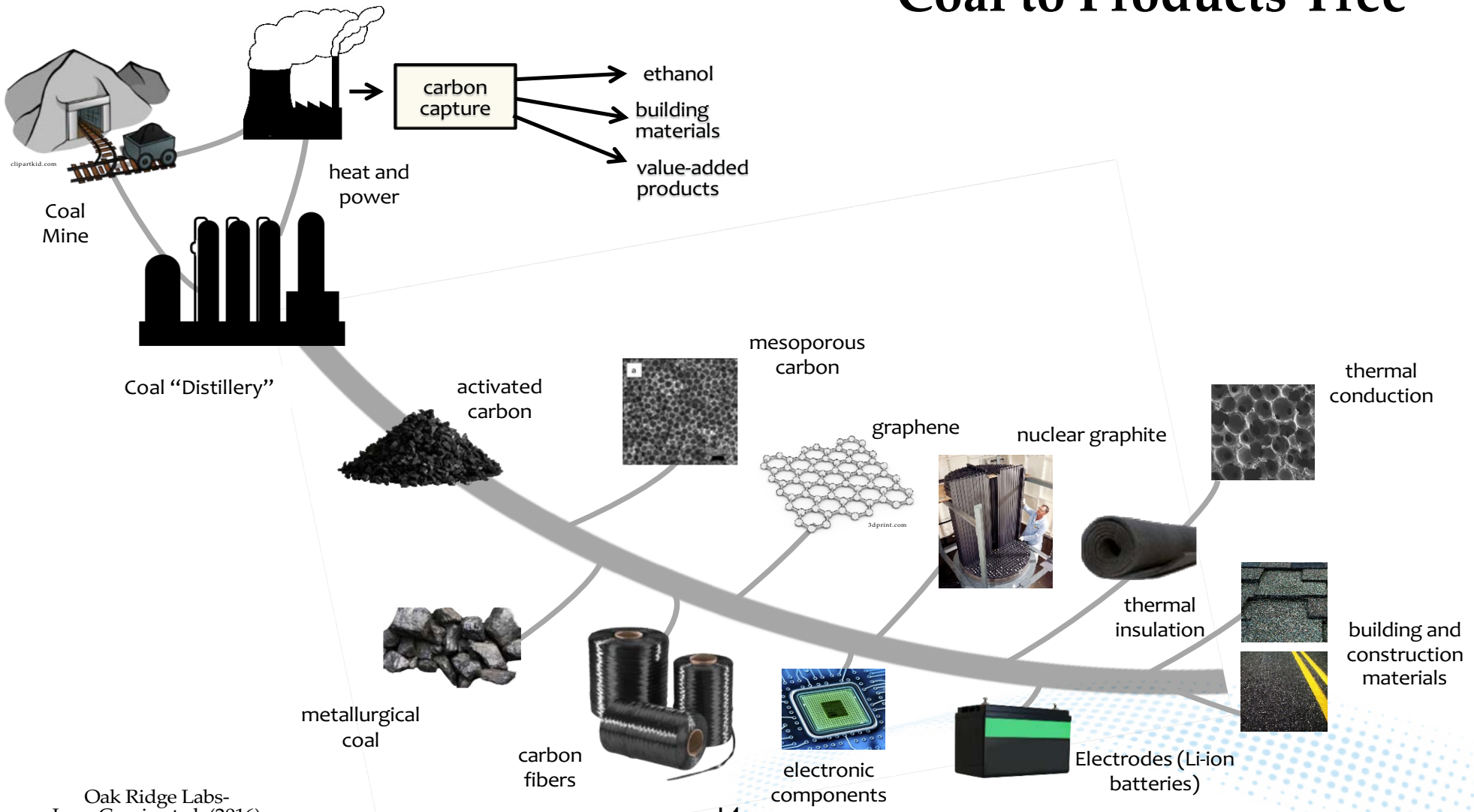
Where are we headed?

Maybe Back to the Future: 1923 Coal Tree



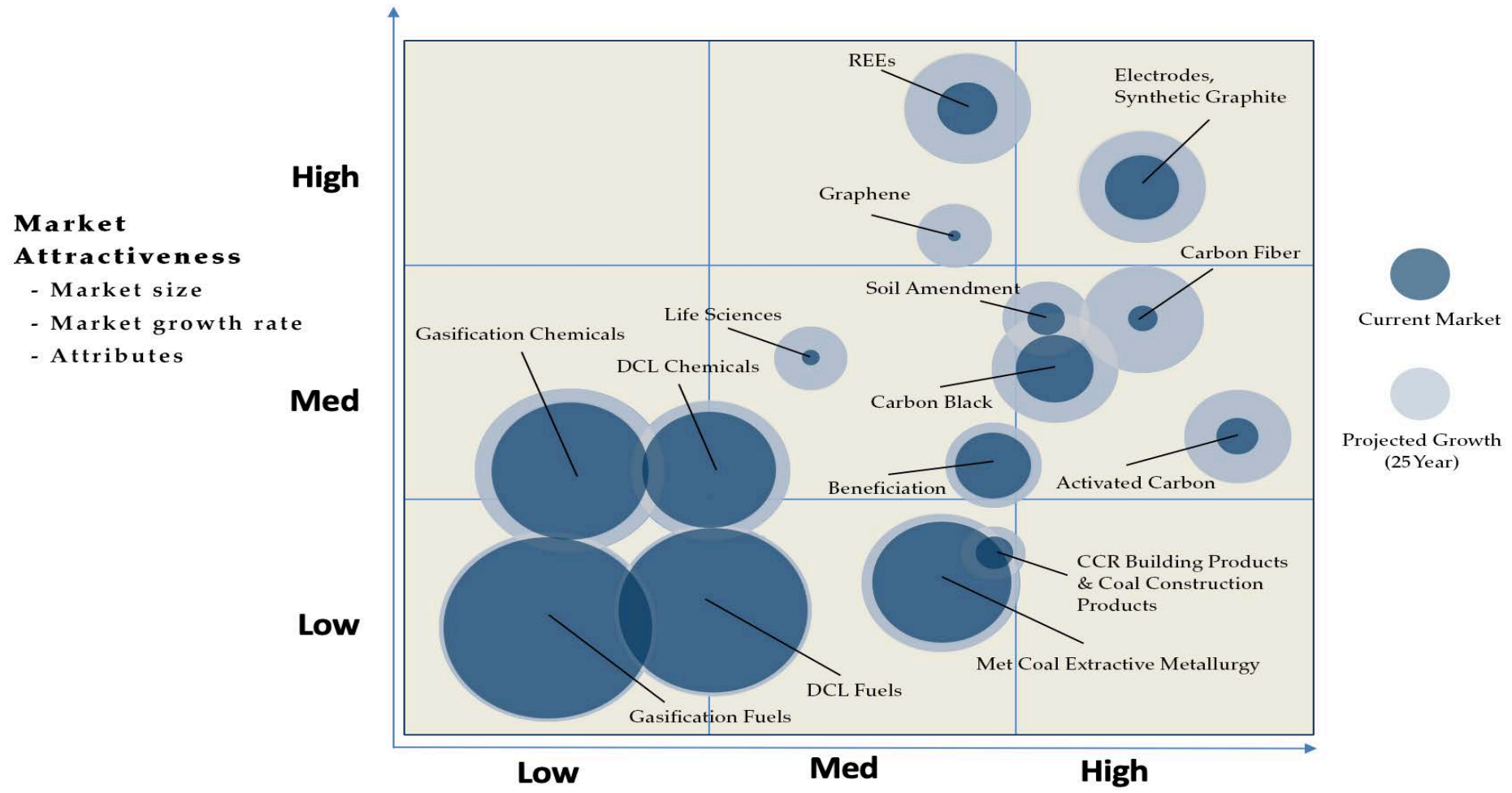
The 21st Century Update

Coal to Products Tree



Oak Ridge Labs-
Lara-Curzio et al. (2016)

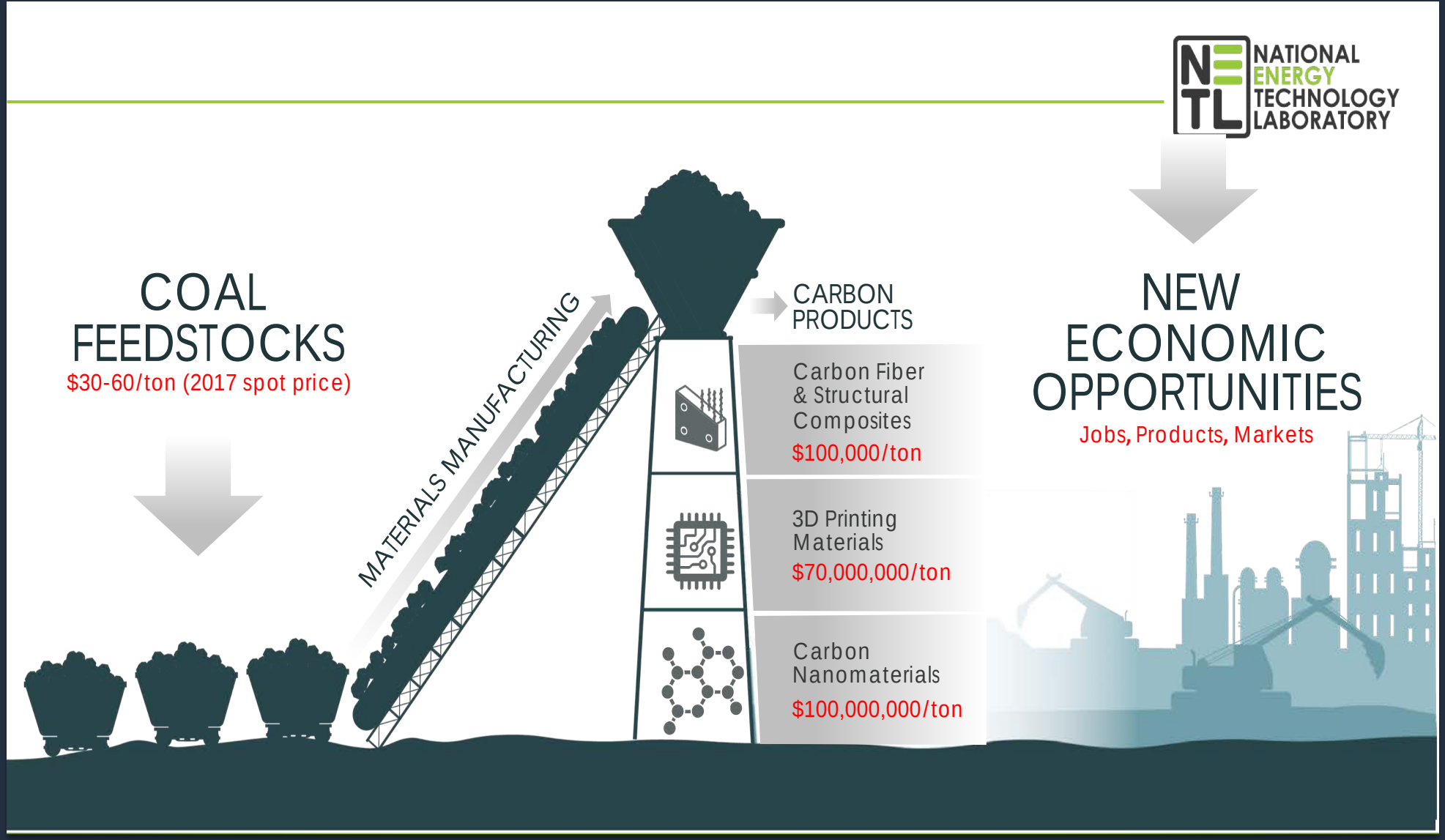
The New Target Markets



Coal to Products Value Proposition

RAMACO CARBON

NATIONAL ENERGY TECHNOLOGY LABORATORY



Who We Are

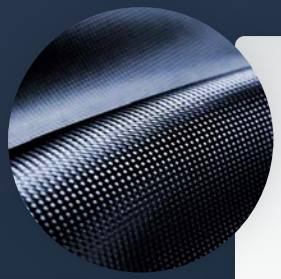
Founded in 2011, **Ramaco Coal** is a coal-based conglomerate with operations in five states. It consists of two main operating companies:

RAMACO RESOURCES

A publicly traded met coal producer (NASDAQ: METC) 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".

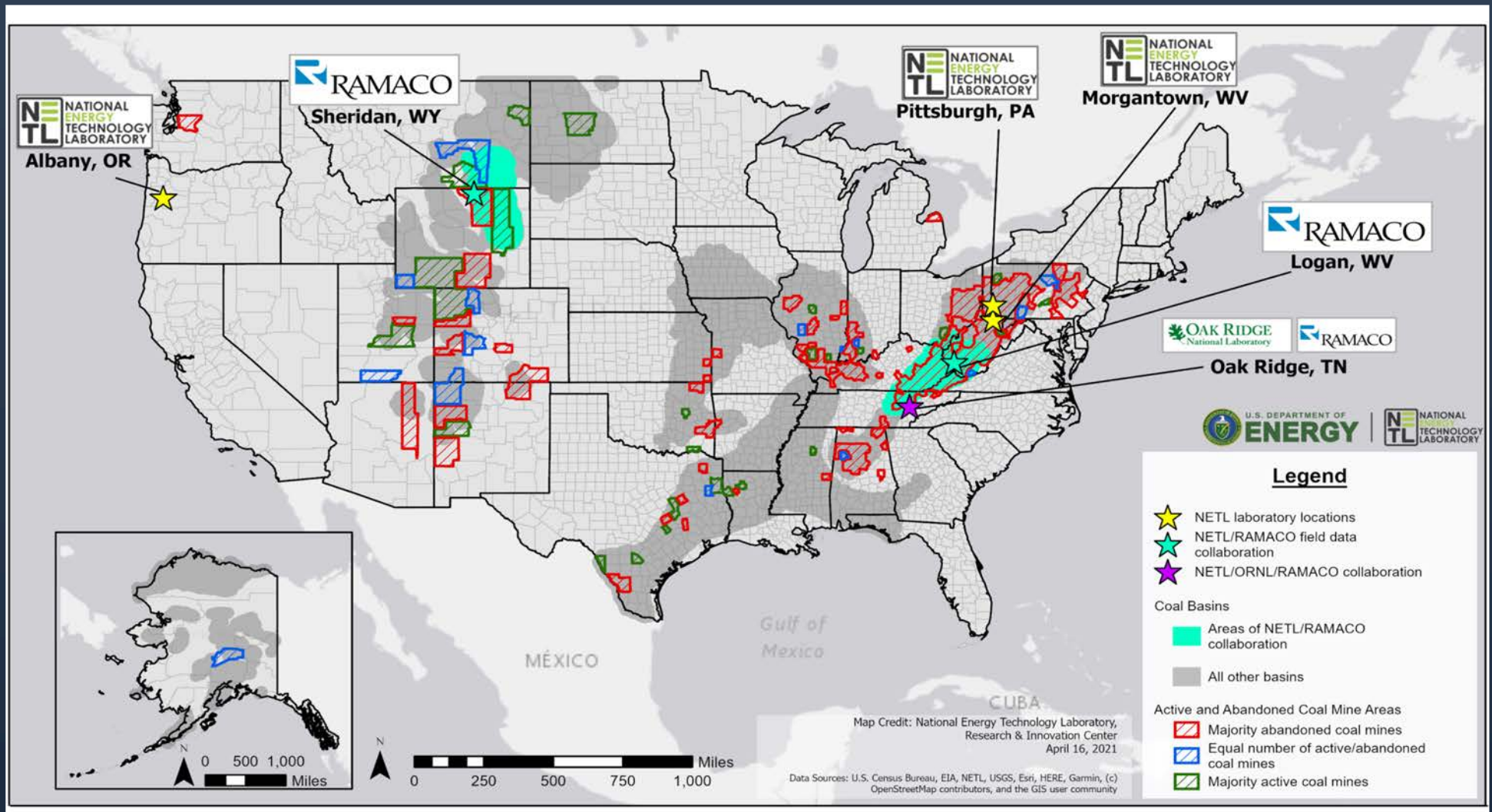
Headquartered in Sheridan, Wyoming.

www.ramacocarbon.com

Where We Are

We operate in two of the major coal basins of the United States: the Central Appalachia Basin (WV, VA, PN) and the Powder River Basin (WY).

With our partners at the National Labs we spread the field even more.



What We Are: A Carbon 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 research-pilot plant park in Wyoming will be completed this summer. An additional lab is in the works in West Virginia.

These research facilities will incubate carbon research to commercialize coal-based carbon products, from bench through commercial 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.

Unique Partners

- We are privileged to work with top U.S. National Labs, research institutes, strategic groups and universities, who form our core research and development network.
- We are also do critical development with both the NETL and Oak Ridge National Laboratory through joint research partnerships on developing a variety of coal process and carbon product and material technologies.
- Over 50 scientists have come together for the past two summers for the **Ramaco Research Rodeo (the "R3")**, a coal-to-products research conference held in Sheridan, Wyoming.
- We are now involved in **five grants from the Department of Energy** to explore novel uses of coal to make carbon 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

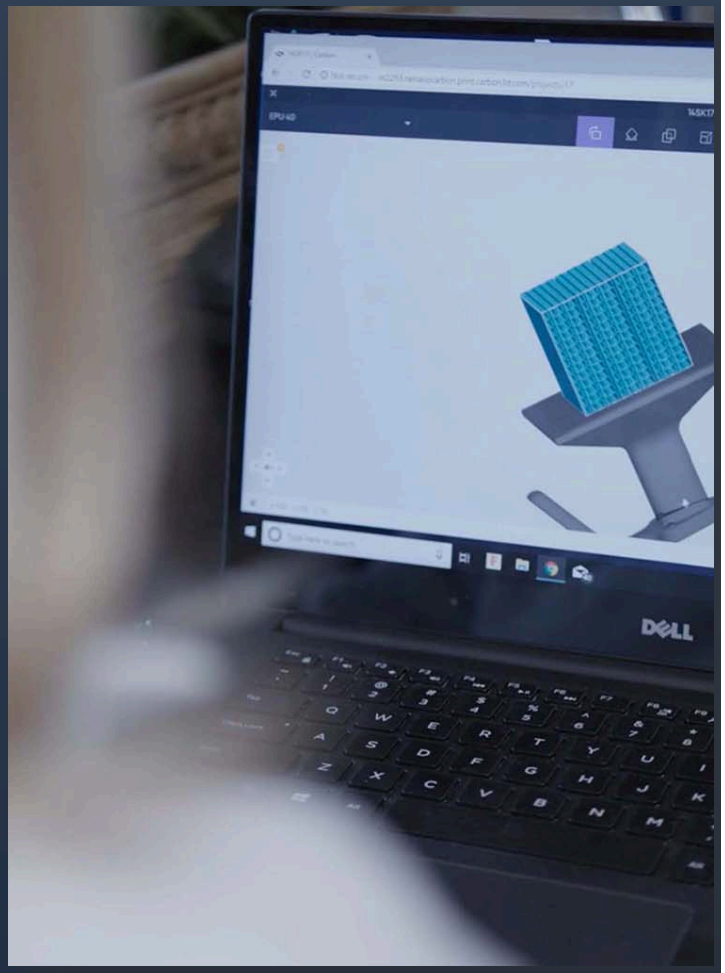
Our Product Focus

We focus on six broad carbon based uses :

1) **Carbon Fiber (“CF”)**
2) **Graphene**
3) **Building Products**
4) **Advanced Porous Carbons**
5) **Bio-Medical Technology**
6) **Rare Earth Elements (“REE”)**

We seek uses that marry advanced materials and advanced manufacturing technologies.

These uses have both a high margin value proposition and can require large coal volumes.



Coal to Cars?

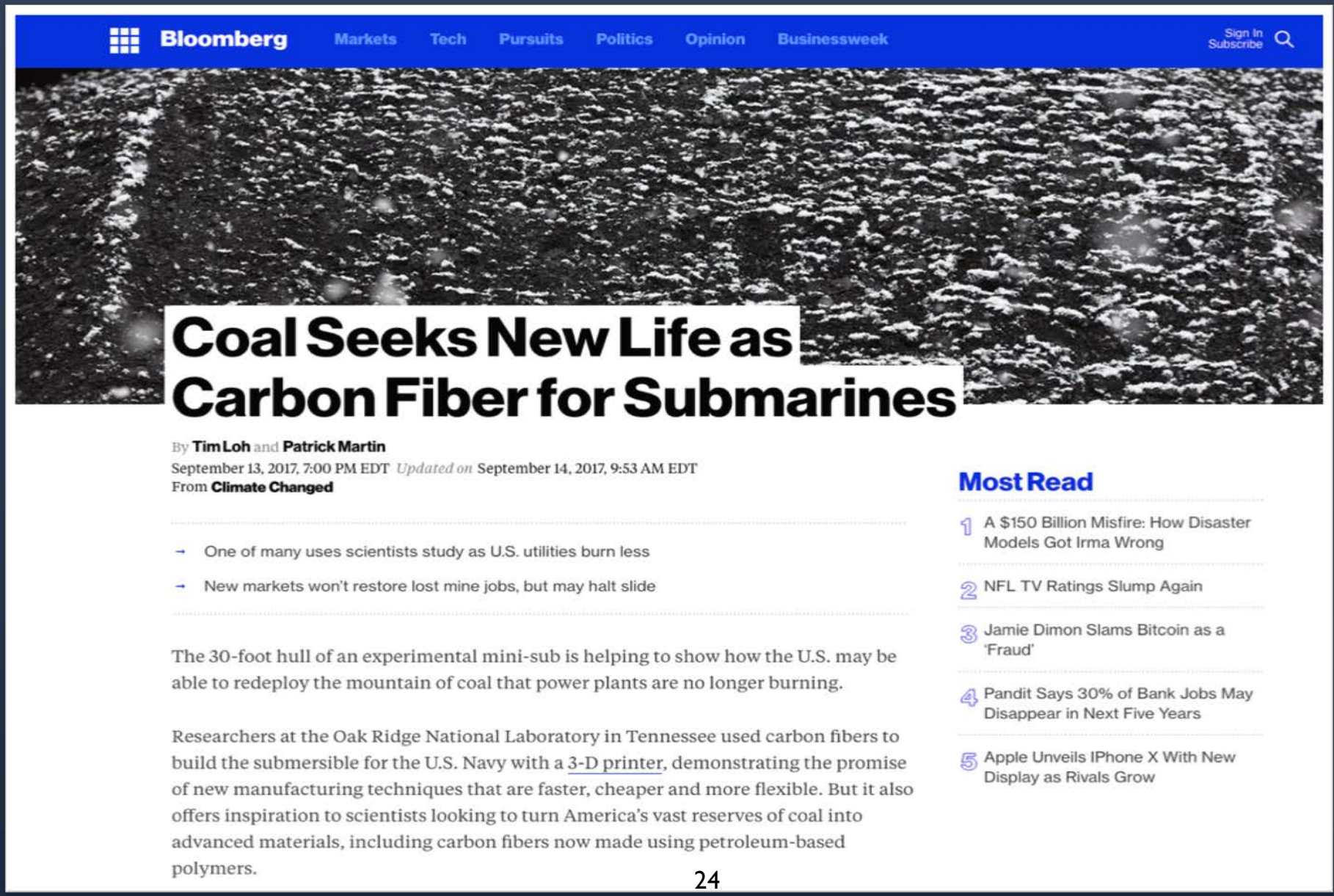
- We are in our 2nd year of a DOE grant with many national partners nicknamed **"Coal to Cars."** The focus is using coal to make low cost carbon fiber for vehicles.
- Carbon fiber is used in less than 10% of cars currently manufactured, despite benefits in gas mileage, strength, and more.
- CF is 4x 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. We are working to drive the price of the coal-based precursor beneath a "tipping point." CF then becomes affordable alternative to steel.
- CF Precursor costs could drop from $25-40 p/lb. to below $5.
- CF cars then move from niche markets — such as F1 racing — to mass market. Lighter vehicles equal less gas consumption and huge environmental benefits.

Evolution of Coal to Carbon Fiber Cars

RAMACO CARBON

FIRST	NOW	NEXT
		
High End & Niche	Low Volume Production of Affordable Car	Mass Market Appeal
		
High End Low Volume Hand Layup	Low Volume Production	High Volume Production

And Perhaps Not Just Cars…



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Coal Seeks New Life as Carbon Fiber for Submarines

By **Tim Loh** and **Patrick Martin**
September 13, 2017, 7:00 PM EDT *Updated on* September 14, 2017, 9:53 AM EDT
From **Climate Changed**

- One of many uses scientists study as U.S. utilities burn less
- New markets won't restore lost mine jobs, but may halt slide

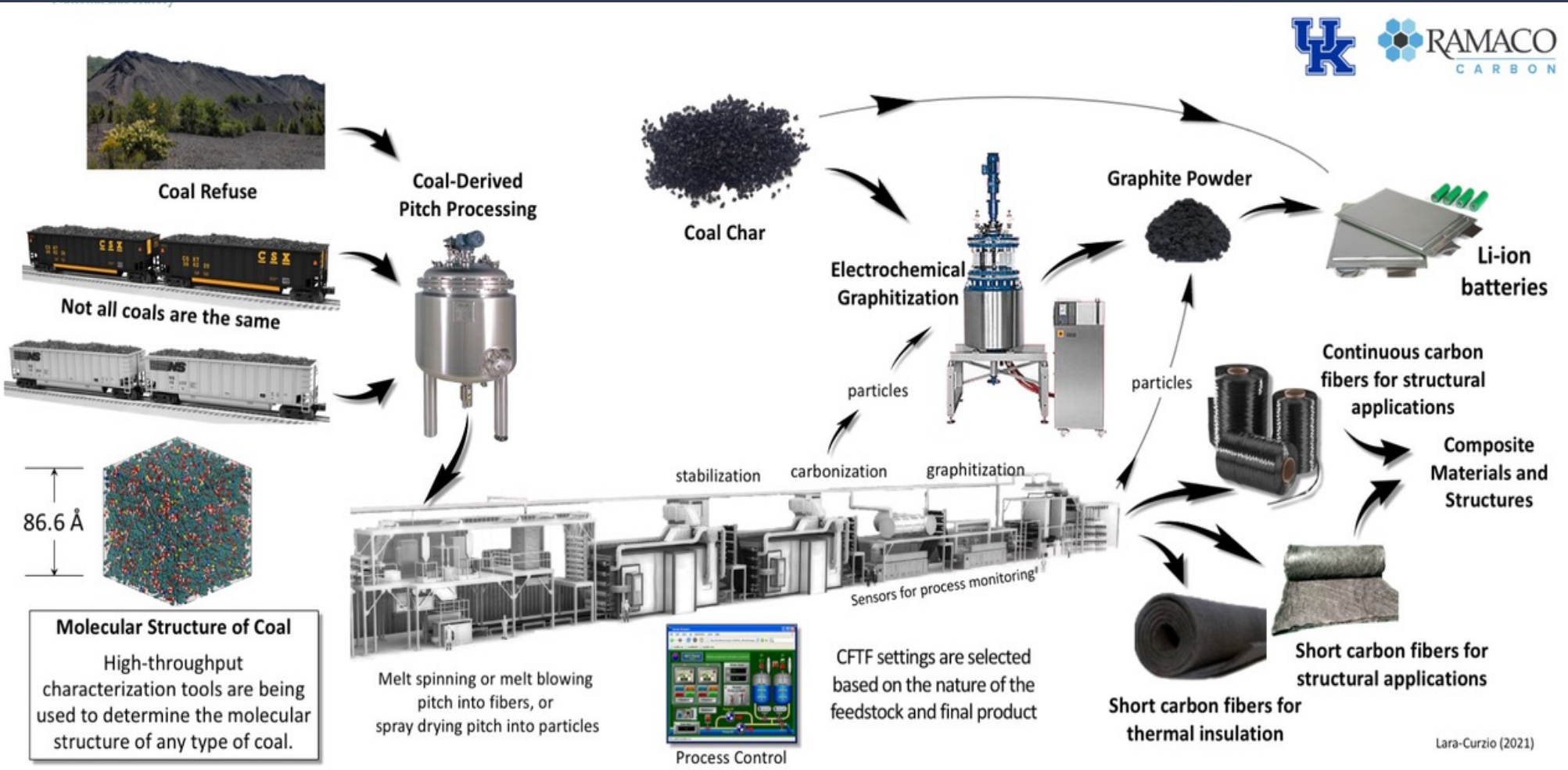
The 30-foot hull of an experimental mini-sub is helping to show how the U.S. may be able to redeploy the mountain of coal that power plants are no longer burning.

Researchers at the Oak Ridge National Laboratory in Tennessee used carbon fibers to build the submersible for the U.S. Navy with a 3-D printer, demonstrating the promise of new manufacturing techniques that are faster, cheaper and more flexible. But it also offers inspiration to scientists looking to turn America's vast reserves of coal into advanced materials, including carbon fibers now made using petroleum-based polymers.

Most Read

1. A $150 Billion Misfire: How Disaster Models Got Irma Wrong
2. NFL TV Ratings Slump Again
3. Jamie Dimon Slams Bitcoin as a 'Fraud'
4. Pandit Says 30% of Bank Jobs May Disappear in Next Five Years
5. Apple Unveils IPhone X With New Display as Rivals Grow

Oak Ridge Carbon Fiber Labs Coal to Products



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

RAMACO CARBON

- In partnership with NETL, we are involved in a ground-breaking environmental "Life Cycle Analysis" (LCA) to assess the environmental 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 (pitch) CF precursors are 85% carbon. Petroleum-based precursors are only 50% carbon. Less processing energy is therefore needed to create CF. Coal-based CF may also involve novel 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.

LCA Goal and Scope

- Goal: To assess the life-cycle environmental impacts of using coal-derived CFRP in light vehicle structural components.
- Scope: The following stages will be considered
  - Production of raw materials
  - Production of vehicle
  - Fuel use during operation
  - Recycling
- Impacts: TRACI impact categories (Acidification, Eutrophication, Greenhouse gases, Ozone depletion, Smog formation, Water use)

LCA Analysis of Carbon Fiber Potential in Vehicles

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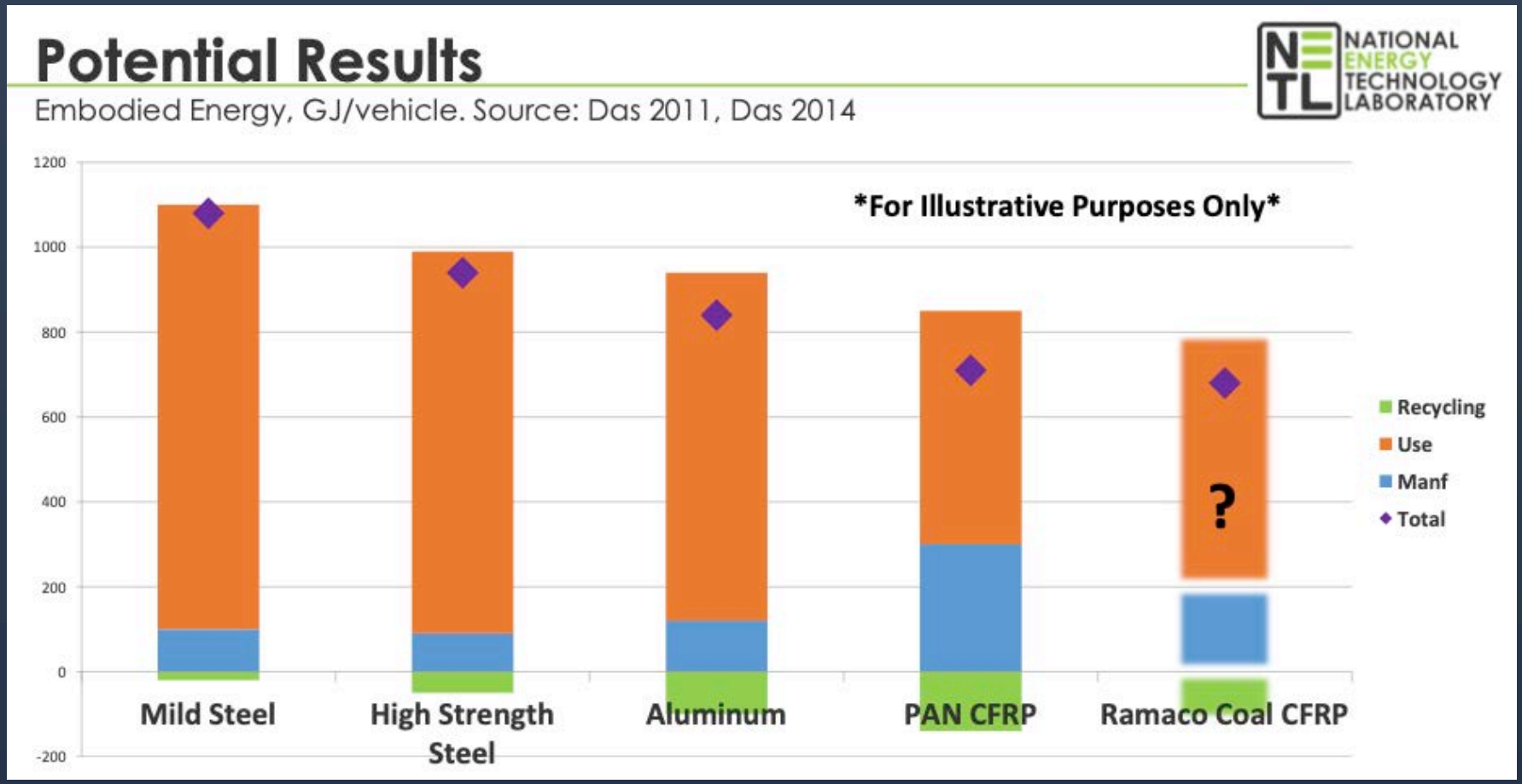

A 10% direct weigh reduction in vehicle weight by using pitch based CF and CFRP can result in a 2-8% fuel reduction.

Secondary weight reductions (parts and drivetrains) can result in even great savings.

Coal to Rare Earth Elements

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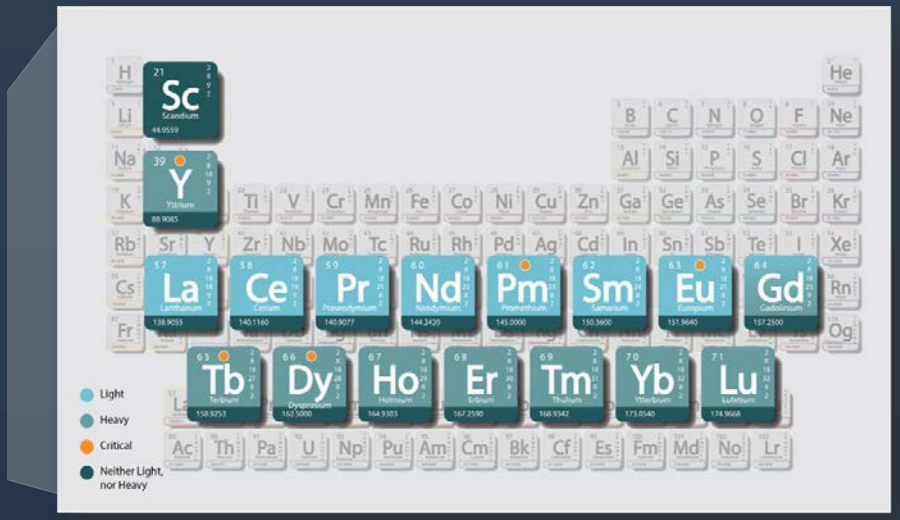
- Rare Earth Elements (REE) are chemical elements/metals found in low concentrations throughout the Earth's crust, making them hard to recover.

- They are found in coal, coal ash, clay, shale, and in over- and under-burdens in quantities measured in parts per million.



- **95% of all REE are imported from China.**

- The global market approaches $10 B per year with the U.S. consuming +10% by volume. Most REEs are imported into U.S. as finished goods, not raw.

- **The level of these imported goods will approach +$1.5 T in 2020.**

REEs are Critical

MAGNETICS

Computer Hard Drives
Disk Drive Motors
Anti-Lock Brakes
Automotive Parts
Frictionless Bearings
Magnetic Refrigeration
Microwave Power Tubes
Power Generation
Microphones & Speakers
Communication Systems
MRI

Nd Tb Dy Pr

DEFENSE

Satellite Communications
Guidance Systems
Aircarft Structures
Fly-by-Wire
Smart Missiles

Nd Eu Tb Dy Y Lu Sm Pr La

CERAMICS

Capacitors
Sensors
Colorants
Scintillators
Refractories

Nd Y Eu Dy Lu Gd La Ce Pr

CATALYSTS

Petroleum Refining
Catalytic Converter
Fuel Additives
Chemical Processing
Air Pollution Controls

Nd La Ce Pr

METAL ALLOYS

NiMH Batteries
Fuel Cells
Steel
Super Alloys
Aluminum/Magnesium

Nd Y La Ce Pr

GLASS & POLISHING

Polishing Compounds
Pigments & Coatings
UV Resistant Glass
Photo-Optical Glass
X-Ray Imaging

Nd Gd Er Ho La Ce Pr

PHOSPHORS

Display phosphors-
CRT,LPD,LCD
Fluorescents
Medical Imaging
Lasers
Fiber Optics

Nd Eu Tb Y Er Gd Ce Pr

We Use REEs Every Day

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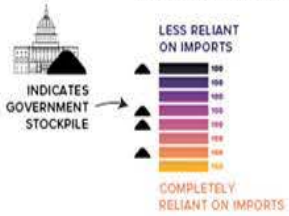
Processing/Separations Tech for UCR REE/CM

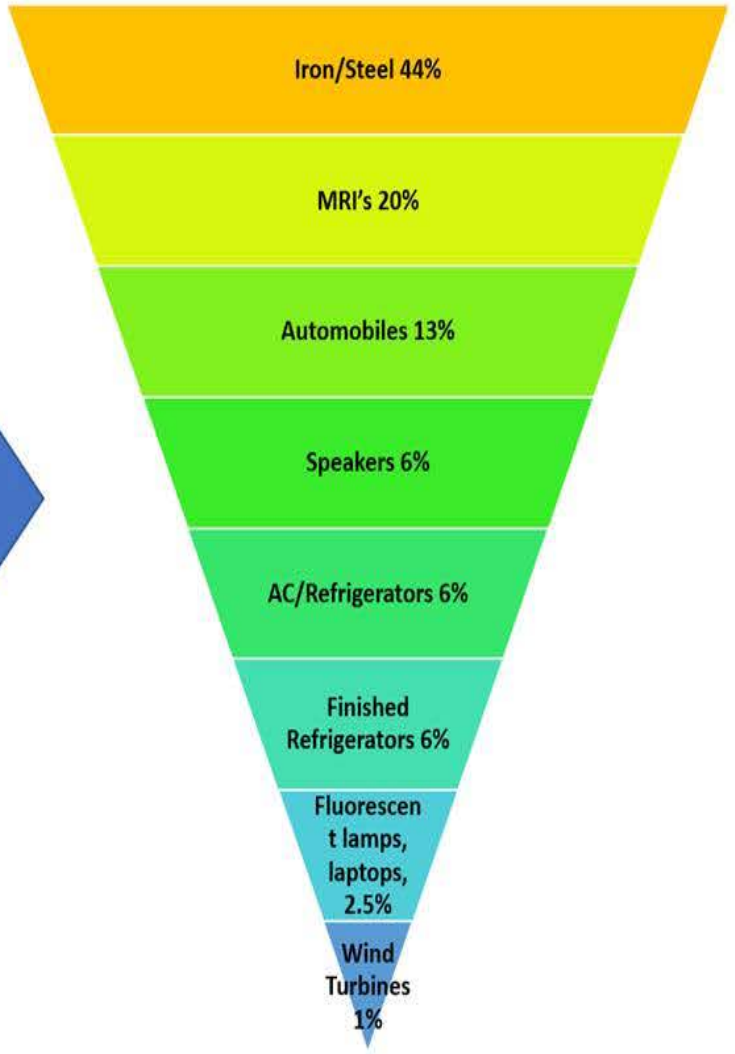
How to read this



Source: https://www.visualcapitalist.com/35-minerals-critical-security-u-s/

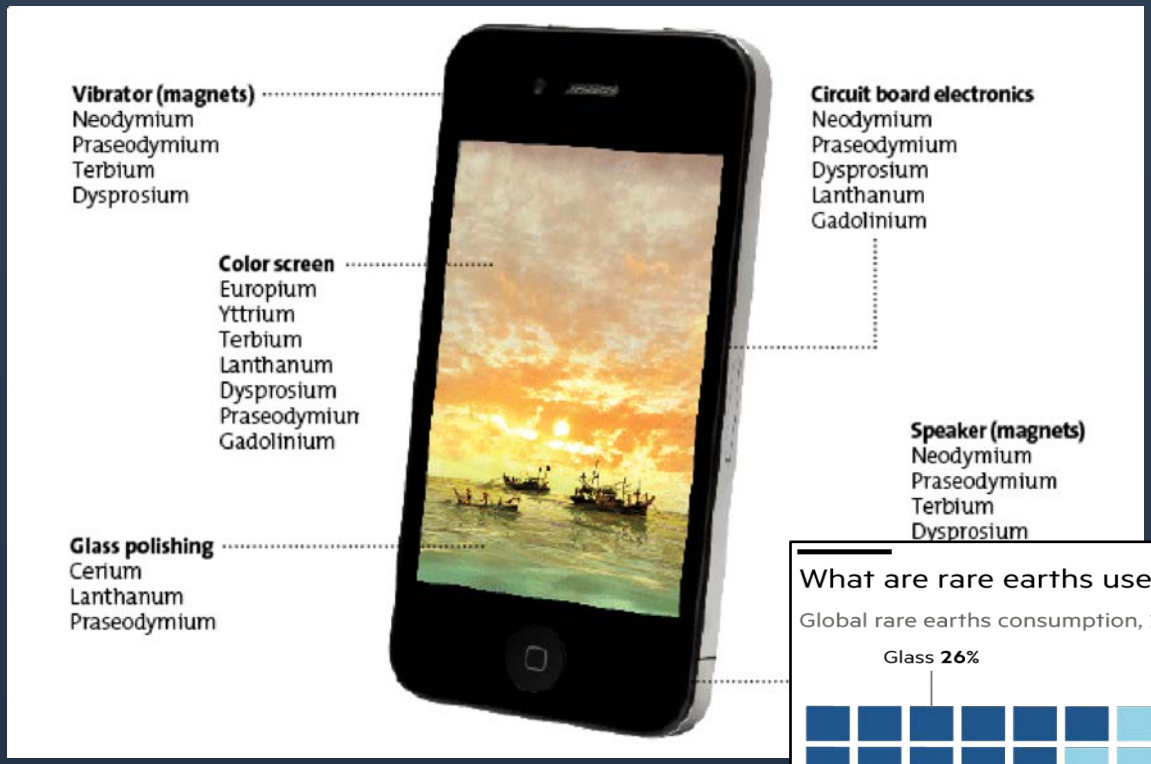
Supply Chain Sectors

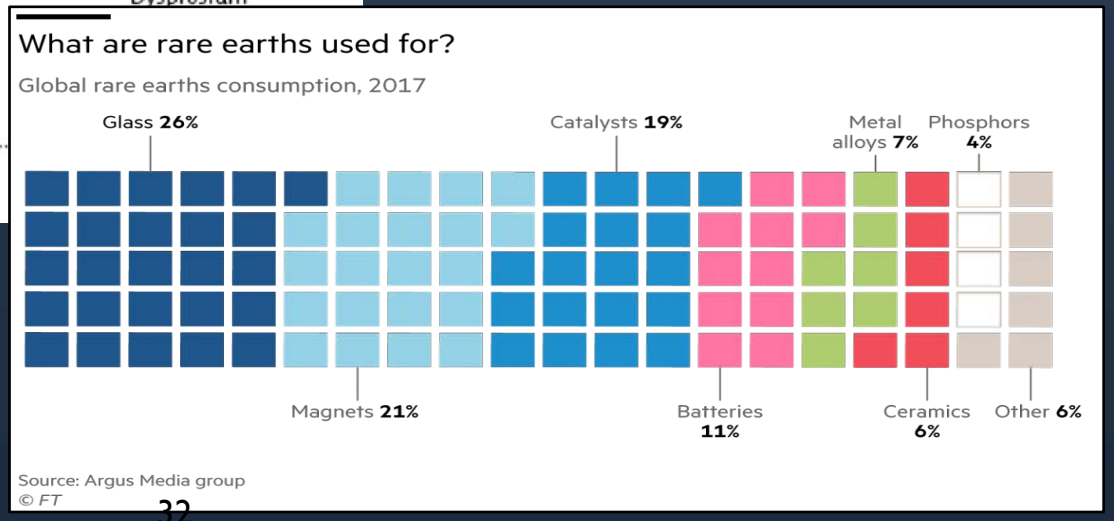
NATIONAL ENERGY TECHNOLOGY LABORATORY



We Use REEs Every Day

Cellphones each contain ~$15 of REEs. Electronic equipment imports into US are ~15% of REE total or +$400 B. Cell phones are ~33% of that total.





The Challenge of REEs

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The U.S. needs to **regain an ability to control the supply of REEs** which are critical to both our National Security and so many industries.

The U.S. Department of Energy, working with the National Energy Technology Laboratory, is attacking the problem by:

- Understanding how (and where) REEs occur in coal and by-products
- Developing with industry, new technologies for prospecting and producing REEs.
- Promoting new transformational separation technologies to produce both more ore quality and greater amounts of REEs from coal.

Coal to Building Products

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Another disruptive large-scale use for coal is building products, which has the potential to require even greater coal volumes than carbon fiber.

The range of *current* product uses is practically endless, and include:

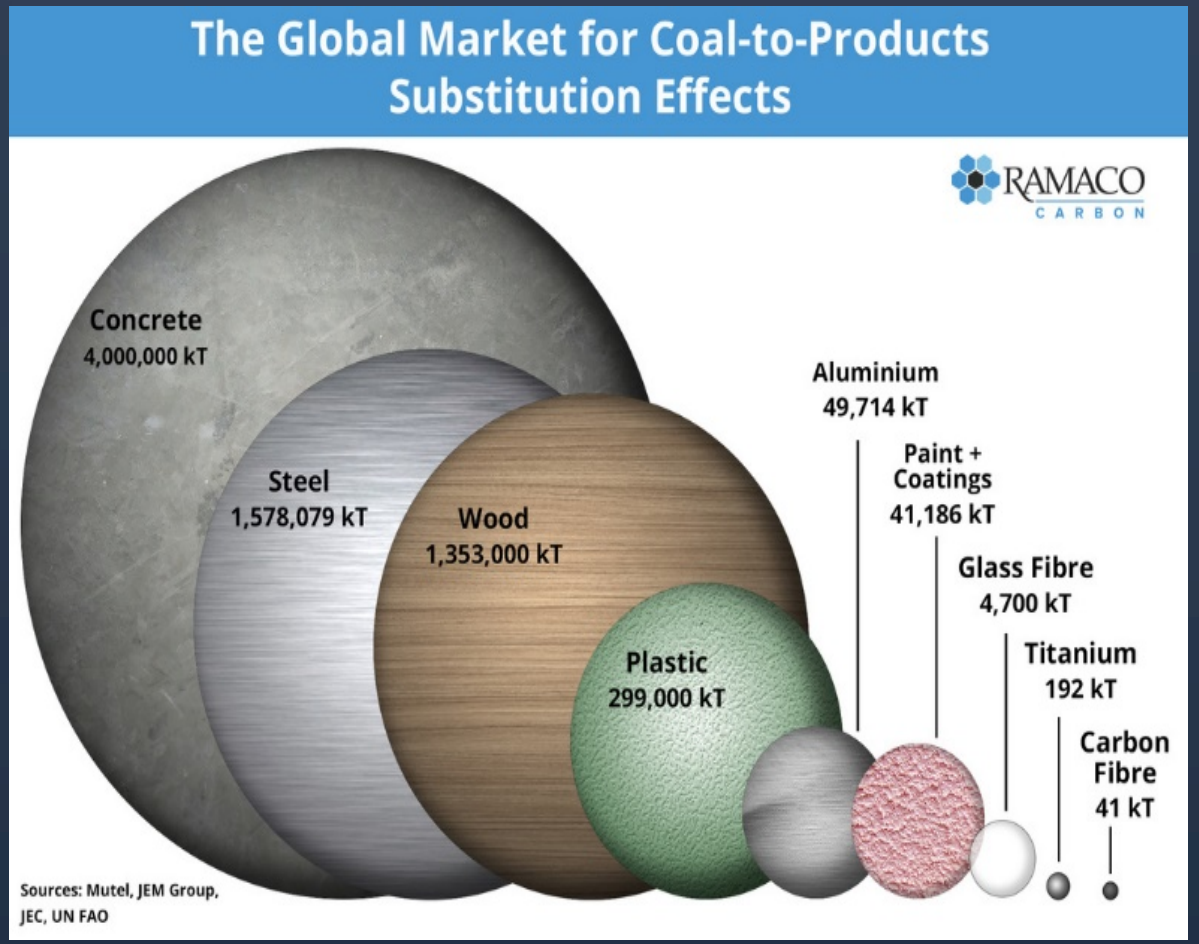
- **Rebar —** CF rebar can provide flexibility to concrete structures, does not expand with temperature changes, is lighter than steel rebar, and does not rust.
- **Roofing —** Coal-based pitch asphalt roof shingles could become a regular feature of buildings.
- **Repair Aging Infrastructure** (think bridge renovations): Can be molded around existing older infrastructure to provide structural strength, increasing lifespan by 2-3x at a fraction of the weight.

Coal to Building Products

- MIT architect Mark Goulthrope, projects by 2050 the global population will increase to ~11 billion people overall. In only 30 years, the world will double the aggregate mass of all building structures currently on the planet.
- **There is not enough concrete, wood and steel to build this reality**.
- Working with our partners at the National Labs, we proposed creating "net negative" CO2 buildings comprised of carbon building materials ("CBM").
- The goal is to have a complete "Carbon Building" by 2030.
- These buildings can be built quicker, lighter, stronger, more easily and less expensively than today's conventional structures.

Coal Building Materials: The "Substitution" Impact

- Over time CBM can replace a large percentage of current Basic Building Materials ("BBM") or be integrated with BBM to create new products.
- If we assume CBM could substitute for ~10% of BBM over time, this could require the equivalence of 2.8 B tons of annual coal consumption.
- CBM can also be combined with BBM as a transition to larger use of CBM.



Potential Global Substitution Markets for Coal-Derived Building Products (2016 Quantities)

Construction & Infrastructure Materials

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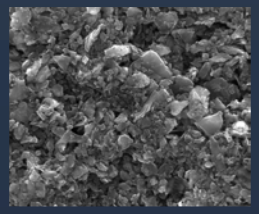

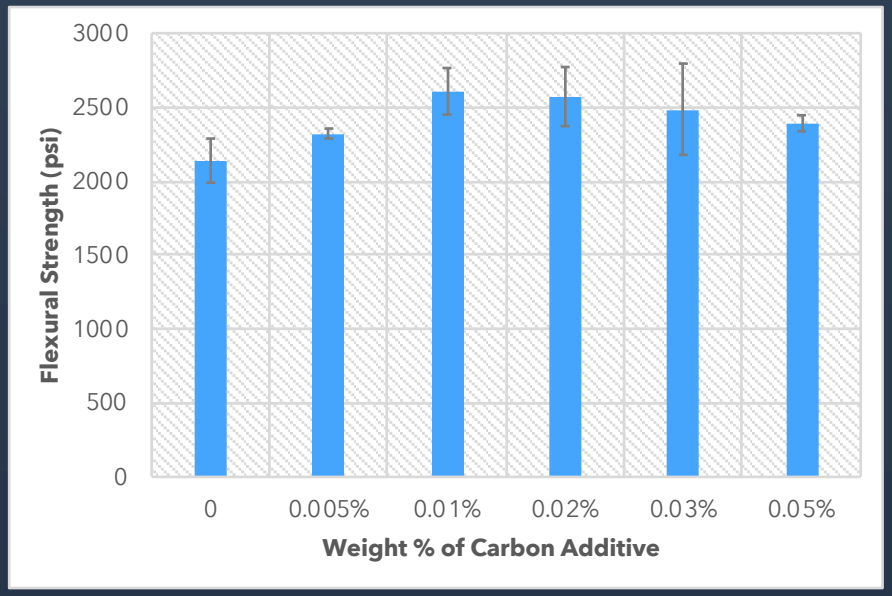

Coal-derived graphene nanoflake in cement/concrete formulations:

- Increases compressive and flexural strength by 15-35%
- Reduces porosity by 35% and permeability by 100%,
- Improves corrosion resistance

Coal Materials: Engineered Graphene Nanoflake

Coal Foams: Early Starts on CBM

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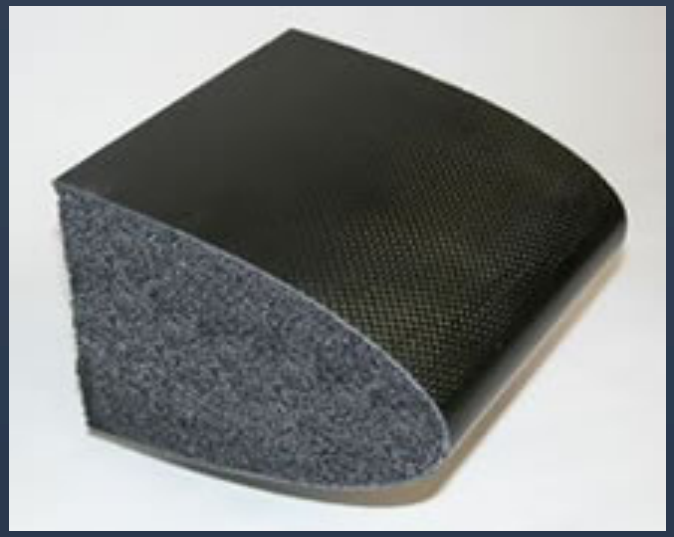

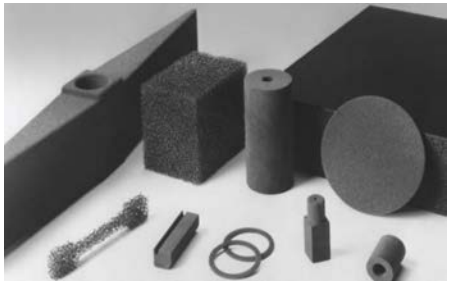

Biosensing & Medical Diagnostics

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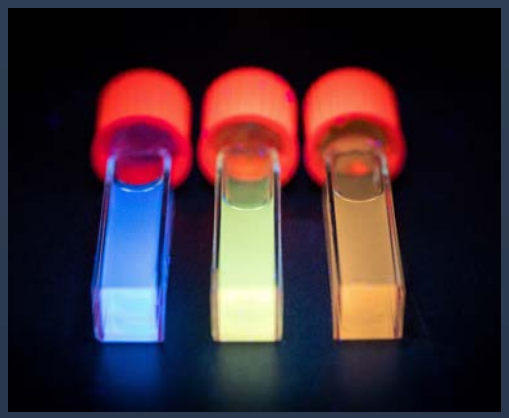
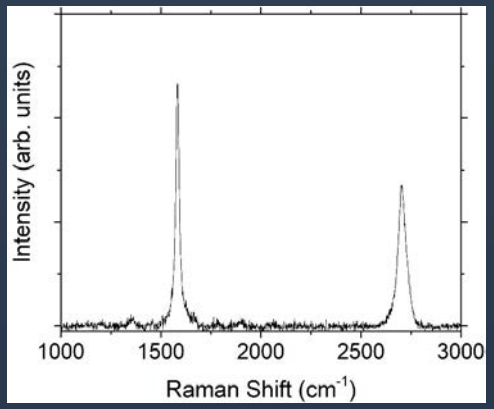
Optical Tags

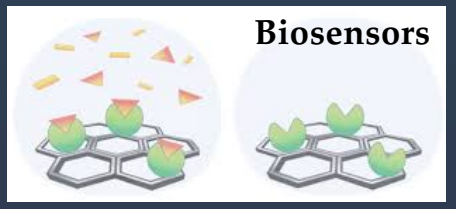


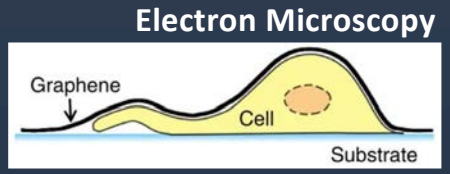
Graphene quantum dots (luminescent)

Used as optical tags for imaging applications

Biosensors & Microscopy







3-6 layer, low defect, graphene from coal CVD

Used for biosensor & electron microscopy applications

Coal Materials: Graphene Quantum Dots, Graphene Films, Carbon Nanosheets

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

Carbon Computer Memory

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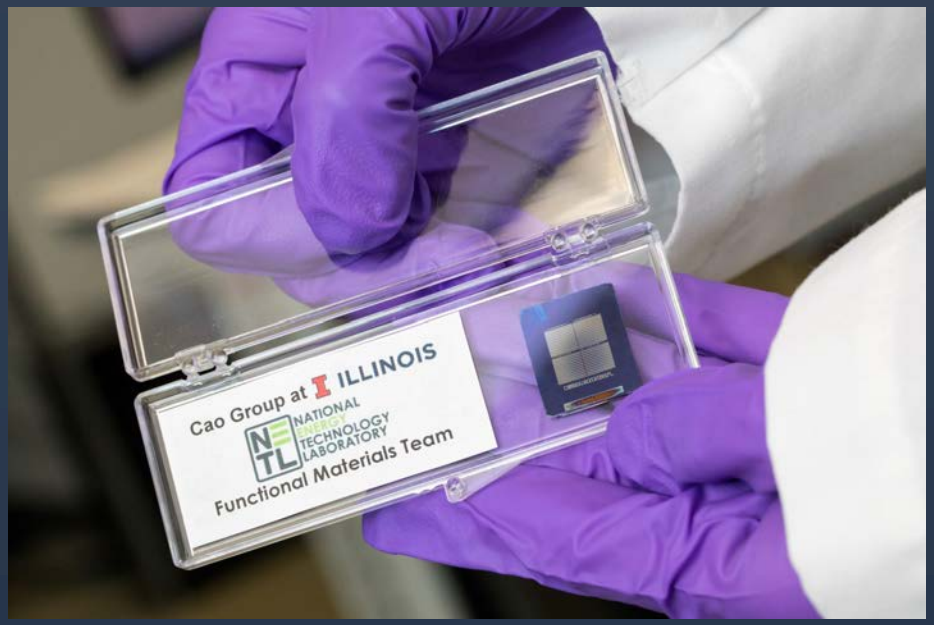

Memristor computer memory devices

- 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

- Lower cost fabrication method
- Improved device-to-device reproducibility
- Better long-term device stability

Coal Materials: Engineered Graphene Quantum Dots

Coal to Resins for 3D Printed Advanced Products

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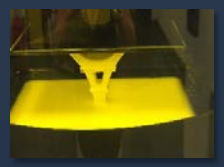
Resin
$99 to
$300/liter

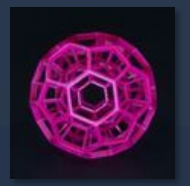
Produce Resins
from Coal

Brook Mine Coal
Current PRB
Price: $12/Ton

**More printers =
More production**

**Wyoming iPark
SpeedCell Printers**





Tomorrow's Assembly Line

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China is Pursuing C2P Tech

- The amount of coal required for coal-to-products can be enormous. Per the IEA, China currently uses ~400+ million tons annually for chemicals, fertilizers and fuels.
- **China's current 5 year plan call for ~370 new CTL/C plants (one new plant a week).**
- Within five years China will consume over **~1 billion tons per year for coal to products**.
- That is roughly double the entire amount (~530 million tons) of coal estimated to be produced in the US in 2020.
- This is roughly the entire amount (~530 million tons) of coal estimated to be produced in the US in 2020.
- There are questions whether these new plants also have strategic military or other purposes. Note the state-owned Hengli $20 billion investment in a coal-to polyester yarn plant supposed for use in making clothing

The Path Forward: Key Points

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#1 The coal industry must innovate to transition to higher value uses than primarily combustion.

#2 The U.S. has both the carbon resource base and the technological prowess to fundamentally reinvent the industry.

#3 We have created the first vertically integrated **"carbon tech"** platform.

#4 "CAMP" manufacturing centers can offer a new path to repurposing older or existing coal communities and higher more sustainable long-term employment.

#5 Innovation and research is the first step. R&D must be leveraged, supported and nurtured in the broadest possible way at both the federal and state levels.

#6 Carbon Ore/Coal can have a dramatically stronger and environmentally oriented future than we can imagine. We just need to unlock the potential of carbon.

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