Coal to Products

Building "Carbon Valleys"

Charlie Atkins- Director of Research & Development, Ramaco Carbon, LLC

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Starting the Conversation

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Does Coal Have a Future?

- The jury is out… Thermal Coal may not prevail against renewables and gas in the "race to the bottom" as the cheapest base load fuel for power generation.
- Yet, the United States has the world's **largest** and **cheapest** coal reserves.
- The **Problem**-Currently, 95% of all coal produced worldwide is burned for **power generation**.
- Only 5% is used to make **higher value products**, think met coal for steel. Met coal sells for a **higher price,** currently almost ~20x PRB coal prices.
- Some reasons Tennessee should help lead the "Carbon Renaissance"?
  - **Oak Ridge National Laboratory** – Leads the world and advanced materials development
  - **Eastman** – Has the lead the US in "Coal to Chemicals" (CtC) since 1920 with 14,500 employees , $9.5B of annual revenue, and historically Eastman used 2.2M tons of coal a year
  - **University of Tennessee** – A leading research university.

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Diversify the Coal Industry

The Opportunity:

Coal is the cheapest source of carbon. But most carbon products are expensive.

They now come from petroleum.

Let's use carbon from coal.

The Objective:

- Create a large volume (high margin) product use for coal based carbon.
- Build an innovative higher tech future for the coal industry, independent of power trends and environmental issues.

Positive Disruption

- Carbon is becoming the dominant "***advanced material***" … think carbon fiber, graphene, graphite and carbon resins.

- Make these advanced materials for less from coal. This could be vastly disruptive. They could replace or enhance most **metals** (i.e. steel, aluminum,) and **basic building materials** (i.e. cement, asphalt, rebar, roof shingles).

- Carbon also has applications in **chemicals** and even **life sciences**.

- All of these are fast-growing, game changing uses, **and can require tremendous volumes of coal**. In some cases think 100 million tons+ per use. The US mined 725 million tons in 2017.

- A few new uses **creates a demand inflection point for the industry**.

Who We Are

Ramaco Coal, founded in 2011, is a coal-based conglomerate with operations in five coal producing states, and three separate companies:

- **Ramaco Resources, Inc.** (**NASDAQ –METC**) **:** A public met coal producer. In 2017 became the first new coal IPO in the U.S. in a decade. Opened five new met coal mines in the past 12 months. Operations in West Virginia, Virginia, Pennsylvania and Kentucky. Projected full annual production of approximately 4+ million tons of high quality/low cost metallurgical coal. **www.ramacoresources.com**.

- **Ramaco Royalty, LP:** A private company that owns approximately 200 million tons of metallurgical coal reserves in Central Appalachia.

- **Ramaco Carbon, LLC:** A private Wyoming-based company focused on "**Coal to Products.**" **www.ramacocarbon.com**.

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Ramaco Carbon
A Vertically Integrated Coal Tech Company

Ramaco Carbon is the first pure "**Coal-Tech**" company. We are the **only strategic coal group** pursuing an integrated resource, technology and manufacturing based approach to new coal uses. We are an incubator of "**Coal to Products**". Our operations are :

- **COAL RESERVE: Brook Mine,** with 1.1 billion tons of coal resource on a 15,000 acre site six miles north of Sheridan, WY. Now under final permit review.

- **RESEARCH PARK (iCAM - Carbon Advanced Materials Center):** Breaking ground this summer. The **iCAM** will house national laboratories, university and private research groups and strategic manufacturing partners. We will conduct applied research to commercialize coal-based carbon products. Bench to pilot stage.

- **INDUSTRIAL PARK (Wyoming iPark):** A 100+ acre "**coal to products**" mine-mouth industrial park. Plants will use research from the **iCAM,** coal from the **Brook Mine** and manufacture advanced carbon products.

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The Trilogy…the First Coal-Tech" company
Coal Resource, Research and Advanced Manufacturing Center

Partners

- **Ramaco** is privileged to be working with some of the top U.S. **research institutes, universities, and strategic groups,** who form the core research and development team.

- Some members are:

  - **National Energy Technology Laboratory**
  - **Oak Ridge National Laboratory**
  - **Western Research Institute**
  - **Carbon, Inc.**
  - **Fluor Corporation**
  - **MIT- The Grossman Materials Group**
  - **Southern Research Institute**

- Also working with Western Research and other partners, on **a U.S. Department of Energy grant** to develop coal as a low cost precursor for carbon fiber to be used in vehicles. We call it **"Coal to Cars."**

Our Focus

- **Ramaco** is focusing on **three** broad uses:

  1) **Coal to Carbon Fiber**
  2) **Coal to Carbon Building Products**
  3) **Coal to Carbon Advanced Materials**

- We seek uses that can marry **advanced materials and advanced manufacturing technologies.**

- These uses have a higher margin value proposition and can require large coal volumes.

- **The Key:** Displace petroleum as the preferred **lower cost carbon feedstock**.

The Displacement Potential of Coal

- Coal's Potential is to make Advanced Materials that are Stronger and Lighter… and Cheaper.

- Example- Carbon Fibers
  - Carbon fiber is 50% the weight of aluminum but 4X as strong
  - Carbon fiber is only 25% the weight of steel but 2X as strong

- **The "Key" to Coal's Advantage… is cost.** Materials from coal can be made cheaper, than from petroleum.

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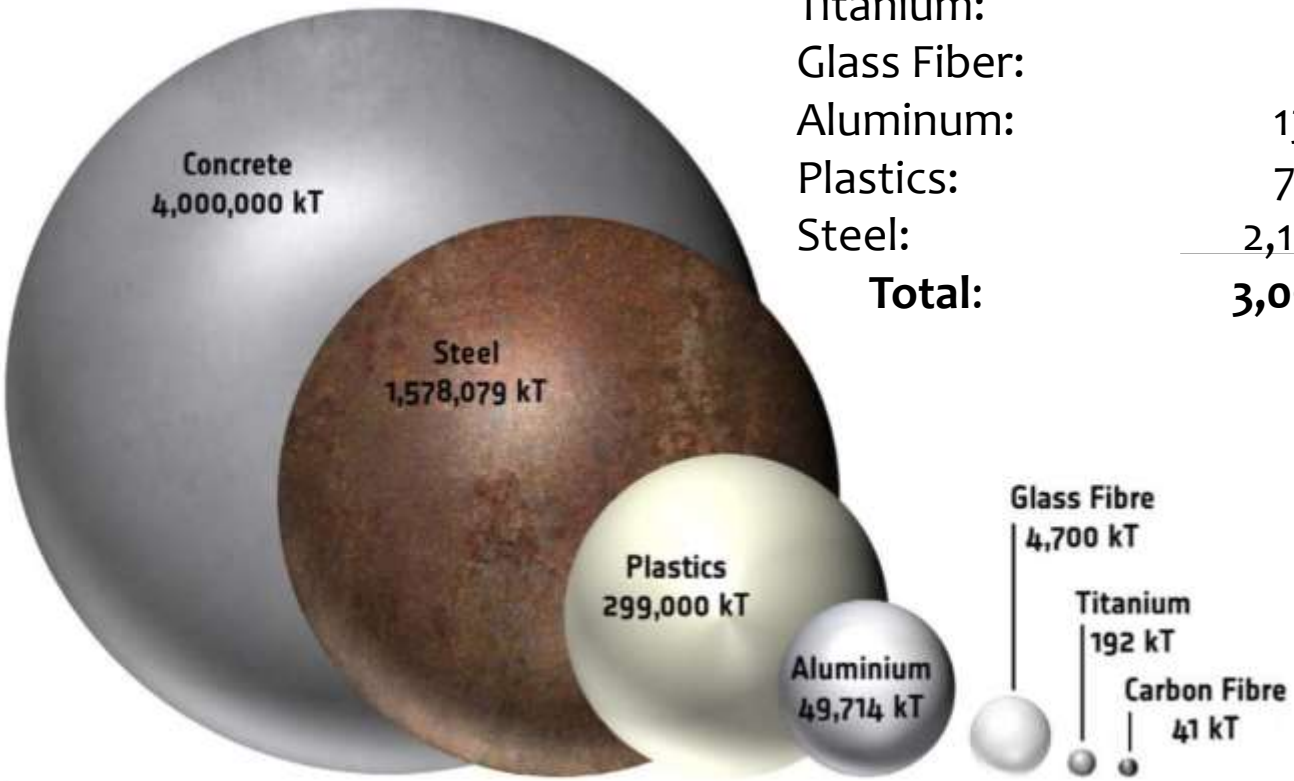
Material Displacement Opportunities are Huge

Annual amount of coal needed to replace:

Carbon Fiber (12% CAGR):	225,000 MT
Titanium:	1,054,000 MT
Glass Fiber:	25,827,000 MT
Aluminum:	136,577,000 MT
Plastics:	764,902,000 MT
Steel:	2,167,691,000 MT
Total:	**3,096,276,000 MT**



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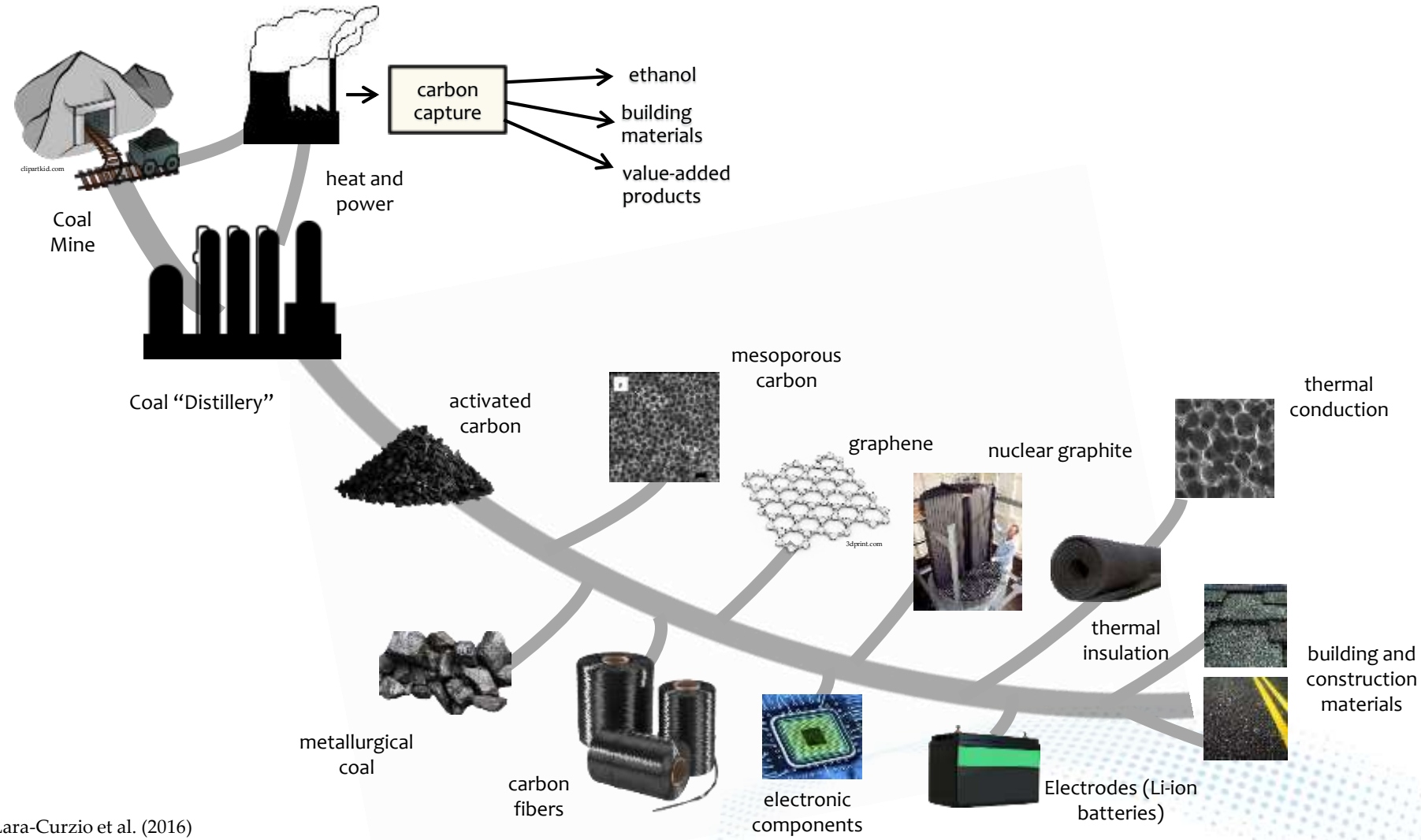
The Coal Products Tree



Lara-Curzio et al. (2016)

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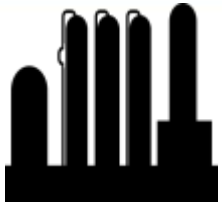
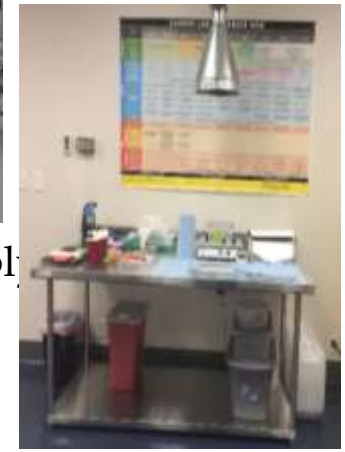


Resin
$99 to
$300/liter

Design

Prep

Wyoming iPark Assembl

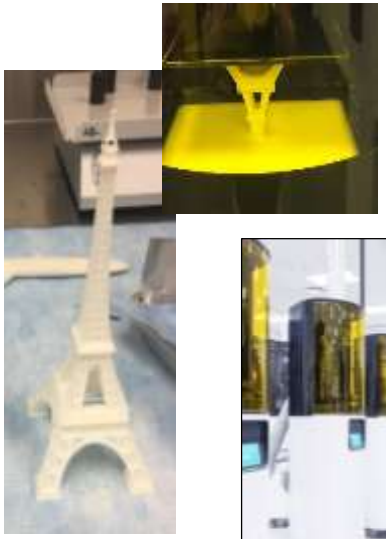


Produce
Resins from
Coal

Print

Produce

Brook Mine Coal
$20 to $30/Ton



More printers = More Production

Manufacturing in 3D
Printing Farms

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Coal to Carbon Fiber

Carbon Fiber is used today, with reinforced plastics (**CFRP**), to displace steel and aluminum **everywhere** where **"light weighting "** **is** important, and cost ***is not***. Examples include:

- Fishing rods, bikes, golf shafts, tennis racquets
- 40% of commercial airliners, 31% of fighter jets

THE PROBLEM IS COST: Today, carbon fiber is 8x more expensive than steel and 2x more expensive than aluminum.

THE REASON IS PETROLEUM: Carbon fiber precursor currently comes from **petroleum.** The cost is about $15+ per pound.

If through R&D we can drop the price of carbon fiber precursor below $5 per pound, it is game over. Carbon Fiber replaces steel and aluminum.

Coal to Cars

- Of roughly 100 million vehicles made each year, carbon fiber is used in less than 100,000. **The barrier is carbon fiber's high cost**.

- We need to drive the price of the coal-based precursor beneath the "tipping point." Carbon fiber then becomes an affordable alternative to steel.

- Carbon fiber cars then **move from a niche market to mass market**.

Coal to Cars…The Evolution

Ramaco's New Carbon Fiber Family Car

(aka the "all Carbon Fiber" McLaren Carbon Series LT "Special Edition")

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Not Only Cars…The Revolution is Beginning

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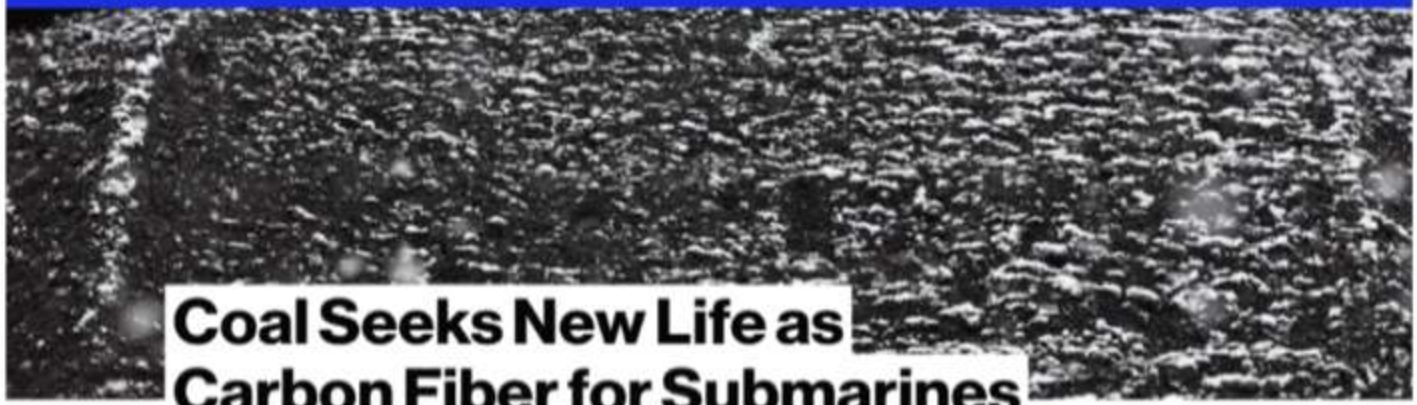

Coal Seeks New Life as Carbon Fiber for Submarines

By **Tim Loh** and **Patrick Martin**
September 13, 2017, 7:00 PM EDT Updated on September 14, 2017, 9:03 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. Pundit Says 30% of Bank Jobs May Disappear in Next Five Years
5. Apple Unveils iPhone X With New Display as Rivals Grow

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Coal to Building Products

- Another disruptive market for coal is **"Building Products."**

- Building products have the potential to require greater coal volumes than carbon fiber.

- The range of product uses is practically endless.

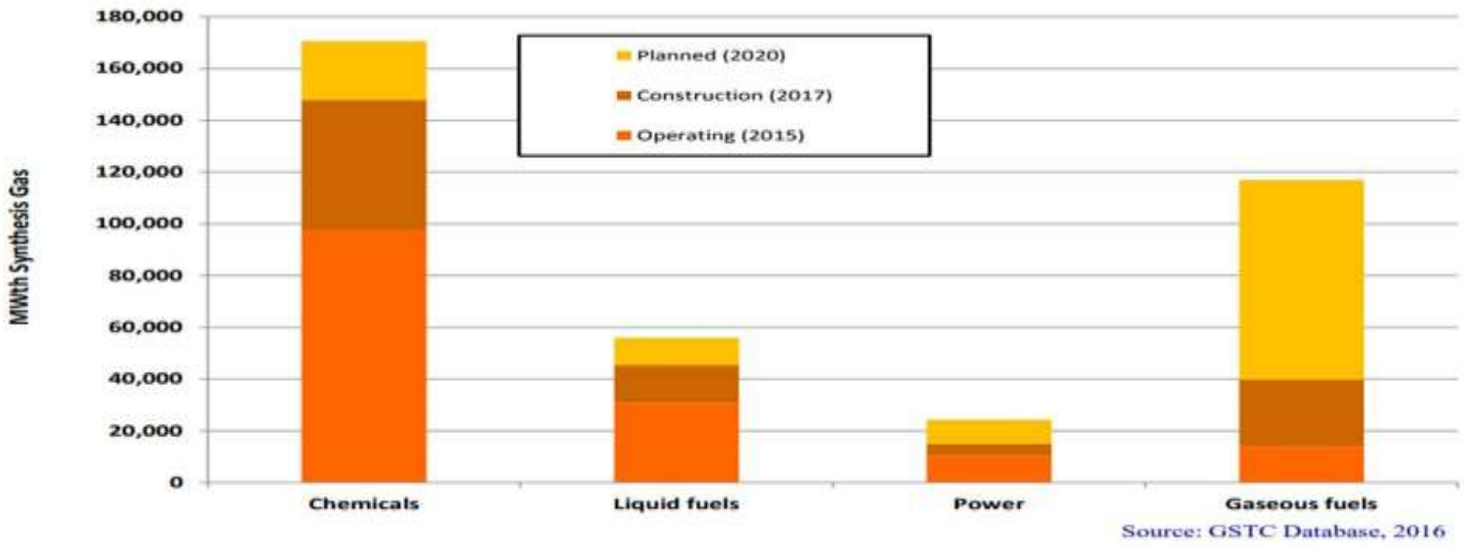
  - **Rebar:** Carbon fiber rebar can provide flexibility to concrete structures, is lighter that current rebar, and does not not rust.

  - **Coal Based Asphalt Roof Shingles**

  - **Repair Aging Infrastructure (think bridge renovations):** Can be molded around existing older infrastructure to provide structural strength. The life span of infrastructure can be increased by 2-3x.

Coal to Carbon Advanced Manufacturing

- Coal to chemicals has been **practiced for decades . We are first targeting Resins for 3D Advanced manufacturing.**
- The growth of the olefins markets, as well as price dynamics in coal and other feedstocks (CH_4 and CO_2) create other new opportunities.
- We are exploring some of these technologies with our partners, specifically Fluor, who was the EPC contractor for coal to liquids projects like Sasol II and III, as well as WRI and SR.



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Combining Coal with Advanced Manufacturing

- Silicon Valley-based company **Carbon, Inc.**, is revolutionizing 3D printing. Its "*CLIP-Continuous Liquid Interface Process*" uses ultraviolet light, oxygen and carbon resins to print solid materials.

- Ramaco Carbon has entered into a production partnership with **Carbon, Inc**. to create advanced carbon-based products, ultimately from coal based carbon resins.

- **Ford, BMW and Adidas** are already working with Carbon, Inc.

- **Ramaco** takes delivery of several Carbon 3D printers this spring to manufacture a wide range of products.

- This is not "smoke stack" manufacturing…

Wyoming iPark
Manufacturing in 3D Printing “Farms”

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Our Assembly Line- “Speedcell” 3D Printers

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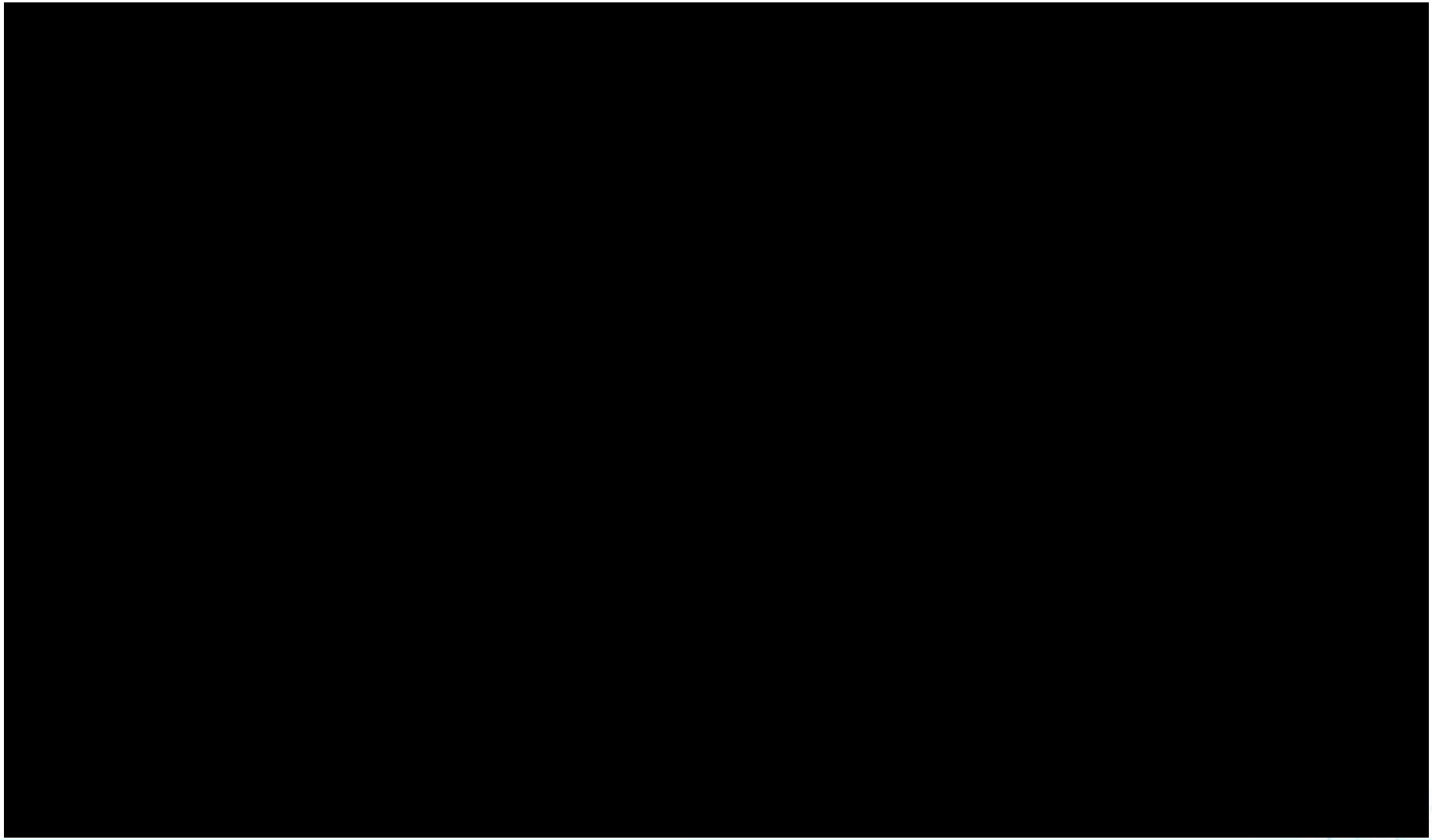
A Demonstration- “The Transformers” meet Coal



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The Way Forward

- The past few years have been very difficult for coal industry. We must adapt and innovate to survive… it is time to **think outside the box. Be Optimistic!**
- Coal needs its own **"Carbon Valley"** …..or multiple Carbon Valleys
- U.S. has both the resource base and the technological prowess to fundamentally reorient the coal industry. We can be **the cornerstone of an advanced materials and manufacturing revolution**.
- **Innovation and research** is the first step. We need R&D and new forms of processing.
- **But R&D needs to lead to widespread Commercial applications.** Create the volume usage.
- **Ramaco's** "Coal-Tech" efforts are the first targeted steps by an industry partner.
- Federal government research support is **essential** to realizing the scale of the opportunity.
- Remember… It starts with a **lump of coal** and the **Power of Carbon**….

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