Massachusetts Institute of Technology

Harnessing the Value of Carbon: Novel Applications of Coal to Carbon Products

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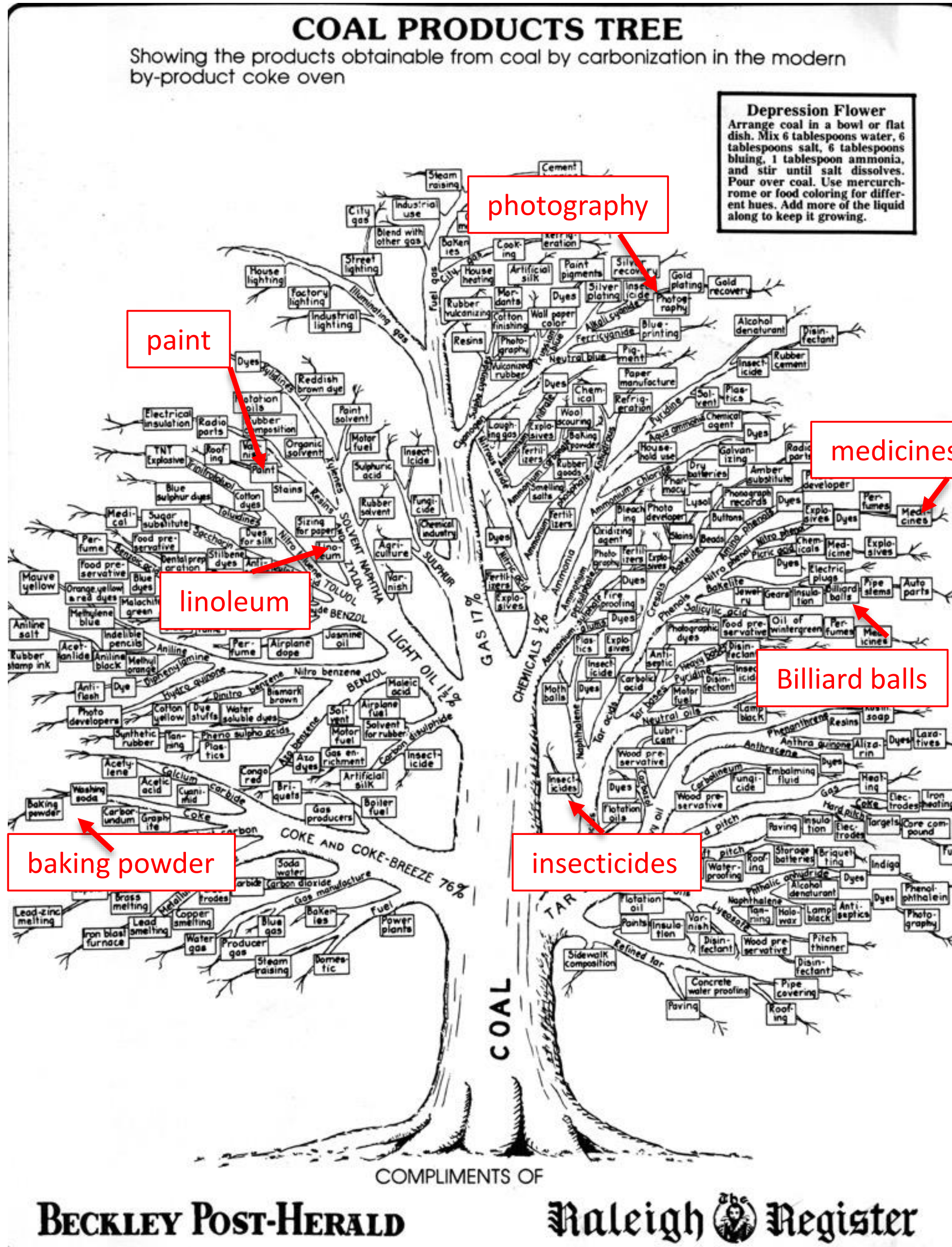
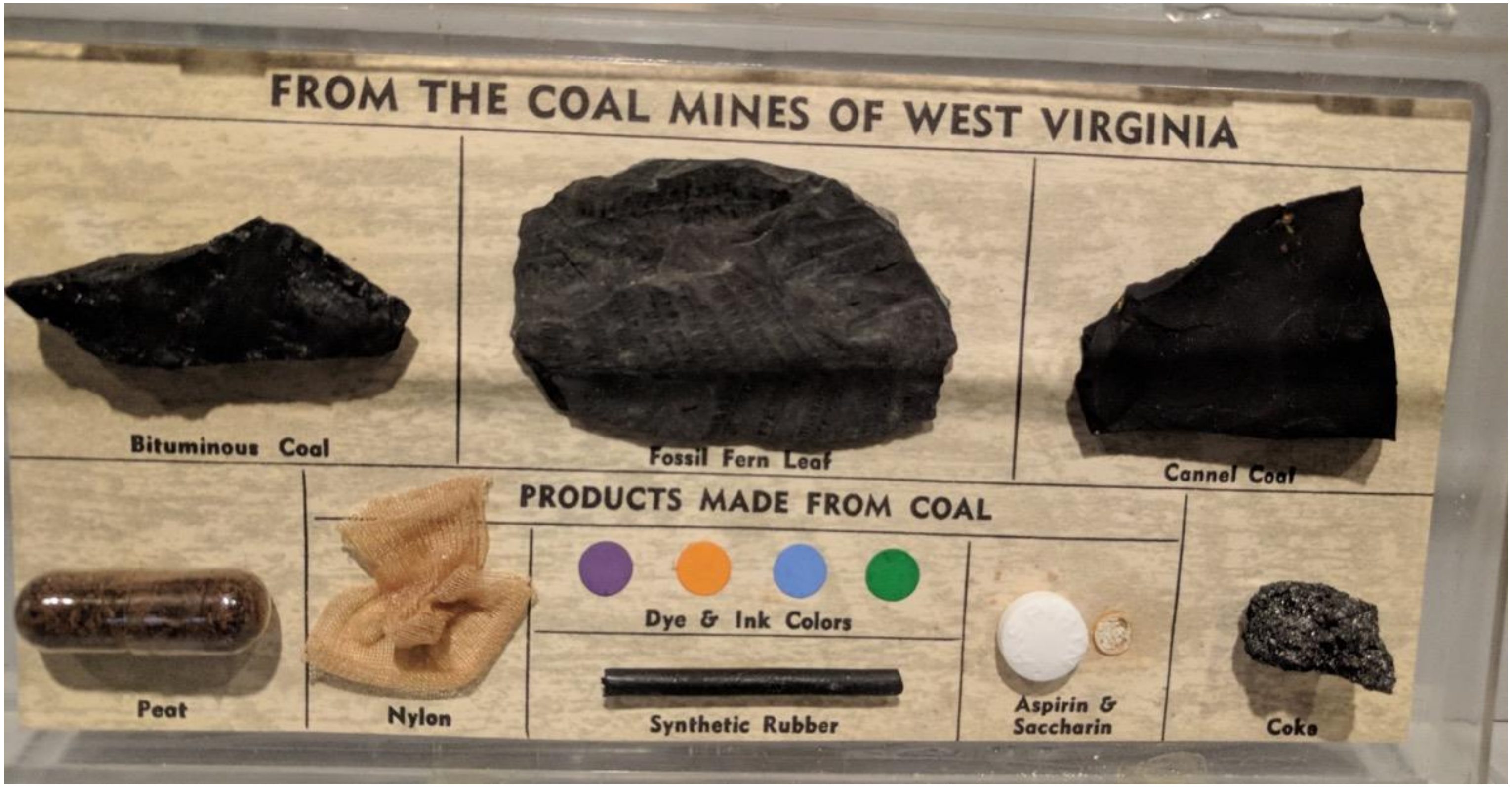
Coal as a feedstock material: Certainly not a new idea

Its use reflects the societal needs and the technology of the time



(1930)

Coal: enabler for novel technologies

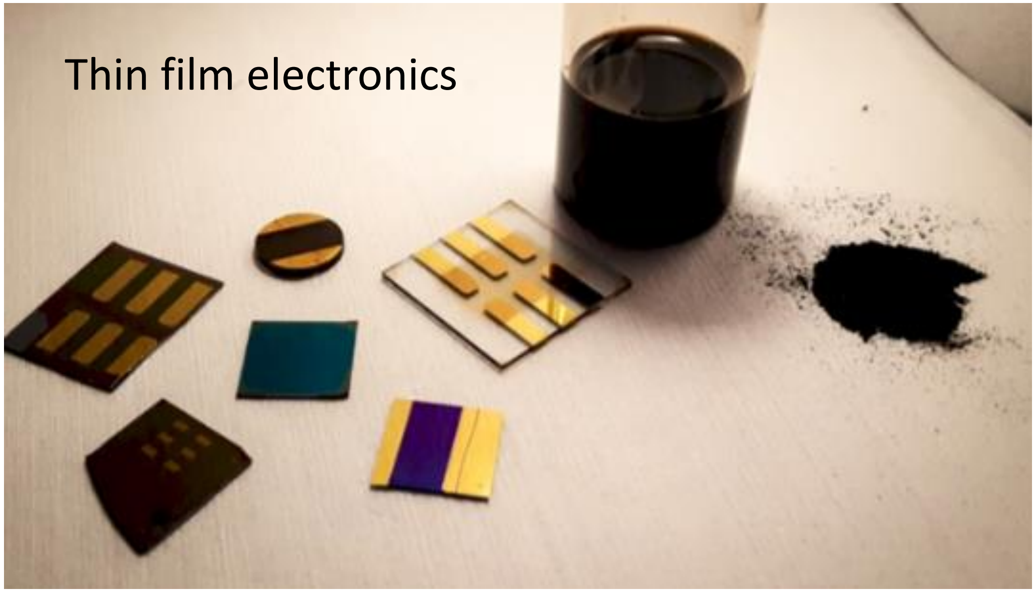


A souvenir made by 6th graders from Huntington, WV for then senator JF Kennedy

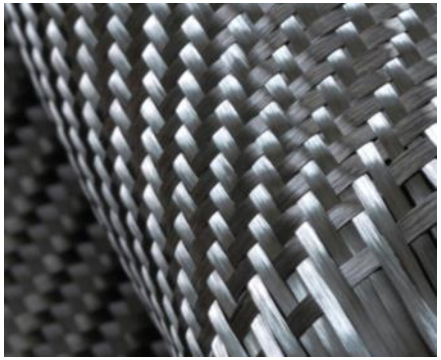
… and yet today we are not fully exploiting coal using the technological and scientific materials understanding of the 21st century

JFK Presidential Library and Museum, Boston, MA - JFK 100 Collection

Coal-to-products in the 21st century



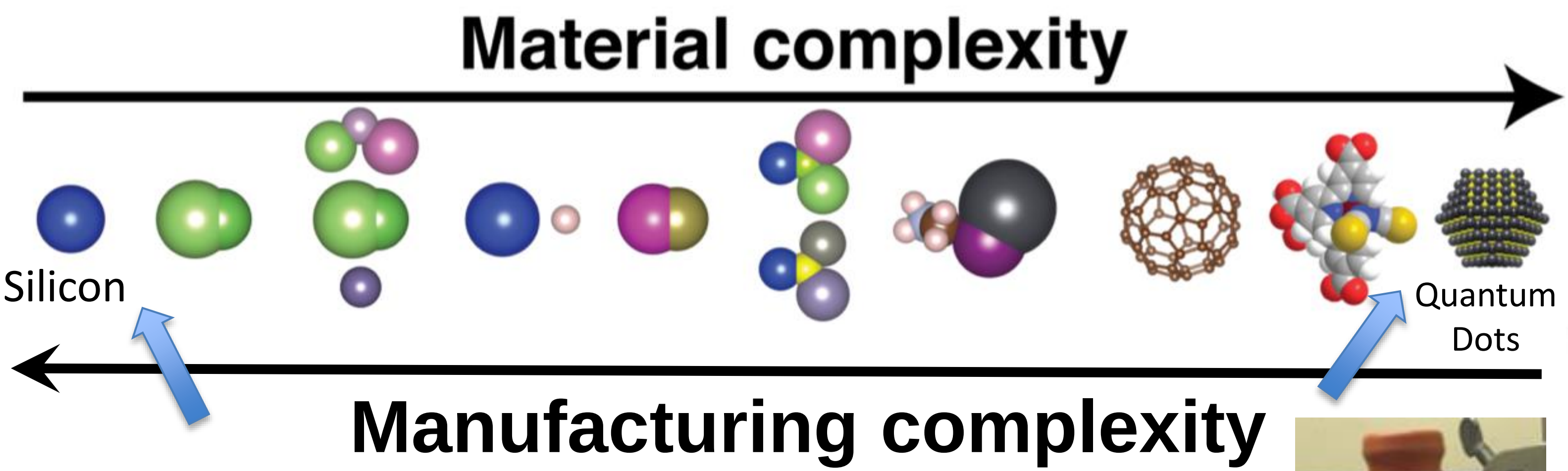
Nanoscale Filtration and Separations

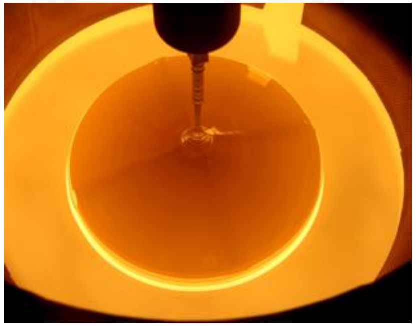


Carbon fibers

Coal-based electronics: Materials vs Manufacturing

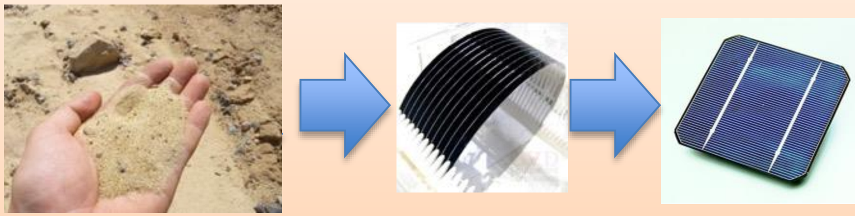
An example: Materials for photovoltaics





An opening for coal?

Materials vs manufacturing:
The case for coal-based electronics



Silicon electronics

Cost: 40-50 USD/Kg

Solar/electronic grade (purity: 99.9999%)

Availability: 150 KTon/year

Coal electronics

Cost: 0.08 USD/Kg

Availability: >700 Mton/year
(U.S. coal production)

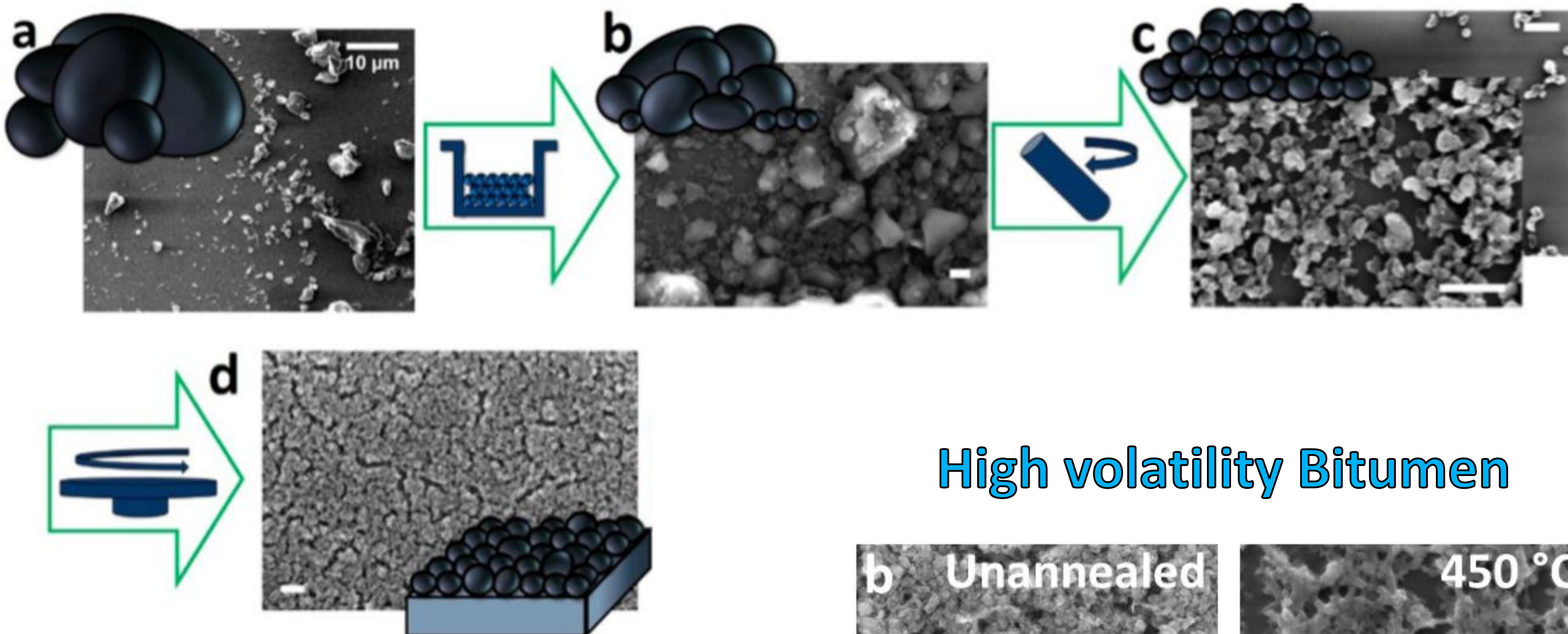
"If you want to make something dirt-cheap, make it out of dirt.

Preferably dirt that's organic and locally sourced."

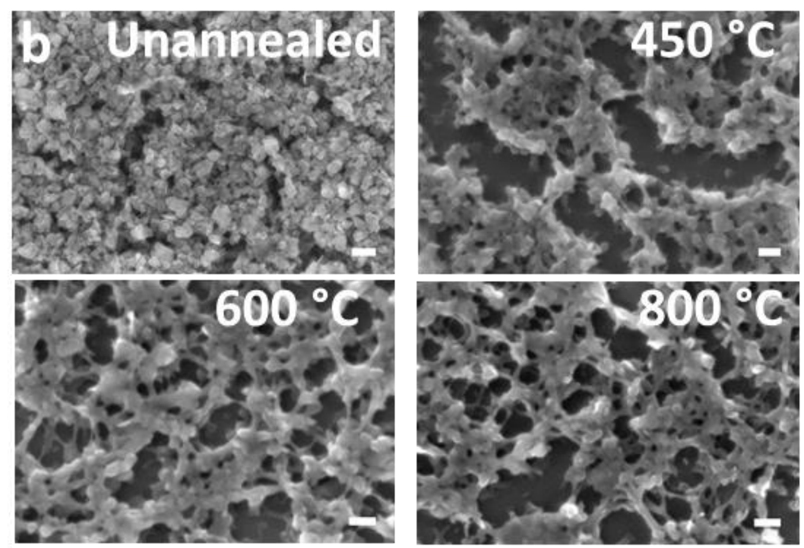
Don Sadoway, TED Talk 2012

US Energy Information Administration (2018)
S. Amendola, Overview of manufacturing processes for solar-grade silicon, RSI Silicon, (2011)

1st challenge: Making coal thin films



High volatility Bitumen



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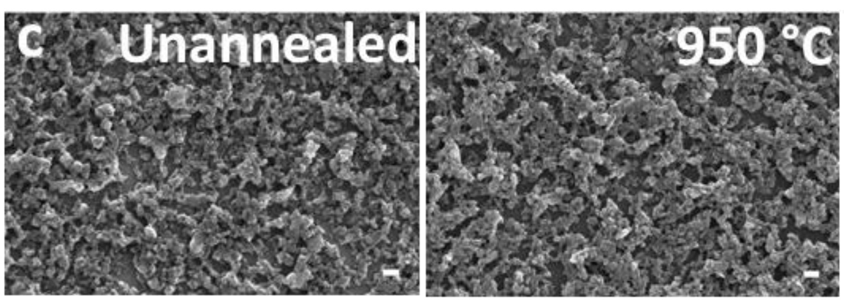
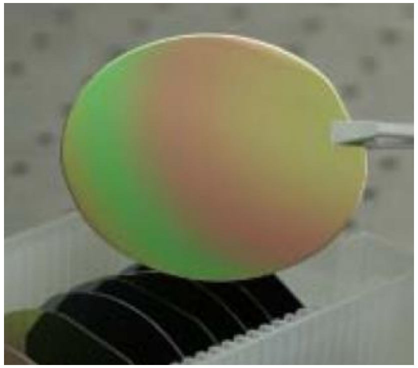


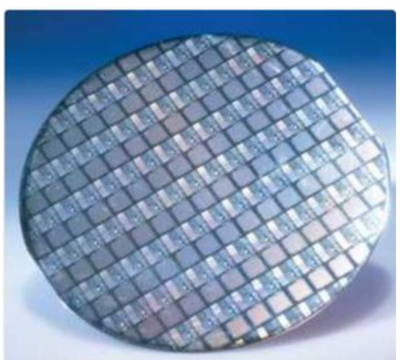
BD Keller, NF, JC Grossman, Nano Letters 16 (2016), 2951

Scale Bars: 200 nm

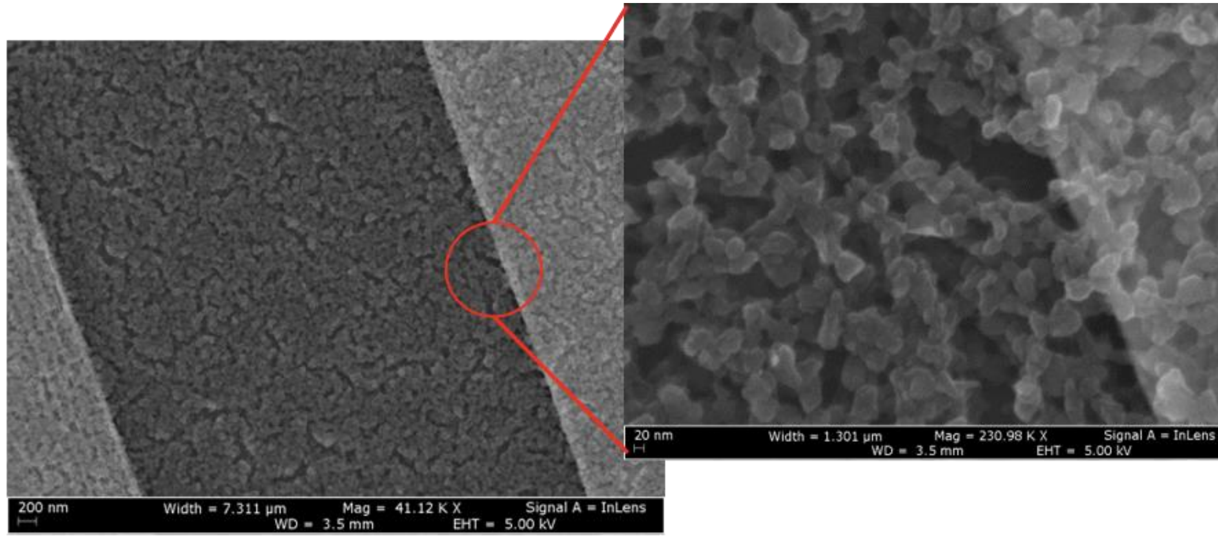
From coal thin films to electronic devices

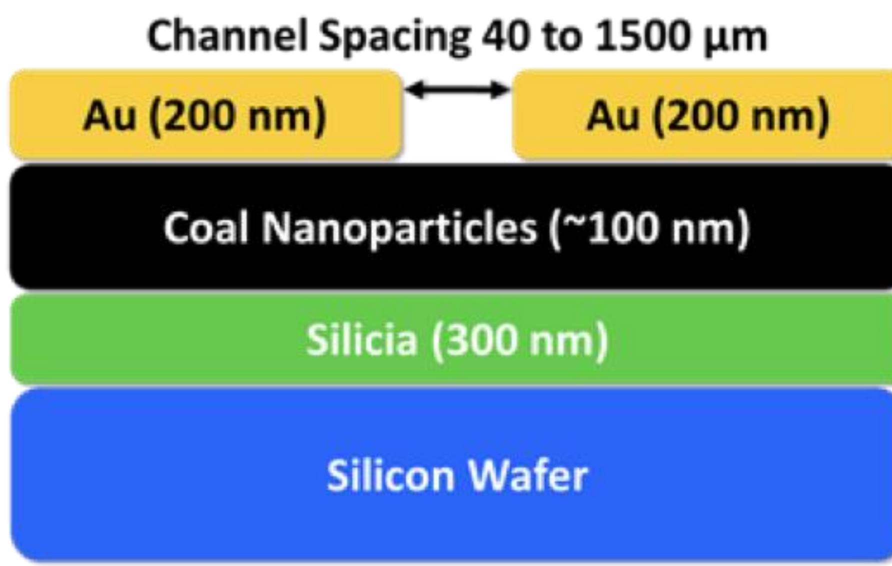
Silicon: From films…



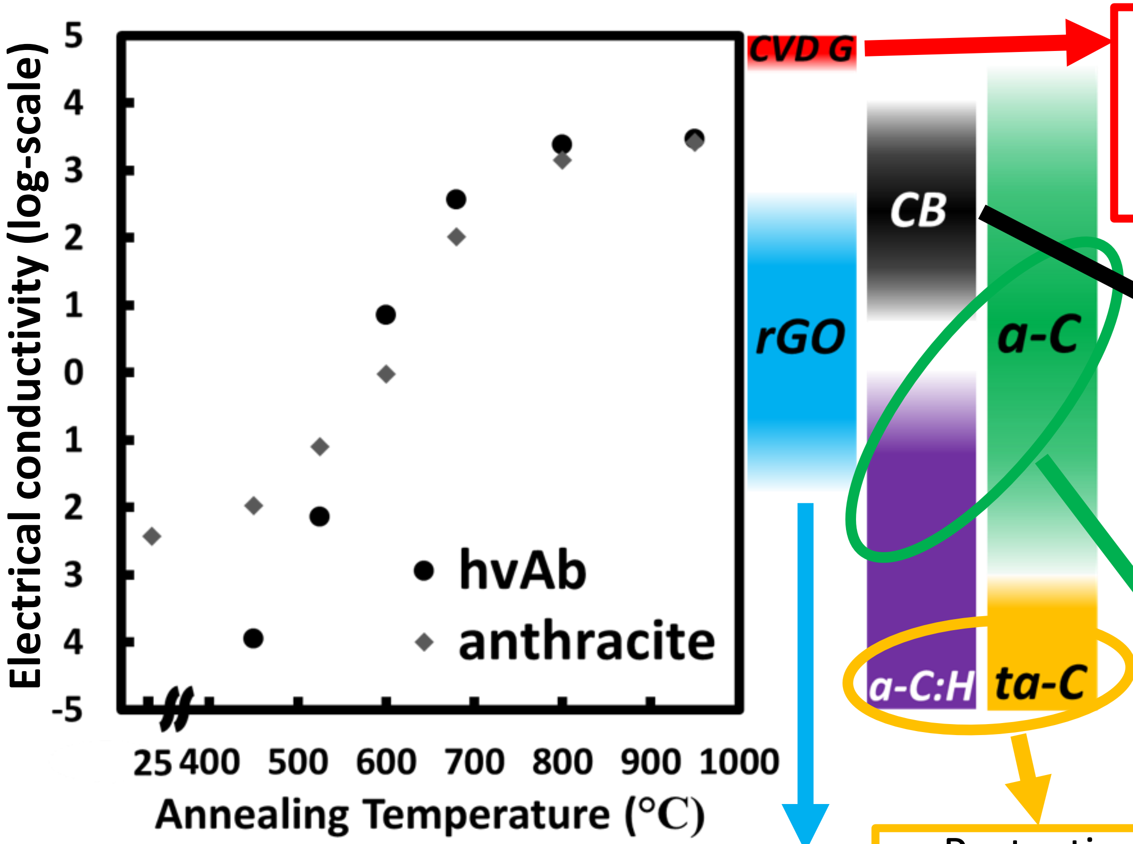


… to electronic devices





Coal complex chemistry:
The key for customized electronics performance



- Always-on transistors
- Transparent conductors
- Ultrathin materials junctions

- Low cost conductivity additive
- Produced from burning tar at 2000 C
- ~0.5 to 1 $/kg

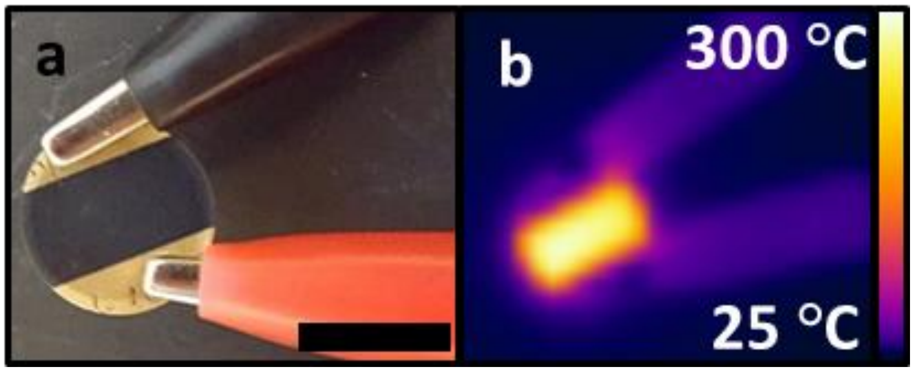
- Battery Electrodes
- Photovoltaics
- Transistors
- Micro force Sensing

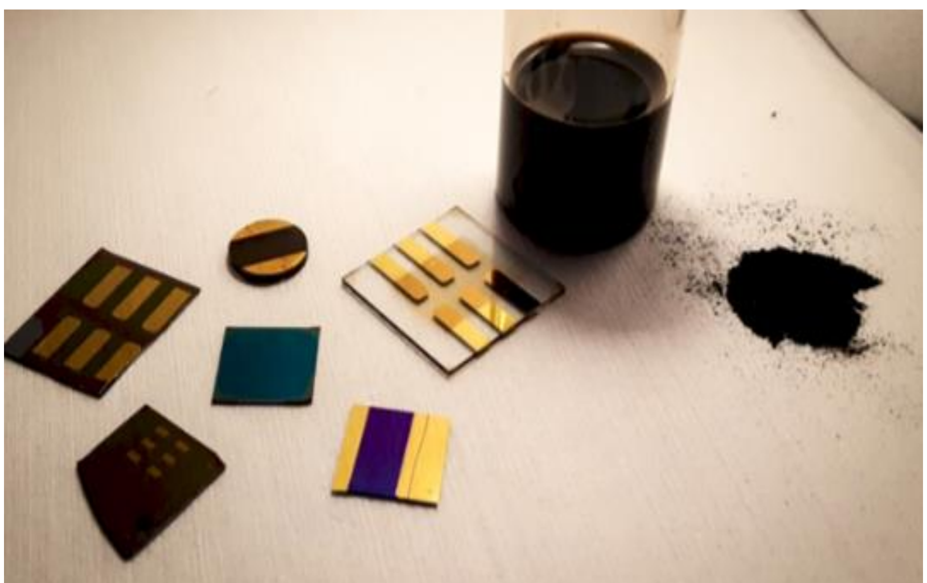
- Protective coatings
- Piezoelectrics

- Low cost graphene alternative

BD Keller, NF, JC Grossman, Nano Letters 16 (2016), 2951

Example: Coal-based thin films as Joule heaters



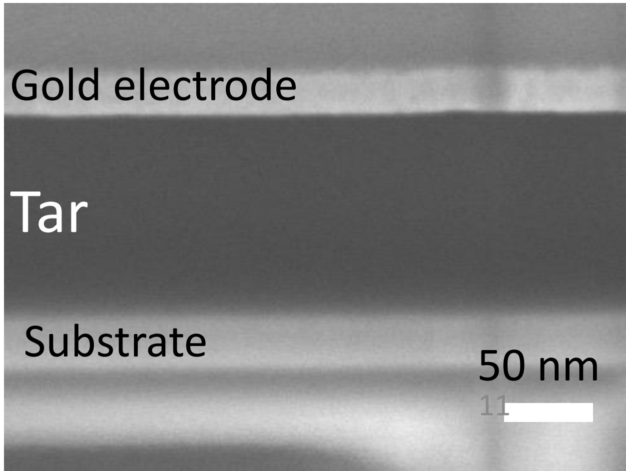


Advantages

- No degradation in air
- Performs as well as graphene
- No encapsulation
- Compatible with semiconductor fabrication tools

Going even thinner (tar): Transparent Joule heaters

- High temperatures
- Stable in air
- Better stability and performer of class leading materials
- Extremely simple manufacturing

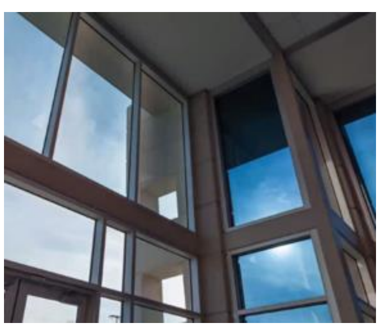


OP Morris, NF, H. Helsen, M. Disko, JC Grossman, Adv Materials, in review (2019)

Coal thin film nanoelectronics: a technology enabler

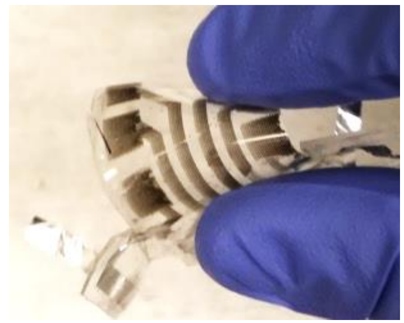
Transparent heaters and electrodes

De-icing



Smart windows

Flexible electronics and sensing



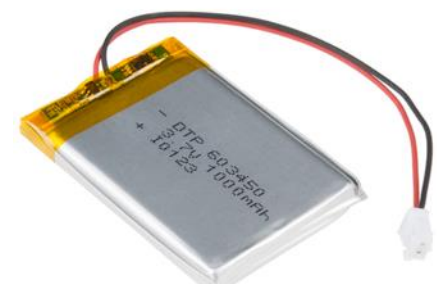
Biosensors

Infrastructure monitoring

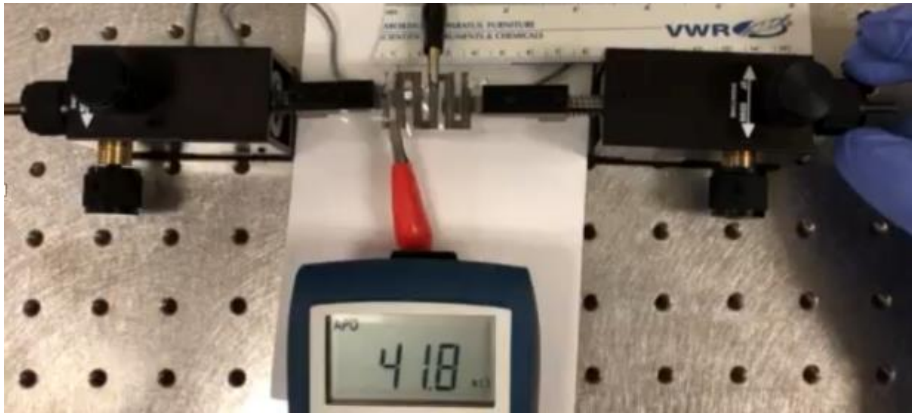
Energy Storage

Supercapacitors for high power applications

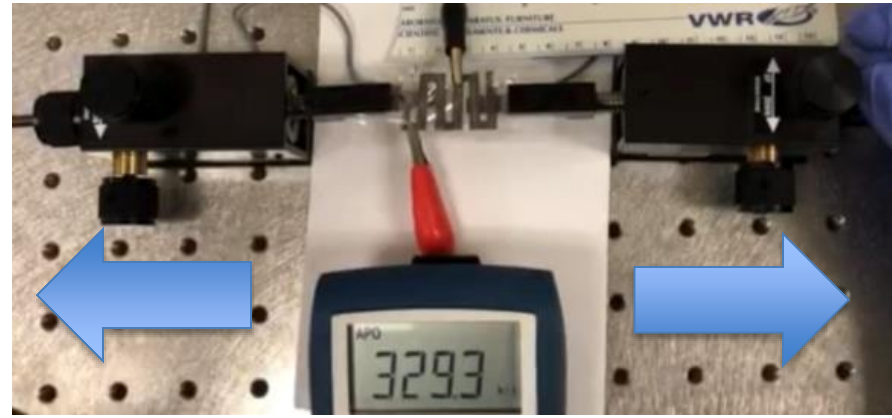
Hi-energy density porous electrodes for Li-ion batteries



Example: Coal-based “fatigue” sensor



Relaxed/unstrained



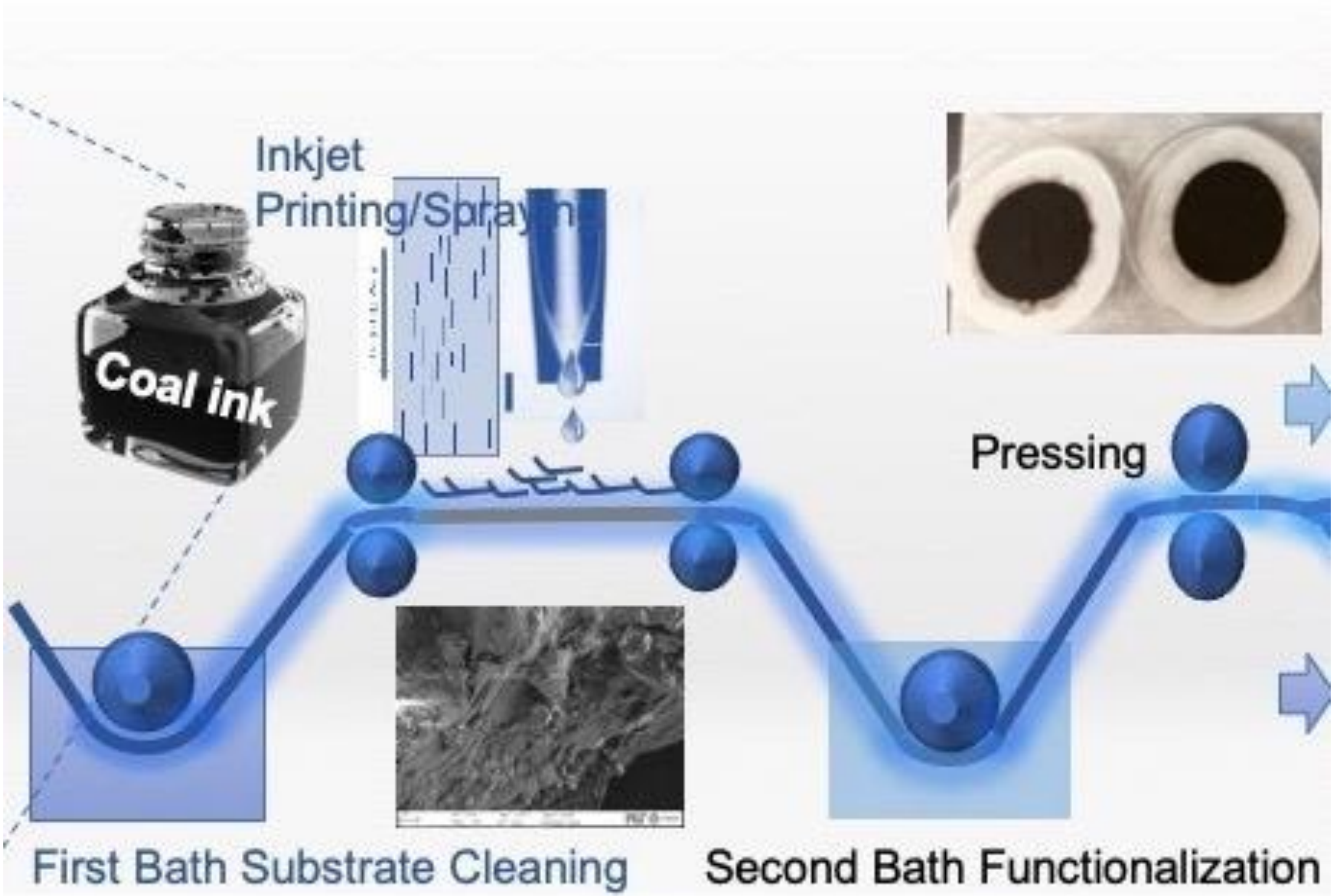
10% strained

Large scale fatigue monitoring

- Real time infrastructural integrity
- Requires large production volume

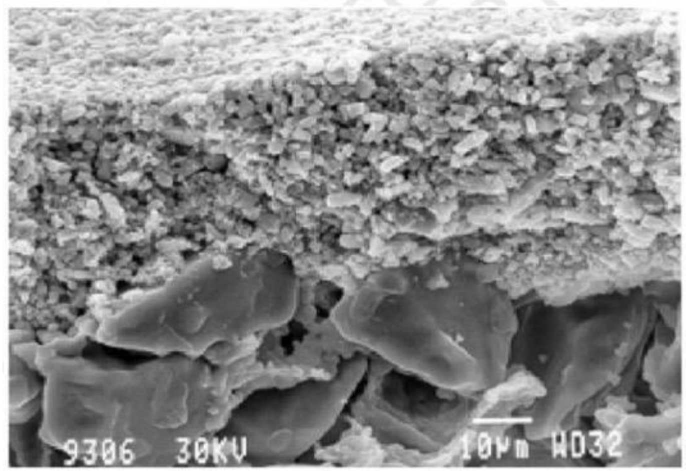
Every building can be a sensor

Additive Manufacturing: A coal-based printing press?



An opening for coal: Nanoscale filtration/separation

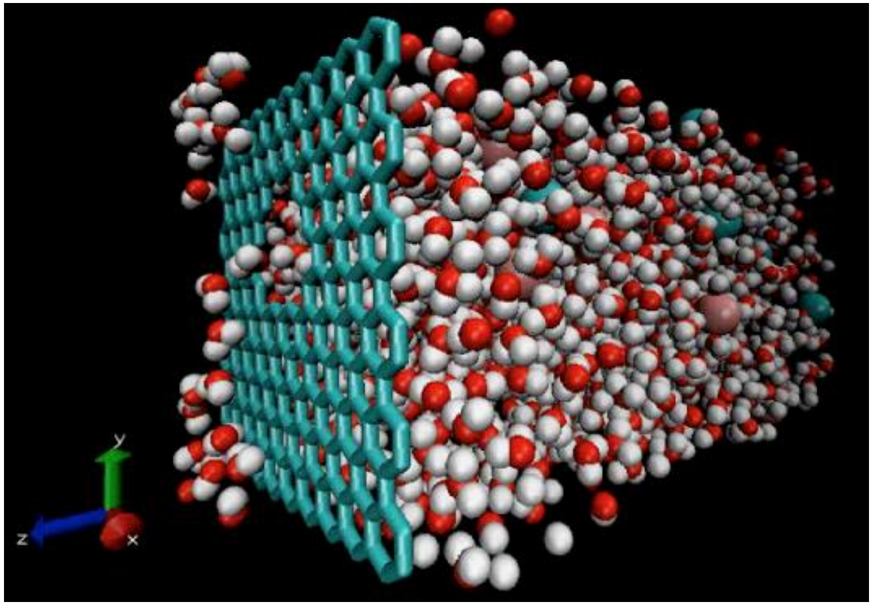
No thermally and chemically robust options

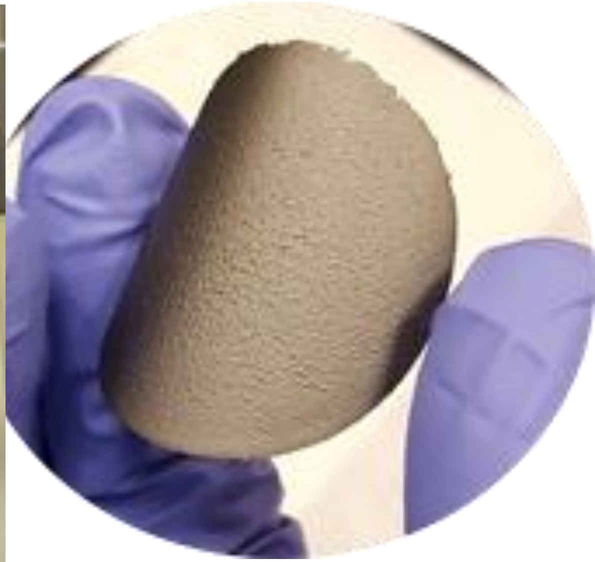


1-5 Nanometers Microns Millimeters

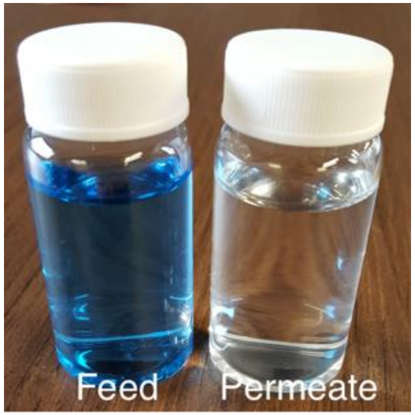
The lack of materials is the limiting factor in stable and robust nanofiltration

Carbon-based nano-filtration: Starting from graphene…





2012 → 2018



Chemically, mechanically & thermally robust platform

Coal-based nano-filtration membranes

Coal nano-powder
Active filtration agent

+

Tar, tar pitch
Binding agent

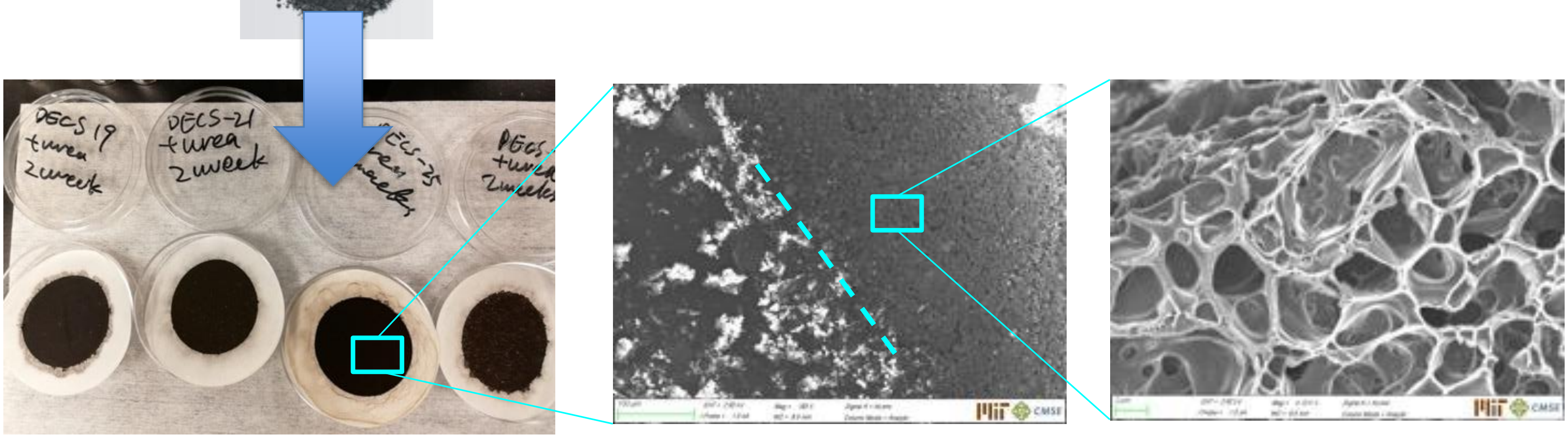
+

Flyash
Inorganic support

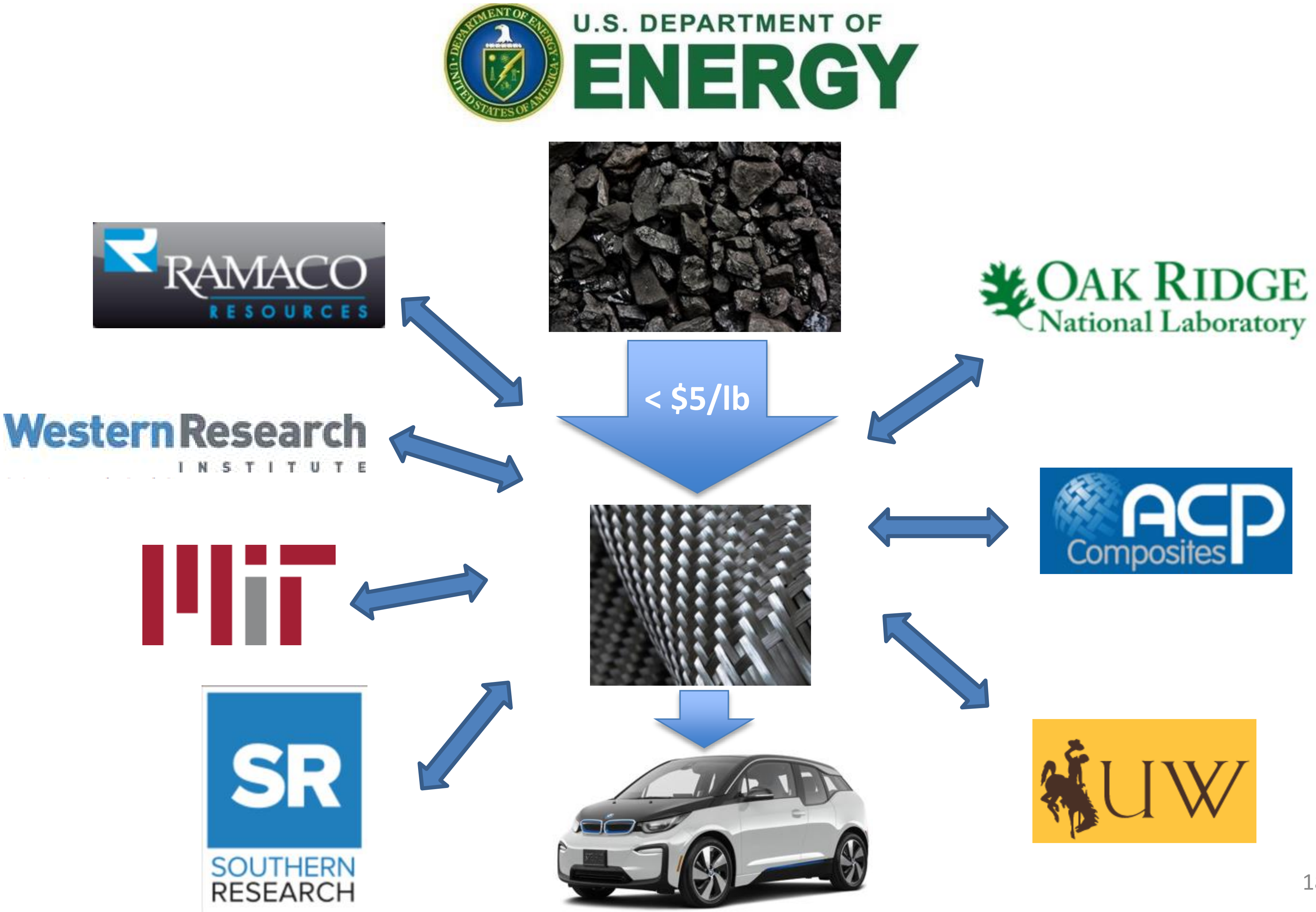
Advantages over synthetic graphene:

- Scalable processing
- Higher yield
- All chemistry needed can be coal-derived

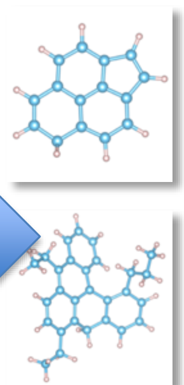
Combination of coal-derived feedstocks opens an incredibly large materials design space



De Pluribus Unum: a consortium for inexpensive coal-based carbon fibers

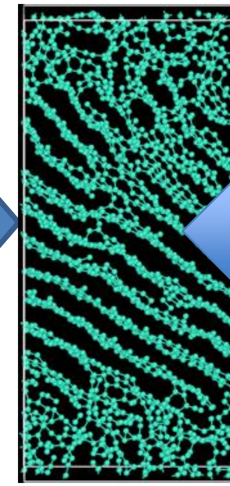


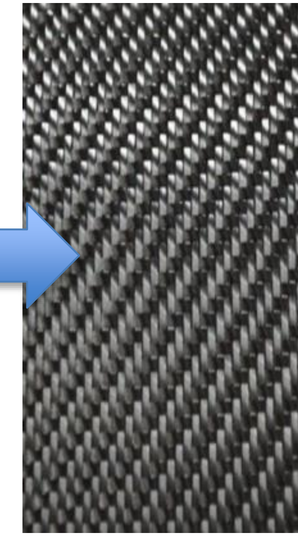
Rapid Computational Prototyping of Pitch to Fiber Manufacturing



Optimization
Coal Tar Pitch
Chemistry and formulation

Optimization
Carbon Fiber
Manufacturing

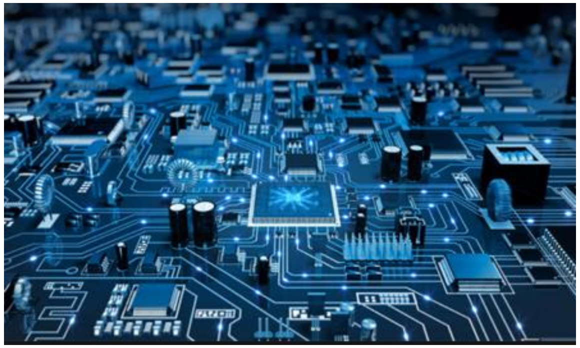




Consortium Data

RAMACO RESOURCES
Western Research INSTITUTE
OAK RIDGE National Laboratory
SR SOUTHERN RESEARCH
UW
ACP Composites

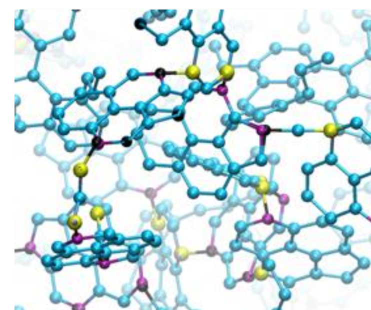
Predictive Machine Learning
Models for Pitch and Fibers
Manufacturing Parameters



Coal as the
sustainable, scalable
source of
high tech materials
of today and tomorrow

Additive manufacturing

Advanced materials modeling and processing



Sustainable sourcing

Funding support

U.S. DEPARTMENT OF ENERGY

ExxonMobil

BOSE

MITei
MIT Energy Initiative

Co-PI: Jeffrey C. Grossman, PhD (MIT)