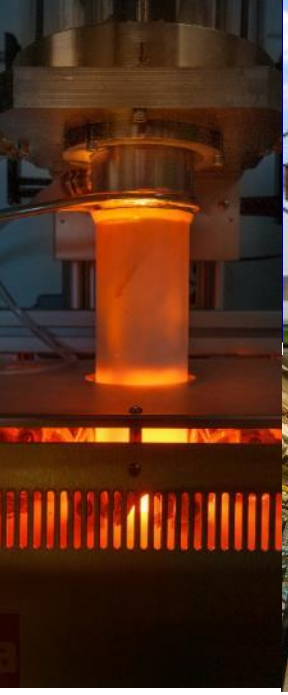





U.S. DEPARTMENT OF ENERGY | Office of Fossil Energy

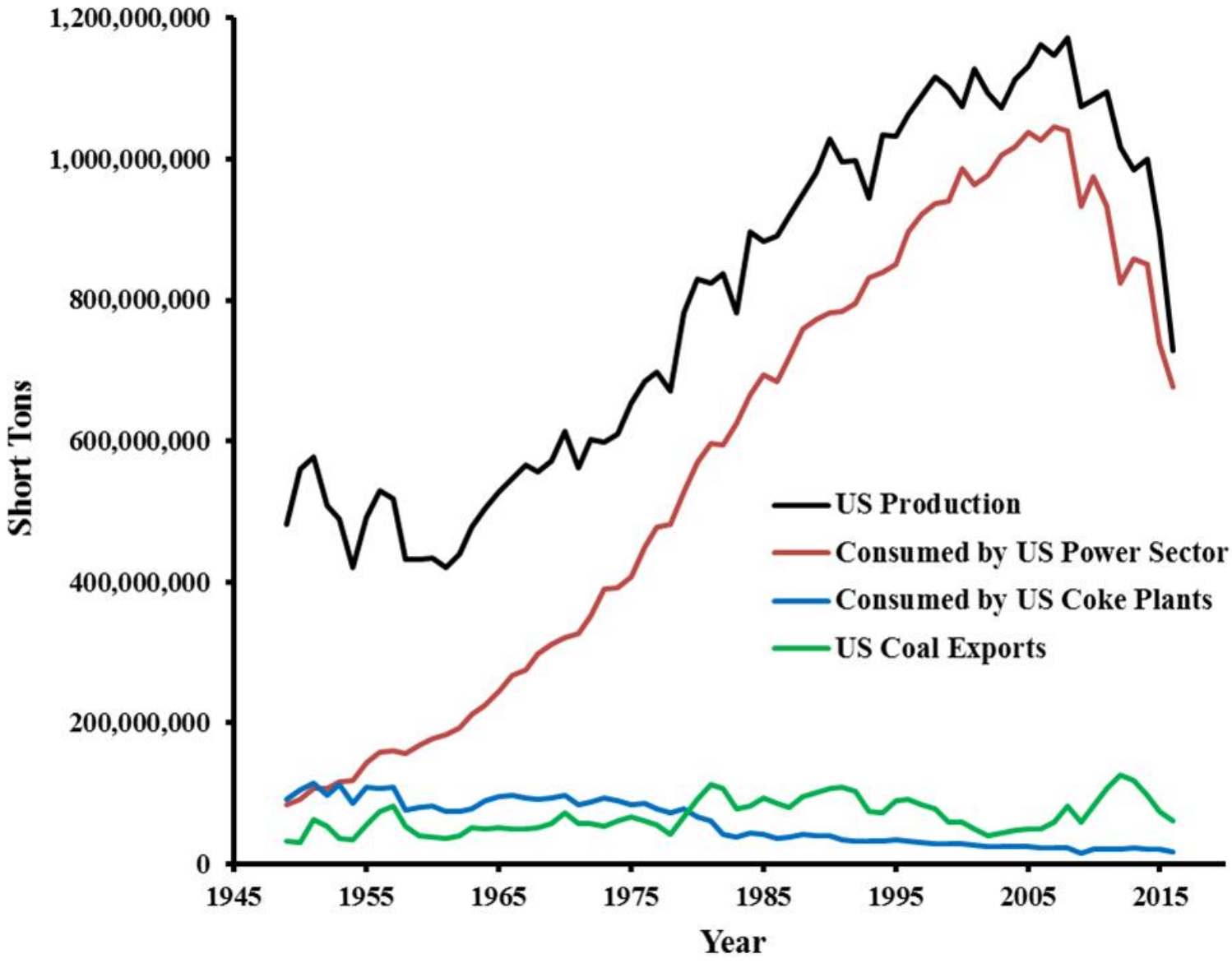
Useful Products from Coal

National Academy of Sciences
October 25, 2018

Angelos Kokkinos

Director, Office of Advanced Fossil Technology Systems

U.S. Coal Production and Use by Key Market Sector



Existing & Past End Use Applications for Coal & Byproducts

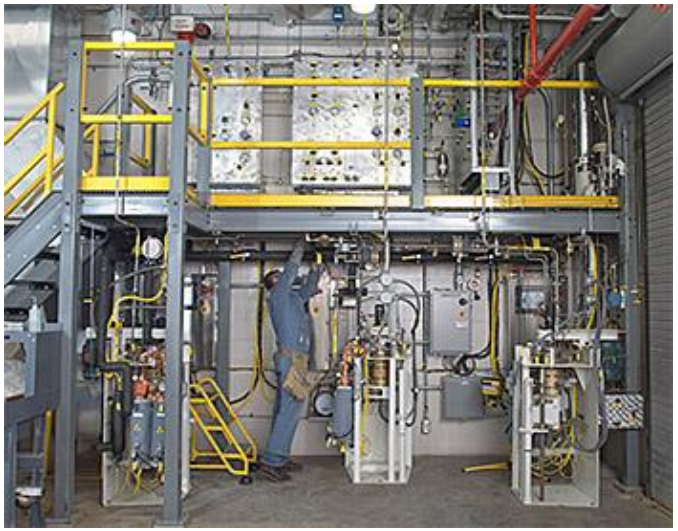
Examples

- **Iron and Steelmaking**
  - Metallurgical Coke
  - Slag Foaming Agent
  - Charge Carbon
  - DRI Reductant
- **Non-Ferrous Metallurgy**
  - Ferroalloys
  - Silicon Metal
  - Aluminum
  - Titanium
  - Germanium
- **Environmental Applications**
  - Municipal Water/Wastewater Filtration Media
  - Activated Carbons
- **Construction Products**
  - Cement Additives (Pozzalons)
  - Lightweight Aggregates
- **Chemicals**
  - Wood Preservatives
  - Fertilizer
  - Aromatics
- **Consumer Products**
  - Medicines
  - Shampoo
- **Carbon Products**
  - Graphite
  - Fibers
  - Rubber Fillers
  - Electrodes

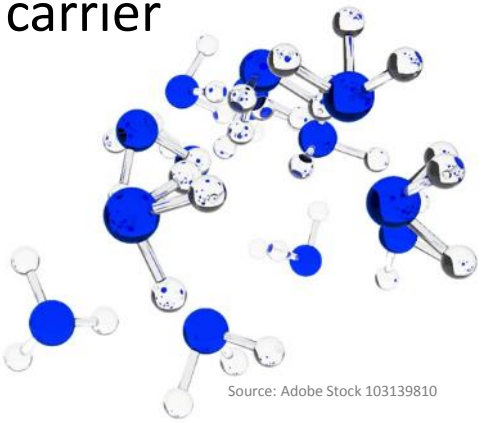
Coal for Value-added Chemicals

DOE Research Areas

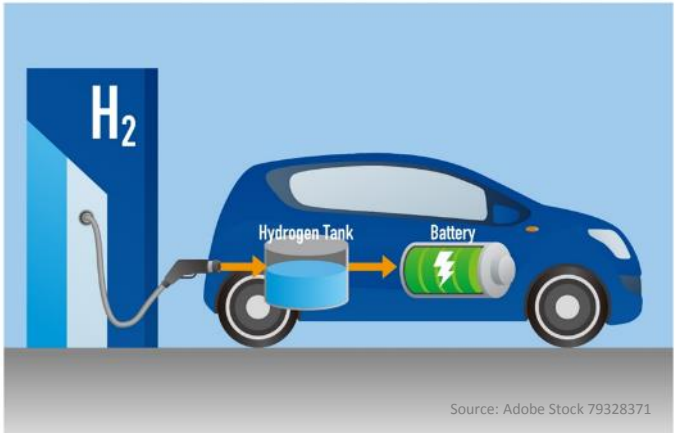
- Coal to Liquids
  - Jet fuel
  - Methanol, an intermediate for chemicals production
- Coal for Ammonia and Hydrogen Production
  - Hydrogen shows promise as an energy carrier



Fischer-Tropsch Synthesis Rig, University of Kentucky



Source: Adobe Stock 103139810

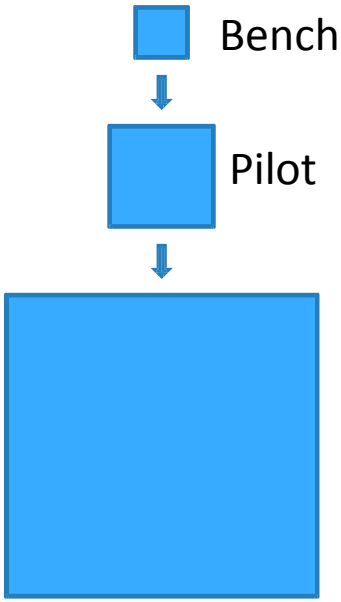


Source: Adobe Stock 79328371

Modular Systems: Speed and Affordability

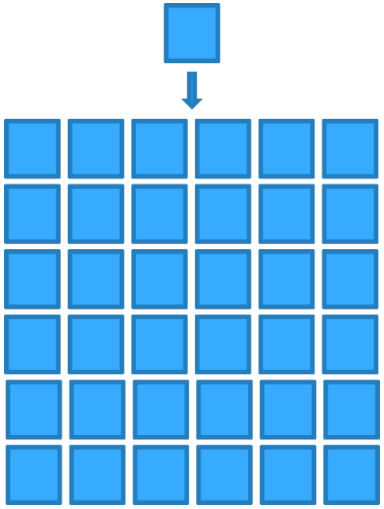
Flexible, small-scale systems enable wide adoption via subsystem repetition

Traditional



- Unreliable scale up
- Long, expensive development
- Incremental progress

Modular



Beat economies-of-scale:

- CFD to rapidly create novel reactor configurations
- Microwave, plasma etc. to intensify reactions
- Advanced manufacturing to replicate reactors at low cost

Example

Velocys: Small, Modular & Efficient GTL Reactors

www.velocys.com

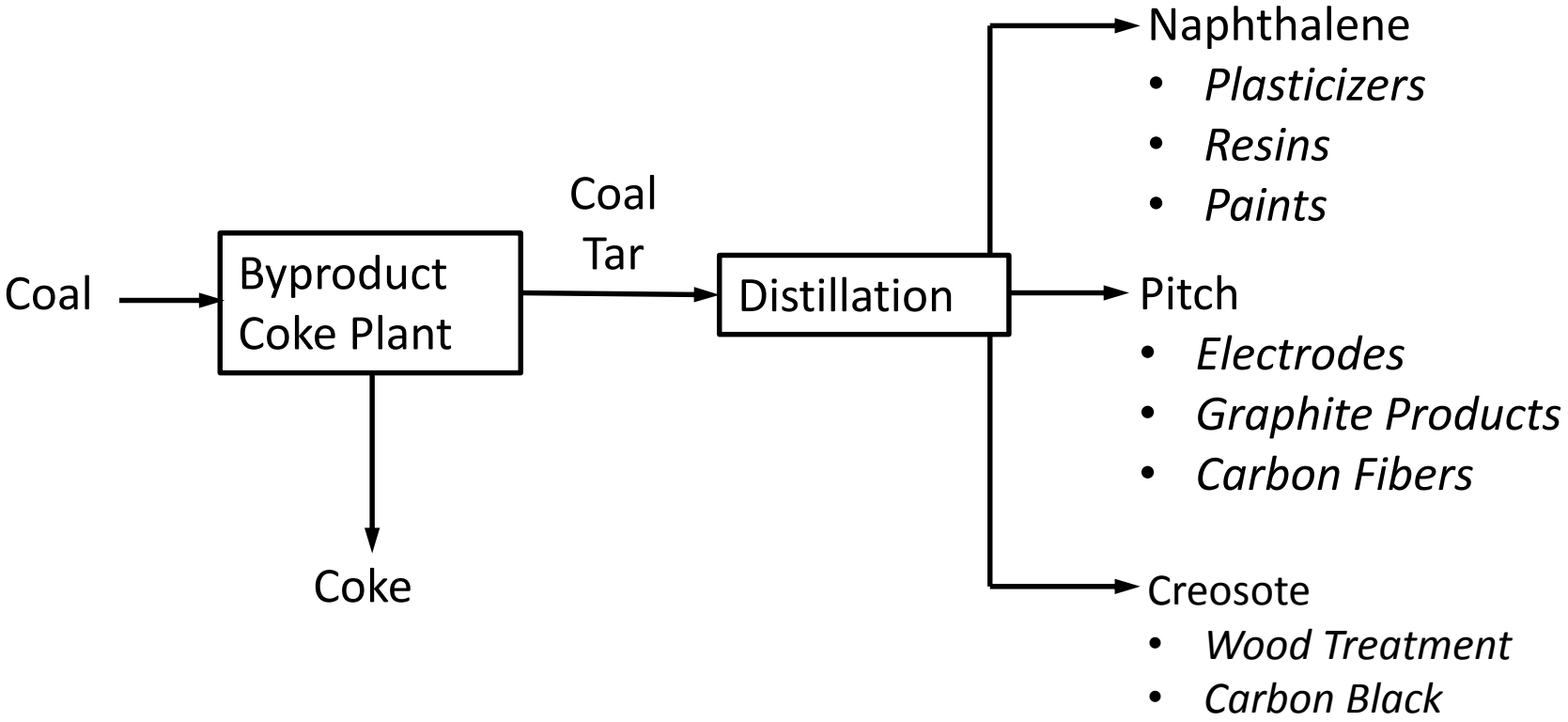
Coal and Non-Ferrous Metallurgy (Examples)

- **Ferroalloy Production**
  - Electrodes from Pitch/Calcined Anthracite
  - Reductant: Coke
- **Silicon Metal**
  - Electrodes from Pitch/Calcined Anthracite
  - Reductant: Low Ash Bituminous Coal
- **Aluminum**
  - Cathodes from Pitch/calcined Anthracite
  - Anodes: Pitch/Petroleum Coke
- **Titanium**
  - Ilmenite Reductant- Anthracite
  - Chlorination: Anthracite or Coke

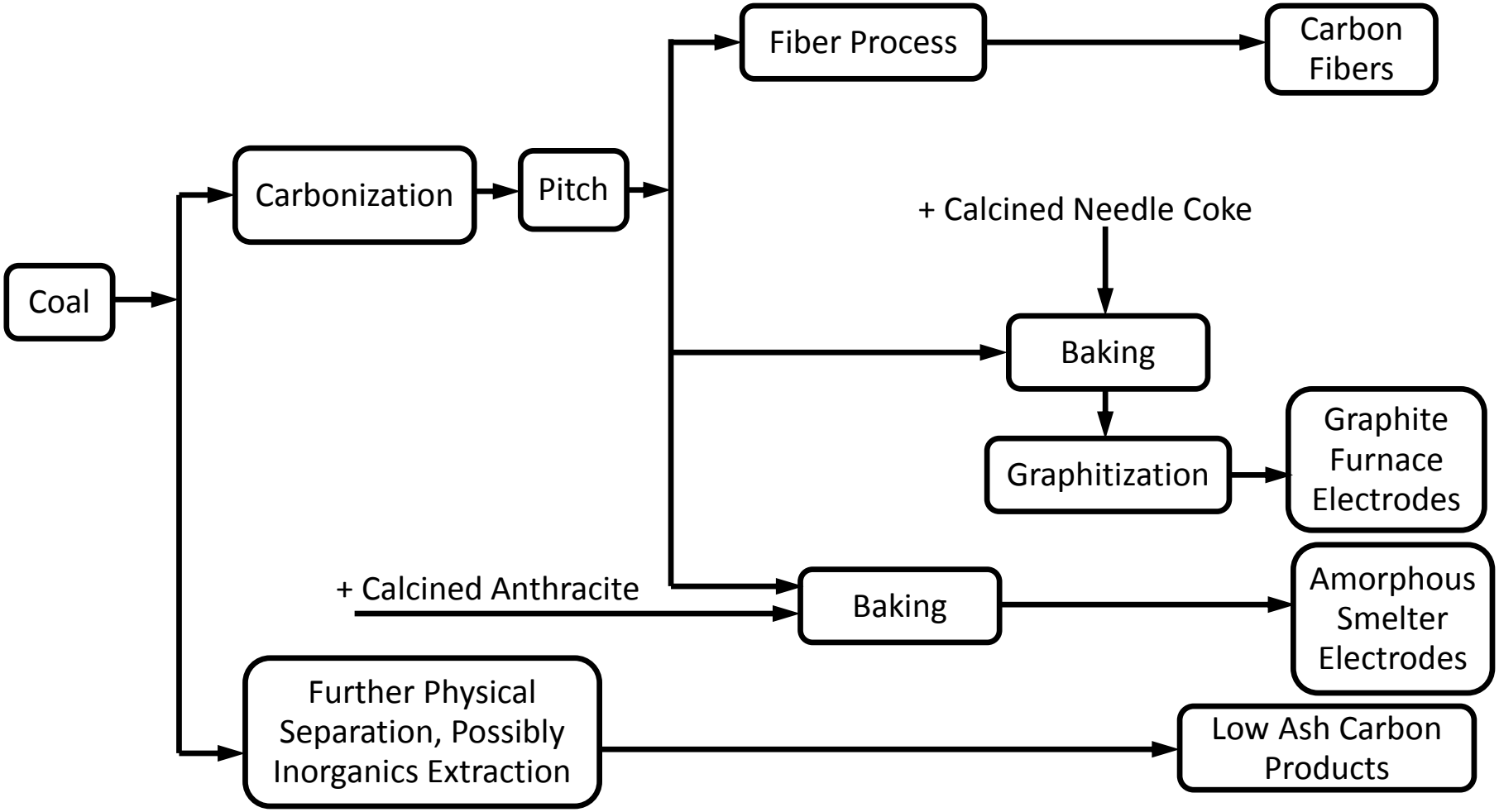
Coal and Environmental Applications (Examples)

- **Water/Wastewater Filtration Media**
  - Narrowly sized to optimize filter bed porosity
  - Must be resistant to attrition during filter backwashing (i.e., hard particles)
- **Activated Carbon**
  - Coal-based activated carbons originally developed for gas masks (1940's)
  - Has been produced from bituminous coal and lignite

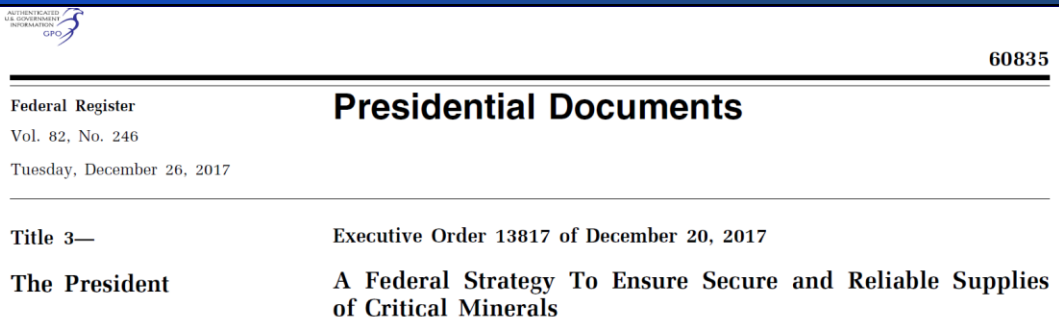
Example: Chemicals from Byproduct Coke Plants



Example Carbon Products Value Chain



USGS Critical Minerals List



60835

Federal Register
Vol. 82, No. 246
Tuesday, December 26, 2017

Presidential Documents

Title 3—
The President

Executive Order 13817 of December 20, 2017

A Federal Strategy To Ensure Secure and Reliable Supplies of Critical Minerals

- Aluminum (Bauxite)
- Antimony
- Arsenic
- Barite
- Beryllium
- Bismuth
- Cesium
- Chromium
- Cobalt
- Flourspar
- Gallium
- Germanium
- Graphite (Natural)
- Hafnium
- Helium
- Indium
- Lithium
- Magnesium
- Manganese
- Niobium
- Platinum Group Metals
- Potash
- Rare Earth Elements
- Rhenium
- Rubidium
- Scandium
- Strontium
- Tantalum

Concentrations Found in U.S. Coal Byproducts (So Far)

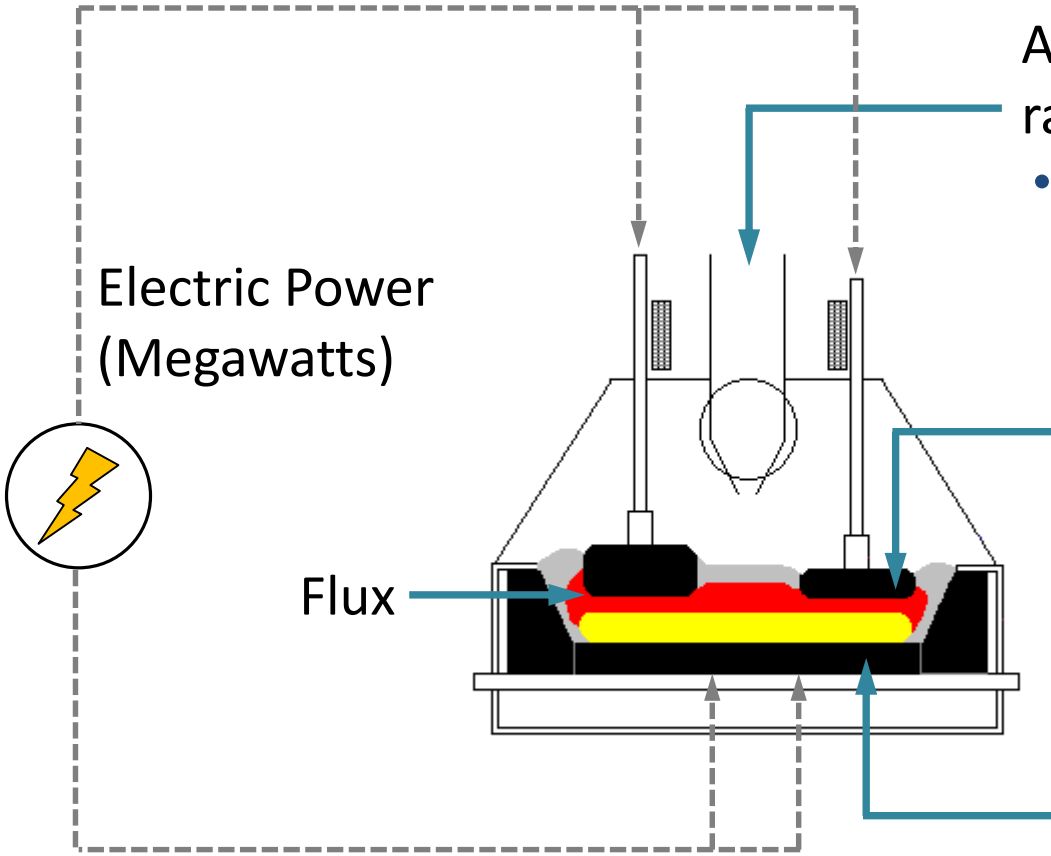
- Cobalt: 1,000+ PPM
- Nickel: 900+ PPM
- Manganese: 1.5+ wt%
- Rare Earths: 800+ PPM
- Zirconium: 2+ wt%
- Hafnium: 500+ ppm
- Yttrium: 1,000+ PPM
- Alumina: 30+ wt%)

Needs:

- Finding more and higher assay materials (sampling and analysis work)
- Laboratory mineral processing and hydrometallurgy testing

Examples of Coal Use in Critical Minerals Value Chains

Aluminum



Alumina from foreign-sourced raw materials (Bauxite)

- Can be produced from U.S. underclays

Anode (pitch and needle coke)

- Needle coke could be produced from coal

Cathode assembly (pitch and calcined anthracite)

Expanded Market Potential for U.S. Coal

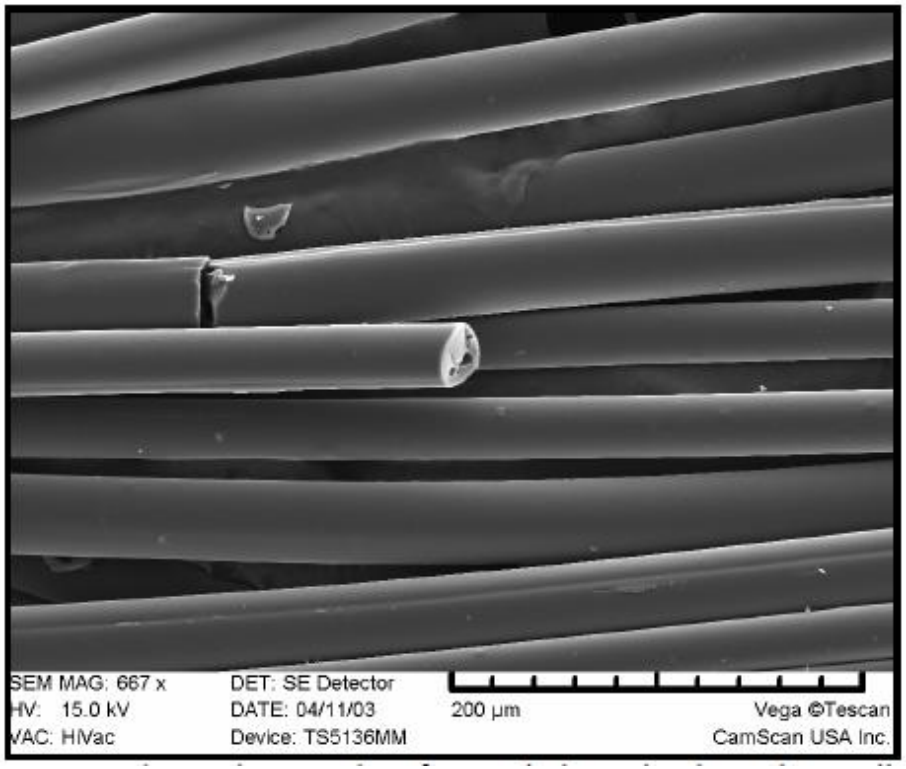
Example Requirements

- **Very Low Ash Content:**
  - Coke for aluminum smelter anodes
  - Expanded use for activated carbon and silicon metal smelters
- **High Alumina Content**
  - Aluminum smelter feedstocks
- **High-Purity Concentrates**
  - Cobalt
  - Manganese
  - Zirconium
  - Hafnium

Expanded Market Potential for U.S. Coal Products

Example Requirements

- **Mesophase Formation Characteristics**
  - Pitches
  - Needle Coke Feedstocks
- **Salable Byproducts**
  - CFB Fuel
  - Construction Products



Coal Upgrading Process Categories and Examples

- **Physical Separations**
  - Coal Preparation (Separates Coal and Rock)
  - Used to Concentrate Critical Minerals
  - Lightweight Aggregate Feedstocks and Pyrites from Coal Products
- **Thermal Processing**
  - Drying
  - Low-Temperature Carbonization
  - High-Temperature Carbonization (Cokemaking)
  - Calcination
- **Chemical Extraction**
  - Organics Extraction
  - Inorganics Extraction (i.e., hydrometallurgy)

Research Challenges

Geology

- Finding the widest range of U.S. coal reserves that can be washed to <1 wt% ash
- Finding the highest concentrations of critical minerals in the U.S. coal measures.

Physical Separations

- Low specific gravity separations to produce low-ash coal
- High specific gravity separations
- Float-sink distributions of critical minerals in coal and coal byproducts
- Multiple product run of mine preparation

Research Challenges

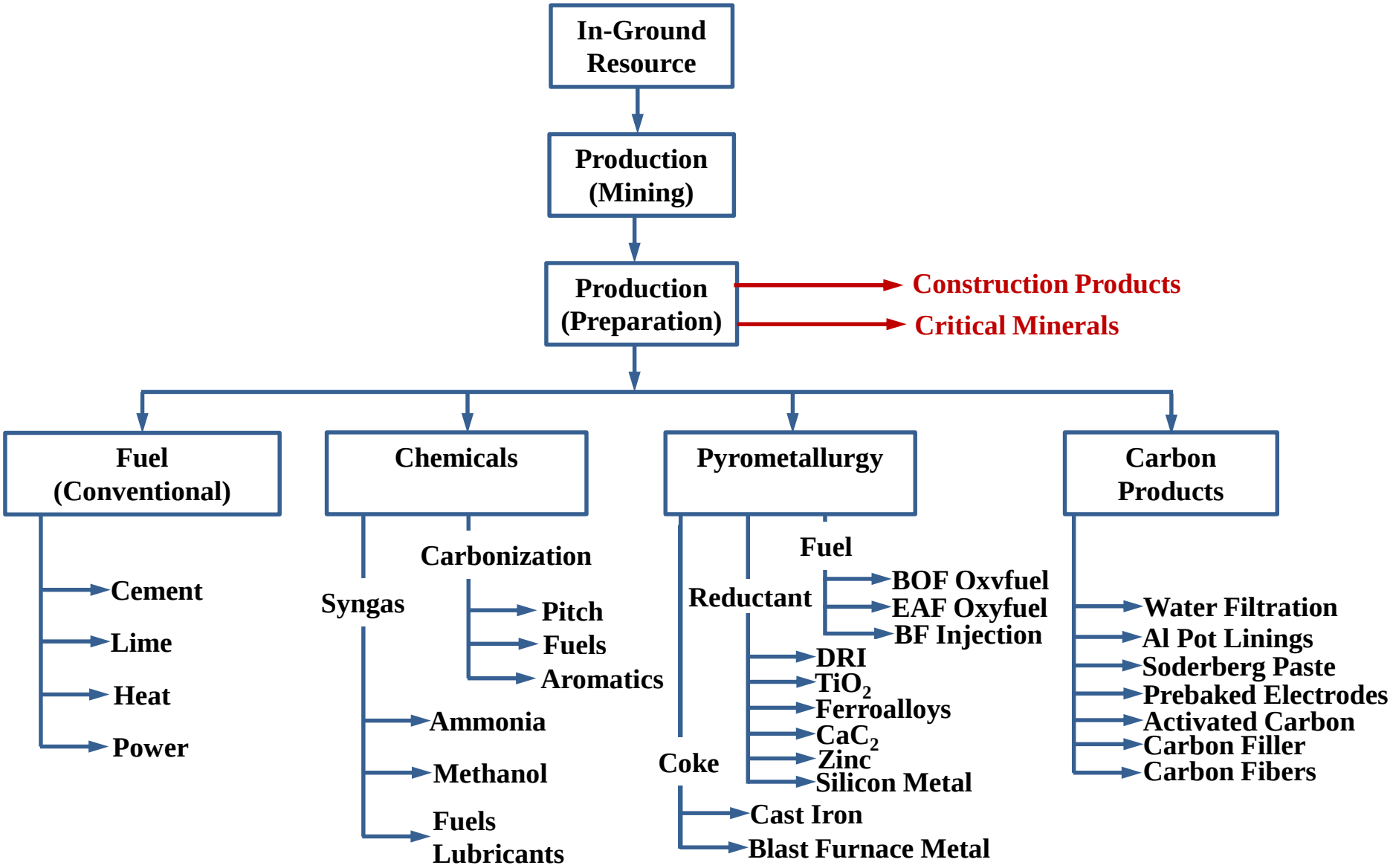
Thermal Processing

- Calcination and graphitization behavior of coal products
- Application of pyro-metallurgy for extraction of critical mineral concentrates
- Optimizing feedstocks for activated carbon production

Chemical Extraction

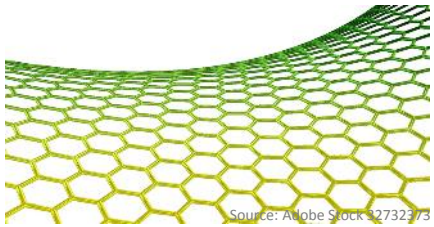
- Optimizing yields for pitch production by direct extraction from coal
- Hydrometallurgical behavior of coal byproducts
  - Extraction of critical minerals
  - Production of environmentally benign tailings

Coal Use in the Manufacture of Useful Products

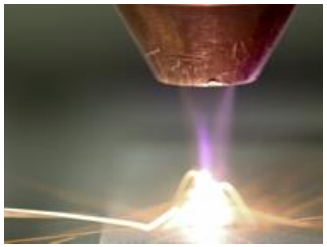


Longer-term Prospects

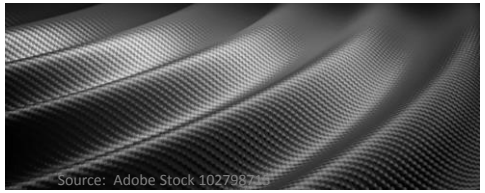
Higher-Value Carbons



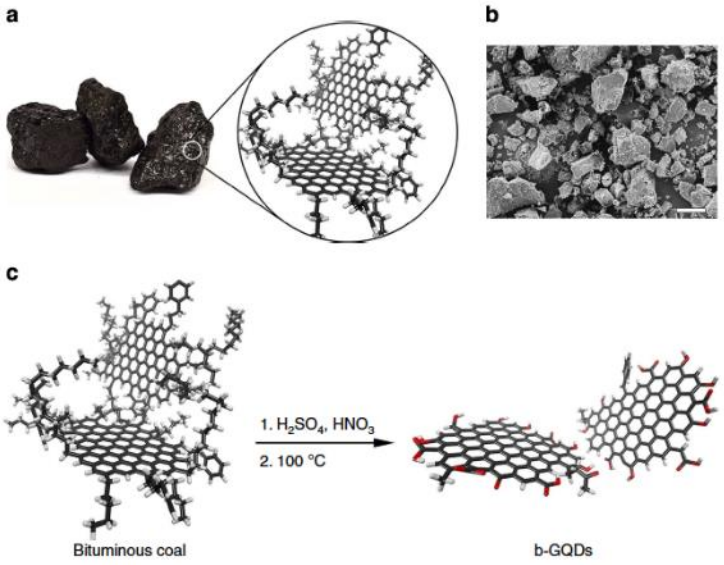
- **Graphene & carbon quantum dots** occur naturally in coal structure.
- **Carbon nanomaterials** currently cost ~ $ hundreds per gram.
  - Coal-based nanomaterials may offer inexpensive alternative.
- Integration of coal into the **value chain of emerging industries**:
  - Nanomanufacturing, additive manufacturing, carbon-based electronic materials, optical materials, and energy storage


Source: ORNL, Additive Mfg. Facility

- **Alternative to conductor & semiconductor materials**
  - Sophisticated, homogeneous systems generally not needed
  - Carbon-based electronics as less expensive option
  - Conductivity of carbon films, wires, printed devices can be controlled over many orders of magnitude.



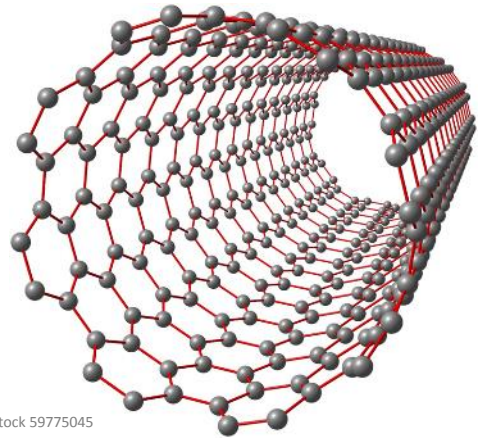
Nanomaterials from Coal



Graphene quantum dots from coal

Source: "Coal as an abundant source of graphene quantum dots" Ye & Tour et. al. Rice Univ., Nature Communications 4, Article number: 2943 (2013) doi:10.1038/ncomms3943

Coal-derived single-walled carbon nanotube



Source: Adobe Stock 59775045

Nanomaterials Possible:

- Graphene, graphene ribbons
- Carbon quantum dots
- Nanotubes

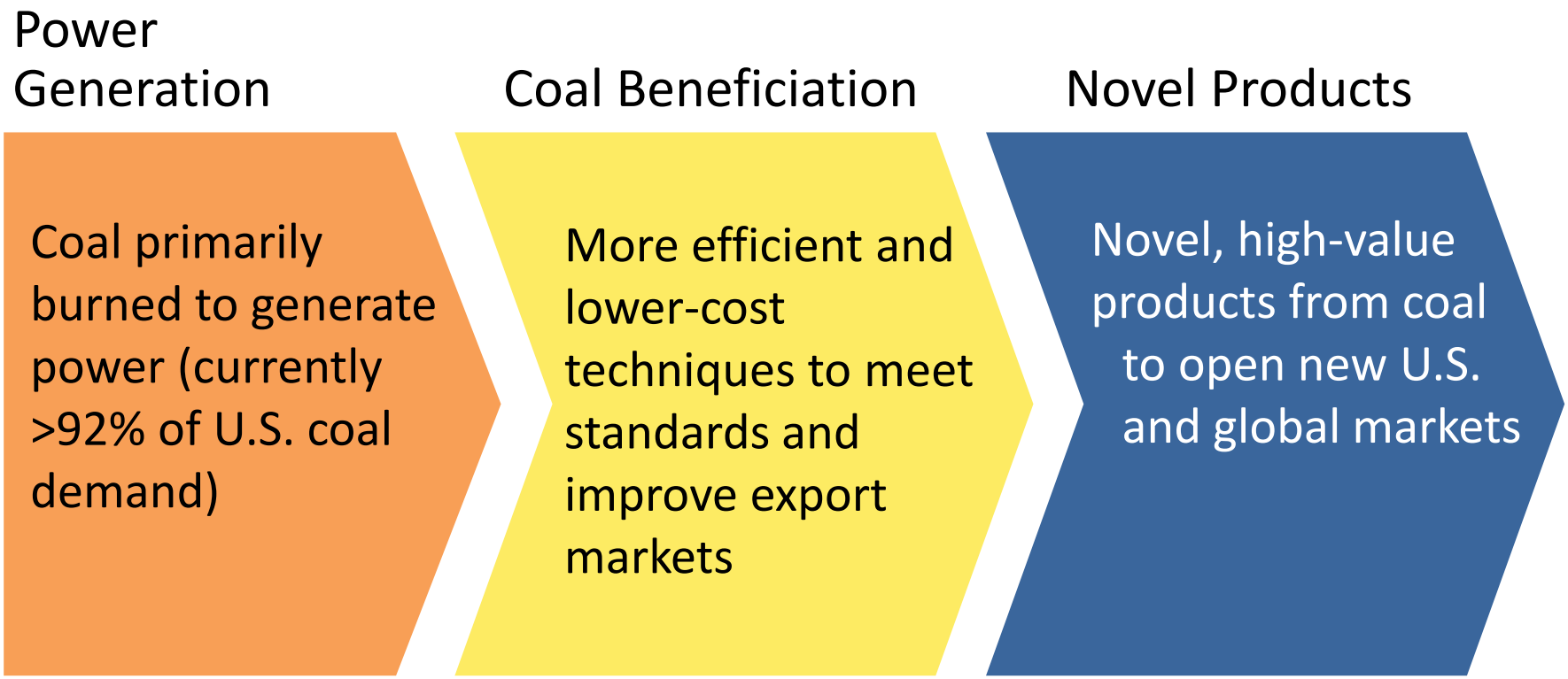
Current Applications

(several commercial):

- Gas diffusion barriers
- Textiles
- 3D printing fluids
- Fuel cells
- Energy storage
- Structural composites

In Conclusion…

We need to change the equation..



(DOE is funding R&D to make this happen!)

Questions?

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