The Future for Coal Use in the U.S.

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Club20 Energy Committee - 2018 Winter Policy Meetings
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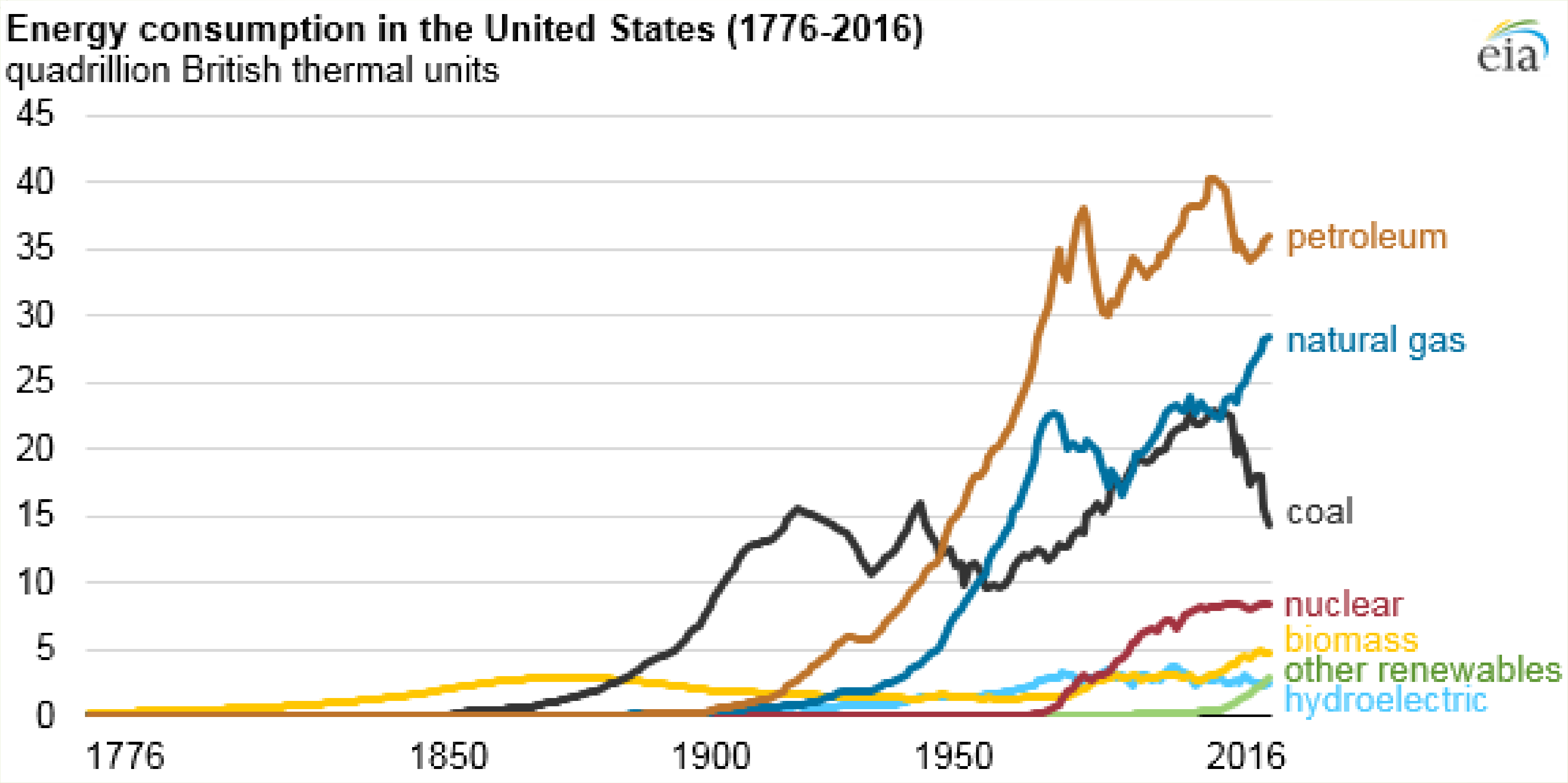
Current Trends in Energy Consumption and Coal Use in the U.S.

Dramatic Reductions in Coal Use in Recent Years



Source: U.S. Energy Information Administration, Monthly Energy Review

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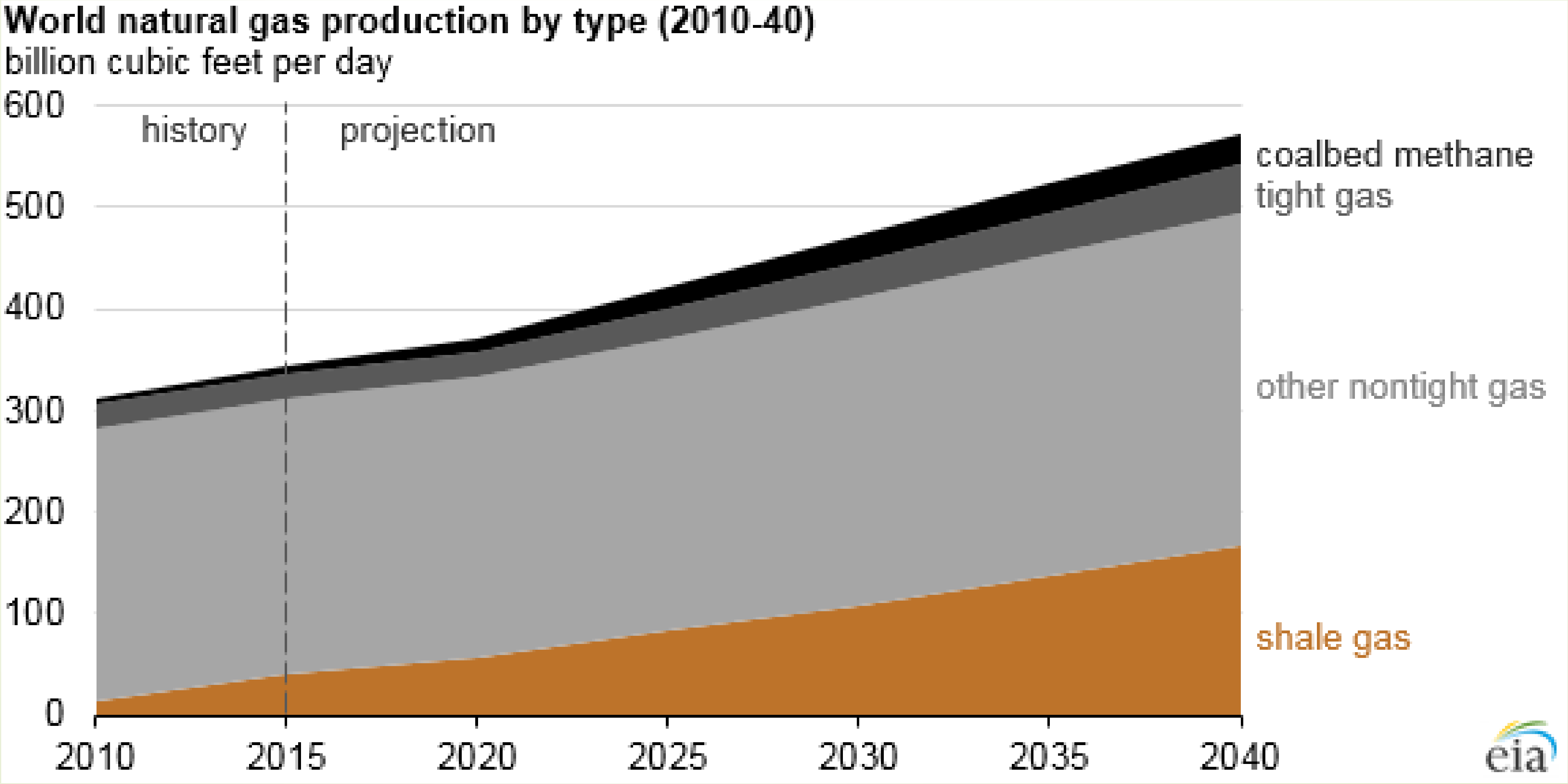
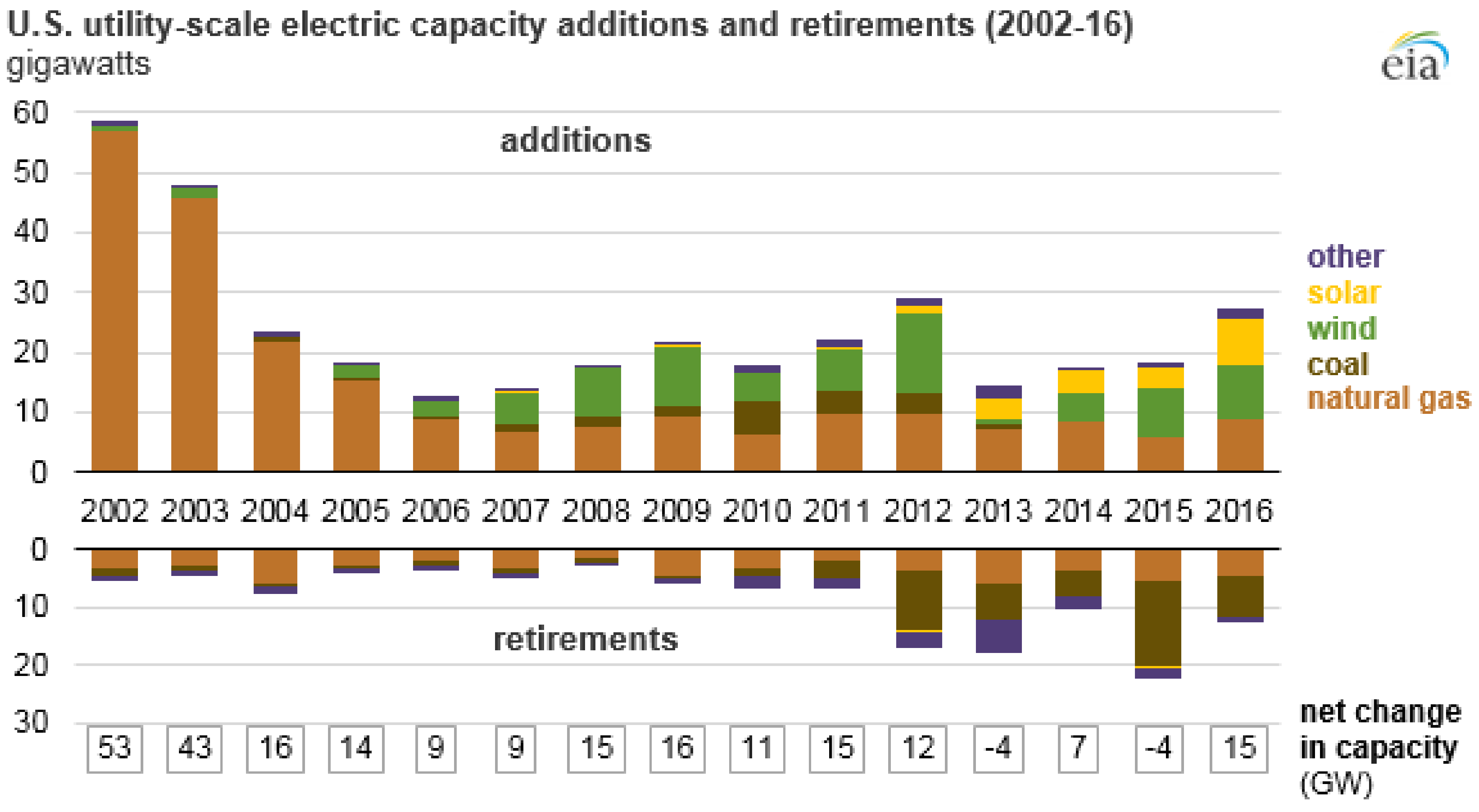
Shale Gas Production Drives World Natural Gas Production Growth



Source: U.S. Energy Information Administration, International Energy Outlook 2016 and Annual Energy Outlook 2016

Changes in U.S. Electricity Generation – New Capacity



Source: U.S. Energy Information Administration (Feb. 2017), Electric Power Annual and Preliminary Monthly Electric Generator Inventory

Electric Power Generation and Fuels Employment

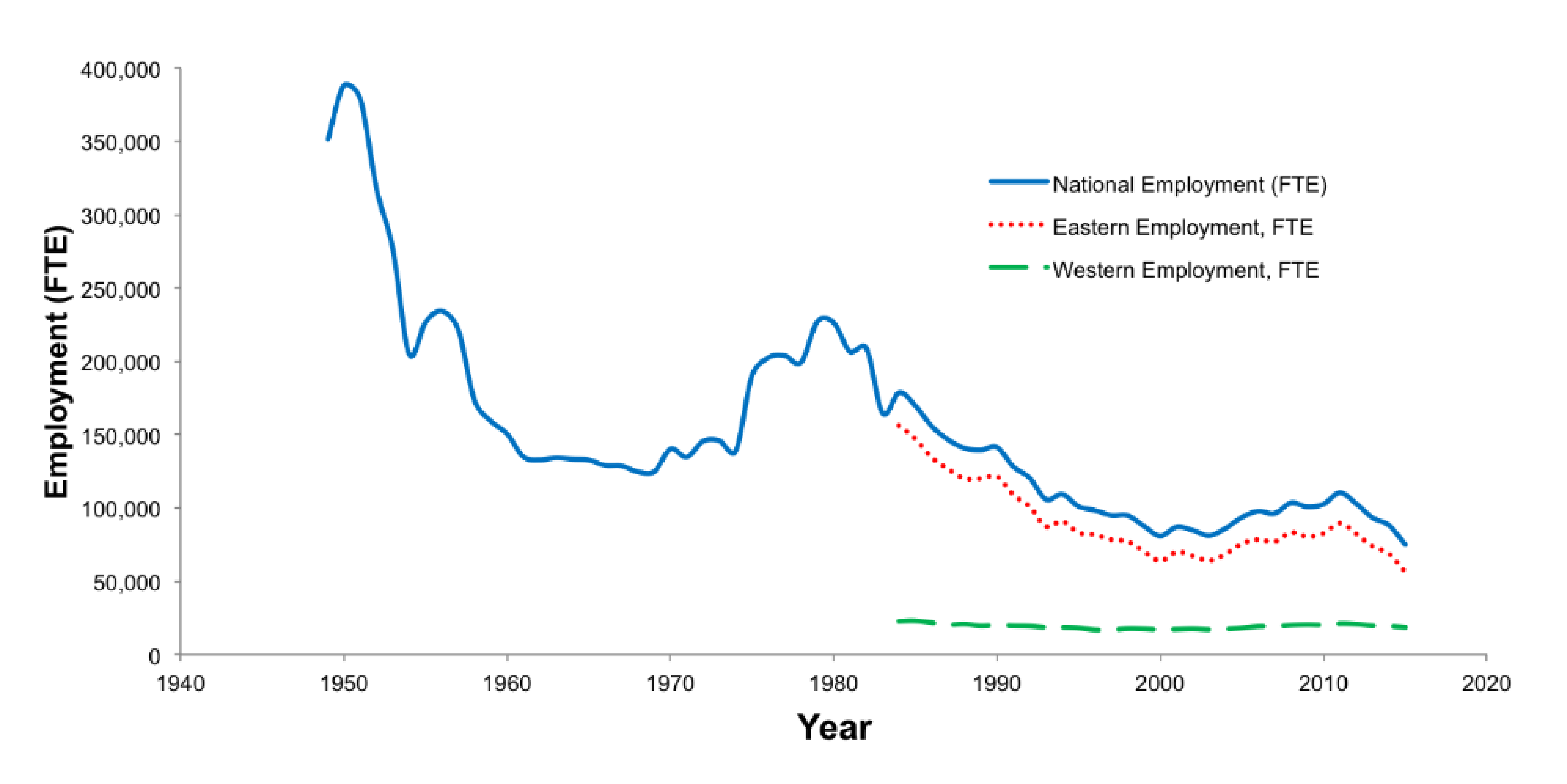
Table 1. Generation and Fuels Employment by Sub-Technology

	Electric Power Generation	Fuels	Total
Solar	373,807	-	373,807
Wind	101,738	-	101,738
Geothermal	5,768	-	5,768
Bioenergy/CHP	26,014	104,663	130,677
Corn Ethanol	-	28,613	28,613
Other Ethanol/Non-Woody Biomass, incl. Biodiesel	-	23,088	23,088
Woody Biomass Fuel for Energy and Cellulosic Biofuels	-	30,458	30,458
Other Biofuels	-	22,504	22,504
Low Impact Hydroelectric Generation	9,295	-	9,295
Traditional Hydropower	56,259	-	56,259
Nuclear	68,176	8,595	76,771
Coal	86,035	74,084	160,119
Natural Gas	52,125	309,993	362,118
Oil/Petroleum	12,840	502,678	515,518
Advanced Gas	36,117	-	36,117
Other Generation/Other Fuels	32,695	82,736	115,431

Taken from 2017 U.S. Energy and Employment Report, https://www.energy.gov/downloads/2017-us-energy-and-employment-report

Employment in Coal Mining, National, Western U.S. and Eastern U.S.

(FTE: Full-Time Equivalent)



Source: U.S. Energy Information Administration, FTE IS COMPUTED FROM PRODUCTIVITY (TONS PRODUCED PER PERSON HOUR), TOTAL COAL OUTPUT ANNUALLY, AND AN ASSUMED 1,900 HOURS PER YEAR FOR A FULL-TIME EQUIVALENT EMPLOYEE.
Also, cited by Charles Kolstad in http://siepr.stanford.edu/research/publications/what-killing-us-coal-industry

Summary of Current Trends

- Dramatic rise in natural gas production due to development of hydraulic fracturing technology
  - has significantly reduced coal use
  - led to overall reductions in CO_2 emissions
- Substantial increases in solar and wind generating capacity has led to
  - shift to greater use of low-C renewable energy
  - unprecedented employment growth in these two industries
- Future of traditional coal-fired power generation is unclear

Future Coal Use – Consideration of Other Potential Uses for Coal

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Alternative Uses for Coal

- High-value Coal Products
  - Production volumes likely reduced relative to electricity generation
- Consideration of coal as high-value raw material vs. use for energy content
  - Potential for development of "coal refineries"
- Examples of potential products
  - Commodity chemicals
  - Rare earth elements
  - Carbon fiber
  - Graphene
  - Hydrogen
  - Others

Will briefly discuss in today's presentation

Coal as a Precursor for High Value-Added Products

Lara-Curzio et al. (2016)

Courtesy: Edgar Lara-Curzio Oak Ridge National Lab

Rare Earth Element Recovery from Coal and Coal Byproducts

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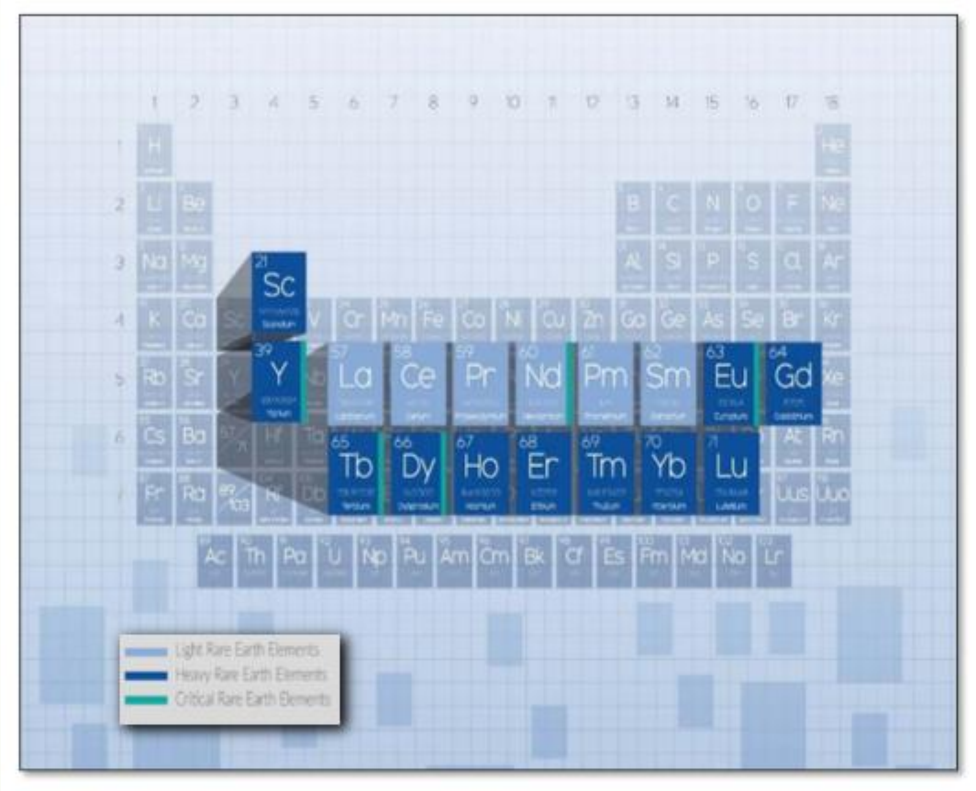
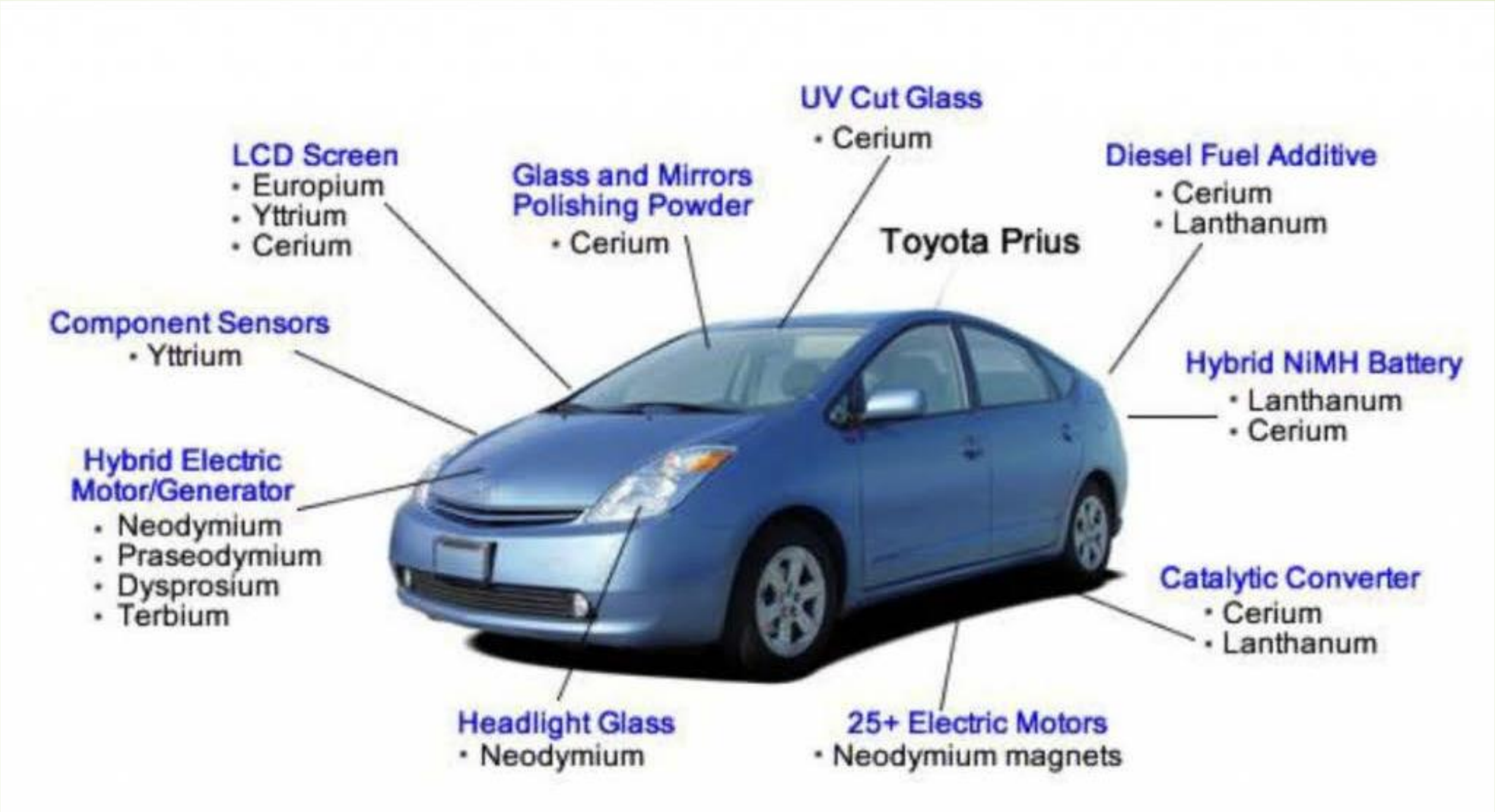
Background – Rare Earth Elements (REE)

- Key elements used in materials for
  - Magnets, batteries, computers, electronics, autos, military/defense, many others
- Market dominated by China *(95% in 2010)*
- Currently, U.S. relies primarily on imports



Courtesy: Mary Anne Alvin U.S. DOE/NETL

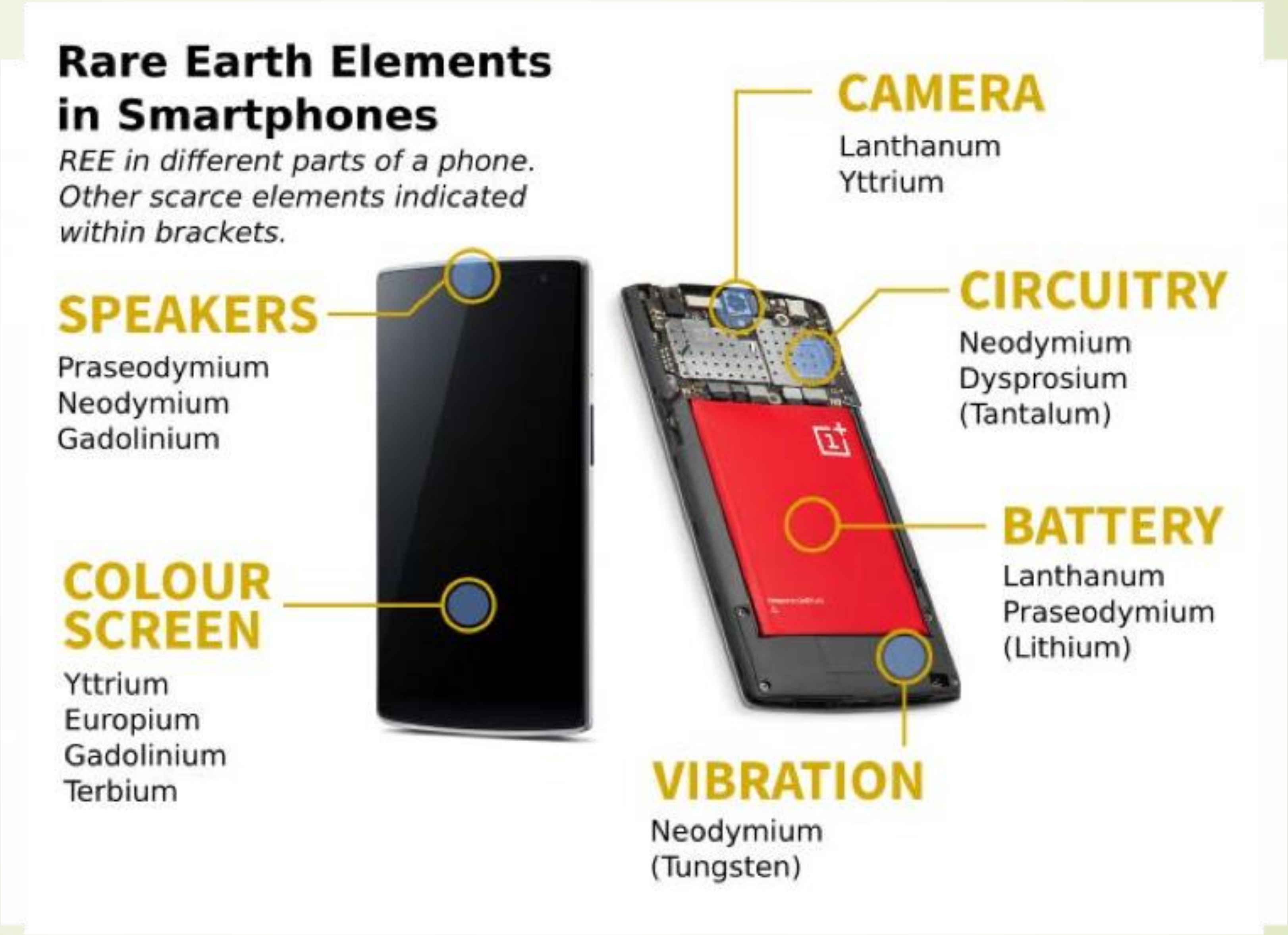
Uses - Rare Earth Elements (REE)



Courtesy:
Edgar Lara-Curzio
Oak Ridge
National Lab

http://www.insightsonindia.com http://cen.acs.org/

Uses - Rare Earth Elements (REE)



Courtesy:
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http://www.insightsonindia.com http://cen.acs.org/

Current Status for REE Recovery from Coal and Coal Products

- Study by DOE/NETL indicates U.S. coal and coal byproducts contain ~11 million metric tonnes of REEs
- Several researchers reported on progress at a recent Clearwater Clean Energy Conference*
  - University of North Dakota (Laudal et al.)
    - surveyed regional coals and associated sediments and REE ranged from 150-200 pm for sediments to 300-600 ppm for coals
  - University of Kentucky & Virginia Tech (Honaker et al.)
    - 60-85% recovery of REEs, depending upon which portion of the mined coal material was used
  - University of Wyoming (Huang et al.)
    - REE's were concentrated in their process from 0.05% in ash to over 10% in products
- U.S. DOE – announced $4 million this past year for 9 new REE research projects

**42nd International Clean Energy Conference, June 11-15, 2017, Clearwater, FL*

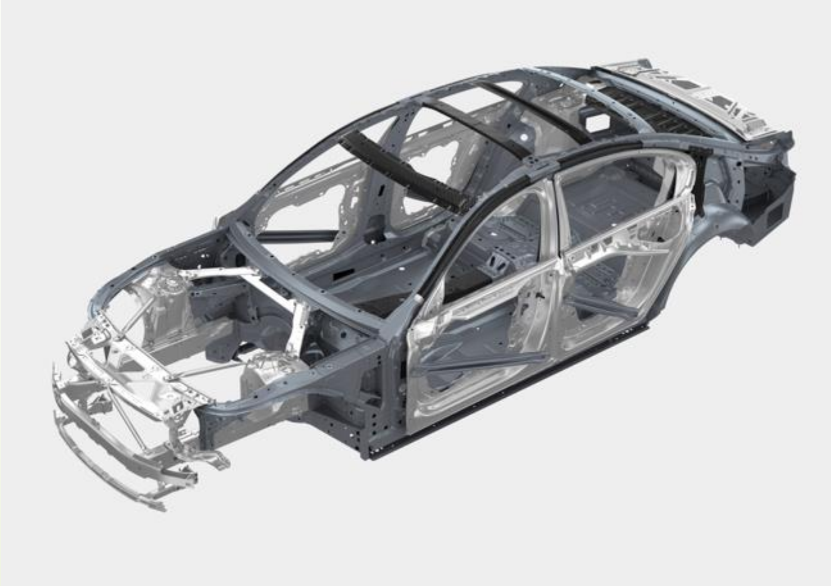
Carbon Fiber Production from Coal

Carbon Fiber Production

- Primary precursor material for carbon fiber(CF) production (90-95%) is Polyacrylonitrile (PAN)
- Primary uses are in carbon composite materials for:
  - Aerospace applications (B787, A350, others)
  - Sporting goods
  - Wind turbine blades
  - High-end automobiles
  - Specialty applications (medical, structural, etc.)
  - Rough guide “5 and 5”
- Main barrier to broader utilization is ***<u>cost</u>***

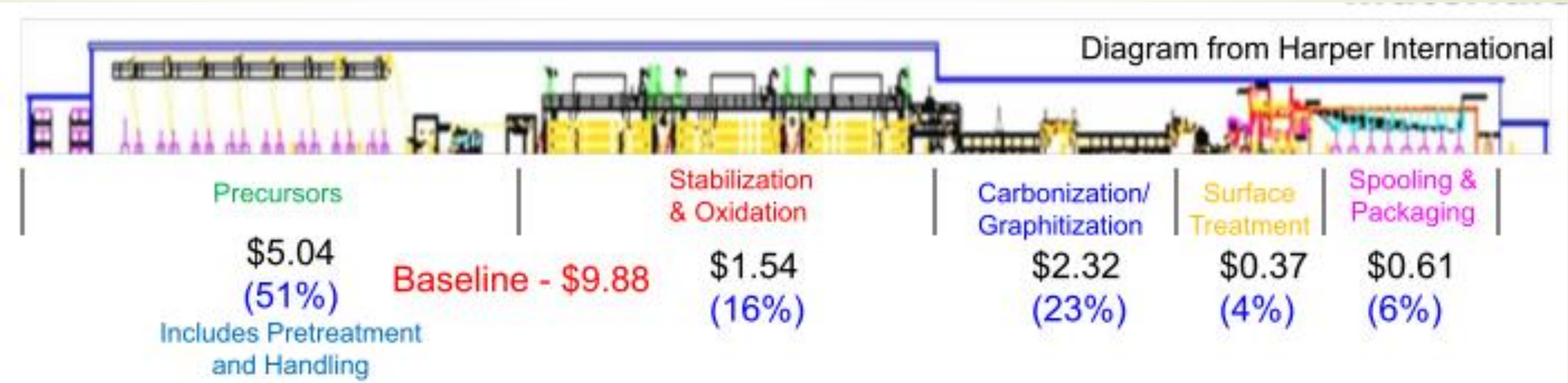
Market for Low-Cost Carbon Fiber

- Total 2016 worldwide production of Carbon Fiber – 200 MM lbs
- Forecasted growth of automotive industry by 2023 – 280 MM lbs additional
  - US automobile production 2016 – 12 MM
  - Example: Ford F-150 truck, 1MM per year @ 20 lbs => 20 MM lbs
- Current fiber is expensive - $10-25/lb
- Our target is <$5/lb



Opportunities for Cost Reduction

- Overall process modifications – difficult to achieve significant reductions



- Direct cost impact by identifying lower cost precursors and increasing yield from precursors

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Processing Coal to Produce Carbon Fiber

$15-$100*/ton Coal

Coal Processing → (e.g., pyrolysis, solvent extraction, etc.)

High MW Tars

Upgrading → (e.g., heat treatment, distillation)

Isotropic & Mesophase Pitch

Other products: Char, lighter liquids, gases

Melt Spinning →

Green Fiber

Oxidation Carbonization Graphitization →

Carbon Fiber

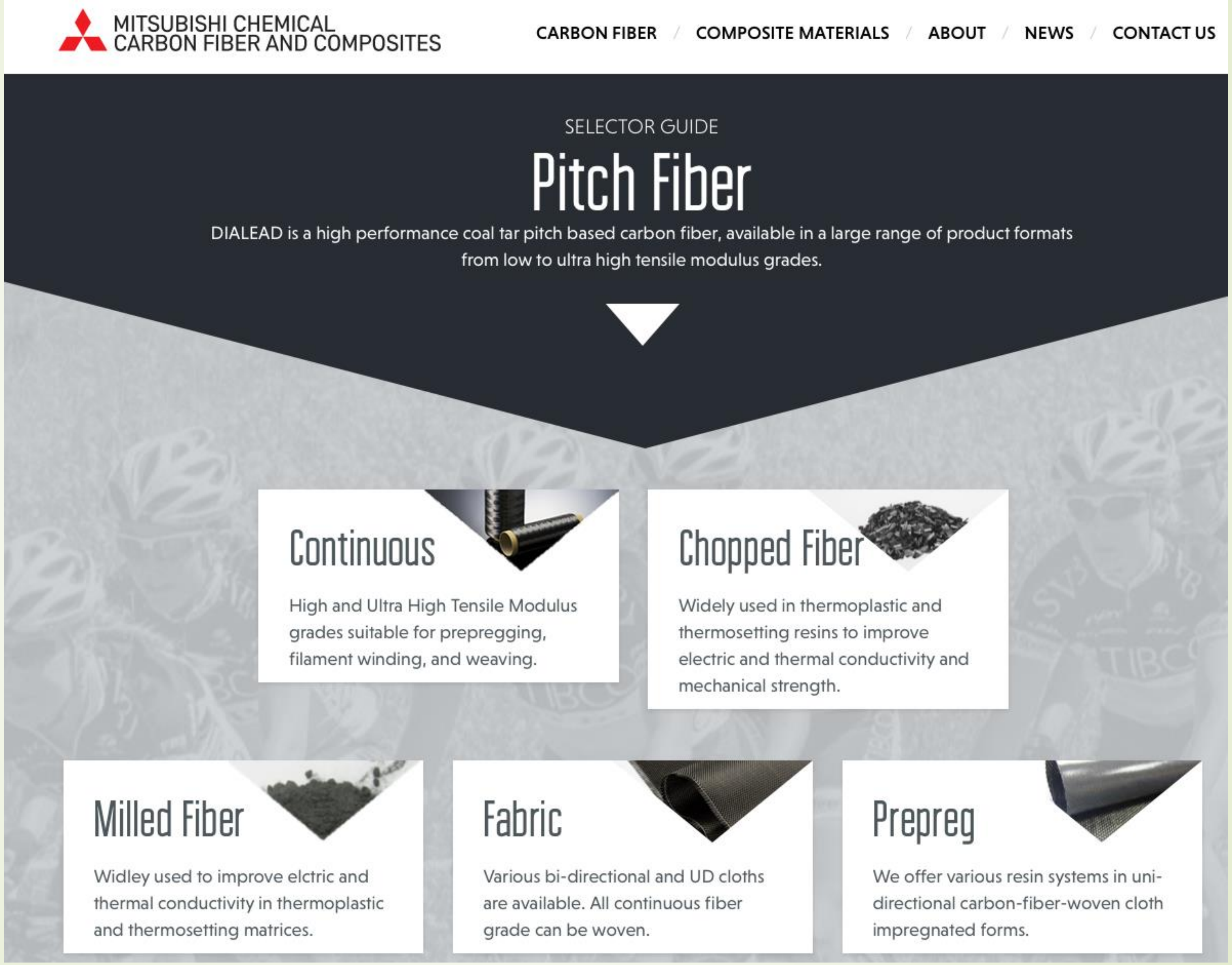
$0.1M/ton Graphitized CF

Combine with Binding Polymer → (e.g., thermoset, thermoplastic)

Carbon Composite Materials

*for some coking coals

Commercial Coal Tar Pitch Fiber



http://mccfc.com/pitch-fiber/

Coal to Carbon Program at the University of Utah/Kentucky*

- Explore viability of Utah coals for carbon fiber (CF) production
  - Will expand to coals from other regions with additional funding
- Investigate avenues for reducing cost for producing CF
  - Facilitates entry into automotive and other consumer markets
- Investigate methods for tailoring fiber properties based on coal chemistry and pitch/fiber production methodologies
- Help develop a new coal-based carbon composites manufacturing industry (with help from UAMMI)
  - To assist Utah and other regions adversely impacted by changes in the coal economy

*funded by Dept. of Commerce/Economic Development Administration (EDA)

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UT/KY Coal to Carbon Fiber Program

University of Utah – Pitch Production

Coal Processing → *(e.g., pyrolysis, solvent extraction, etc.)*

High MW Tars

Upgrading → *(e.g., heat treatment in inert atmosphere)*

Isotropic & Mesophase Pitch

Identify Correlations Between Processing Conditions and Final Properties

Melt Spinning →

Green Fiber

Oxidation Carbonization Graphitization →

Carbon Fiber

Fiber Characterization → (e.g., thermoset, thermoplastic)

University of Kentucky – Fiber Production

Summary – Coal to Carbon Fiber

- Opportunities exist for carbon fiber as a high-value coal product
- Carbon fiber market can expand to accommodate increased production
  - Automotive, wind turbine blades, etc. – key will be cost
    - 10% penetration of automotive market => triple current CF production
- Economics for carbon fiber production improved through co-production of other coal products (e.g., rare earths)
- Utah/Kentucky/UAMMI program
  - Completed first year – have successfully spun CF from coal
    - CF production/characterization/optimization underway
  - Very high interest from many coal-producing states
  - Interest from carbon composite and automotive industries
  - Exploring opportunities to scale-up bench-scale efforts

Concluding Comments

- Significant decrease in coal utilization in the U.S. due to
  - extensive shale gas production
  - increases in solar and wind generating capacity
  - concerns over global carbon levels
- Need to shift our perspectives on coal
  - Not just an energy resource
  - Great potential as a raw material for higher-value products
  - May provide additional economic opportunities for distressed coal-mining regions in the U.S.

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