LIGNIN-BASED CARBON FIBERS: A ROUTE TO ENERGY INDEPENDENCE IN THE USA

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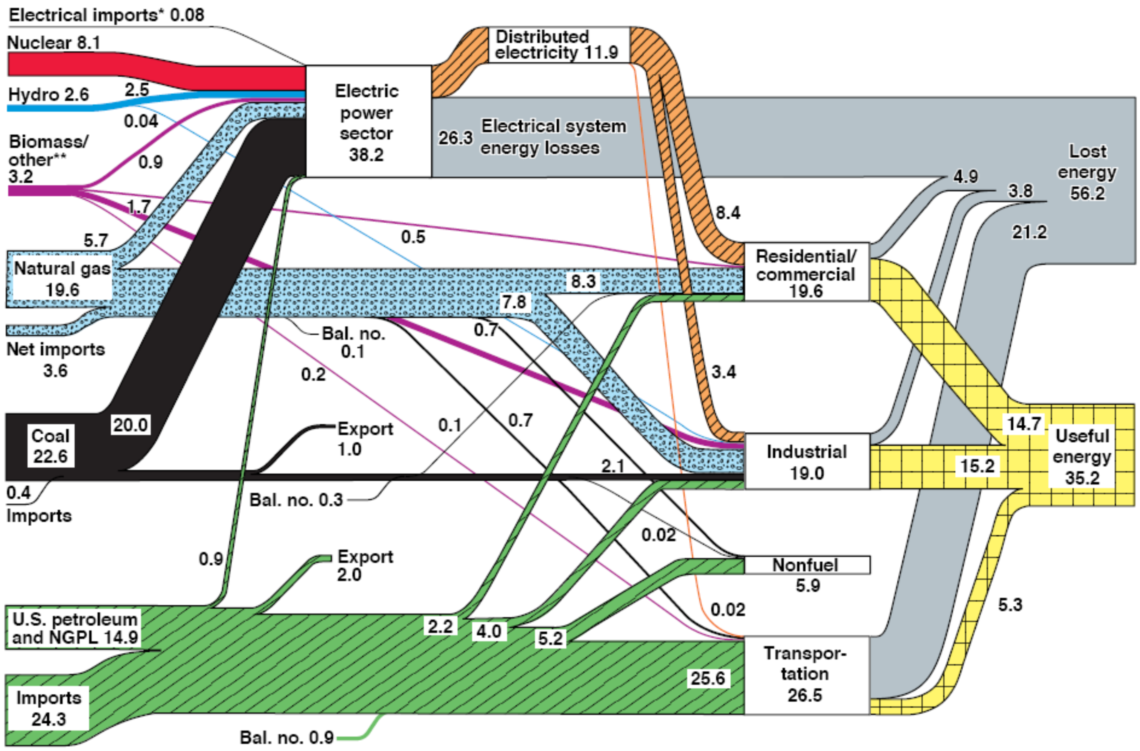
Lignin is a natural, renewable resource material that is used to produce commercial products, but it also has potential for wider scale use in new applications with environmental benefits. This paper discusses work at Oak Ridge National Laboratory on the utilization of lignin as a precursor material for production of carbon fibers. The primary objective is to develop more energy-efficient, cost-effective processes for production of carbon fibers for use in composite materials for vehicles, which would substantially reduce vehicle weight, decrease fuel consumption, lower greenhouse gas emissions, and from a political standpoint greatly reduce the dependence of the United States on foreign oil. Body-in-White modeling indicates that over 50% of the steel in a vehicle could be replaced with carbon fiber without impacting vehicle crash worthiness. However, carbon fiber is currently too expensive for large scale automotive use, which necessitates a large reduction in cost to about $10/kg. All aspects of carbon fiber production and use are being addressed in the research, including isolation of lignin from biomass, spinning it into precursor fiber, thermal processing into carbon fiber using advanced techniques, and production and crash worthiness testing of automotive composite parts. In addition, lignin-based activated carbon fibers are being produced and tested for other environment-related applications, including VOC and CO_2 capture.

The population of the United States comprises just 5% of the world's total population, but accounts for almost 25% of the world's total energy consumption. The United States is by far the largest energy consumer country, its energy consumption exceeding that of the combined total of the next two largest consumers, China and Russia. Almost 30% of the US energy consumption is for transportation (Figure 1), which predominantly uses oil as the fuel source; e.g., for gasoline and diesel fuels (Figure 1). More to the point, transportation fuels account for about 75% of the oil used in the US, of which about 60% is imported, and is increasing substantially while domestic oil production is declining (Figure 2). This heavy dependence on imported oil for transportation fuels (and other uses) has serious connotations for the United States from, for example, fuel availability and security standpoints. There are many options for reducing the dependence of the USA on imported petroleum resources, not the least of which is the larger scale use of alternative fuels produced from renewable resources, the current political front runner. However, a significant reduction in the nation's dependence on imported petroleum will necessitate a multifaceted approach in which all means of reducing energy consumption are addressed and integrated. In this context, it is essential to substantially improve the fuel economy of vehicles produced in, and imported into, the USA. One route to achieving this objective is through a substantial reduction in vehicle weight (often referred to as "lightweighting" of vehicles). It should not escape our attention that a very important additional benefit of increasing vehicle fuel economy is a reduction in greenhouse gas emissions, notably carbon dioxide; to put this into perspective, 1,850 million metric tons (1,850,000,000 tons) of carbon dioxide were emitted by vehicles on US roads in 2002.

Advanced materials, including metals, polymers, and composites play an important role in improving the efficiency of transportation engines and the fuel economy of vehicles. Weight reduction is one of the most practical ways to increase the fuel economy of vehicles while reducing exhaust emissions; as a rule of thumb, reducing the mass of a vehicle by 10% will increase fuel economy by 6%. During the decade of 1975-1885, US automotive manufacturers were driven to double the fuel economy of gasoline-fueled cars to meet tougher standards imposed by the US government (Corporate Average Fuel Economy, CAFÉ, standards). In addition to improving the fuel efficiency of vehicle engines, one response was to replace the bulky and heavy cast iron engines with lightweight aluminum engines. The use of lightweight, high-performance materials will continue to contribute to the development of vehicles that provide better fuel economy, yet are comparable in size, comfort, and safety to today's vehicles.

Figure 1. U.S. Energy Flow Trends – 2002
Net Primary Resource Consumption ~97 Quads



Source: Production and end-use data from Energy Information Administration, *Annual Energy Review 2002*.
*Net fossil-fuel electrical imports.
**Biomass/other includes wood, waste, alcohol, geothermal, solar, and wind.

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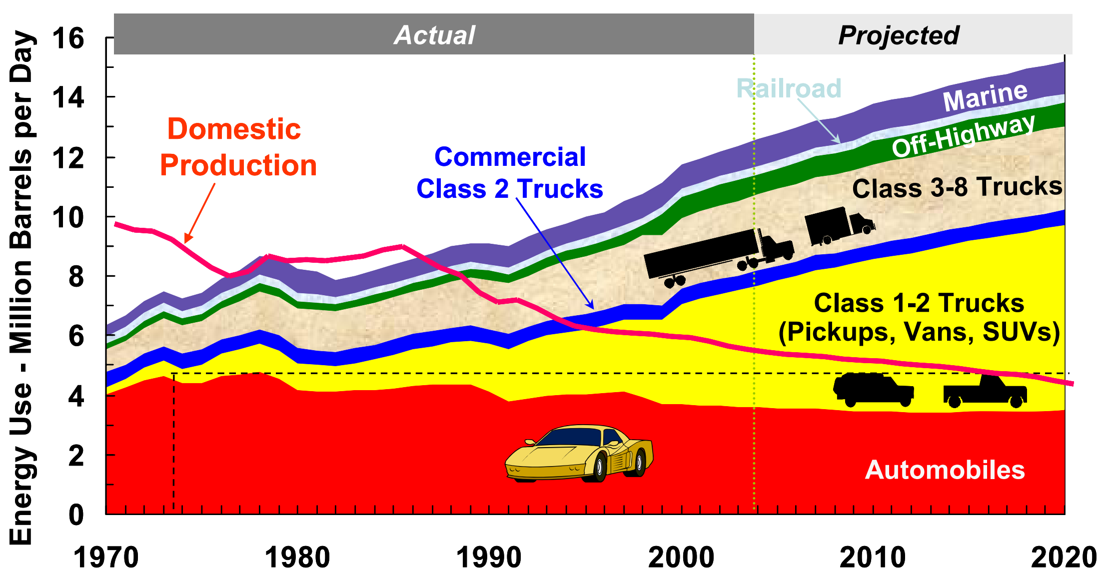
Figure 2. US Petroleum-based Fuel Usage for Transportation



Sources: *EIA Annual Energy Outlook 2002*, DOE/EIA-0383(2000), December 2001
Transportation Energy Data Book: Edition 21, September 2001.

More recently, the United States Department of Energy (DOE) set goals to, by the year 2020, develop materials and manufacturing technologies that, if implemented in high volume, could reduce the weight of a vehicle's structure and subsystems by 50%. As an example of progress made in the lightweighting of vehicles, 11 pounds of carbon fiber replaced 200 pounds of steel in the 2004 model of the Dodge Viper. With barely 4000 units produced per year, the Dodge Viper neither represents a mass-produced nor typical car; nevertheless, the use of this relatively small quantity of carbon fiber and the correspondingly large reduction in vehicle weight obtained does demonstrate the potential opportunity for very substantial vehicle weight reduction without impacting crash worthiness, etc. Computer modeling and actual crash worthiness testing have demonstrated that vehicle parts produced from carbon fiber reinforced composite materials can absorb as much or more energy from the impact as steel, thereby enhancing protection of the vehicle occupants. The two materials absorb energy differently; when steel is struck in a collision, it collapses like an accordion, but when a carbon-fiber composite is crushed, it absorbs energy through multiple fracture processes.

The advanced materials research conducted under the direction of the U.S. Department of Energy and the FreedomCAR and Vehicle Technologies (FCVT) Program is directed towards ensuring that the nation's transportation energy and environmental needs are met by making available affordable, full-function cars and trucks that use less petroleum-based fuel and produce fewer harmful emissions. Carbon-fiber composite materials have the greatest potential for lightweighting of vehicles, but the challenge is to develop new processes that will substantially reduce the cost of carbon fibers for this purpose. The research work described in this paper is funded under the DOE FCVT Program, and is directed towards the utilization of renewable resource materials, notably lignin, for the production of low cost carbon fiber (LCCF) for composite materials for lightweighting of vehicles.