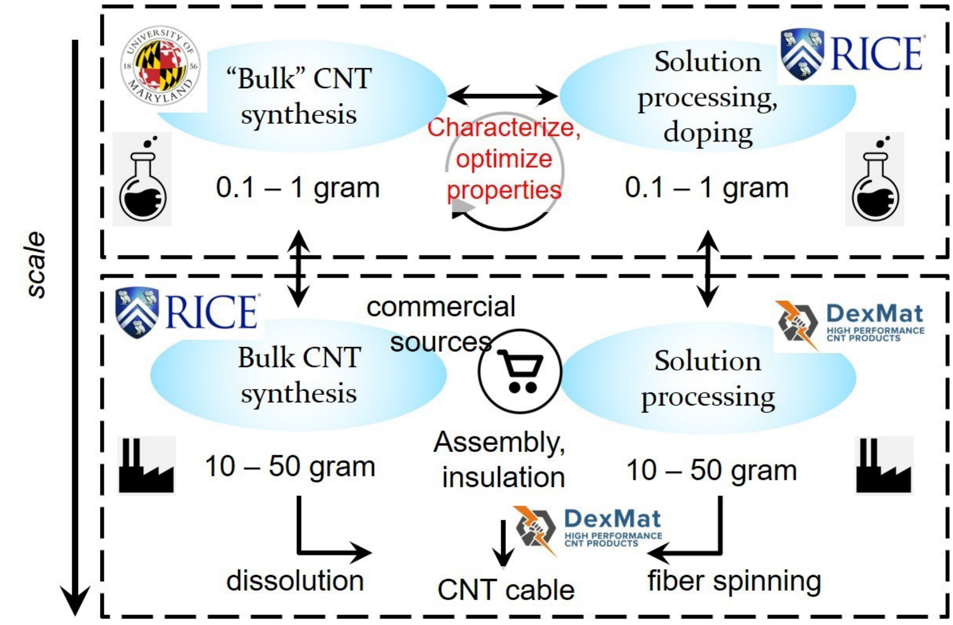
U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY



Schematic for CNT growth and fiber spinning. *Graphic image courtesy of Rice University.*

Carbon Conductors for Lightweight Motors and Generators

Enabling increased motor efficiency using a novel high electrical conductivity carbon nanotube technology

Motors are a near-ubiquitous technology used throughout American industries. They help to cool the buildings we work in, move materials from one location to another, and enable the cooling and refrigeration of materials. In total, motor systems consume approximately 68% of electricity in the U.S. manufacturing sector.

Since their discovery, the exceptional material properties of carbon nanotubes (CNTs) have shown promise for use in a variety of applications. For motor applications, the very low weight, high strength, and rapidly improving electrical and thermal properties of CNTs make them ideal for use as a conductor winding material to replace copper and aluminum. However, these properties have been demonstrated at the molecular-scale only and remain to be proven in laboratory scale cables before they can be optimized and utilized for commercial-scale applications.

This project will take advantage of the material properties of CNTs to develop a scalable, high throughput, and economic commercial manufacturing process to produce lightweight, strong, and highly thermally conductive CNT wires. These wires could be used to lightweight electric motors, replacing the heavier and mechanically weaker copper and aluminum winding materials in-use today. The innovative CNT wires, which are also corrosion and oxidation resistant, will greatly improve the performance, energy efficiency, and reliability of electrical machines, especially at high temperatures.

Benefits for Our Industry and Our Nation

Electric motor systems account for over two-thirds of electricity usage in the U.S. manufacturing sector. The successful development of this project can lead to a number of important benefits, including:

- Improved motor efficiencies as a result of the higher frequency operation and reduced material heating. The improved efficiency motors will save American industrial facilities money on their electricity bills.
- Reduced system weight due to the lightweight nature of the carbon nanotube winding materials that are expected to be one-fifteenth the weight of copper and less than a quarter of the weight of aluminum per unit length.
- Increased reliability due to the CNT's high resistance to flex fatigue. Tests show that CNT fibers do not break even after a billion cycles, lasting far longer than copper wires that break after a million cycles. The result is an improved bottom line for American industry due to less motor maintenance and longer lifetime operation.

Applications in Our Nation's Industry

Motors are critical equipment in a variety of vital applications across all industrial sectors, including pumps, fans, compressed air, materials handling and process, and compressors in industrial facility HVAC systems.

Project Description

The project objective is to demonstrate highly scalable manufacturing of high performance carbon nanotube (CNT) conductors and their application as winding materials for next-generation electric motors. The project will leverage a solution-based growth technique that has led to the highest published values for electrical conductivity and mechanical strength of CNT fibers. This technique shows promise to be scaled up to commercial production by emulating known processes used in the industrial scale production of carbon fibers and Kevlar. The proposed CNT growth process is completely decoupled from the fiber manufacturing, allowing each process to be optimized independently to achieve the desired material properties in a scalable and cost effective process. The result will be the development of the first carbon conductor that is suitable for use in lightweight electric motors and generators.

Barriers

- Optimizing the growth and doping of the CNT wires to produce the desired material and electricity properties.
- Establishing a high-volume, scalable production process of high quality CNT fibers, without sacrificing properties such as the fiber electrical conductivity.
- Optimizing wire insulation thickness and material, the number of turns and wire gauge for the CNT winding in motors.

Pathways

This project is organized into two phases. In Phase 1, the project team will produce a 1 m long, 200 µm diameter insulated CNT conductor with a specific conductivity 25% higher than current state of the art at 150°C. Phase 1 will focus on optimizing CNT growth for improved fiber conductivity. The project team will design and build lab-scale and mid-scale (few grams per day) growth reactor systems to develop optimized growth techniques that will be further improved by doping and use of different sources of CNT materials. Short CNT fibers will be produced using the discontinuous blade coating method. Insulation strategies will also be pursued to hold the electrical conductivity within 10% at 150°C.

In Phase 2, the project team will optimize CNT growth and improve CNT fiber performance to produce a 28 AWG** thick insulated CNT conductor with a specific conductivity that is more than double current state of the art.

Milestones

This 3 year project began in 2017.

- Determine the best doping techniques that produce a 30% increase in electrical conductivity at 150°C (Complete)
- Design and build lab-scale and mid-scale growth reactor systems and use the reactor systems to optimize lab-scale CNT growth based on materials properties including purity, crystallinity, diameter, and length (2018)
- Produce an insulated 200 µm thick CNT fiber of length >1 m, density > 0.8 g/cm^3, and specific conductivity of 6.6 kSm^2/kg at 150°C—which exceeds that of copper (2018)
- Develop an empirical model to assist in improving CNT material properties and use this model to establish optimized key growth conditions that meet the project goals (2019)
- Produce an insulated 28 AWG wire of length > 1 m, density > 0.8 g/cm^3, and specific conductivity > 11 kSm^2/kg at 150°C (2019)

Technology Transition

The project team includes two industrial partners who will be able to leverage their large-scale production experience to commercialize and deploy this innovative American technology. Irvin Global Industries will provide industrial CNT synthesis experience for the design of the reactor system to improve the CNT growth system to deliver high-quality CNTs and provide critical analysis of reactor scale-up options. DexMat is a Houston-based startup that focuses on the industrial production of CNT fibers using a patented method first developed at Rice University. The company will spin CNT fibers and test their properties and assemble the fibers into wire.

Project Partners

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**AWG stands for American Wire Gauge, the U.S. standard of non-ferrous wire conductor diameters. 28 AWG is equivalent to a wire diameter of 0.321 mm (321 µm).