# Carbon conductors for lightweight motors and generators

**DE-EE0007865**

**Rice University, University of Maryland, DexMat, Irvin Global Industries**

**April 2017- Oct 2019**

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U.S. DOE Advanced Manufacturing Office Program Review Meeting
Arlington, VA
June 11-12, 2019

# Overview

## Timeline

- Awarded 3/30/2017
- Projected End date Sept 2019
- Project 80% complete

## Budget

| | FY 16 Costs | FY 17 Costs | FY 18 Costs | FY 19 YTD Costs | Planned Funding (YTD – Project End Date) |
|---|---|---|---|---|---|
| DOE Funded | _ | $118k | $385k | $320k | $178k |
| Project Cost Share | _ | $14k | $36k | $44k | $20k |

## Barriers

- Aligning the carbon nanotubes in the cable without breaking connections
- Methods to increase length of individual carbon nanotubes can result in lower quality structures
- Dopants to improve electron transfer between nanotubes don't necessarily end up where you want them

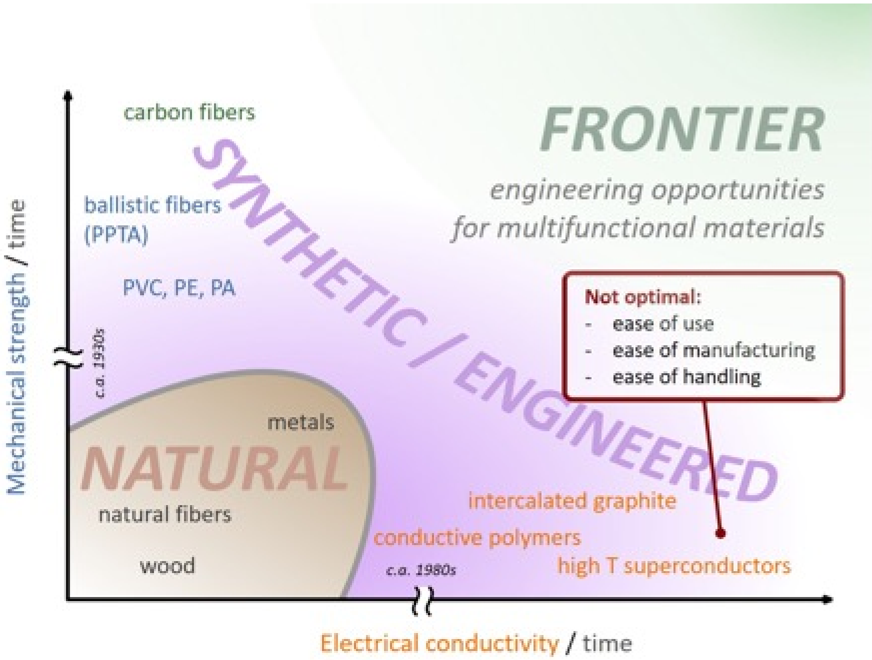
## Partners

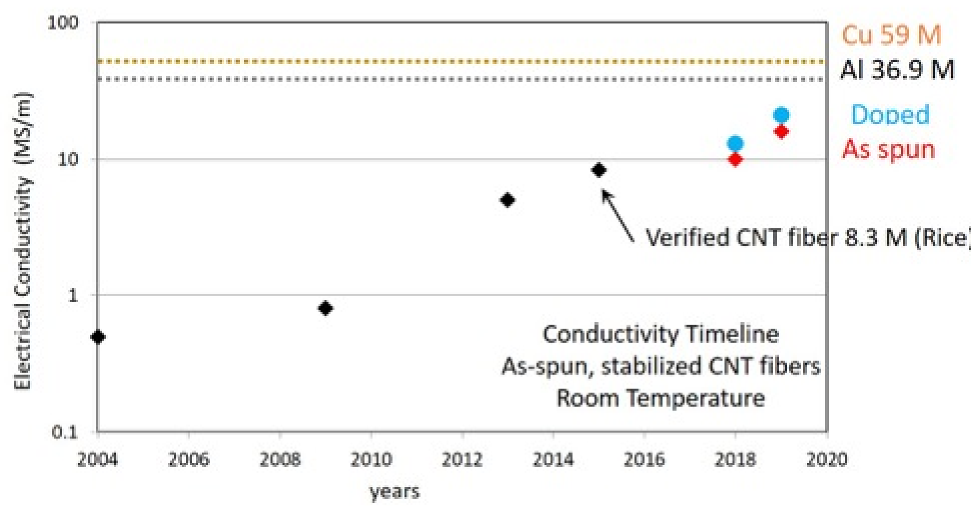
- University of Maryland
- DexMat
- Irvin Global Industries

# Project Objective

**Problem**: metals are presently used as motor winding conductors; they are heavy, prone to corrosion, and fragile at small size → Need for a lightweight, strong conductor

**Goal**: Demonstrate high conductivity carbon nanotube (CNT) conductors as winding material for electrical motors; develop scalable manufacturing process for CNT conductors



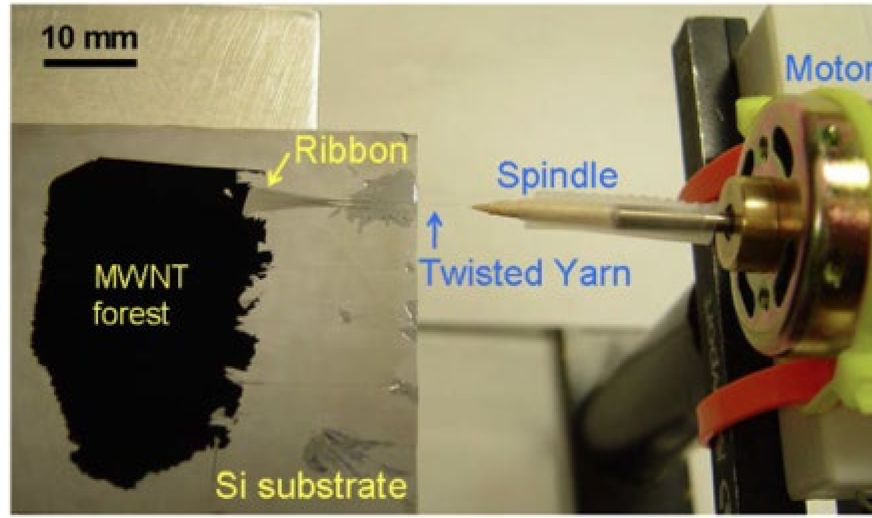



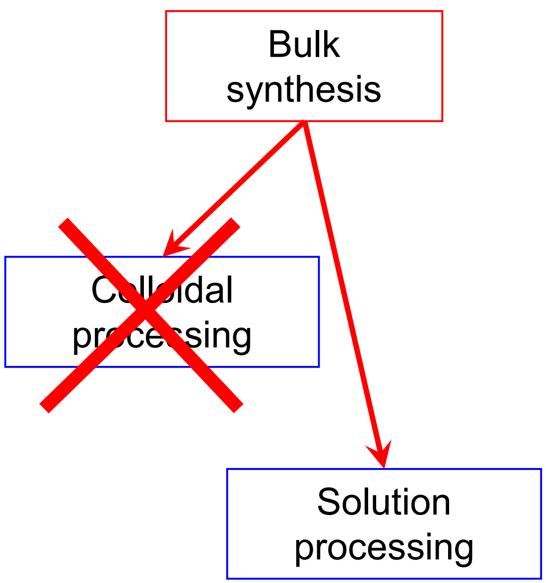

**Challenges**:

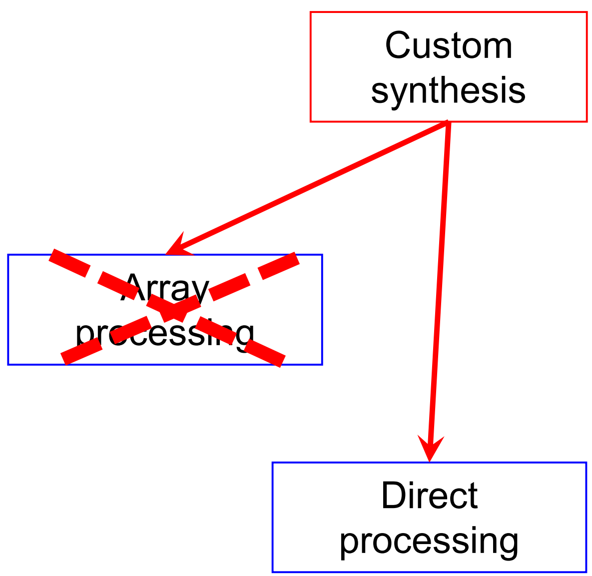
- Produce high quality CNTs → reach target electrical conductivity
- Translate properties of CNT fibers from lab to large scale
- Optimize CNT doping and conductor insulation for high-temperature stability

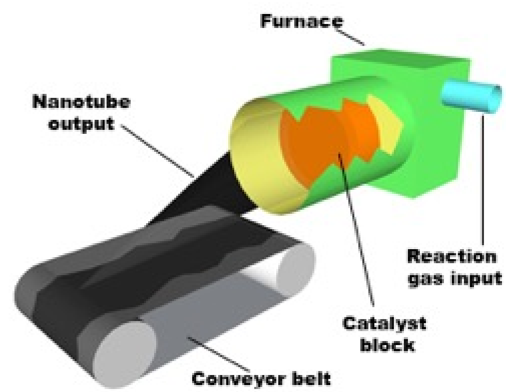
# Technical Innovation

## Limits of current practice:

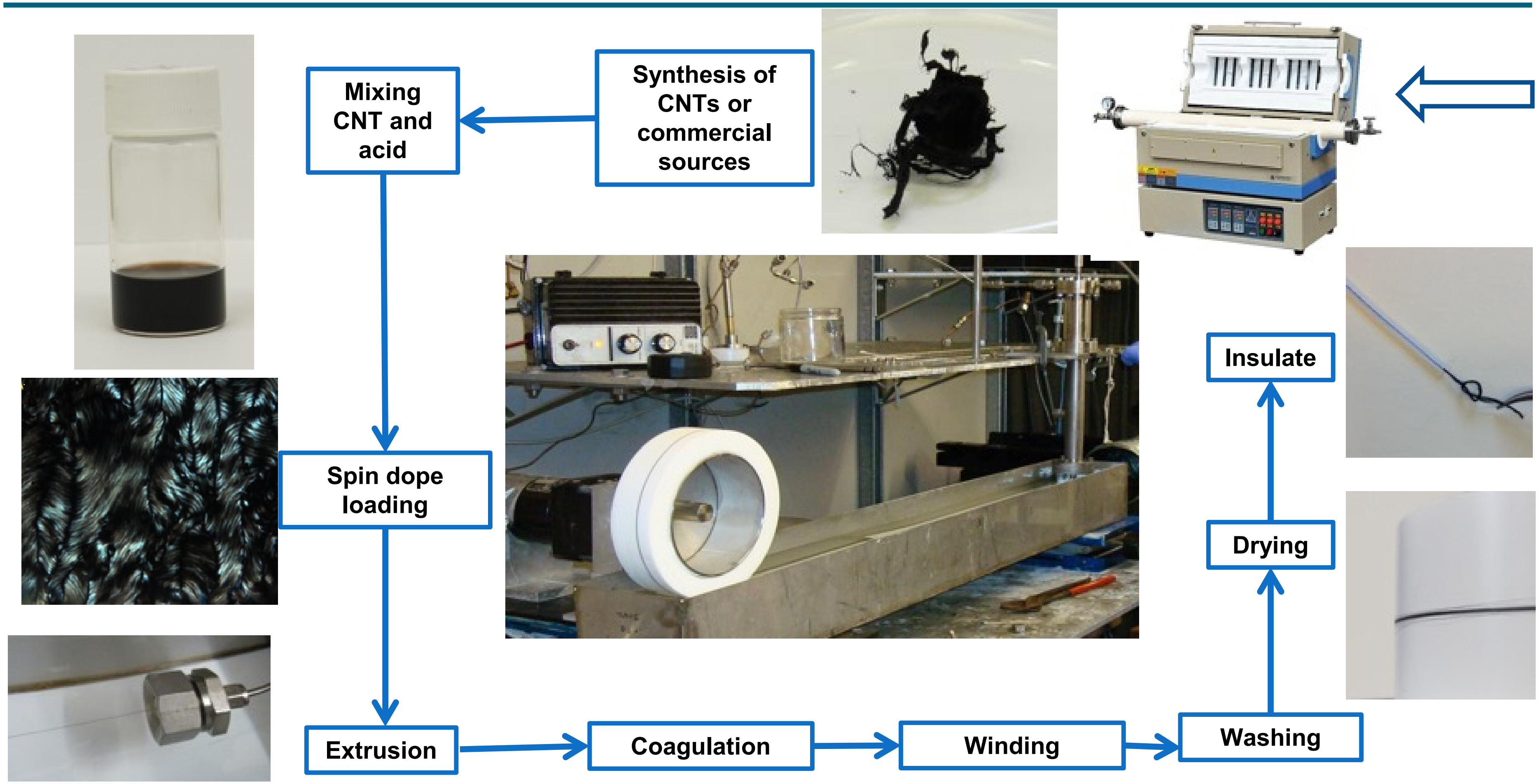




Nanocomp Reactor

# Technical Innovation




**Our approach**: scalable & allows independent optimization of CNT synhesis & fiber spinning

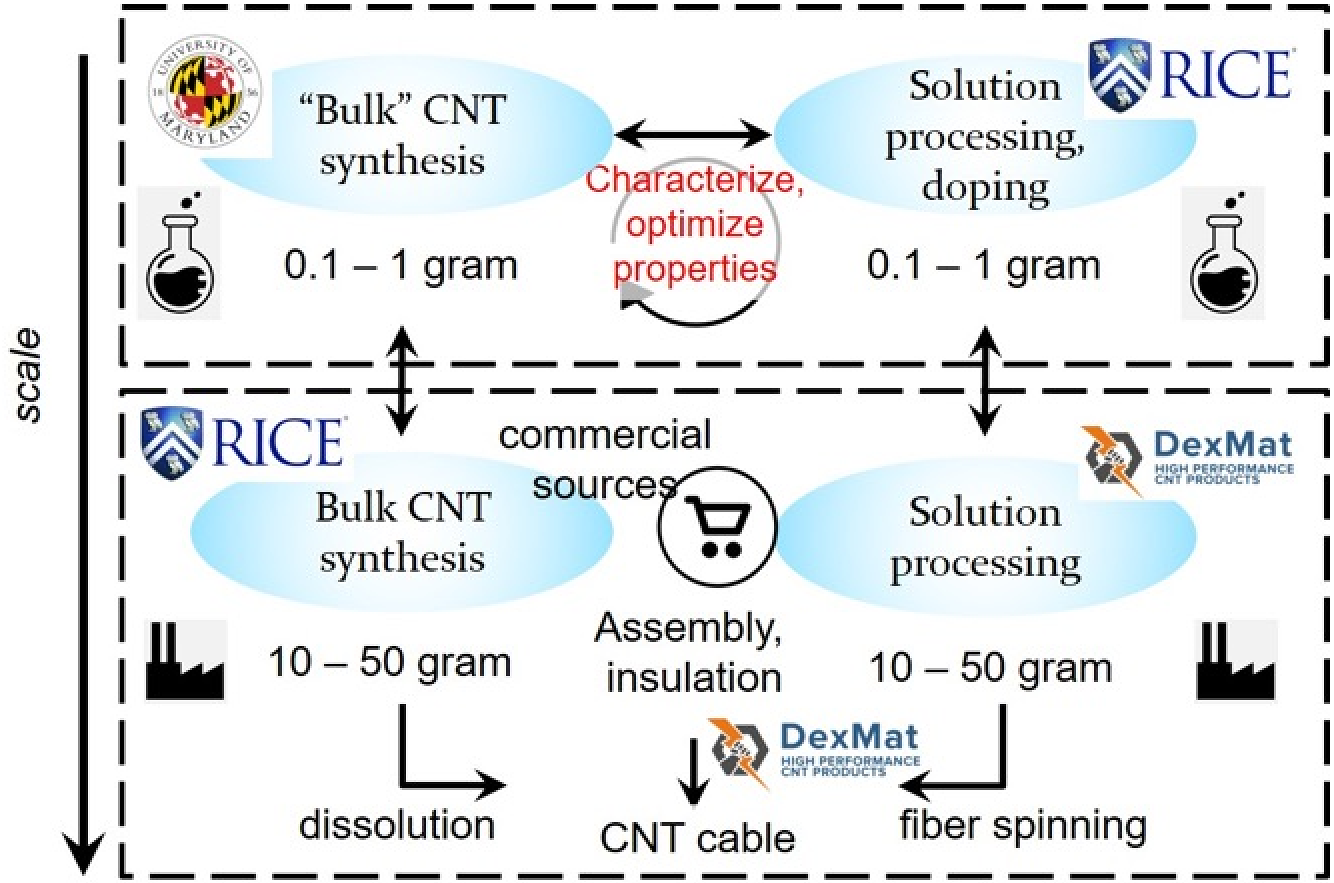
UNIT OPERATION approach: each step can be optimized separately

**Cost aspect**:

- Optimal CNT synthesis to lower cost of CNTs; our solvent is widely used in industry and inexpensive
- Wet fiber spinning is cheaper than solid state spinning

*Behabtu, Ma, Pasquali, et al, Science, 2013*

# Technical Approach




**Potential project risks and unknowns:**

Low performing CNTs produced "in house"

→ Work with CNT manufacturers and purchase their material

→ Work in parallel between Rice and University of Maryland to obtain optimal recipes

→ Introduce CNT synthesis industry experience (Glen Irvin) in the team

# Transition (beyond DOE assistance)

**Motor market: $99.85 B** in 2014 and expected to reach **$141.7 B** in 2022
(*source: Electric motor market analysis, Grandview research:2015*)

**CNT conductors for winding material:**
- Lightweight
- Electrically and thermally conductive
- High flex fatigue resistance
- Resistant to corrosion

**Application in motors - advantages:**
- Increase energy efficiency → energy saving
- Avoid the need to rewind due to failures
- Lightweight motors

## Commercialization approach:

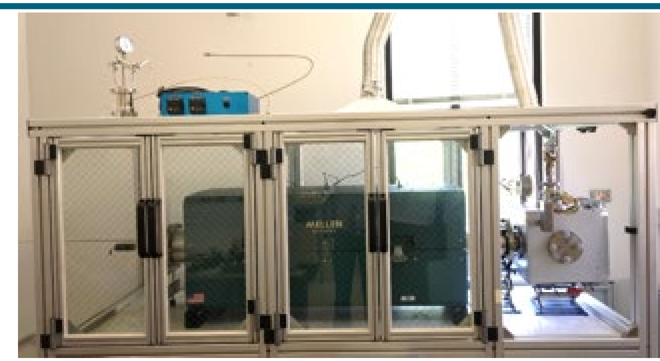
DexMat
HIGH PERFORMANCE CNT PRODUCTS

Scale up of CNT fiber conductor

REGAL BELOIT
TECO Westinghouse
SIEMENS
LEROY SOMER
TOSHIBA

OEMs for motor producers and rewinding industry

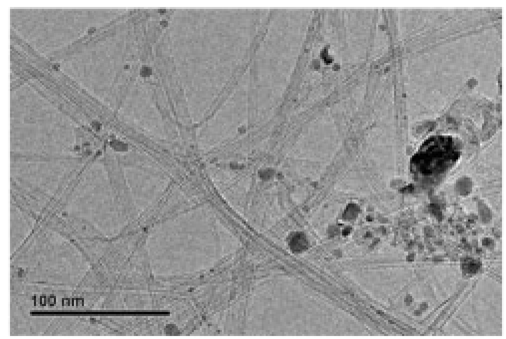
# Results and Accomplishments

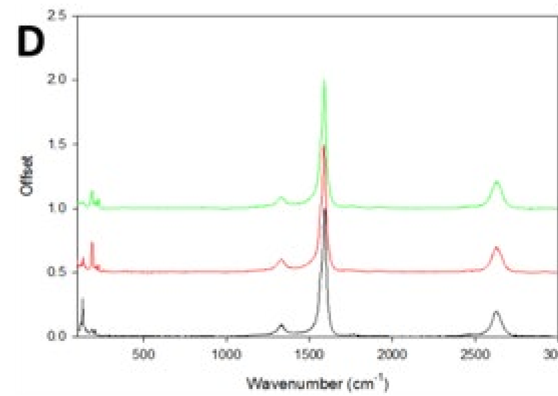


Progress:

• CNT synthesis reactors (Rice and UMD) operational and producing high-quality CNTs

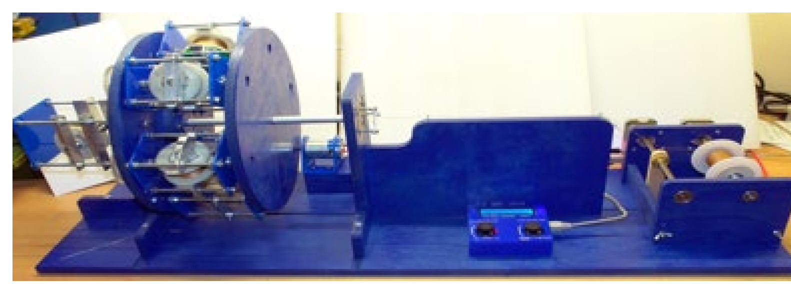
- High-quality CNTs produced
- Conductivity above 0.5 MS/m (without doping)




• Spinning and braiding machines operational at Rice and DexMat, producing fibers and wires

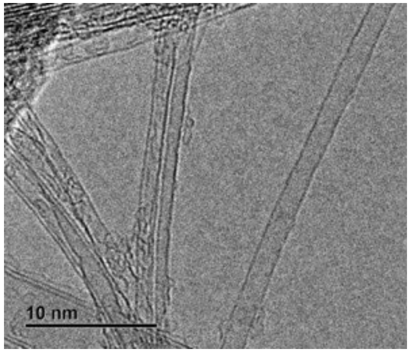
- 10 MS/m conductivity achieved without doping
- Highest ever attained in continuous CNT fibers

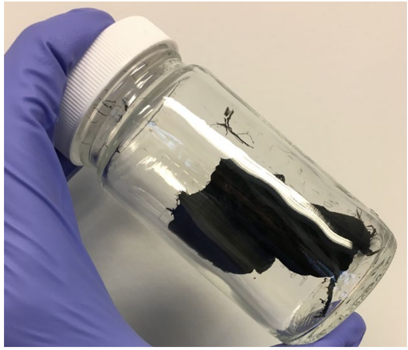


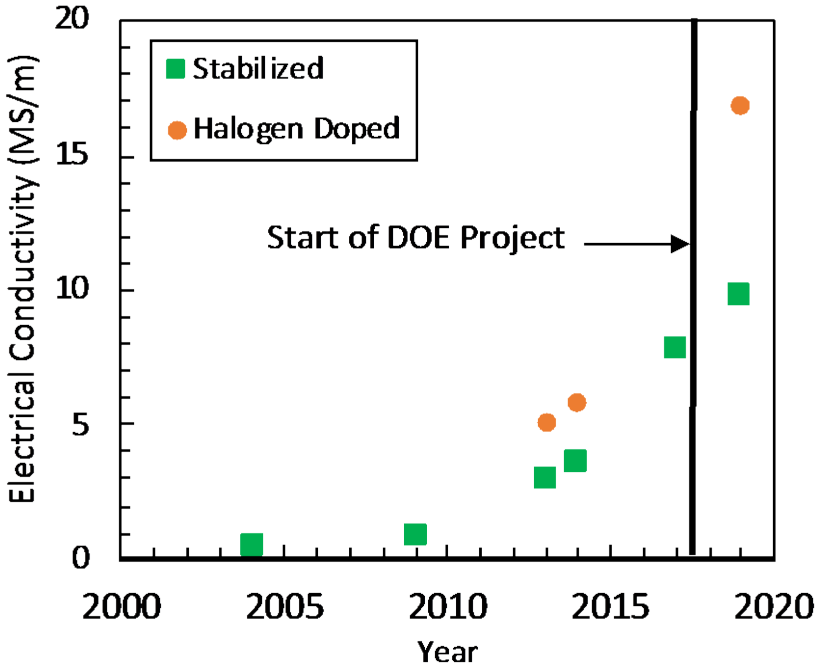
# Results and Accomplishments

**Growth:**

- Long (est. 10 micron) , high quality CNTs produced from lab-scale reactor
- High quality CNTs from MSGRS in quantities large enough to make fiber






**CNT Conductor Production:**

- Record specific conductivity for CNT fibers (>5,500 $Sm^2/kg$)
- Scaled up fiber spinning to yarns >500 um in diameter
- Neat CNT fibers with conductivity greater than 9 MS/m

**Doping:**

- Mixed halide doping of CNT fibers achieving conductivity higher than **16 MS/m.**

**Coating:**

- Lab scale continuous coating process developed

**Further Research:**

- CNT fiber conductivity modelling