Concept Summary - TEAM NANO

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With **3 years** and **$5M**, we want to **revolutionize** *battery technology*!

The plan: take an old idea – ***SUPERCAPACITORS*** – and turn it into the future of **energy storage** using ***GRAPHENE*** and ***CARBON NANOTUBES (CNTs)***.

The end result: a new age of batteries that, compared with Li-ion batteries, have...

- **equal *energy storage capacity***
- **10 times** the ***power***
- **100-1000 times** the ***recharging speed***
- **100-1000 times** the ***recharging cycle life***

Concept Summary – The Potential

This technology will have a *profound impact on sustainable energy* by providing the capacity to store and transport energy from sustainable generation sources with efficiency comparable to fossil fuels, giving electrical power an economic advantage over combustion power to match its ecological superiority. By matching incentives with external costs in this way, ***CNT-graphene supercapacitors*** will facilitate **FAST CHANGE** in *SUSTAINABLE ENERGY MARKETS*.

Innovation and Impact

The two aspects of energy storage devices that determine their effectiveness:

energy density: how much energy can be stored

and

power density: how quickly the energy can be put to use

The Tradeoff:

Capacitors: **high power density** but **low energy density**

versus

chemical batteries: **high energy density** but **low power density**

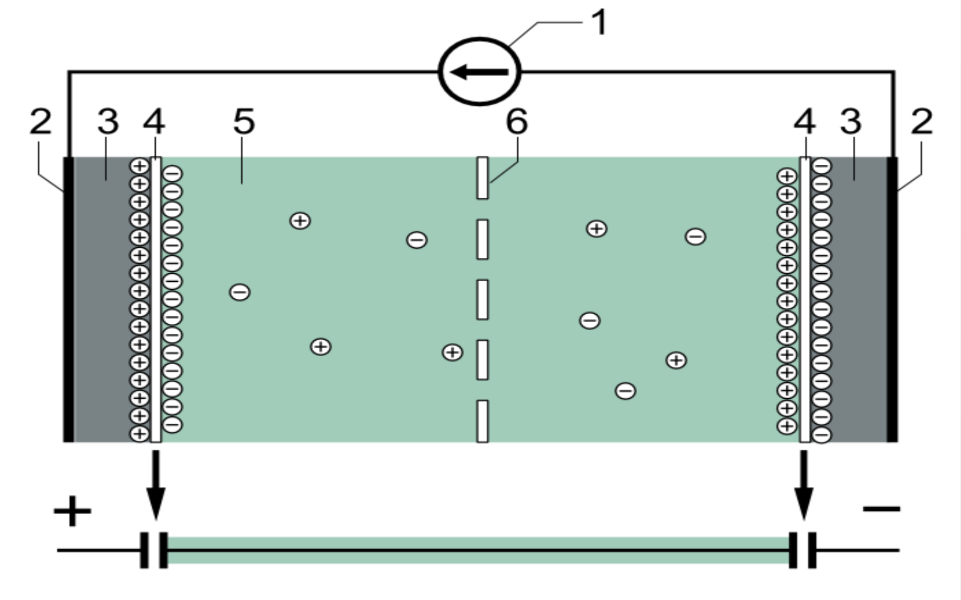
Innovation and Impact

In the 1960s, **supercapacitors** hit the scene, offering only slightly less storage capacity than Li-ion batteries and the charge/discharge rate of electrolytic capacitors.

So, what *are* **supercapacitors?**

They operate on the same principle as a regular capacitor – that is, storing energy in the field between two conductors – but use electrolytic methods:

two electrodes separated by an ion-permeable membrane (separator), and an electrolyte ionically connecting both electrodes. When the electrodes are polarized by an applied voltage, ions in the electrolyte form electric double layers of opposite polarity to the electrode's polarity.



This is essentially a capacitor with a dielectric material inserted, but instead of a dielectric for polarization, it uses an electrolyte, with ions moving rather than dipoles aligning.

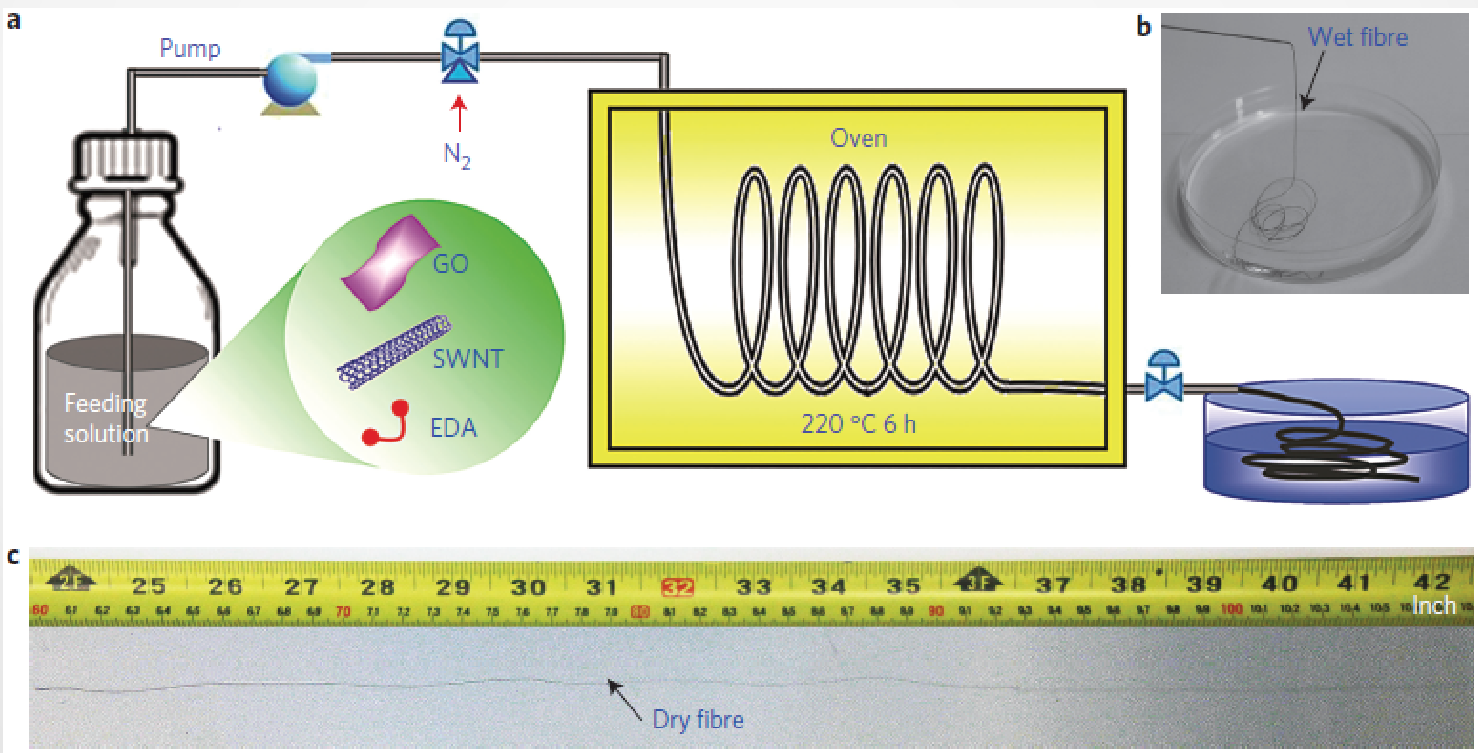
Innovation and Impact

<u>**The PROBLEM with regular supercapacitors:**</u> since the energy density depends on the surface area of the electrodes, supercapacitors had to be very large to compete with the storage capacity of chemical batteries

<u>**The SOLUTION:**</u> using the ***nanotechnology of graphene and carbon nanotubes (CNTs)*** by *covering the conducting surface of the supercapacitors with a dense "forest" of CNTs*, *rooted in single-layer graphene*, we can achieve the same energy density as lithium ion batteries

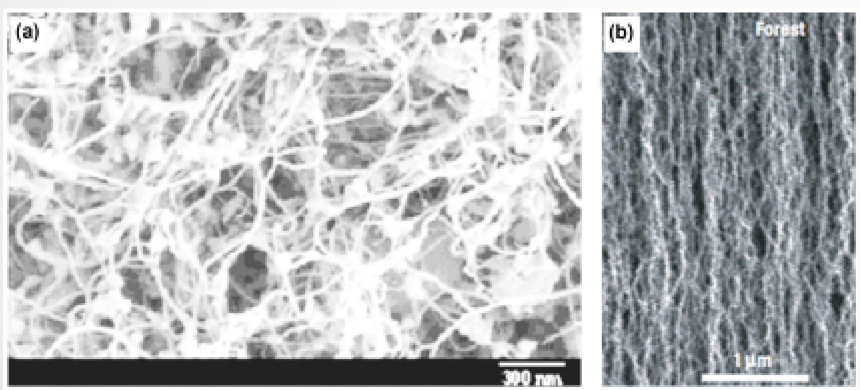
Innovation and Impact

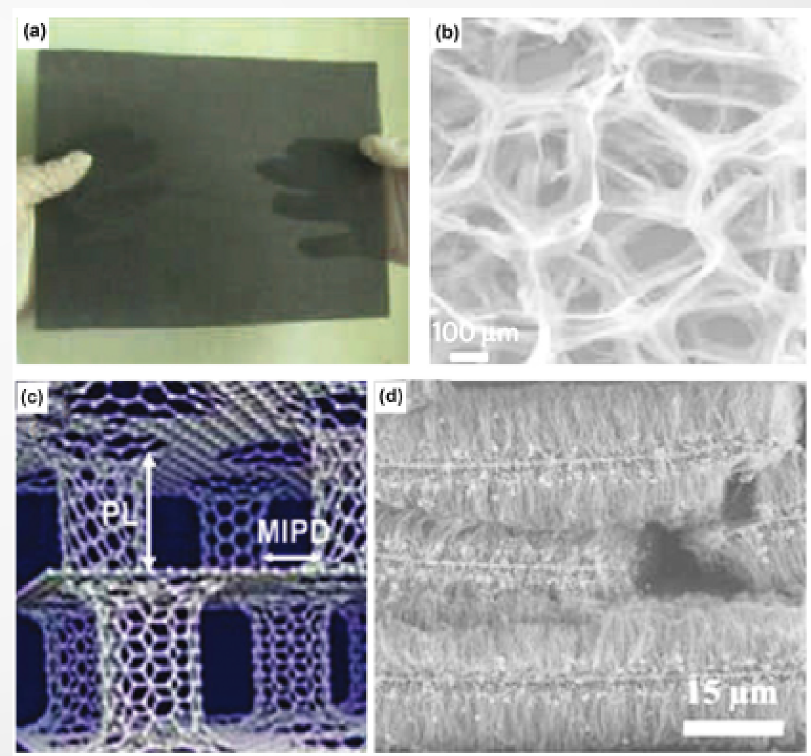
Already in 2013, a group at Nayang Technological University developed a scalable method for synthesizing CNT-graphene capacitive fibers with **396 SQUARE METERS of surface area PER GRAM**



Innovation and Impact

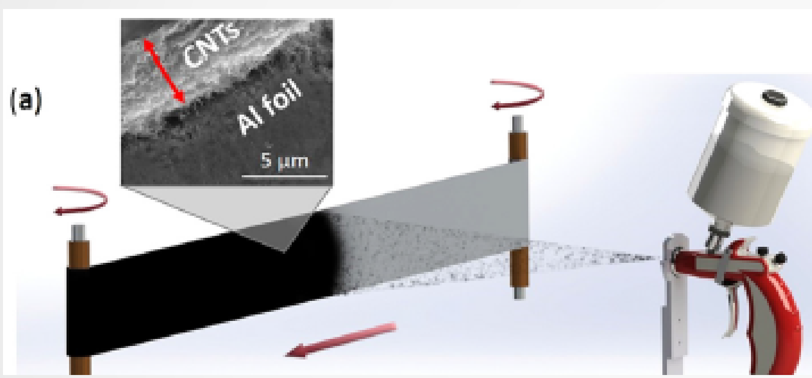
Since then, many collaborations have developed techniques to **"grow" these dense lattices of CNTs** with an **extremely inexpensive and robust** deposition process, and for **building layers of these conducting meshes for use in supercapacitor batteries**.

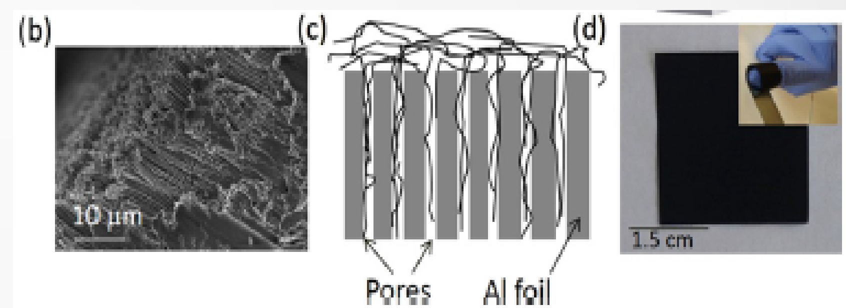




Innovation and Impact

The most cost effective layer production to date uses **spray technology** for **roll-to-roll manufacturing of industrial scale CNT-graphene supercapacitors**





The impact of this technology will be *to revolutionize energy storage,and to begin a new age of portability for electrical power*. In addition, the CNT fibers have the conducting capacity to serve as the most compact and efficient electrical wiring material to date!

Innovation and Impact: *The Specs*

Function	***Supercapacitor***	***Lithium-ion***	***CNT-Graphene Supercapacitor***
Charge time	***1 – 10 seconds***	***10 – 60 minutes***	***1 – 10 seconds***
Cycle life	***1 million or 30,000h***	***500 and higher***	***1 million or 30,000h***
Cell voltage	***2.3 to 2.75V***	***3.6 to 3.7V***	***2.5 to 3.5V***
Specific energy (Wh/kg)	***5 (typical)***	***100 – 200***	***100 – 200***
Specific power (W/kg)	***Up to 10,000***	***1,000 to 3,000***	***5,000 to 15,000***
Cost per Wh	***$20 (typical)***	***$0.50 - $1.00 (large system)***	***$0.25 - $1.00 (scalable system)***
Charge temperature	***–40 to 65°C***	***0 to 45°C***	***–40 to 65°C***
Discharge temperature	***–40 to 65°C***	***–20 to 60°C***	***–40 to 65°C***

Proposed Work

<u>Two simultaneous projects</u>:

1. Research that combines modeling simulations and hard experiment to optimize the design of the single supercapacitor sheet

2. Development of prototypes for energy storage systems in specific applications, namely: electric vehicles, mobile communication devices, and sustainable generation systems

Proposed Work

Three Primary Deliverables:

1. **Operational prototype** for **commercial batteries** with ***CNT-graphene supercapacitor technology*** to **completely replace Li-ion batteries in portable electronic devices**

2. **Operational prototype** for ***electric car power storage*** using less mass and volume, **distributed over an internal lining**, providing the **improvements on power and energy density** over today's models and, most importantly, enabling **full battery charge within minutes** and a **zero-maintenance lifetime to exceed that of the vehicle**

3. **Operational prototype** for ***integrated energy storage systems*** to be ***fitted to the entire range of sustainable energy generation***, enabling **efficient storage of the electricity generated by wind, solar, and other sustainable energy sources**

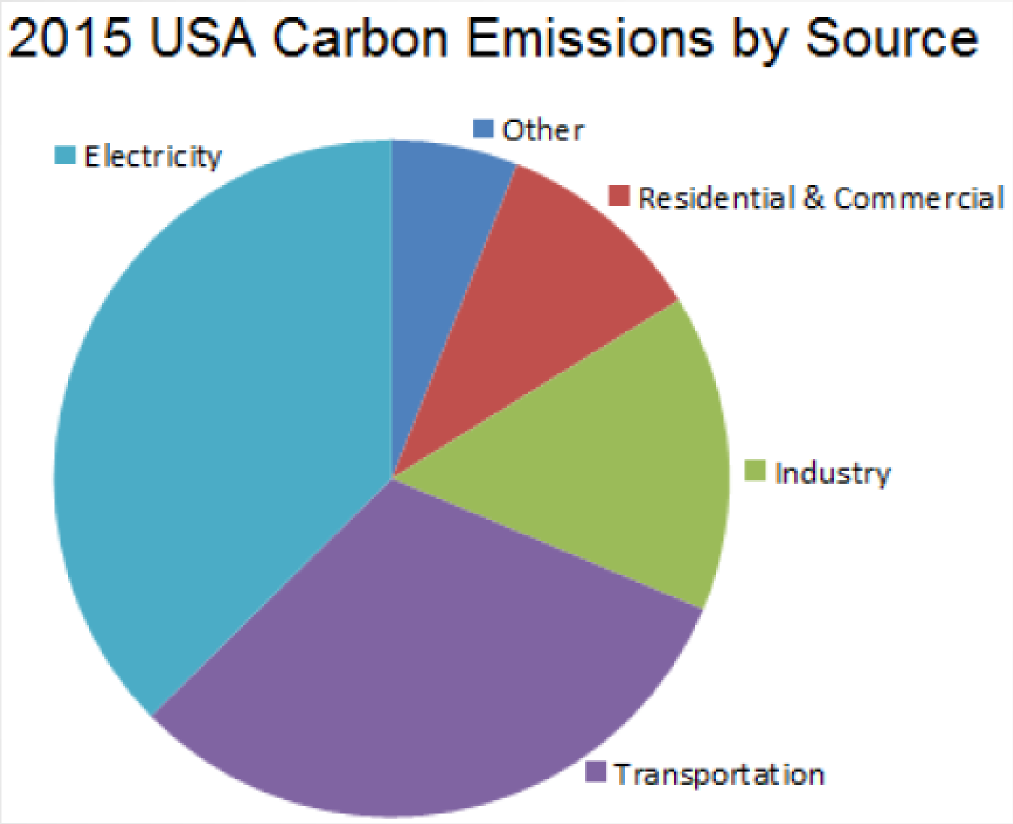
Proposed Work

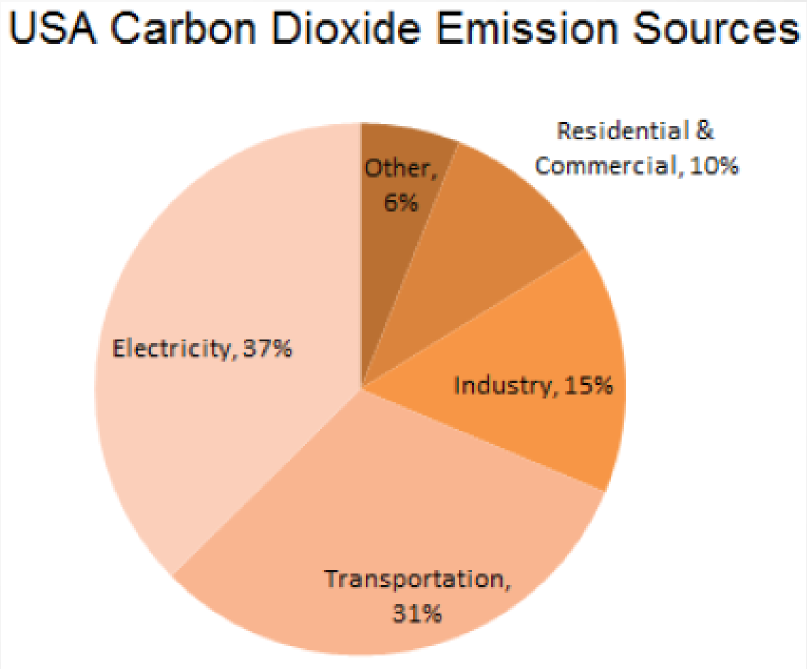
The only **other approach** to battery innovation that could compete is the use of CNT-graphene structures in Li-ion cells, but this would ultimately be **inferior** to the supercapacitor approach because of numerous factors including the **lower availability** of Li, the **shorter cycle life** of chemically driven batteries, the **smaller operational temperature range**, and the **less-scalable manufacturing processes**.

With the **CNT-graphene supercapacitor** approach, we will **revolutionize energy storage** and pave the way for the era of nanoscale electronic connectivity. There are no significant theoretical barriers left to surmount. The only remaining obstacles are: unforeseen engineering issues (which is why we need to conduct this research), retrofitting of existing devices, and political pushback from established dealers of existing energy storage technologies.

These obstacles are without question surmountable, and with the help of this funding we will soon see a new era of battery technology that will open the sustainable energy industry to a vast sea of new possibilities!

Sustainability Impact





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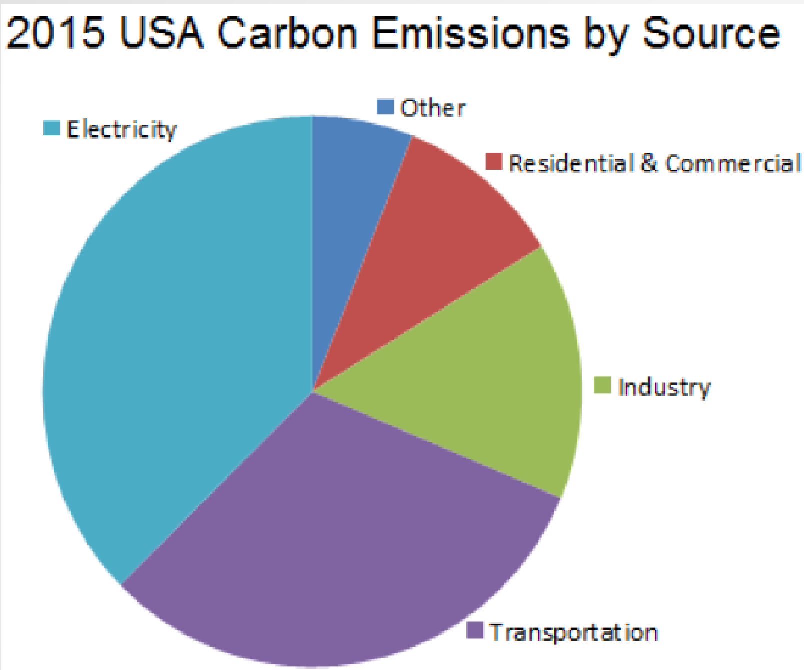
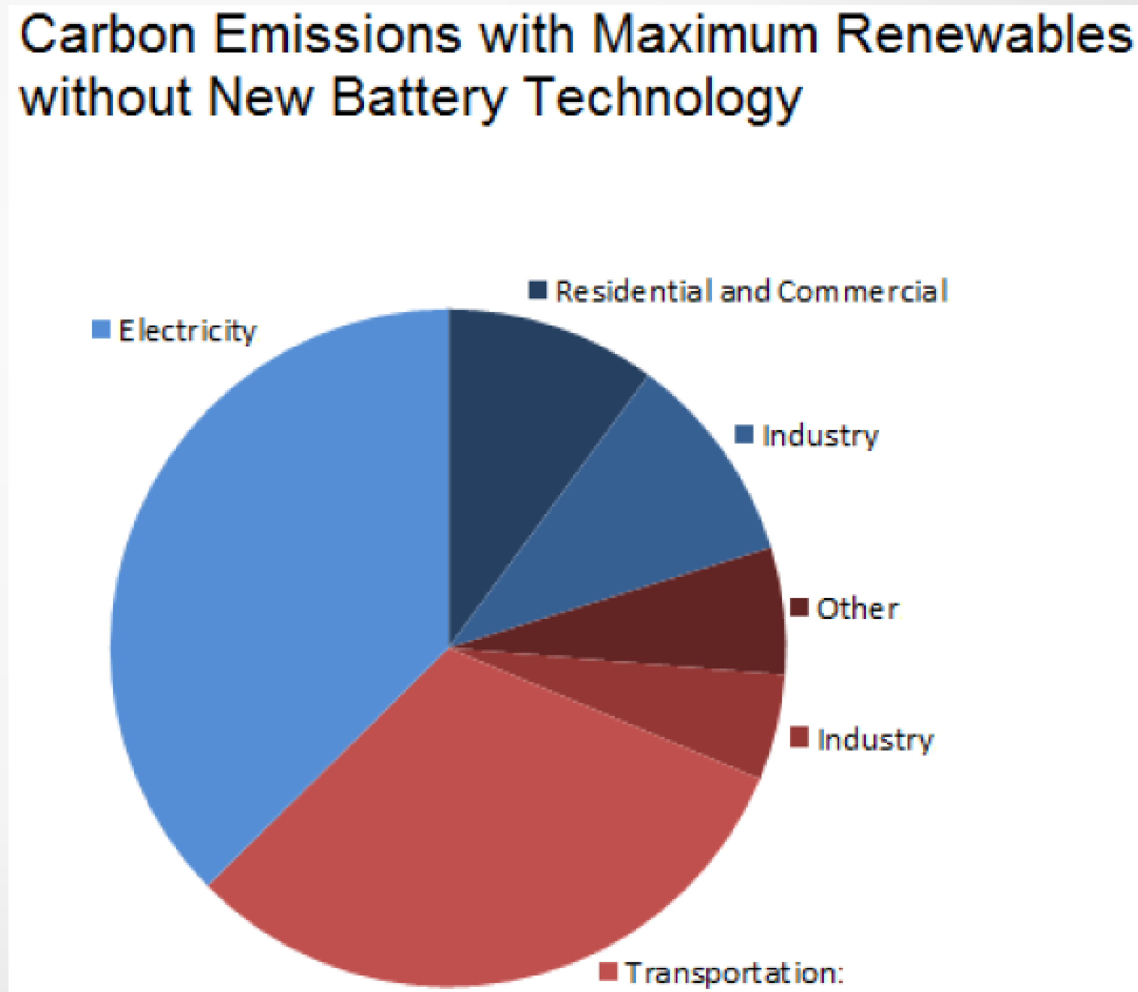
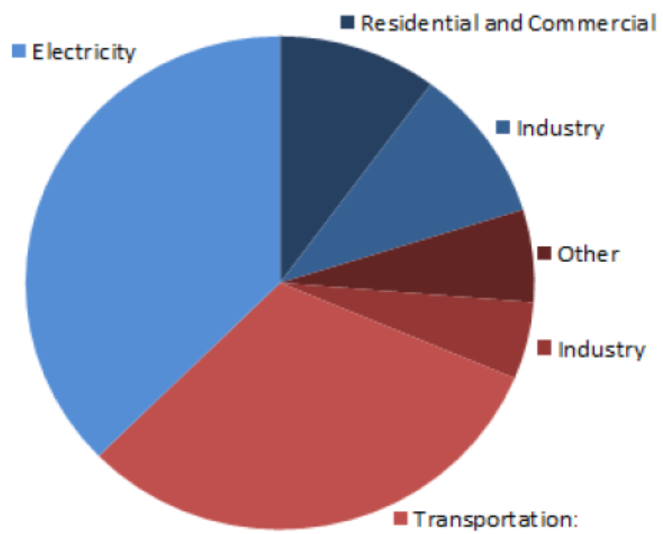




Sustainability Impact

Carbon Emissions with Maximum Renewables without New Battery Technology



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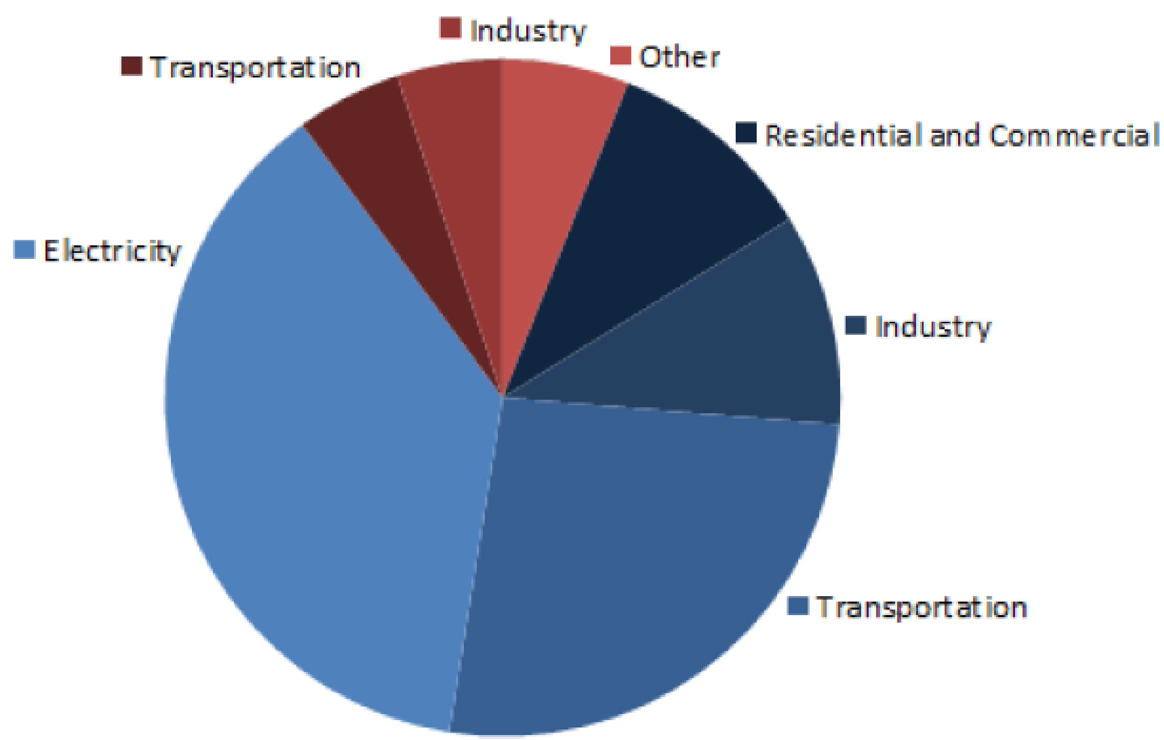

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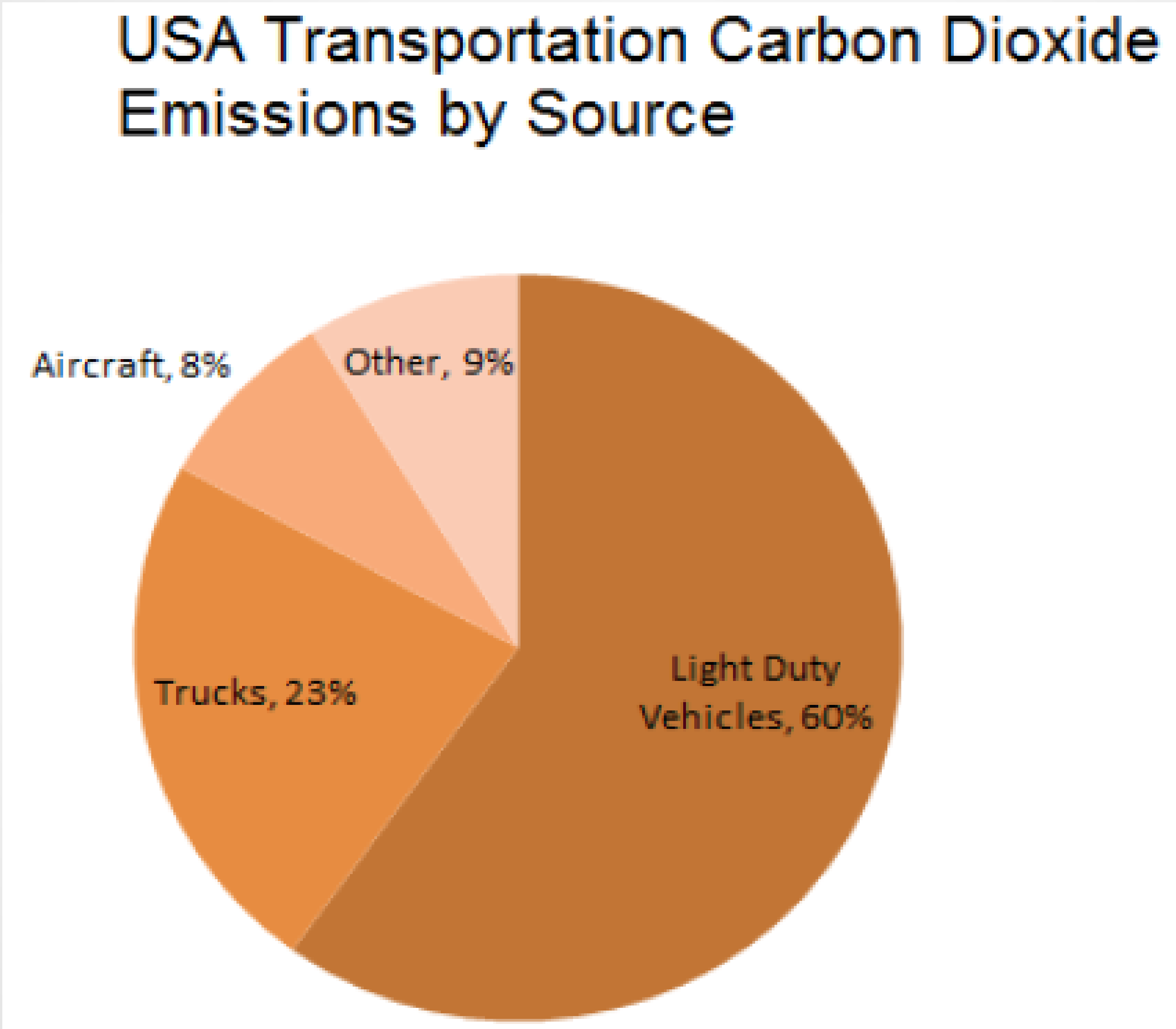

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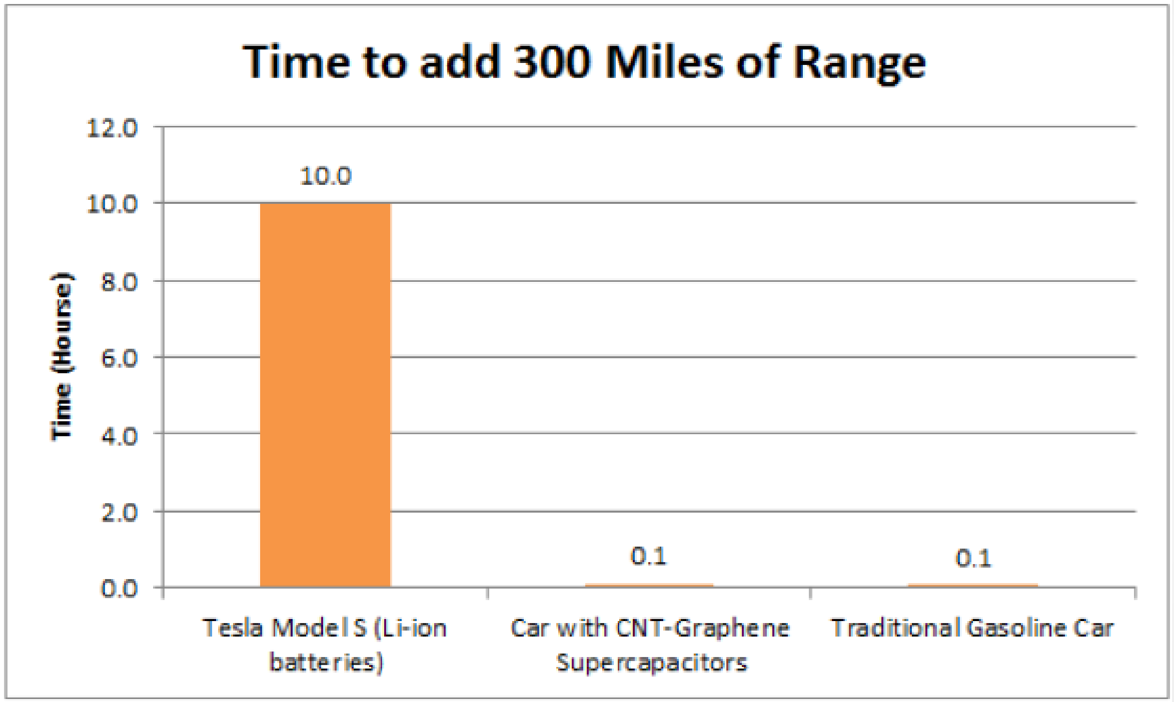
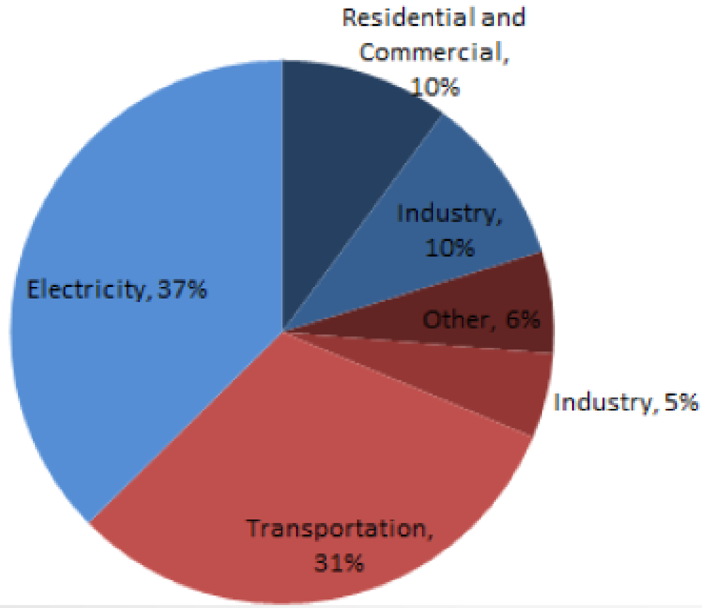


Sustainability Impact

Best Case Scenario Emissions Reduction Without Li-ion Replacement



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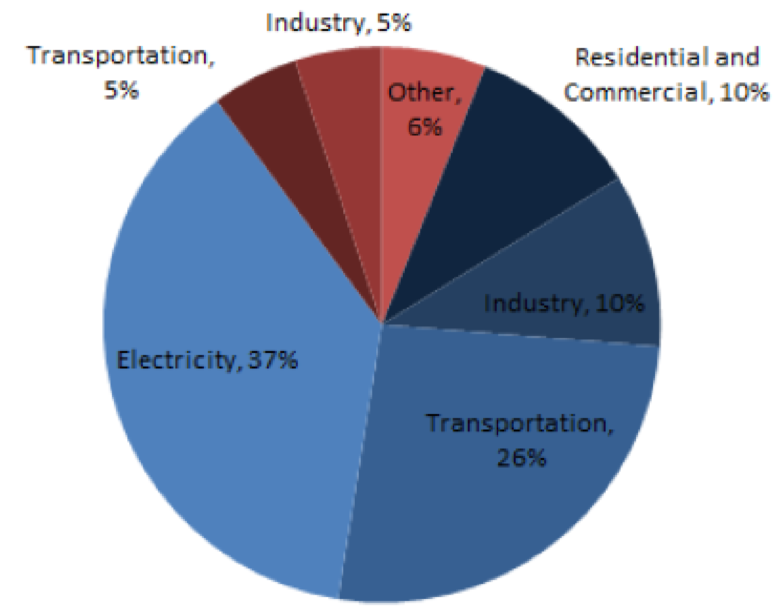

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