Diverting Plastic Landfill to Advanced Carbon-nanomaterials

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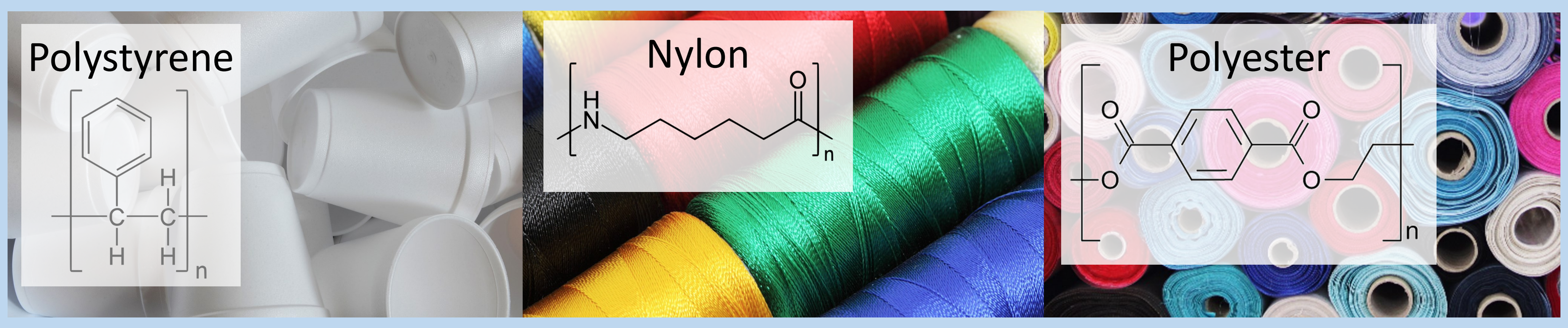
The Problem with plastic

Plastic is a tremendously useful material being lightweight , durable and inexpensive. This has led plastics to become a staple material and its hard to imagine life without them. However some of these positive material properties lead to problems when considering the end of their life[1].

Due to the nature of some plastics they can be difficult to recycle effectively using tradition recycling methods. This can be because of chemical structure and additives included, such as flame retardants and pigments. Furthermore plastic products made from recycled plastics are often considered inferior in quality. This in turn makes fresh plastics more economically desirable [2].

Using the LI-CVD process it is possible to change the perspective on plastics as a problematic waste product to a valuable untapped resource. As plastic primarily consists of hydrogen and carbon, this makes them excellent candidates for chemical conversion into advanced carbon nanomaterials. The LI-CVD process is able to use a variety of unconventional plastic sources that aren't commonly recycled such as:

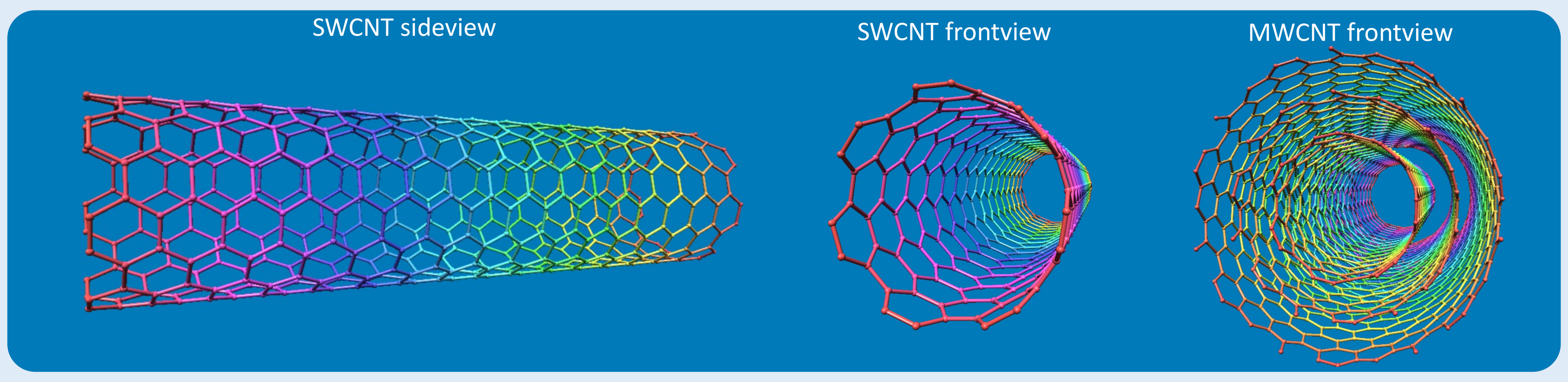
Here are some examples of some hard to recycle plastics currently being used in our research to produce CNTs:



Here are some examples of unconventional plastic products currently being used for CNT growth:

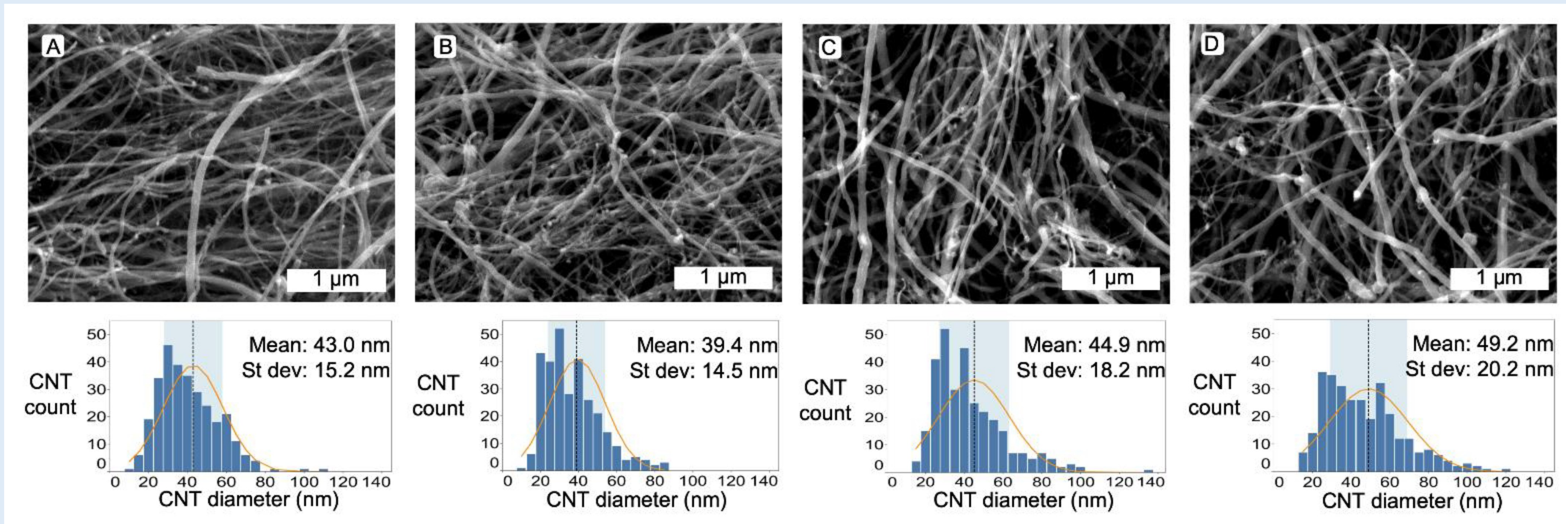
What is a carbon nanotube (CNT)?

Carbon nanotubes (CNTs) are a form of giant covalent carbon structures, putting them in the same category of other carbon structures such as graphite and diamonds. The structure of carbon nanotubes is extremely interesting, with them forming long tubular structures with high aspect ratios (Length:Width). A CNTs structure is akin to rolling a sheet of chicken wire into a tube[3], however in this case the chicken wire is a single sheet of graphene only an atom thick. CNTs take two forms, single walled (SWCNT) or multi walled (MWCNT). Single walled nanotubes consist of 1 layer of carbon where as multi walled consist of many.



Carbon nanotubes have a number of interesting properties including:

- High tensile strength: theoretically predicted to be in the range of 100-200Gpa. However in practice spinnable MWCNTs have a recorded range of 20-90Gpa [4] with longer nanotubes being measured at 0.68Gpa [5]
- Light weight: with a density of 1/6th that of coppers [2]
- Both electrically conducting or semiconducting: depending on chirality

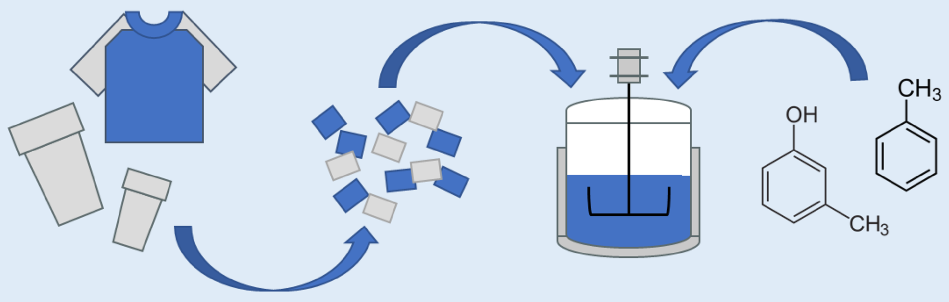


SEM images of CNTs produced from polystyrene (PS) A) 0wt%PS B) 1wt%PS C) 2wt%PS D) 4wt%PS [2]

Dissolution

For plastic to be converted into CNTs, the plastic must be first dissolved to form a plastic slurry. This is a less common method for the production of CNTs from plastic. The majority of other methods opt instead for CNT growth from a light hydrocarbon gas formed in a separate pyrolysis process. However, direct injection of a plastic slurry has several benefits: [2]

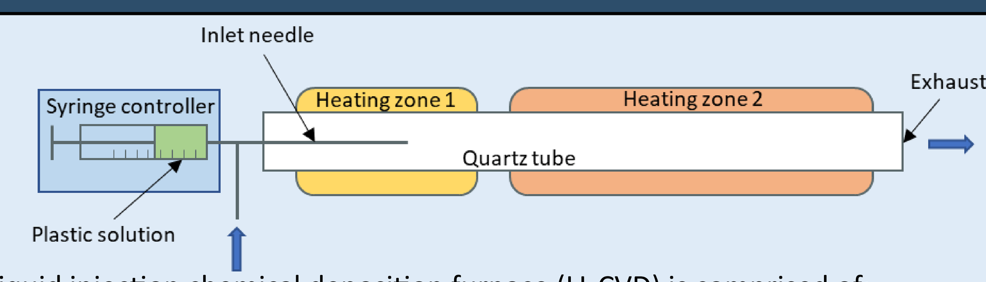
- Dissolution breaks down the polymers macro structure, untangling the polymer chains, increasing the reactive surface area.
- Polymer decomposition begins to occur lowering the required energy for C-H bond scission, which in turn allows the use of mixed plastic feedstocks.
- Insoluble plastic additives such as flame retardants and pigments can drop out of solution, effectively cleaning the plastic.
- The plastic slurry can be transported via pipes and pumps allowing the process to be more industrially scalable.
- Dissolving plastics increases the carbon density of the feedstock which can have positive impacts on CNT yield.



The plastic is dissolved using 3 main steps:

1. **Resizing the desired feedstock via shredding/cutting.** This increases the available surface area for dissolution and allows the slurry to be mixed during the process.
2. **Plastic pieces and desired solvents are inserted into a heated stirred vessel, t**hen left until a homogenous slurry is formed . This dissolution could require hours or a few days depending on the plastic used.
3. **The plastic slurry is then filtered.** This removes any particulates that could not be dissolved.

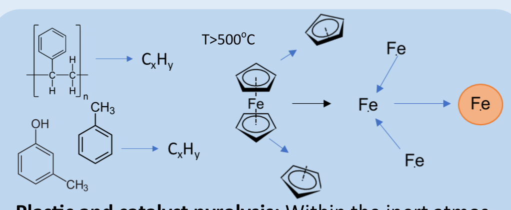
Liquid injection CVD



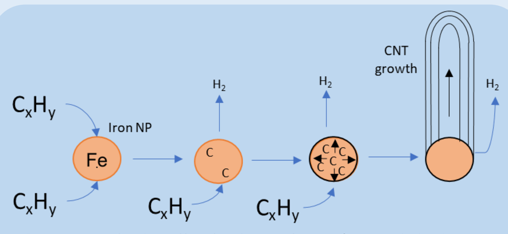
The liquid injection chemical deposition furnace (LI-CVD) is comprised of:

- **The injection pump and needle:** used to control the flow of plastic slurry into the furnace.
- **The carrier gas control and inlet:** used to control the composition and flow conditions of the reaction atmosphere.
- **The heated quartz reaction tube**: heated in the range of 700-1000°C that contains the reaction and provides a surface for the CNTS to deposit.

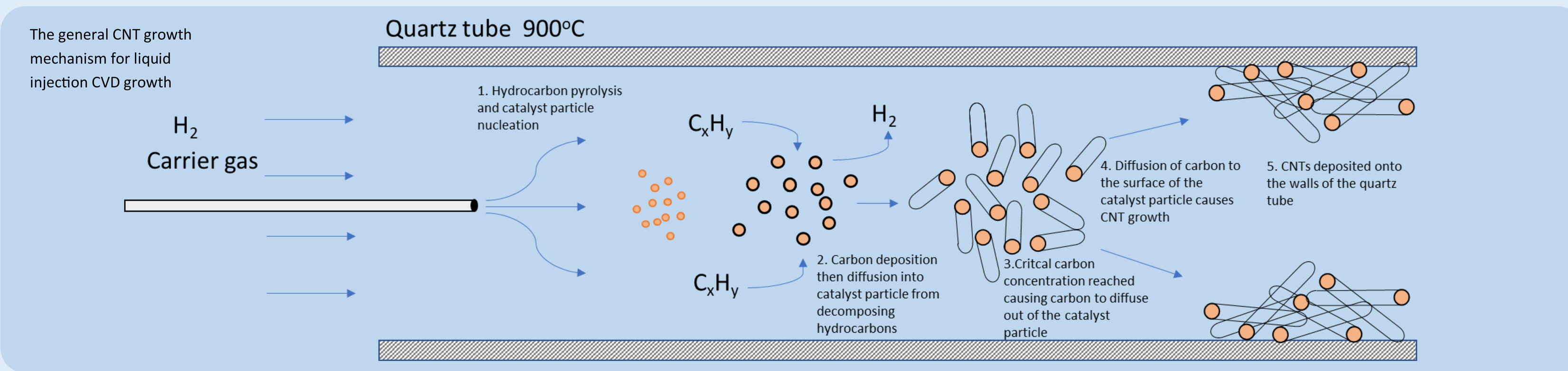
Catalyst addition: Before the plastic slurry can be converted into CNTs, a catalyst needs to be added. The catalyst comes in the form of a organometallic compound, in this case ferrocene is used. The catalyst is very important as it not only lowers the required activation energy, but also provides the site for CNT growth. The size and shape of the nucleated catalyst nano particles (NPs) will also impact important structural properties of the CNTs such as diameter, chirality and number of walls.



Plastic and catalyst pyrolysis: Within the inert atmosphere inside the reactor tube at high temperature, the hydrocarbons present in the plastic and catalyst begin to thermally decompose into smaller HC molecules. When the catalyst decomposes it releases its metallic component, allow metallic nanoparticles to nucleate. These NPs provide the site for CNT growth.



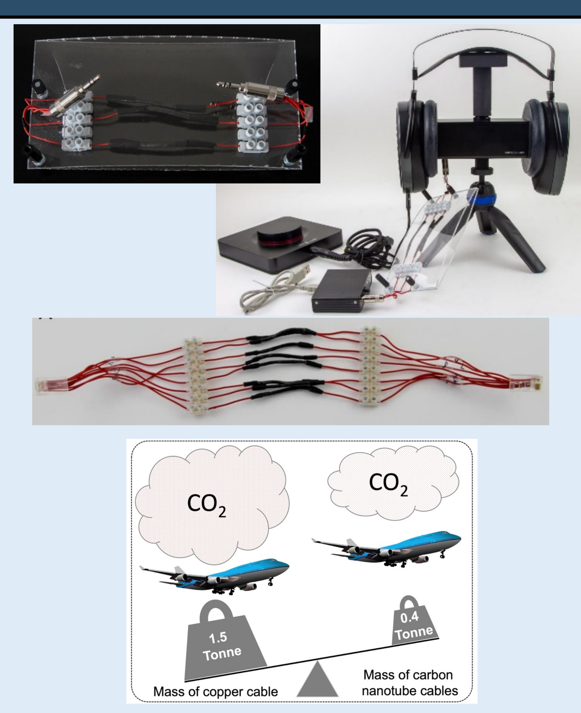
CNT growth: Smaller hydrocarbons formed during pyrolysis now adsorb onto the surface of the iron NPs. Carbon is deposited onto the catalyst NP and hydrogen is released. The carbon diffuses into the NP and the concentration of carbon begins to rise. Once the concentration of carbon reaches a critical point, carbon begins to crystalise out of the NP, causing a CNT to grow.



CNT applications

CNTs make excellent electrical conductors if the correct chirality and purity is achieved. Therefore this gives rise to the application of CNTs within electronics. Our research group have developed 2 proof of concept electrical cables synthesized using the liquid injection CVD process from plastic slurries. These come in the form of a fully functional audio[6] and ethernet cable[2]. This could show CNTs as a sustainable future alternative to copper cables, as they can be grown from previously unrecyclable waste plastics. This would not only be diverting plastic waste from landfill but lowering the environmental impact of copper mining.

One future application being investigated is the use of CNT electrical cables within airline planes, as there density is 1/6th that of coppers. Using CNT cables would lower the mass of any electronics on board and lead to lower fuel requirements[2].



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Future work

- Further investigate viable plastic feedstocks
- Employ methods to capture important hydrocarbon compounds from exhaust gas for reuse
- Employ methods to extract hydrogen gas from the exhaust stream

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