Recycling of Sirius Modules

White Paper

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Introduction

Recycling reduces the environmental impact of the graphene supercapacitor, as graphene is a problematic material for the environment. The recycled graphene has proved to be of a quality similar to pristine material. Its recovery generates an environmental credit that is 90% of the production burden for all categories by displacing the production of new graphene for polymer reinforcement applications.

When a more efficient graphene production can be industrialised, graphene supercapacitors will have the potential to become the technology with the lowest environmental impact.

Most of environmental impact occurs during the production phase of graphene's LCA. The impact range includes Global Warming Potential, Ozone depletion, human toxicity, particulate matter, Ionising radiation (human health effect), Photochemical Ozone formation, Acidification, Terrestial eutrophication, freshwater eutrophication, Ecotoxicity, resource depletion (water), resource depletion (fossil and mineral).

In the study the recycling was modelled by substitution, whereby the recovered material displaced the production of the same pristine material. The quantity displaced depends on the quality of the material recovered compared with the pristine material. When the recovered material displaces the production of pristine material, it reduces the environmental burden of the production.

For recycling all data was measured in the laboratory at the University of Nottingham and used to simulate a commercial-scale process with SuperPro Designer. All other processes belonging to the background system (rubber and paper incineration and aluminium or stainless steel recycling) were modelled using secondary generic datasets available inside GaBi 6 databases.

The Recycling Process

The recycling process steps:

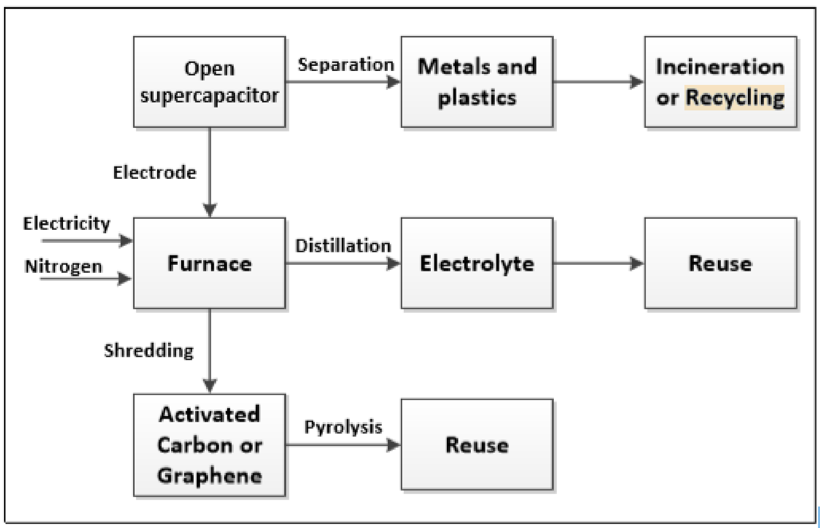
1) Cutting the supercapacitor in order to extract the electrodes. Cutting can be done either manually or with an automated process depending on the volumes.
2) All remaining materials are easily separated and collected either manually or with a set of cyclones and filters and then recycled or incinerated separately. (The recovered paper and rubber are considered incinerated, while aluminium and stainless steel are considered recycled).
3) The electrodes undergo a pyrolysis process in order to detach the active material from the aluminium substrate.
4) After pyrolysis the electrodes are shredded in water
5) The shredded suspension is filtered in order to separate the aluminium from the active material.
6) The heating process

The Pyrolysis Process (Stage 3 of Recycling)

The pyrolysis process for electrodes starts with placing the electrodes in a nitrogen swept reactor heated at 200 C in order to evaporate and recover the acetonitrile by distillation. When the process is completed after approximately 15 min, the temperature is increased to 350 C and maintained for about one hour. This second heating step could be also performed at 600 C for 5 min.

Without a temperature increase, at 200 C, the binder is not decomposed and the carbon recovered from the aluminium substrate is only 40%. In this way, instead, it is possible to recover 95% of the activated carbon with a surface area per gram that is 95% of the original. The 600 C alternative decomposes all the binder allowing the recovery of 100% of the material but it also collapses some micro pores in the activated carbon structure halving the value of the surface per gram.

The results of the study showed the same quality of the recycled graphene as the pristine material.



If the pyrolysis is run at 200 C, the reinforcement increases by 8% the tensile strength of the polymer. If graphene underwent the 5 min pyrolysis at 600 C there is a 12% increase in tensile strength.

The recycling of active material is modelled for substitution so the active material recovered is set to replace pristine one.

Recycling Efficiency

The graphene is recovered to its 100% potential and allowing for 10% process inefficiency is set to replace 90% of new graphene production. The acetonitrile recovered, instead, was generally around 40%. It is considered reusable and therefore displacing new production as in the case of the active materials.

It is clear that the more the production is energy intensive, the more the credit given by the recycling through avoided production is substantial and positively impacting the overall results.

Graphene based supercapacitor prototype recycling: - 10% heat lost every hour at 200 C equals to 3% heat loss for this step as the time of operation is 15 min. - 20% heat lost every hour at 600 C equals 7% heat loss heat loss for this step as the time of operation is 20 min (5 min at 600 C + 15 min ramp up)

The main energy consuming component is the furnace while the cutting and the separating activities are very small contributors to the overall energy consumption according to the measurements done. The second most consuming device is the pump (for the nitrogen circulation) that consumes a hundred times less than the furnace and is therefore a minor concern.

Pyrolysis of active materials	1 gram	1 electrode	
Activated Carbon (350°C)	0.0021	0.0011	MJ
Graphene (600°C)	0.0038	0.0010	MJ
Graphene (200°C)	0.0019	0.0005	MJ
Graphene (350°C)	0.0025	0.0007	MJ

Conclusion and Recommendation

Graphene recycling boosts positively the environmental credits in all categories (except for the ionising radiation) as recycled graphene displaces new graphene.

The recycling process, when performed at commercial-scale, is able to recover high quality material (high purity graphene) that shows the same properties as pristine graphene if used as polymer reinforcement.

Based on the literature review, it is apparent that recycling of graphene, aluminium and stainless steel provides high quality material recovery and offsets the environmental impacts at the production stage of supercapacitor cells, as well as the modules.

References

1) Mohan, V. (2019). Handling and Risk Mitigation of Nanoscale Graphene and Related Materials: Some Considerations and Recommendations. Journal of Carbon Research
2) Cossutta, M. (2016). Life cycle analysis of graphene in a supercapacitor application. PhD thesis, University of Nottingham.