Carbon-based electrodes for energy recovery from salinity gradients

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XXXIII Cycle

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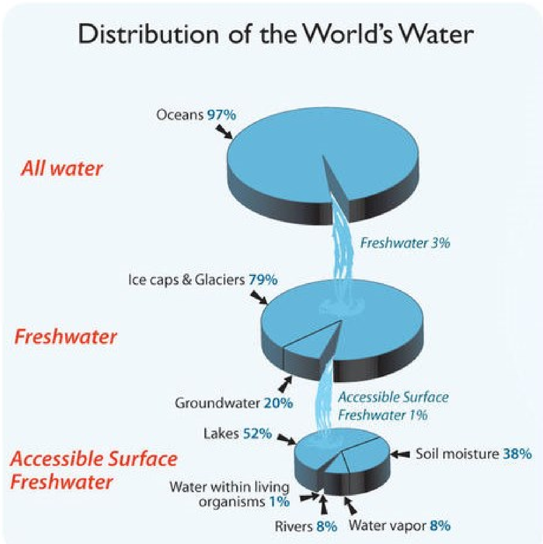
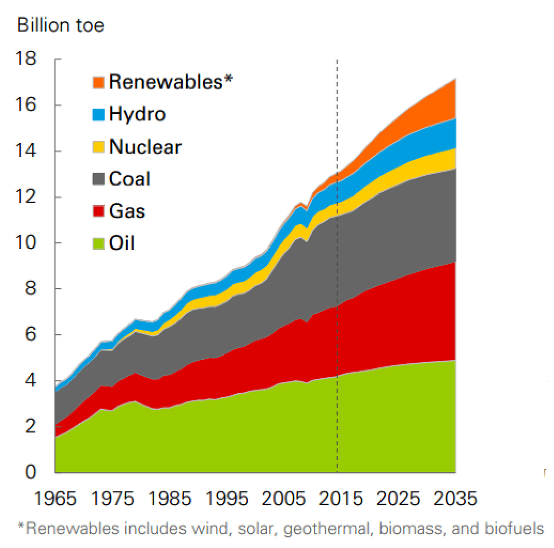
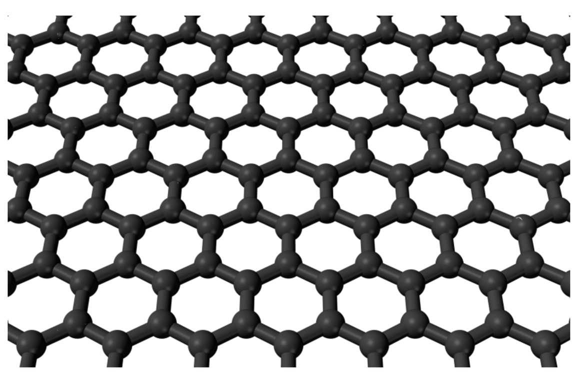
Research context and motivation

- Clean water is a resource essential for all life on Earth and human activities. In the recent years, the world is facing enormous challenges to satisfy the increasing demand for freshwater. More than 70% of the planet surface is covered by water, but only 3% is the mass of freshwater and, even worse, only a small portion of it is easily accessible.



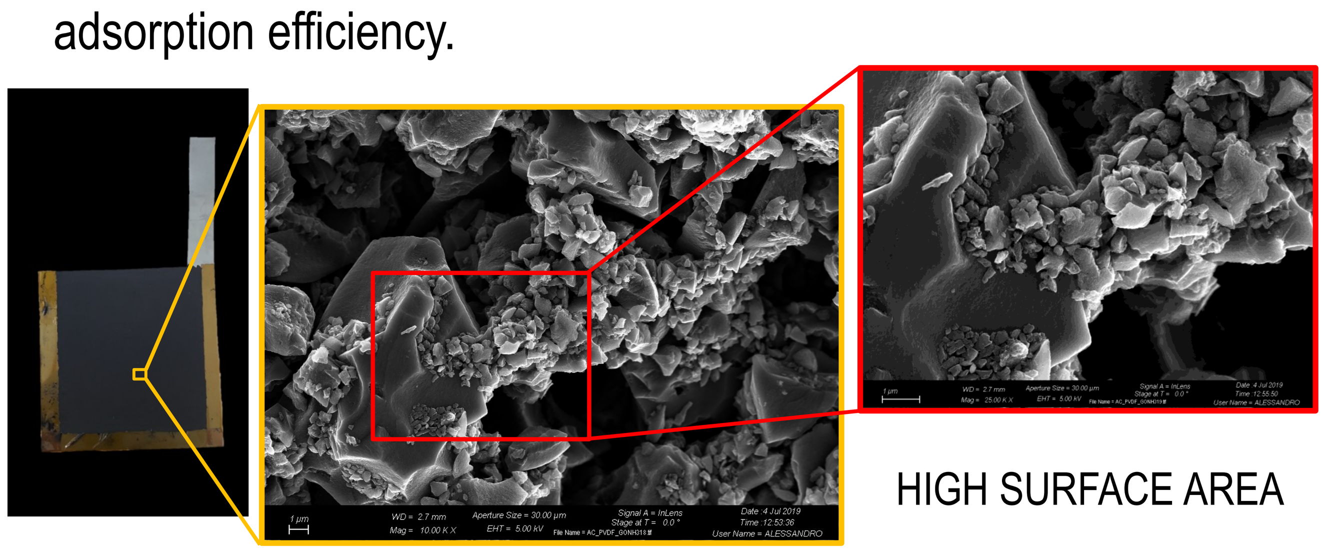


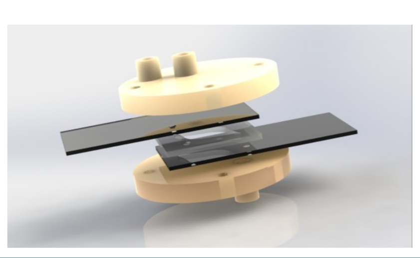
- Contemporarily, the world is facing an increasing demand of energy. Actually, the energetic requirement is 15 TW and this energy is mostly supplied by non-renewable sources (oil, coal, natural gas), which strongly contribute to the greenhouse effect and air pollution. Only less than 20% of the total energy is supplied by renewable sources like solar, hydro, geothermal, wind and biomass.
- In the recent years, the researchers focused their attention on carbon-based materials like activated carbons, graphene and graphene oxide. Having many interesting properties (high surface area, high degree of porosity, chemical resistance, electrical conductivity, etc.), they are promising materials to be studied and employed in effort to overcome the global problems described.



Adopted methodologies

- Activated carbon is the base material used to build the electrodes used in capacitive deionization. Polyvinyldene fluoride dissolved in dimethyl sulfoxide is added to the activated carbon to obtain a paste which can be coated over a planar metallic substrate used as current collector.
- Modification of the electrodes is performed adding a net charge to the activated carbon. To do so, activated carbon has been mixed with graphene oxide, either functionalized or not.
- A dedicated cell is used to evaluate the salt adsorption, together with a peristaltic pump and a conductimetric probe. Cyclic voltammetry method is used to estimate the charge adsorption efficiency.





Future work

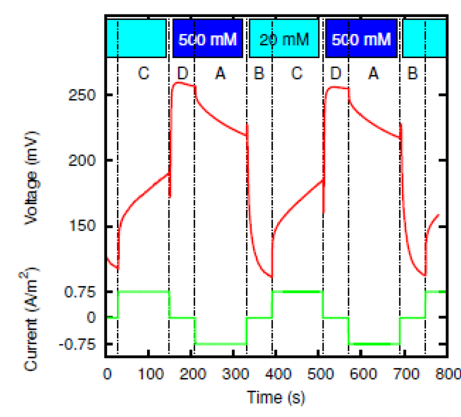
- For what concerns the capacitive deionization, improvement of desalination performance (electrosorption capacity) are actually under study. The results obtained with graphene oxide-based charged coatings are promising. To go beyond that, ionic exchange membranes are being tested.
- The CapMix technique, a newly emerging method to harvest energy from salinity gradient based on the cyclic charge and discharge of porous electrodes in salty water, will be investigated starting from the solid knowledge acquired from the capacitive deionization.

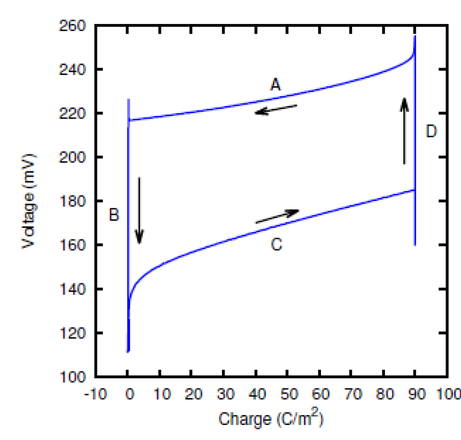
Submitted and published works

- Castro, C., Cocuzza, M., Lamberti, A., Laurenti, M., Pedico, A., Pirri, F., Rocca, V., Borello, E., Scaltrito, L., Serazio, C., Viberti, D., and Verga, F., "*Graphene-Based Membrane Technology: Reaching Out to the Oil and Gas Industry*", Geofluids, vol. 13, 2018, pp. 1-13
- Pedico, A. , Lamberti, A., Gigot, A., Fontana, M., Bella, F., Rivolo, P., Cocuzza, M., and Pirri, F., "*High-Performing and Stable Wearable Supercapacitor Exploiting rGO Aerogel Decorated with Copper and Molybdenum Sulfides on Carbon Fibers*", ACS Applied Energy Materials, 2018, pp. 1-8
- Pedico, A. , Lamberti, A., Bianco, S., Kara, S., Fontana, M., Periolatto, M., Martignoni, V., Pirri, F., and Tresso, E., "*Graphene oxide membranes for water purification*", MELPRO2018, 2018, p. 153
- Pedico, A., Fontana, M., Bianco, S., Kara, S., Periolatto, M., Carminati, S., Pirri, F., Tresso, E. and Lamberti, A., "*Graphene oxide membranes for Oil & Gas application: efficient removal of BTX traces from produced water*", Journal of Membrane Science, 2019, SUBMITTED

Addressed research questions/problems

- All over the world, there is a constant phenomenon of energy dissipation due to the natural mixing of freshwater coming from lakes and rivers into the seawater. Considering all the rivers on Earth, the power at stake is around 1 TW. Actually, there are no plants in the world taking advantage of this phenomenon to produce clean and renewable energy.

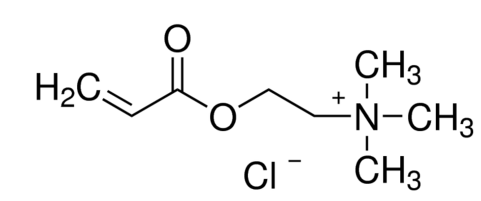




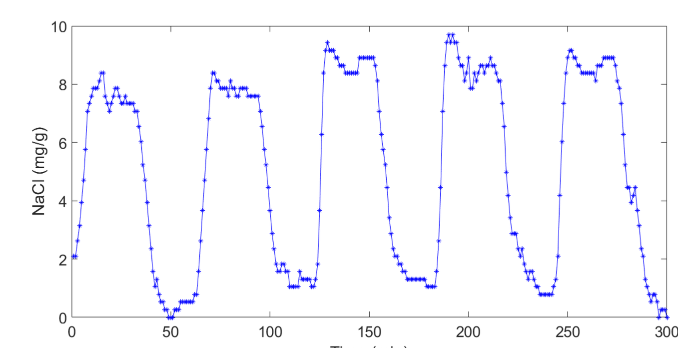
- A new emerging technology called Capacitive Mixing (CapMix), still under early research stage, seems to be promising to recover energy where a natural mixing of waters at different salinity occurs. The idea is to charge the electrodes of a supercapacitor while they are immersed in a high salinity solution and then discharge them when in contact with a low salinity solution. The energy gain comes from a spontaneous voltage rising inside the device caused by a double layer expansion. However, the main problem of this technique is the self-discharge of the electrodes. Therefore, new materials will be first tested for capacitive deionization, a simpler technique which exploits the same ions' storage principle. It is promising for helping to answer the global call for freshwater. Then, the best performing materials selected in this way will be tested for CapMix.

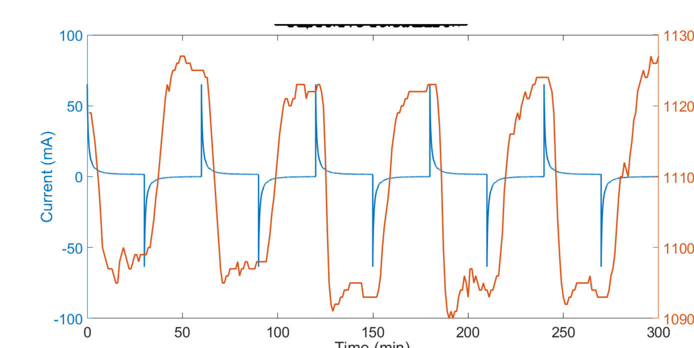
Novel contributions

- A two-step functionalization of graphene oxide has been exploited to obtain a new charged material with high surface area. This process involves a chemical reduction step and then an UV-mediated polymer grafting on graphene oxide surface using (2-(Acryloyloxy)ethyl)trimethylammonium chloride.

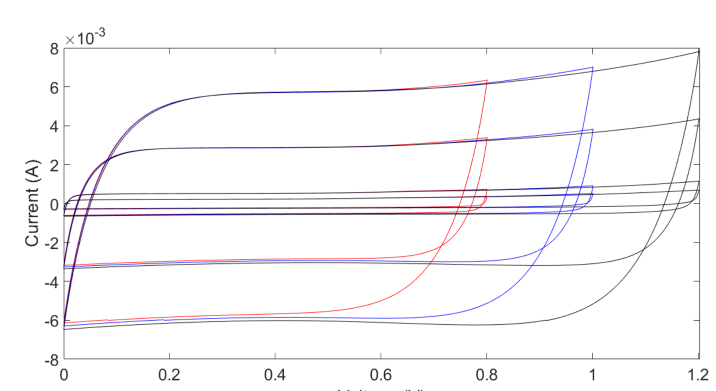


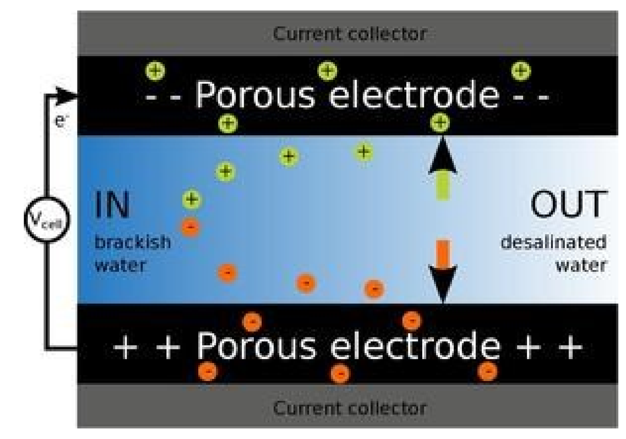
- Salt absorption capacity (SAC) of 9 mg/g is achieved using an asymmetric device exploiting one positive-charged and one negative-charged electrode. Most of materials in literature exhibit a SAC of 0.1÷6.0 mg/g. However top-performing ones reach 10-14 mg/g.





- Stunning charge efficiency of 98% is obtained, well above the usual 40÷60%. Such efficiency is comparable to more costly devices exploiting ionic exchange membranes (charge efficiency range: 90÷99%)





List of attended classes

- 03NQMPF – Advanced experimental physics (7/6/2019, 60h)
- 01NUWKI – Chimica-fisica dei materiali per le nanotecnologie (18/7/2018, 36h)
- 02LWHRV – Communication (15/2/2018, 5h)
- 01SFPRW – Desalinizzazione di acqua: processi, materiali e prospettive (15/6/2018, 26h)
- 01SHMRV – Entrepreneurial Finance (21/3/2018, 5h)
- 01LCPIU – Experimental modeling: costruzione di modelli da dati sperimentali (23/2/2018, 33h)
- 01SZPKG – Introduzione alla microscopia elettronica (19/9/2019, 22h)
- 01SHKKG – Photovoltaics: Physics, Materials and Engineering (31/5/2018, 25h)
- 08IXTRV – Project management (15/2/2018, 5h)
- 01RISRV – Public speaking (15/2/2018, 5h)
- 01SZQKG – Spettroscopia di impedenza per processi elettrochimici (21/12/2018, 20h)
- 01LEXRP – Strumenti e tecnologie per lo sviluppo del prodotto (8/5/2018, 25h)
- 02RHORV – The new Internet Society: entering the black-box of digital innovations (13/3/2018, 6h)
- 01QORRV – Writing Scientific Papers in English (21/2/2018, 15h)
- 01MQLKI – X-ray diffraction by materials (2/7/2018, 25h)