Nanotechnology Convergence for Materials and Resource Recovery

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Outline

- **Background: Critical materials and global sustainability**
- **Nanotechnology for materials recovery: Overview of recent advances**
- **Nanotechnology convergence for materials and resource recovery: Outlook**
- **Discussion**

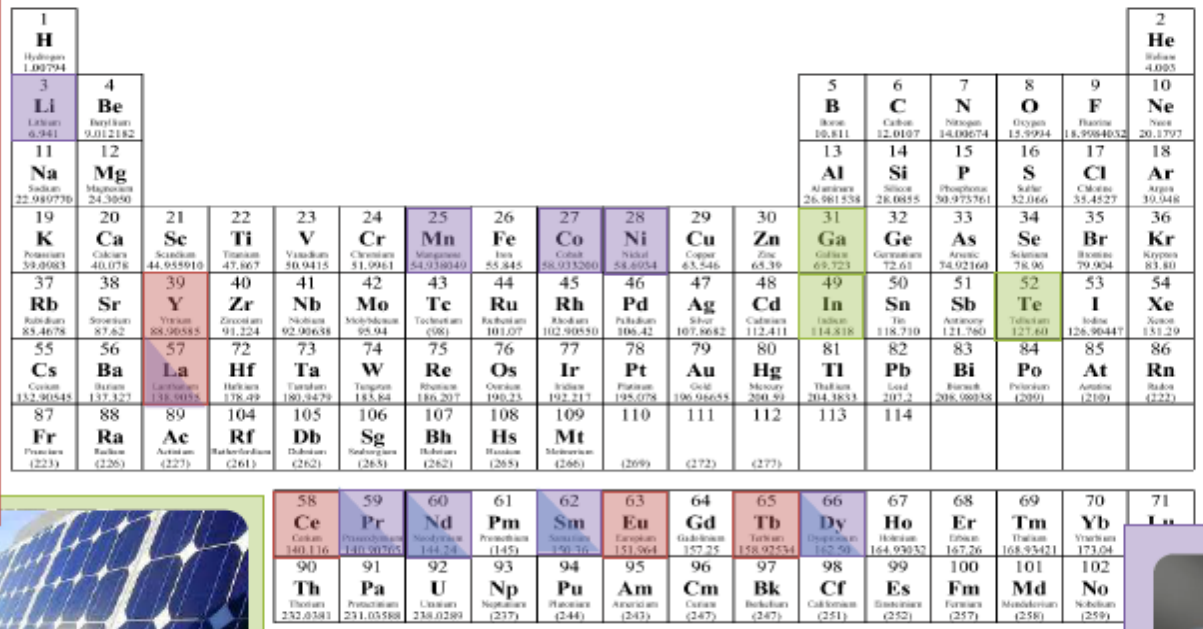
Critical Materials and Global Sustainability

- Like energy and water, the availability of technology metals and valuable elements is critical to a sustainable society and world economy.
  - Information technology and communication
  - Renewable energy (solar, wind, batteries)

- Development and deployment of the clean energy technologies and sustainable products, processes and manufacturing industries of the 21st century will require large amounts of critical metals and elements.

- Significant amounts of phosphorus (P) will also be needed as the world faces the daunting challenge of doubling the amount of food it currently produces in order to feed around 9 billion people in the next 30 years

Critical Metals and Clean Energy Technologies



Vehicles

Lighting

Solar PV

Wind

Bauer, D. DOE Critical Materials Strategy. Invited Presentation at 2014 ACS Presidential Symposium on Separation Science and Technology as a Convergence Platform for SusChEM (http://www.aiche.org/cei/conferences/suschem-critical-materials-workshop/2014)

Critical Materials Supply and Global Sustainability

China's ban of rare earth elements (REEs) exports to Japan in September 2010 brought this issue to the front of the sustainability research agenda

The New York Times

GLOBAL BUSINESS

Amid Tension, China Blocks Vital Exports to Japan

By KEITH BRADSHER SEPT. 22, 2010

HONG KONG — Sharply raising the stakes in a dispute over Japan's detention of a Chinese fishing trawler captain, the Chinese government has blocked exports to Japan of a crucial category of minerals used in products like hybrid cars, wind turbines and guided missiles.

Chinese customs officials are halting shipments to Japan of so-called rare earth elements, preventing them from being loading aboard ships at Chinese

- In response, the US, EU and other industrial countries (incl. Japan and South Korea) began developing "Critical Materials Strategy."
- In January 2013, the DOE established the "Critical Materials Institute," an Energy Innovation Hub led by Ames Laboratory (Iowa) to "Address Shortages in Rare Earth and Other Critical Materials"

Materials Sustainability and the Linear Economy

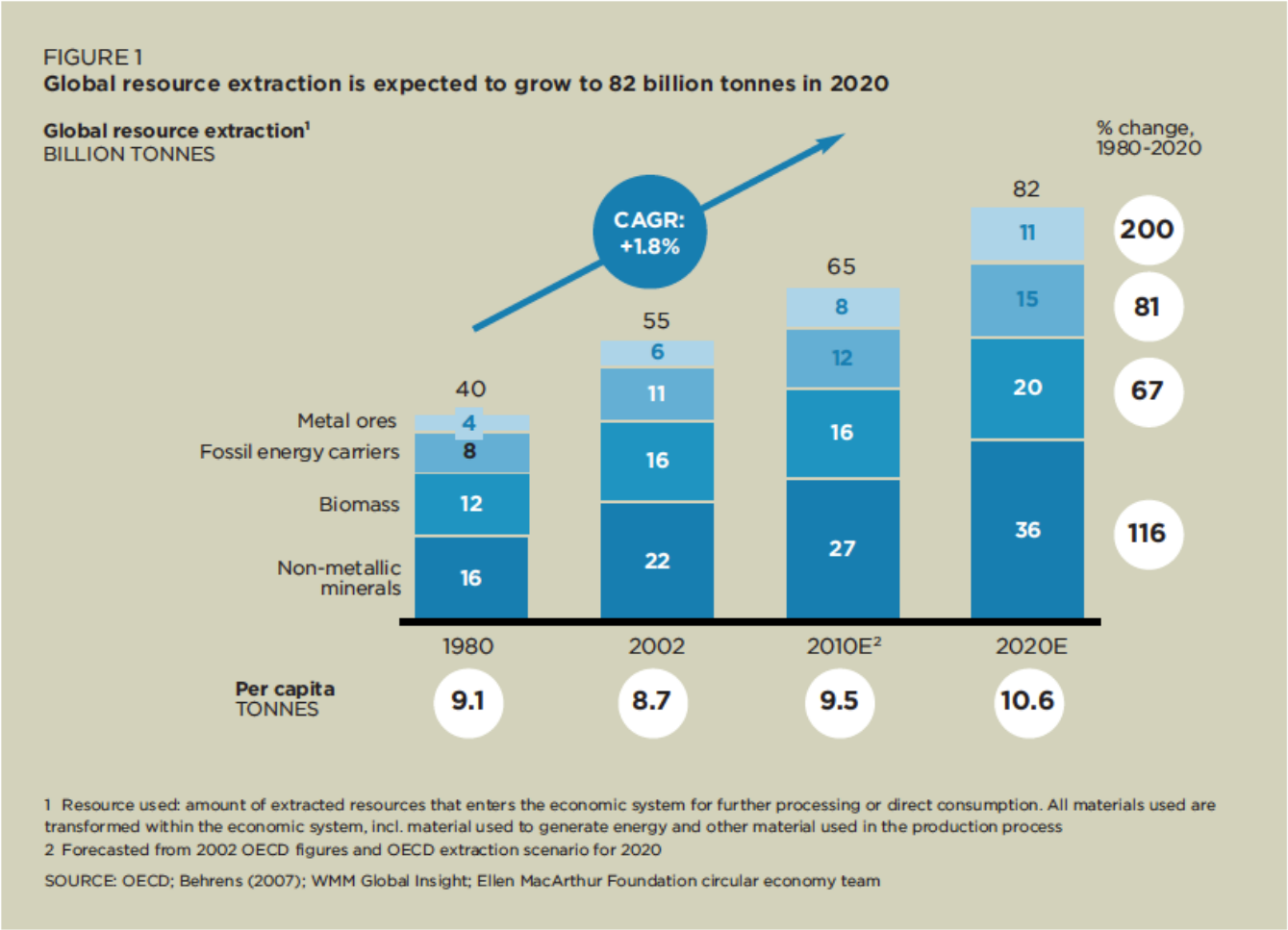
- Our current economy is based on a "linear model" of resource consumption that follows a 'take-make-dispose' pattern.

- "Companies harvest and extract materials, use them to manufacture a product, and sell the product to a consumer—who then discards it when it no longer serves its purpose".

Ellen MacArthur Foundation. Toward the Circular Economy: Economic and business rationale for an accelerated transition.

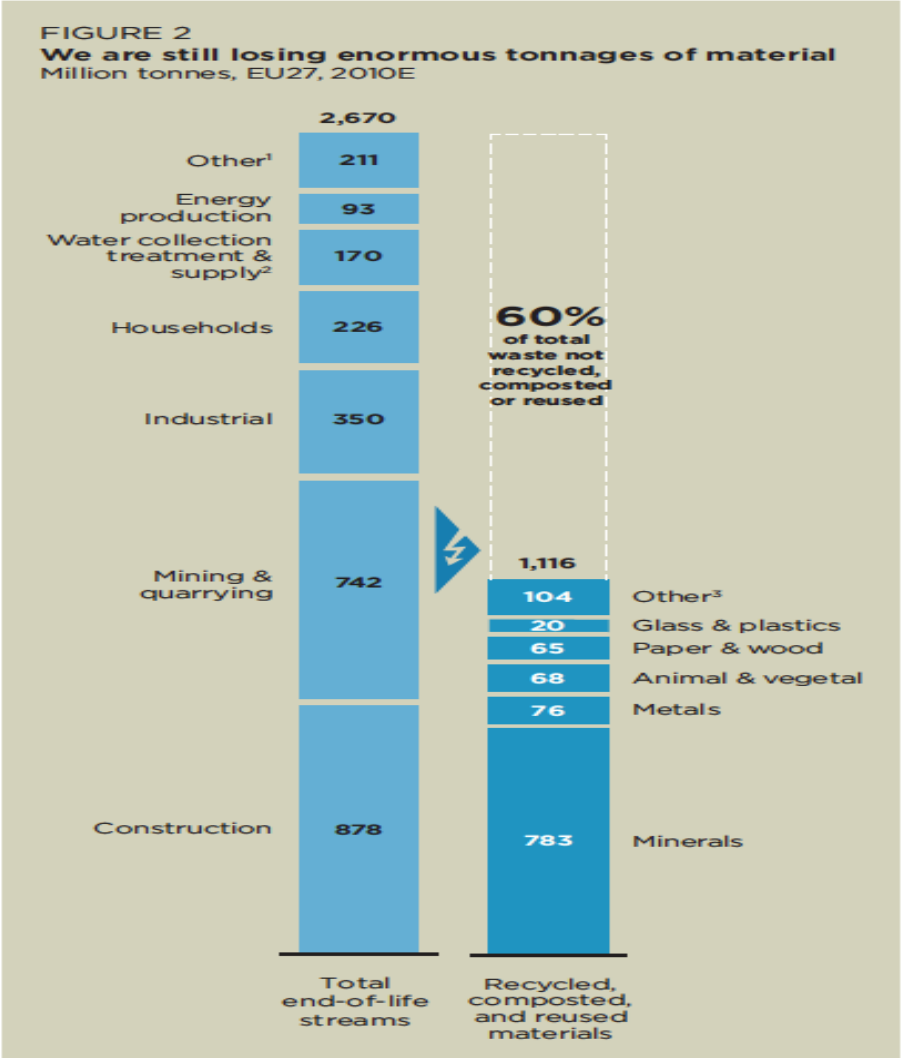
Available online at
http://www.ellenmacarthurfoundation.org/assets/downloads/publications/Ellen-MacArthur-Foundation-Towards-the-Circular-Economy-vol.1.pdf

The Linear Economy Consumes Huge Amounts of Raw Materials



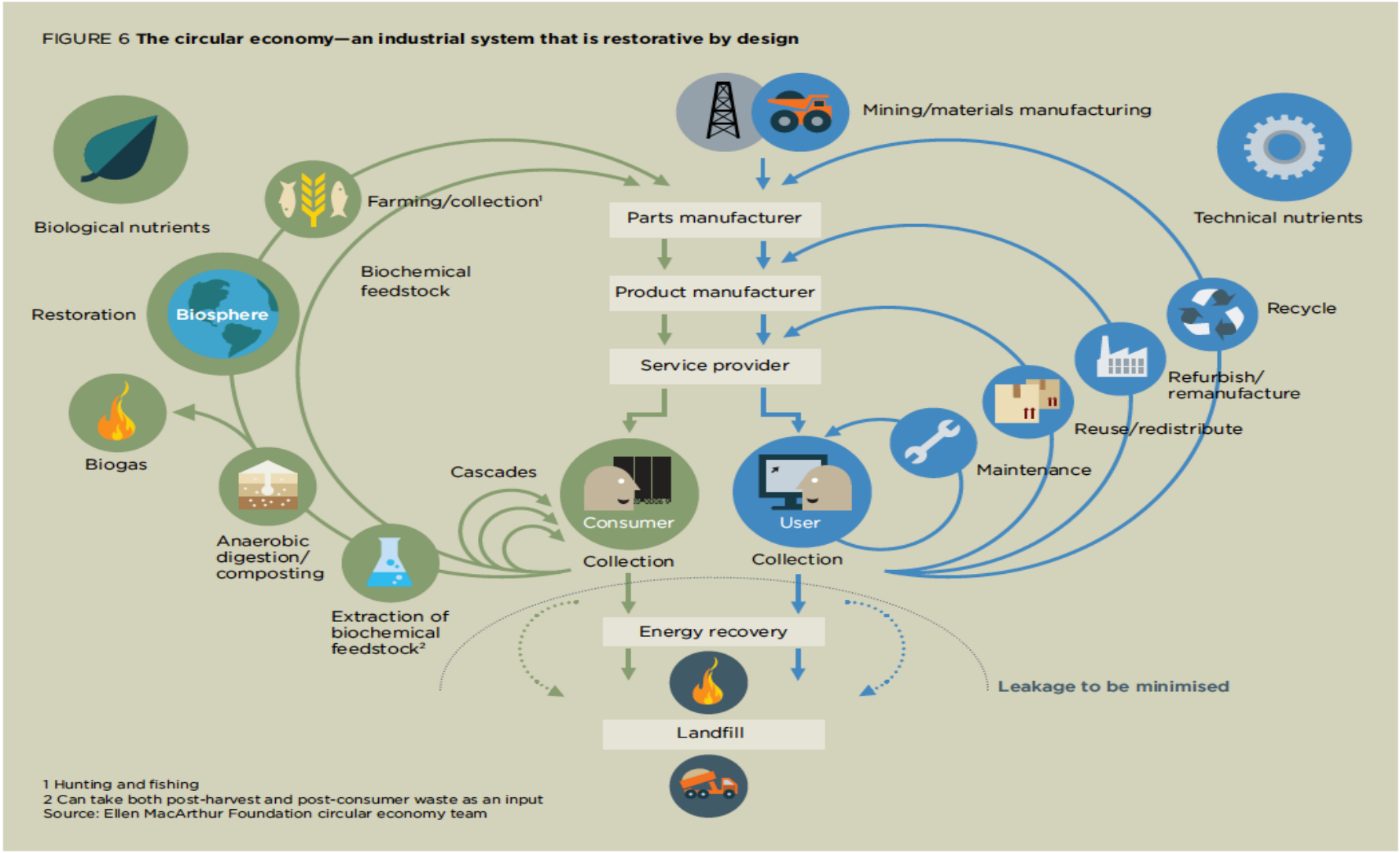
Available online at http://www.ellenmacarthurfoundation.org/assets/downloads/publications/Ellen-MacArthur-Foundation-Towards-the-Circular-Economy-vol.1.pdf

The Linear Economy Wastes Huge Amounts of Materials



Available online at
http://www.ellenmacarthurfoundation.org/assets/downloads/publications/Ellen-MacArthur-Foundation-Towards-the-Circular-Economy-vol.1.pdf

Alternative to the Linear Economic Model: The Circular Economy



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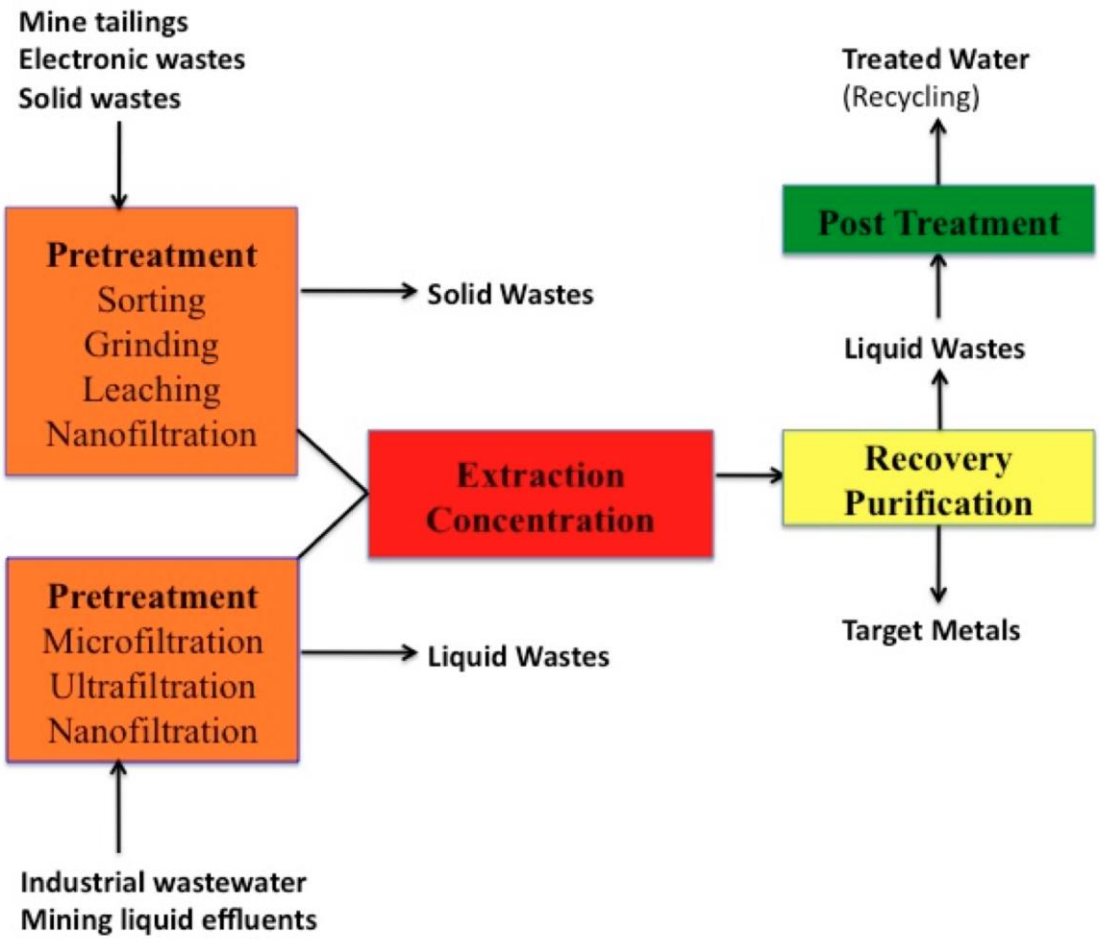
Nanotechnology as Enabling Platform the Circular Economy

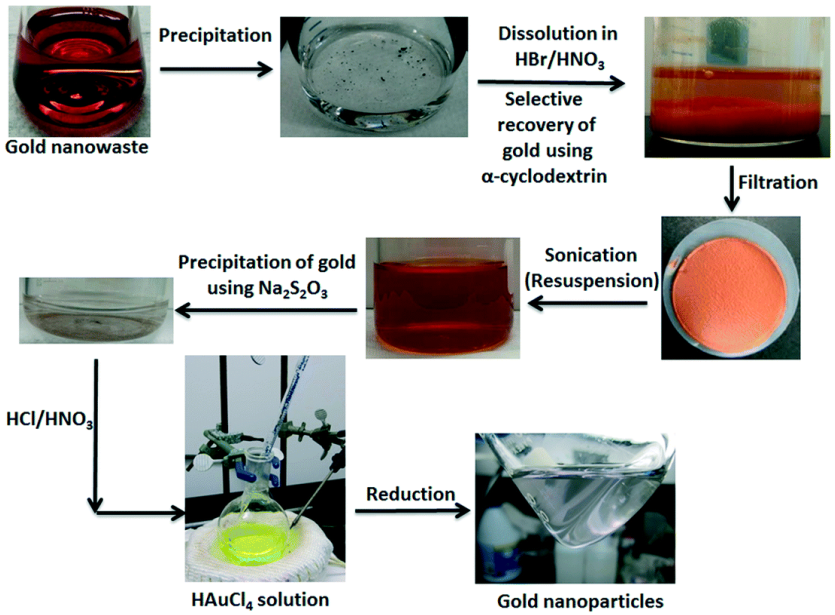
Extraction of critical metals (Technical Nutrients) from discarded consumer products (Urban Mining), mine tailings and liquid waste streams

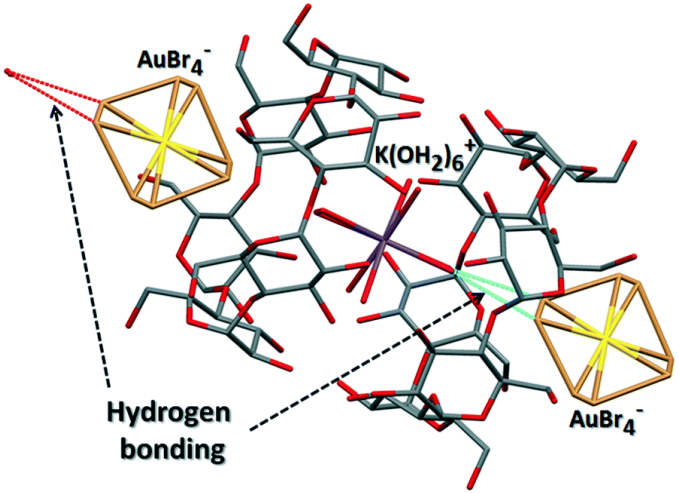


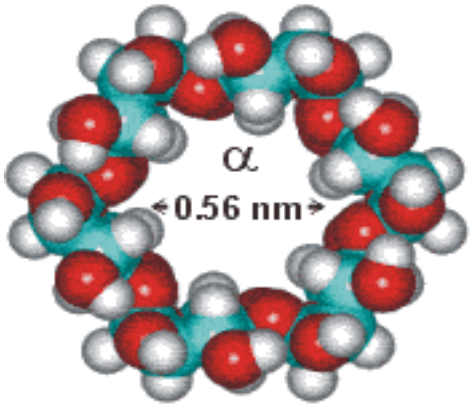
Fromer, N. and Diallo, M. S. *J. Nanopart. Res*. **2013**, 15, DOI: 10.1007/s11051-013-2011-9.

Nanotechnology as Enabling Platform for Urban Mining: Recovery of Critical Metals from Nanowastes

Example 1: preparation of gold nanoparticles using Au nanowastes as precursor materials (Circular Nanotechnology)



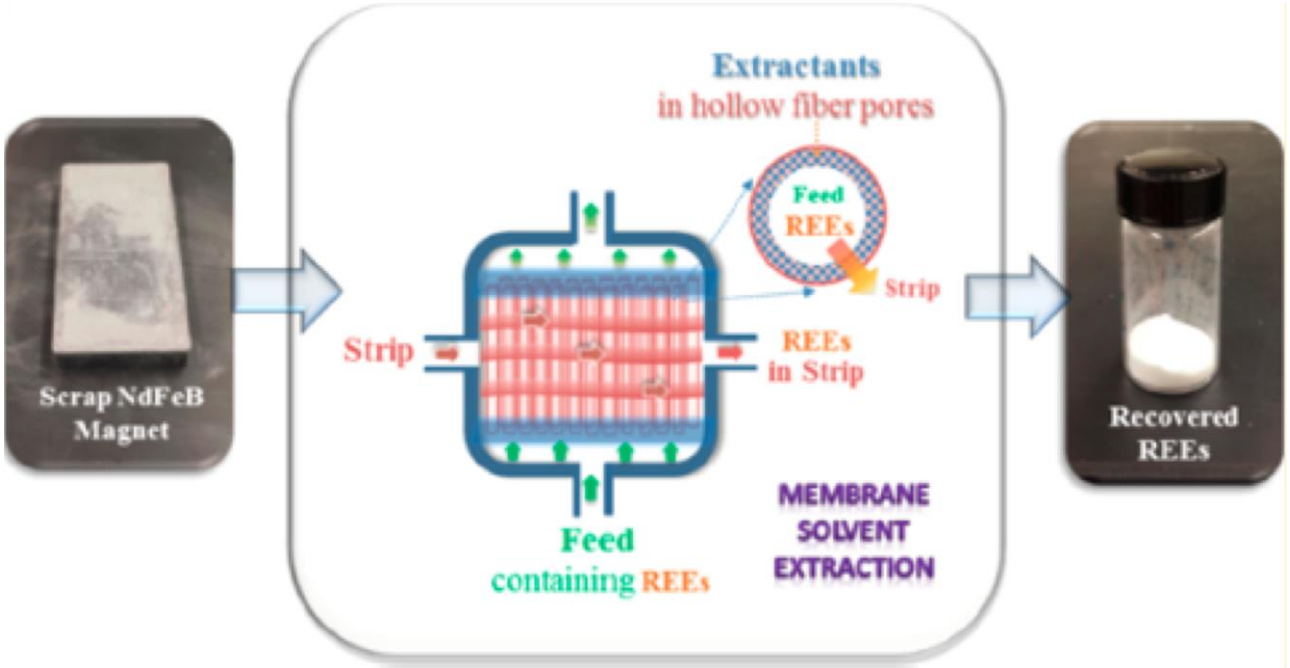




Vikesland, P. J. and co-workers. *Environ. Sci.: Nano*, **2016**, 3, 1133-1143

Nanotechnology as Enabling Platform for Urban Mining: Recovery of Critical Metals from Discarded Consumer Products

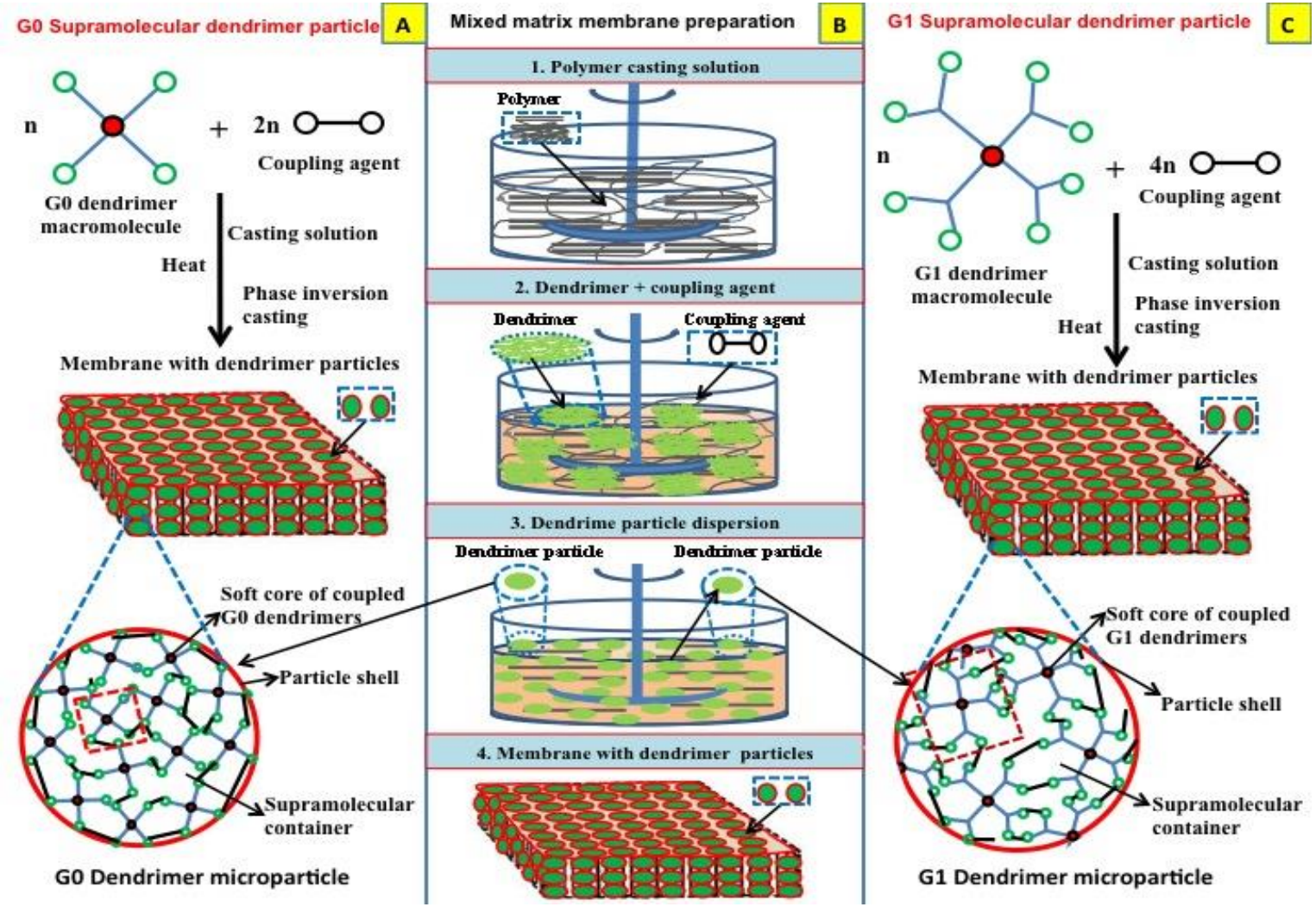
Example 1: Recovery of rare-earth elements (REEs) from permanent magnet scraps magnet by membrane assisted solvent extraction (MASE)



Bhave, R. R. and co-workers. *Environ. Sci. Technol.*, **2015**, 49 (16), pp 9452–9459

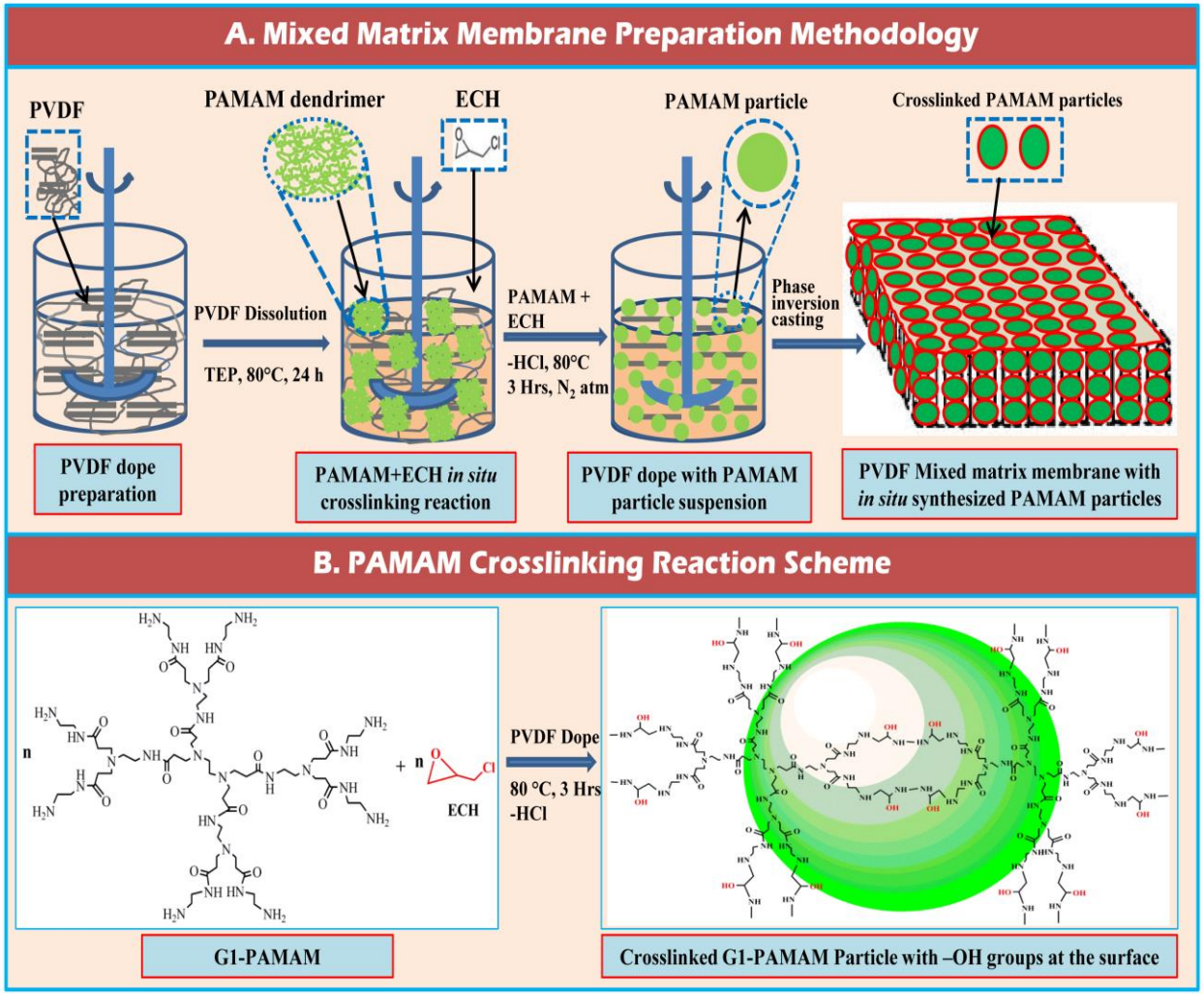
Next generation of nanostructured membrane materials for metal extraction from solutions are critically needed

New Directions: Low Pressure Membrane Absorbers With In-Situ Synthesized Supramolecular Dendrimer Particles Using Low Generation Dendrimers As Precursors

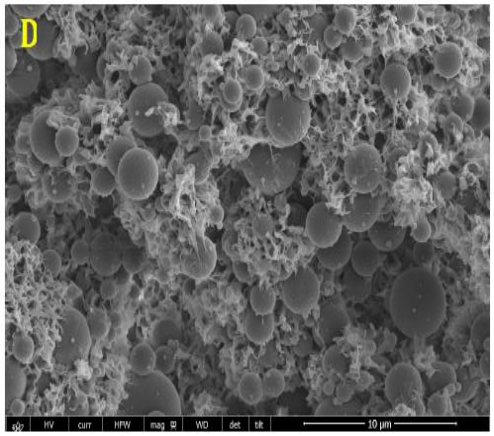


Diallo, M.S. and co-workers. US Patent Application (Pending).

Nanotechnology for Metal Recovery from Liquid Waste Streams: Preparation of PVDF Membrane Absorbers With In Situ Synthesized Supramolecular Dendrimer Particles Using G0 and G1 PAMAM Dendrimers as Precursors



MDP-G1 Membrane



Diallo, M.S. and co-workers. *Environ. Sci. Technol.* **2015**, 49, 9431-9442.

Cu(II) Recovery from Aqueous Solutions by Ultrafiltration Using a Membrane Absorber With In-Situ Synthesized GI PAMAM Dendrimer Particles

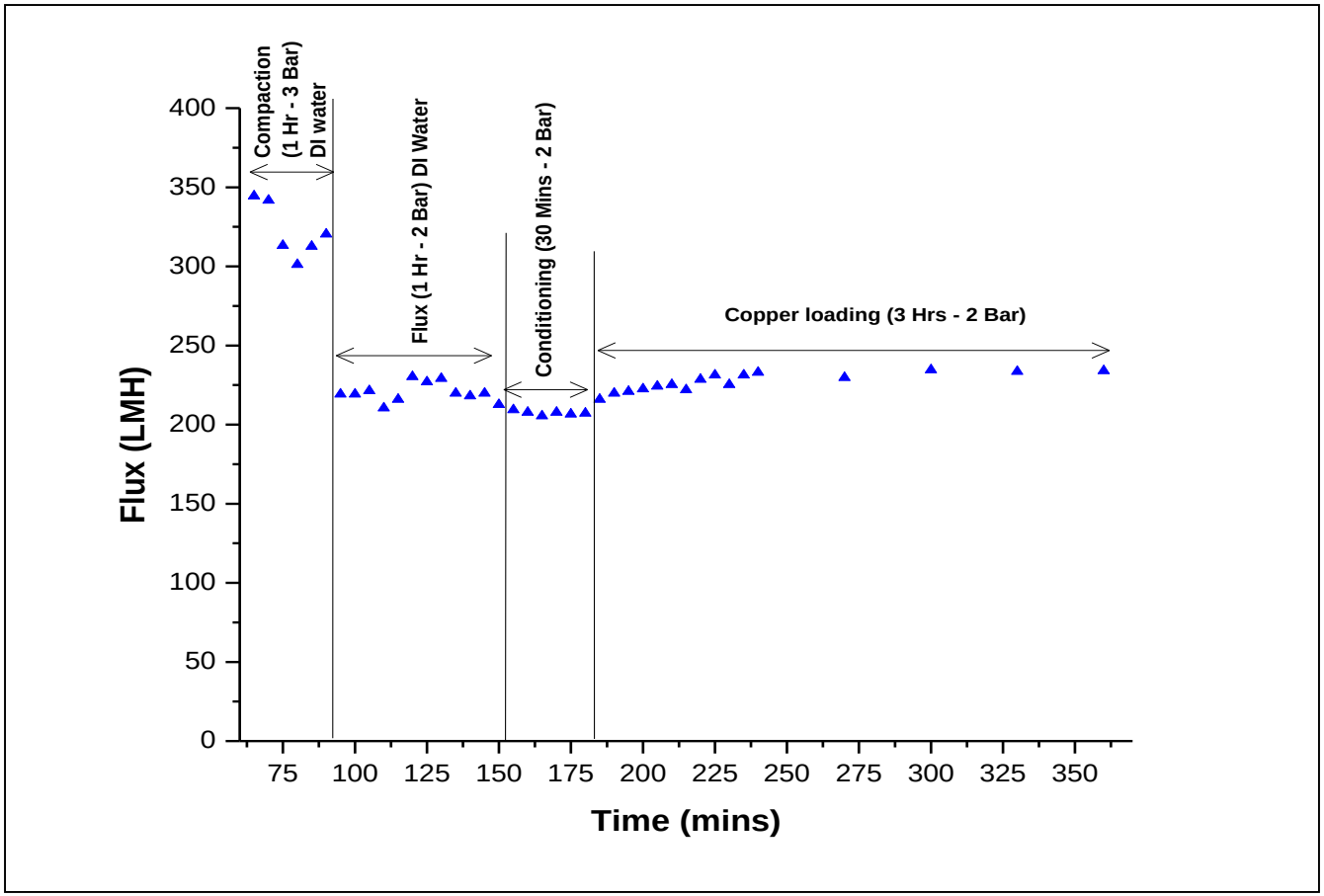
Custom-Built Teflon Lined Ultrafiltration System

MDP-G1 Membrane

Membrane area: 24 cm^2

Diallo, M.S. and co-workers. *Environ. Sci. Technol.* **2015**, 49, 9431-9442.

Cu(II) Recovery from Aqueous Solutions by Ultrafiltration Using a Membrane Absorber With In-Situ Synthesized GI PAMAM Dendrimer Particles: Metal Loading and Flux Measurements

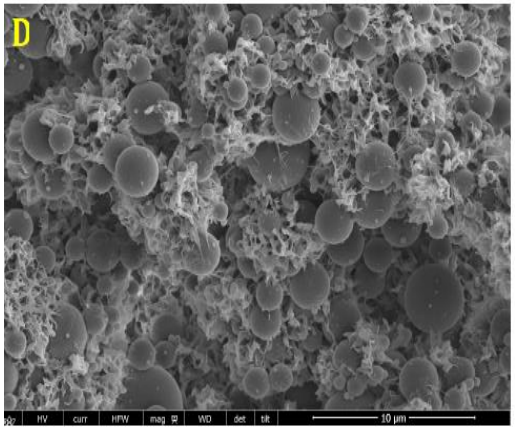


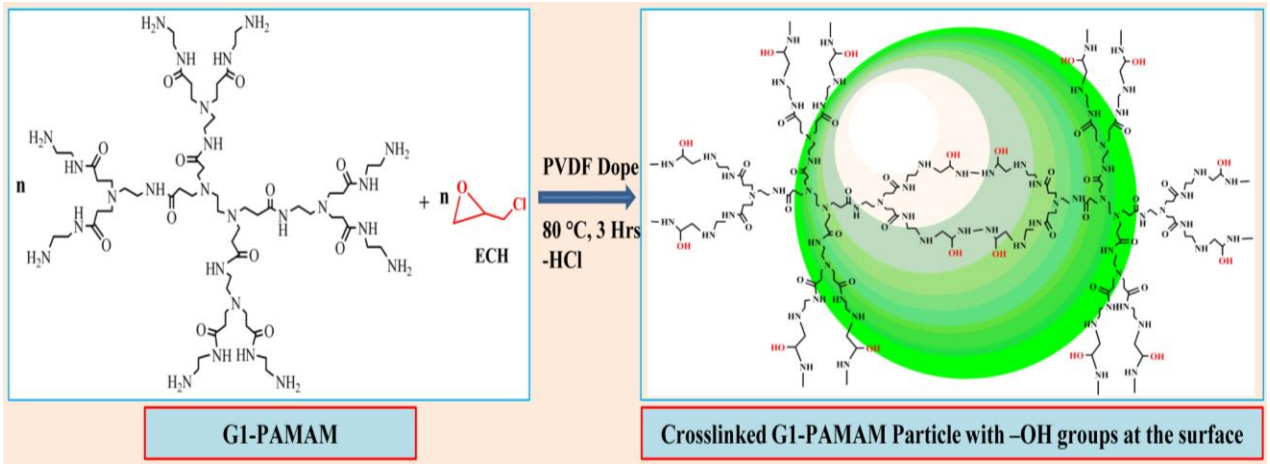
Cu(II) Laden MDP-G1 Membrane

A 2 L of a solution of Cu(II) [10 mg/L] at constant pH (3, 7 and 9) was pumped trough each membrane at 2 bar.

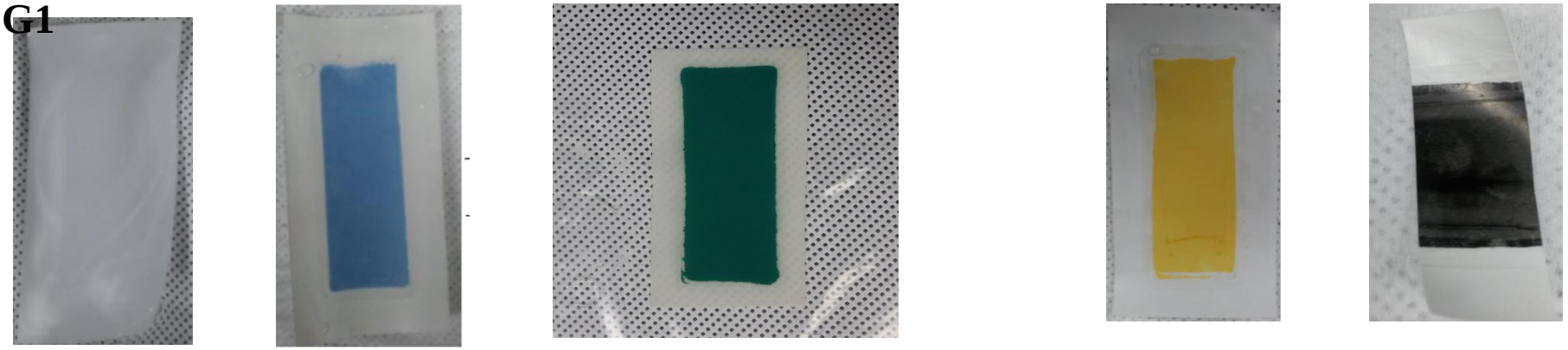
Diallo, M.S. and co-workers. *Environ. Sci. Technol.* **2015**, 49, 9431-9442.

Membrane Absorbers With In-Situ Synthesized GI PAMAM Dendrimer Particles as Enabling Platform for Metal Recovery





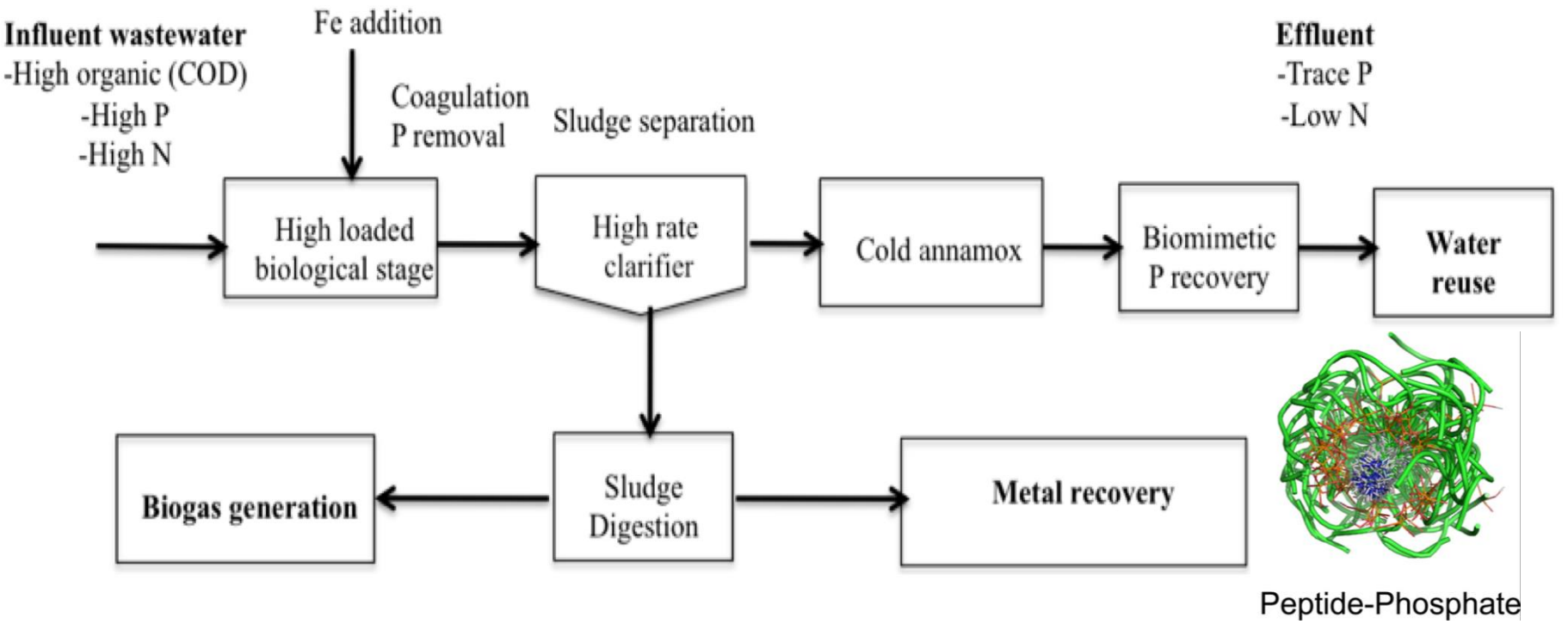
MDP-G1 **Cu^{2+}/MDP-G1** **Cu^{2+}-Ni^{2+}-Co^{2+}-Zn^{2+}/MDP-G1** **Pt^{4+}/MDP-G1** **Pt^{0}/MDP-G1**



Diallo, M.S. and co-workers. *Environ. Sci. Technol.* **2015**, 49, 9431-9442.

Outlook: Nanotechnology Convergence for Materials and Resource Recovery

A model wastewater factory of the future: Integration of wastewater treatment with phosphorous (P) recovery, water reuse, biogas generation and metal recovery from sludge.

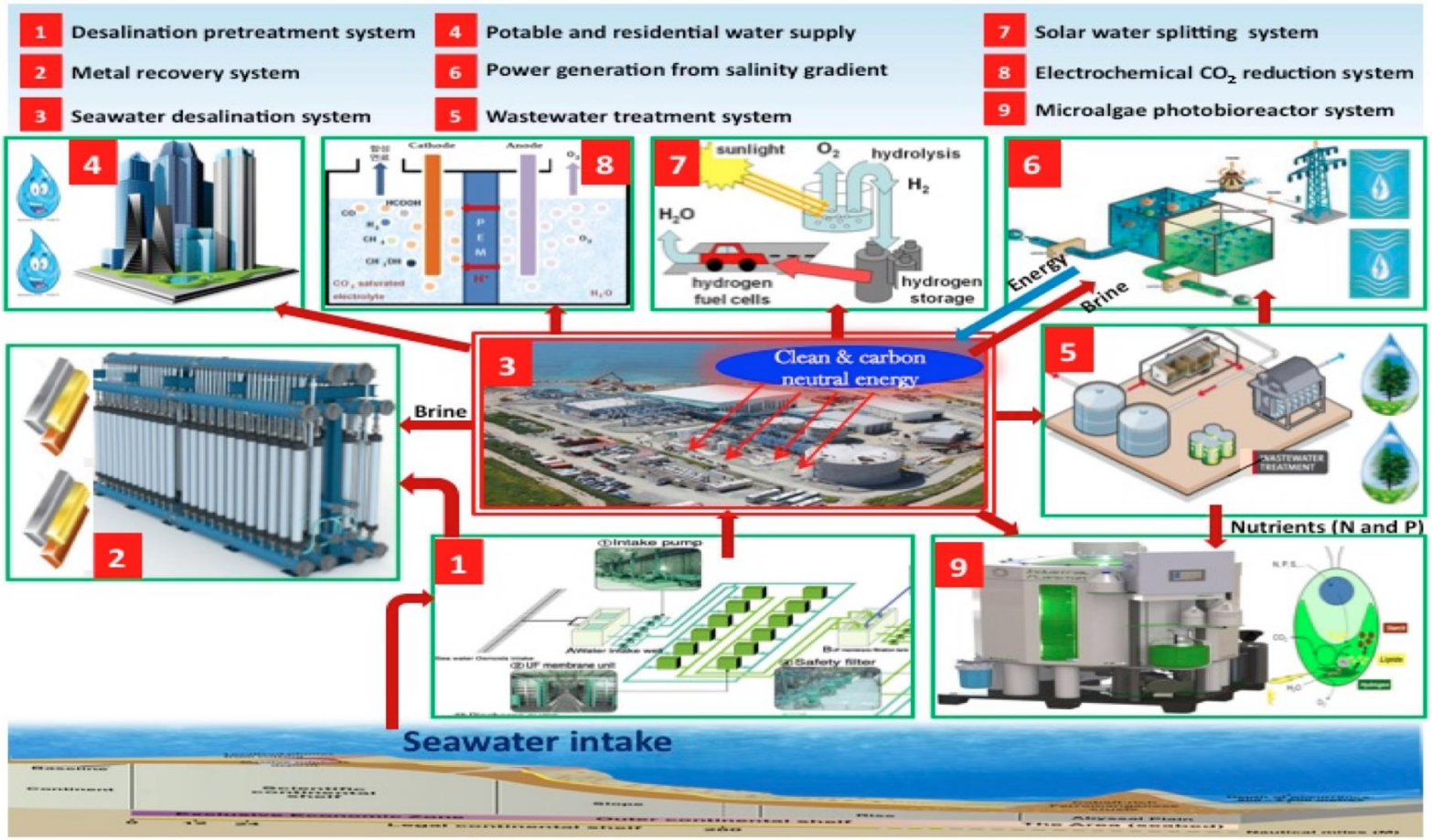


Nanobiotechnology

Adapted from Wilfert et al. *Environ. Sci. Technol.*, **2015**, 49, 9400–9414

Outlook: Nanotechnology Convergence for Materials and Resource Recovery (Cont)

A model seawater factory of the future: Integration of clean water production for potable usage and agriculture with energy generation and resource recovery including metal mining.



Adapted from Diallo, M.S and co-workers. *Environ. Sci. Technol.*, **2015**, 49, 9390−9399

Questions and Panel Discussion

1) **What are the unique contributions that Nanotechnology can make to advance a sustainable water-food-energy nexus?**

1) **What are current grand challenges that can be addressed in the next decade?**

2) **How do we handle the gap between basic discovery and translation to applications?**