TECHNICAL BULLETIN:

Green Chemistry as it relates to RegenOx™ *In-Situ* Chemical Oxidation

The Concept of Green Chemistry

The term "green" is used to describe processes, products, or activities that have little or no detrimental effects to the environment and human health and safety. In recent years, the American Chemical Society (ACS) and the United States Environmental Protection Agency (US EPA) have emphasized the importance of green chemistry for the chemical industry. From the EPA website on this subject, the concept is briefly defined as follows:

"Green chemistry, also known as sustainable chemistry, is the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances. Green chemistry applies across the life cycle, including the design, manufacture, and use of a chemical product"

- US EPA website: www.epa.gov/gcc/

To further define the concept of green chemistry, both the US EPA and the ACS have cited the book "Green Chemistry, Theory and Practice" by Anastas and Warner,[1] which defines twelve principles of green chemistry. In the context of these twelve principles, we have determined the RegenOx technology to be distinctly green, as it meets 10 out of the 12 principles. The principles are outlined below with descriptions of how the RegenOx chemistry complies on nearly all accounts.

Twelve Principles of Green Chemistry[1]

And how they are reflected in the RegenOx™ In Situ Chemical Oxidation Technology

1. **Prevent waste:** Design chemical syntheses to prevent waste, leaving no waste to treat or clean up.

   RegenOx is manufactured from commodity chemicals in such a way that there is no waste resulting from its production.

2. **Design safer chemicals and products:** Design chemical products to be fully effective, yet have little or no toxicity.

   RegenOx has a two-part formulation with little or no toxicity: RegenOx part A is comprised primarily of sodium percarbonate, a relatively low-toxicity oxidant that is commonly employed in household products such as detergents (e.g. OxyClean™), and whitening toothpastes. Part B, the activator, is comprised of silicates and iron. These low-toxicity constituents are combined to formulate a patent-pending, highly effective catalyst for oxidative destruction of contaminants.

3. **Design less hazardous chemical syntheses:** Design syntheses to use and generate substances with little or no toxicity to humans and the environment.

   RegenOx is formulated by Regenesis without the use of any toxic ingredients or byproducts.

4. **Use renewable feedstocks:** Use raw materials and feedstocks that are renewable rather than depleting. Renewable feedstocks are often made from agricultural products or are the wastes of other processes; depleting feedstocks are made from fossil fuels (petroleum, natural gas, or coal) or are mined.

   Oxidants for In-Situ remediation are inorganic materials and are therefore not derived from renewable plant-based materials. However, the water, silicate, iron, and carbonate ingredients, once mined from the earth, are returned to the subsurface when the product is applied for remediation.

5. **Use catalysts, not stoichiometric reagents:** Minimize waste by using catalytic reactions. Catalysts are used in small amounts and can carry out a single reaction many times. They are preferable to stoichiometric reagents, which are used in excess and work only once.

   The production of RegenOx results in zero waste, therefore a catalyst is not necessary. However, in the end-use of the product, RegenOx Part B functions as a catalyst (or "activator") for oxidation of contaminants. This allows for effective remediation of contaminated sites with a minimal use of oxidant (RegenOx Part A). In other words, the amount of Part A required to remediate a given contaminated site is greatly reduced by the catalytic action of Part B. This minimizes overall chemical usage and the associated environmental impacts. This is a significant "green advancement" over other products currently in use in the marketplace that require stoichiometric reagents to activate the oxidation reaction such as high concentrations of alkaline activators (e.g. sodium hydroxide) or acid activators (e.g. sulfuric acid).

6. **Avoid chemical derivatives:** Avoid using blocking or protecting groups or any temporary modifications if possible. Derivatives use additional reagents and generate waste.

   RegenOx Parts A and B are formulated without the use of protecting groups or temporary chemical modifications. This minimizes waste and maximized energy efficiency.

7. **Maximize atom economy:** Design syntheses so that the final product contains the maximum proportion of the starting materials. There should be few, if any, wasted atoms.

   RegenOx Parts A and B contain 100% of their starting ingredients, and their production can be described as atom-economical.

8. **Use safer solvents and reaction conditions:** Avoid using solvents, separation agents, or other auxiliary chemicals. If these chemicals are necessary, use innocuous chemicals.

   RegenOx Part B reaction ingredients, and ultimately the constituents of the final products act also as the solvent for the reaction to occur. These environmentally friendly materials allow

for a process that has no waste and uses no solvent that need be removed, recycled, or destroyed. RegenOx Part A, as a blend of solid powdered and granular ingredients, requires no solvent to formulate. The sodium percarbonate portion is produced using water as a solvent.

9. **Increase energy efficiency:** Run chemical reactions at ambient temperature and pressure whenever possible.

   Synthesis of RegenOx Part B is a liquid-phase reaction that is operated in a stirred batch reactor at ambient temperature and pressure to maximize energy efficiency. RegenOx Part A is a granular product formulated by blending powdered ingredients at ambient conditions.

10. **Design chemicals and products to degrade after use:** Design chemical products to break down to innocuous substances after use so that they do not accumulate in the environment.

    By design, Regenesis products are made to have little or no detrimental impact on groundwater quality or the environment. The action of RegenOx in the subsurface causes the destruction of harmful contaminants in groundwater. The residuals from this process have little or no toxicity and minimal detrimental impact on the environment compared to competing technologies. These residuals include carbonates, silicates, iron oxides, and other inorganics that are soil-like in nature. The end products of complete contaminant oxidation are simply water and carbon dioxide in most cases. The carbon dioxide is not released to the atmosphere as a waste gas, rather it is generated within the subsurface aqueous environment and sequestered largely as carbonic acid, bicarbonate and carbonate.

11. **Analyze in real time to prevent pollution:** Include in-process real-time monitoring and control during syntheses to minimize or eliminate the formation of byproducts.

    No byproducts are formed in the synthesis and formulation of RegenOx Part B or the formulation process of RegenOx Part A.

12. **Minimize the potential for accidents:** Design chemicals and their forms (solid, liquid, or gas) to minimize the potential for chemical accidents including explosions, fires, and releases to the environment

    All chemical oxidants carry some safety risks as a result of their oxidizing nature. In the scheme of chemical oxidants and catalyzed oxidation reactions, RegenOx is among the safest of materials to manufacture, handle, ship, store and apply. This is due to the favorable properties of percarbonate, and the ability of RegenOx part B to leverage the thermodynamic energy in sodium percarbonate to destroy recalcitrant contaminants like petroleum hydrocarbons and chlorinated solvents.

References

1. Originally published by Paul Anastas and John Warner in **Green Chemistry: Theory and Practice** (Oxford University Press: New York, 1998). Taken from: http://www.epa.gov/greenchemistry/pubs/principles.html

