CHEM 489 Advanced Environmental Chemistry – Spring 2020

WORKSHEET #3 ANSWER KEY

Worksheet #3: Green Chemistry, Sustainable Development and the UN SDGs.
Due - Tuesday, February 18

(1) Green Chemistry, Sustainable Development and the UN SDGs.

(a) In the production of a consumer product, sustainable chemistry often refers to the product itself, while green chemistry refers to the production process. Explain what this statement means.

Sustainable chemistry often refers to industrial processes that create better products, result in fewer pollutants, and are profitable. However, the process in creating these products may not be considered.

Green chemistry, in contrast, is more innovative. It deals with the fundamental aspects of chemistry at the molecular level without regard for industrial processes or profitability. This is the new type of chemistry that utilizes greener production methods, involves cleaner chemical derivatives, and addresses some of the ethical issues related to environmental responsibility.

Sustainable chemistry cannot be conducted in the absence of green chemistry.

(b) Explain why using reactions with high atom economy is important for sustainable development.

Chemical processes with low atom economy suggests that a significant percentage of reactant mass ends up as waste. This may include hazardous reactant chemicals, solvents and auxiliaries, and potentially hazardous byproducts. This would violate the concepts of sustainability in the production of hazardous waste and poor usage of natural resources.

Chemical processes with a high atom economy suggests a more efficient and sustainable process with the production of less waste and less hazards.

(c) What is the metric of Process Mass Intensity (PMI)? Why is the PMI a good yardstick to drive sustainable processes in the pharmaceutical industry? For reference, use the chart below.

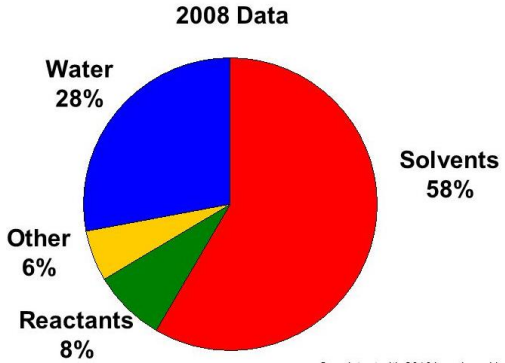
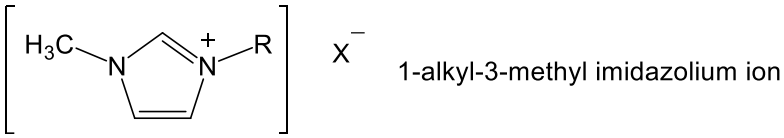


Chart A. Percentage of chemical waste in the pharmaceutical industry.

The PMI compares total mass used in a process to mass of the desired product. The PMI includes all materials used in synthesis (i.e., Reagents, solvents water, etc.), where the ideal PMI is 1 (kg/kg) with zero for the E-factor. Tens of kg of waste are produced per kg of product in the fine chemicals industry, and hundreds of kg of waste are produced per kg of product in the pharmaceutical industry. The chart to the right suggests that solvents comprise over 50% of this pharmaceutical waste.

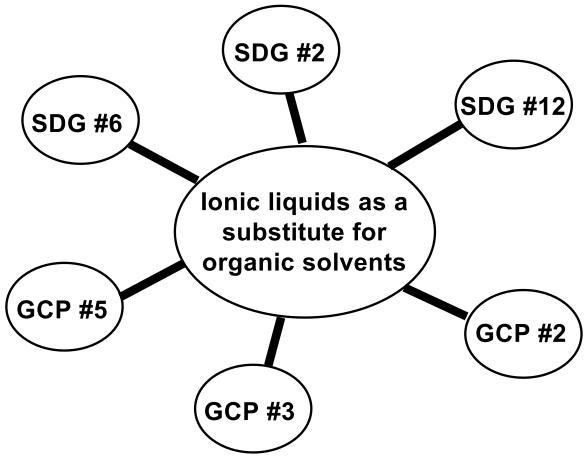
(2) Green Chemistry and the Sustainable Development Goals Applied to Ionic Liquids. Room temperature ionic liquids refers to organic salts that are a new class of environmentally friendly alternative solvents. A general example of an imidazolium-based ionic liquid is shown below:



1-alkyl-3-methyl imidazolium ion

Ionic liquids have the following beneficial characteristics as compared to traditional organic solvents:

- Immeasurably low vapor pressure (non-volatile)
- Non-flammable
- Boiling points in excess of 300°C
- Polar and non-polar
- Can be recycled and reused



To answer this question, you will need tables of the UN SDGs and the 12 Principles of Green Chemistry. Both of these can be found on the class web page.

The chart at the right proposes connections between the central topic of ionic liquid technology, the UN SDGs (SDG), and Green Chemistry Principles (GCP).

(a) Justify each connection to the central topic.

(b) If you disagree with a connection, explain why, suggest an alternative, and explain your alternate choice.

GCP #2 (not a good match): Synthetic methods should be designed to maximize incorporation of all materials used in the process into the final product. The second principle of green chemistry can be simply stated as the "atom economy" of a reaction. Atom economy asks the question "what atoms of the reactants are incorporated into the final desired product(s) and what atoms are wasted?"

GCP #2 is not a good match here as solvents are not typically used as reactants. It would be better to include GCP #1, it is better to prevent waste than to treat or clean up waste after it has been created. It has been shown that solvents account for 50 – 80 percent of the mass in a standard batch chemical operation. Moreover, solvents account for about 75% of the cumulative life cycle environmental impacts of a standard batch chemical operation.

GCP #3 (good match): Chemical products should be designed to preserve efficacy of function while reducing toxicity. Minimizing toxicity, while simultaneously maintaining function and efficacy, may be one of the most challenging aspects of designing safer products and processes. Achieving this goal requires an understanding of not only chemistry but also of the principles of toxicology and environmental science.

GCP #5 (good match): The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary wherever possible and, innocuous when used. Solvents and mass separation agents of all kinds matter a lot to the chemistry not to mention the chemical process and the overall "greenness" of the reaction. In many cases, reactions wouldn't proceed without solvents and/or mass separation agents. Solvents and separation agents provide for mass and energy transfer and without this, many reactions will not proceed.

SDG #2 Zero Hunger (probably not the best match): It is time to rethink how we grow, share and consume our food. If done right, agriculture, forestry and fisheries can provide nutritious food for all and generate decent incomes, while supporting people-centered rural development and protecting the environment.

(continued)

A better match would be any of the following:

Goal 3: Ensure healthy lives and promote well-being for all at all ages: Safer solvents that can be reused will reduce waste and help ensure healthy lives and promoting the well-being at all ages is essential to sustainable development.

Goal 9: Build resilient infrastructure, promote sustainable industrialization and foster innovation: Investing in the development and use of safer solvents in the pharmaceutical industry could be crucial to achieving sustainable development and empowering communities in many countries. It has long been recognized that growth in productivity and incomes, and improvements in health and education outcomes require investment in infrastructure.

Goal 13: Take urgent action to combat climate change and its impacts. The production and use of volatile solvents can contribute to climate change, disrupting national economies and affecting lives, costing people, communities and countries dearly today and even more tomorrow.

Goal 14: Life below water. Careful management of this essential global resource is a key feature of a sustainable future. and
Goal 15: Life on Land. By protecting forests, we will also be able to strengthen natural resource management and increase land productivity.

SDG # 6 (good match): Ensure access to water and sanitation for all. Clean, accessible water for all is an essential part of the world we want to live in and there is sufficient fresh water on the planet to achieve this. However, due to bad economics or poor infrastructure, millions of people including children die every year from diseases associated with inadequate water supply, sanitation and hygiene.

SDG #12 (good match): Ensure sustainable consumption and production patterns. Sustainable consumption and production is about promoting resource and energy efficiency, sustainable infrastructure, and providing access to basic services, green and decent jobs and a better quality of life for all. Its implementation helps to achieve overall development plans, reduce future economic, environmental and social costs, strengthen economic competitiveness and reduce poverty.