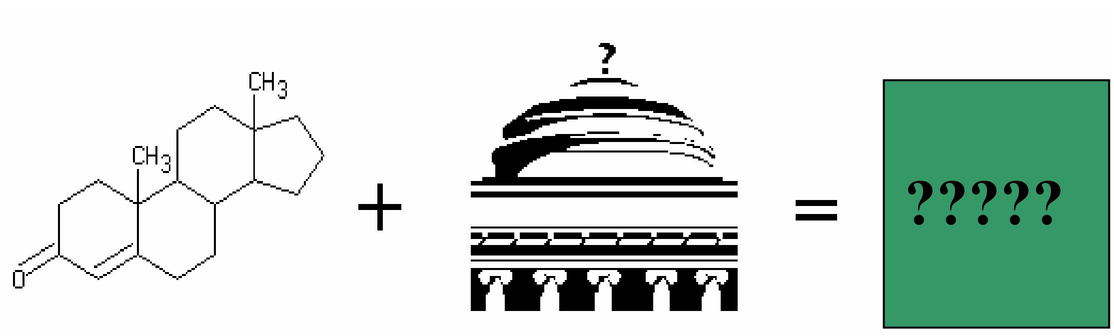

Green Chemistry and MIT

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11.122 Term Project
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I. Motivation/Purpose

Three times this semester, I came across the intriguing case study of a general chemistry laboratory course in Switzerland that had been redesigned by Professor Hanns Fischer in 1989 to drastically reduce the amount of chemical waste it produces.[1] In the book Natural Capitalism, and at lectures given by William McDonough[2] and Amory Lovins[3], this course at the University of Zurich was invariably describing in glowing terms:

> "Instead of teaching the students once-through, linear thinking … Fischer … decided to *reverse the process* …[teaching] instead how to turn the toxic wastes back into pure, simple reagents. This would save costs at both ends and encourage "cyclic thinking"[4]

The abstract of Fischer's technical paper, which describes his methods in more details, is no less striking:

> "A first year chemistry laboratory course for 170-210 students has been reorganized to minimize its chemical residues by input reduction and substitution, networking of material flows, separate collection and recycling at the source. Compared to previous years, the problematic wastes were reduced by a factor of ca. 100 and total now less than 15 kg per academic year."[5]

So against the backdrop of a semester-long course on the impacts of industry on society, which included detailed discussion of the problems associated with hazardous chemical waste (outlined below), this example seemed especially relevant to me. Further, being in

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[1] H. Fischer, "Environmental Protection by Practical Chemistry", *Chimia* 45, 1991

[2] William McDonough, lecture given at MIT, Cambridge MA, October 1, 2001. William McDonough is a distinguished sustainability architect and lecturer. He was voted a "Hero for the Planet" by Time Magazine, and received the Presidential Award for Sustainable Development in 1996. For more info, see http://www.mcdonough.com.

[3] Amory Lovins, 21st Annual E. F. Schumacher Lectures, Amherst College, Amherst, MA, October 27, 2001. Amory Lovins, co-founder of the Rocky Mountain Institute, is a noted physicist, energy expert, lecturer, and sustainability promoter. For more info, see http://www.rmi.org.

[4] Hawken P, Lovins A, Lovins LH, Natural Capitalism, Little, Brown & Company, September 1999, pg 71.

[5] H. Fischer.

a university setting, I was provided the unique opportunity to investigate the greater applicability of such a model, here in my own “back yard”.

This project was undertaken with two specific goals:

1. To investigate the applicability of Fischer’s techniques as a means of reducing chemical waste here at MIT.
2. To investigate what more could be done to reduce chemical waste at MIT.

What follows is a general discussion of the context in which this project was undertaken, as well as an assessment of the issues associated with hazardous waste at MIT, and some possible future courses of action.

II. Introduction

It is estimated that the United States produces over 260 million tons of hazardous waste every year – that's about 1 ton for every citizen! Thus, while America enjoys the fruits of its industry's technological, medical, and commercial advances, it is saddled with the pesky annual task of finding a home for 520 billion pounds of useless, toxic stews. These toxic stews are the end product of a "linear" industrial model, succinctly described in the book Natural Capitalism:

> "Raw materials are introduced. (Enter nature, stage left.) Labor uses technologies to transform these resources into products, which are sold to create profits. The wastes from production processes, and soon the products themselves, are somehow disposed of somewhere else. (Exit waste, stage right) The "somewheres" in this scenario are not the concern of classical economics: Enough money can buy enough resources, so the theory goes, and enough "elsewheres" to dispose of them afterward."[6]

The "somewhere else" for hazardous waste usually means a landfill. About two-thirds of all hazardous waste ends up buried in the ground. Other "acceptable" forms of disposal include incineration and burial at sea.

Landfills, however, leak toxics into the ground and groundwater. Likewise, incinerators emit noticeable levels of harmful gases into the air, and drums at the bottom of the ocean do not all stay sealed forever. Additionally, some hazardous waste is clandestinely dumped directly into bodies of water or the ground. In short, a significant and ever increasing amount of hazardous waste is ending up in our air, water and soil rather than in some fictitious hazardous waste heaven.

William McDonough puts the Industrial Revolution (and its extraordinary waste generating capacity) into an interesting perspective, writing:

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[6] Hawken, Lovins & Lovins, pg 7.

"If someone were to present the Industrial Revolution as a retroactive design assignment, it might sound like this:

Design a system of production that

- puts billions of pounds of toxic material into the air, water, and soil every year
- measures prosperity by activity, not legacy
- requires thousands of complex regulations to keep people and natural systems from being poisoned too quickly
- produces materials so dangerous that they will require constant vigilance from future generations
- results in gigantic amounts of waste
- puts valuable materials in holes all over the planet, where they can never be retrieved
- erodes the diversity of biological species and cultural practices"[7]

Put in such terms, the negative aspects of the Industrial Revolution seem surprisingly clear. Nevertheless, this is an admittedly one-sided view. Obviously, producing hazardous waste is never a company's primary intention, but rather an externality associated with the production of useful and profitable products. Additionally, the positive aspects of the Industrial Revolution – e.g. increases in life span, decreases in infant mortality, and increases in wealth and quality of life – are tangible to many people. Further, many companies are not blind to the problems caused by their pollution, and recently some have taken drastic steps to reduce and minimize pollution they cause.

The current movement toward "eco-efficiency" - lowering pollution and waste through reducing, reusing and recycling - has considerable inertia and has enlisted several large corporations. The potential economic benefits derived from lowered waste management and material procurement costs, coupled with the legal requirement to comply with stricter governmental regulations has made most larger businesses in America more environmentally aware. There is a vast literature of environmental

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[7] William McDonough and Michael Braungart, "The NEXT Industrial Revolution*", The Atlantic Monthly,* October 1998.

initiatives undertaken by industry during the past 20 years. McDonough and Braungart cite 3M's saving of over $750 million on pollution-prevention measures and Du Pont's 75% reduction in airborne cancer-causing emissions since 1987 as hallmarks of the "eco-efficient" movement.[8] They also quote the founder of the World Business Council for Sustainable Development, Stephan Schmidheiny, as saying:

> "'I predict that within a decade it is going to be next to impossible for a business to be competitive without also being 'eco-efficient' – adding more value to a good or service while using fewer resources and releasing less pollution.'"[9]

Nevertheless, with the shear volume of hazardous waste being produced, and an economy focused on continual growth, one is justified in worrying that piecemeal reductions of pollution to regulated levels do not address the fundamental design flaw of American industry, nor will they solve the myriad problems associated with industrial pollution. Indeed McDonough and Braungart point out that

> "Eco-efficiency instead [of solving pollution problems]
>
> - releases *fewer* pounds of toxic material into the air, water, and soil every year
> - measures prosperity by *less* activity
> - *meets or exceeds* the stipulations of thousands of complex regulations that aim to keep people and natural systems from being poisoned too quickly
> - produces *fewer* dangerous materials that will require constant vigilance from future generations
> - results in *smaller* amounts of waste
> - puts *fewer* valuable materials in holes all over the planet, where they can never be retrieved
> - standardizes and homogenizes biological species and cultural practices"[10]

While "eco-efficiency" is a well-intentioned concept and an important first step in pollution reduction, the key to eliminating the problems associated with waste is to eliminate the concept of waste from industrial activity. This requires a drastic paradigm

[8] Ibid.
[9] Ibid.
[10] Ibid.

shift and a lot of creativity; nevertheless, in recent years, tangible alternatives to the linear flow industrial model have become more visible. Eco-industrial parks[11], products of service[12], living machine wastewater treatment plants[13] and biodegradable furniture trimmings[14] all demonstrate the possibilities and benefits of closing loops and planning industrial material cycles in order to "design out waste" . In order to truly solve the problem of hazardous waste production, the concepts that have produced these innovations – i.e. waste equals food, services can replace goods, and toxicity is unacceptable – must be applied.

In recent years, there has been much disagreement over the definition of sustainability. No definition is universal. Nevertheless, it is plain to see that generating 520 billion pounds of hazardous waste annually is unsustainable. It is unsustainable because the waste is going into our air, water, and soil. Though we may try to isolate the waste, containers leak. Though individual companies may reduce their pollution levels dramatically, annual hazardous waste production is not decreasing dramatically. While we may have enough money now to buy a mildly safe and remote home for our hazardous waste "somewhere else", it is sad to think of the progressive (and unending) destruction of the natural environment that such a disposal system necessitates.

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[11] http://www.sustainable.doe.gov/business/ecoparks.shtml

[12] One of the quintessential examples of a product of service, constantly extolled by Hawken, Lovins, McDonough et al., involves the worlds largest carpet producer, Interface. Refer to http://www.resource-americas.com/reclamation/reclamation.htm for more information.

[13] http://www.livingmachines.com

[14] http://www.dtex.com/products/prd_wm01.htm

III. Green Chemistry

The Royal Society of Chemistry defines Green Chemistry as follows:

> "A challenge for chemists … to develop products, processes and services in a sustainable manner to improve quality of life, the natural environment and industry competitiveness"[15]

It is a movement within the chemistry community to put their industry in line with the principles of sustainable development, by creating, championing, and putting to use environmentally benign chemical procedures that can replace more toxic ones. A quick glance at some principles of Green Chemistry practically repeats the values espoused by Hawken, the Lovinses, and McDonough:

- Waste prevention is better than treatment or clean-up
- Chemical synthesis should ideally use and generate non-hazardous substances
- Chemical products should be designed so as to be non-toxic
- Catalysts are superior to reagents
- Raw materials should increasingly be renewable
- Chemical products should break down into benign products

Some examples of these concepts put to practice follow below:

Scale reduction: Reducing the amount of inputs into a reaction whenever possible will reduce the amount of product and waste. This simple technique for waste prevention may seem at odds with the goals of industry - whose profits are generally based on quantity of product produced and sold - yet it has already been employed in certain cases. One interesting case involves DuPont and Ford. Rather than buying actual paint for its cars, Ford has contracted with DuPont for a car painting service. So instead of getting paid more to produce more paint, DuPont is gets paid more to produce more painted cars. In this arrangement, DuPont can save money by reducing – not increasing – the amount of paint it makes and uses! Scale reduction is especially well suited to University teaching laboratories, where the technique and experience gained is paramount, and obtaining large quantities of product is insignificant.

Solvent selection/regeneration: Organic solvents are ubiquitous in chemistry, because they facilitate so many important reactions. However, this ubiquity combined with their volatility, toxicity, and potential toxicity (upon incineration) makes organic solvents especially problematic. A large proportion of hazardous waste is comes from organic solvents "contaminated" by the products and reactants of the reactions they facilitate. One step toward pollution control is the selective exclusion of certain organic solvents that are known to be especially problematic as wastes. In order to take a larger step toward sustainability, it is important to realize that an organic solvent "contaminated" by one reaction may be able to be repurified, instead of discarded, after a reaction. However, the common practice in laboratories is to dump a wide variety of organic wastes into one giant trash can. Once this is done, the Second Law of Thermodynamics (which states that the universe is becoming irreversibly more disordered with time) virtually guarantees

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[15] http://www.chemsoc.org/networks/gcn/about.htm

that no materials of use could be recovered. This negates the whole concept of "waste equals food" which is essential to sustainability. Examples of solvent selection/regeneration will be discussed below.

Toxic elimination/substitution: This principle is simple to understand. If a chemical is toxic, don't use it.

Material flows and cycles: This is the concept of waste equals food, put to practice in chemistry. Instead of designing reactions as isolated linear progressions from products to waste, the potential exists to create within universities, businesses, or even industry as a whole, networks that channel a large variety of materials into large cycles of reactions (much like nature does), where the waste from one becomes the inputs for another. Such closed loops provide a way of dealing with essential, but toxic or potentially toxic (i.e. upon incineration) chemicals. Refer to Figure 1 for a schematic of such material flows.

Separate collection of waste: Briefly mentioned above in connection with solvent regeneration is the importance of keeping wastes from different reactions separate. The less wastes are mixed, the easier they are to recover to useable products. Vigilance in managing their reaction wastes separately like this will enable chemists to feel like they are making a tangible contribution to sustainable waste management while instilling in them a sense of personal responsible and duty.

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[16] H. Fischer.

IV. University Hazardous Chemical Waste Production

Chemical and petrochemical companies are estimated to account for 70% of the total hazardous waste produced in the US. Thus any attempt to drastically reduce hazardous waste in the US must focus on changing these industries. Conversely, universities only generate an estimated 1% of the total hazardous waste produced in America (~520 million pounds). While this pales in comparison to the petrochemical and chemical companies, it is not insignificant by any means. Focusing on the elimination of university chemical waste as a means of attacking the greater problem makes sense for several reasons, among them:

- The elimination of 520 million pounds of chemical waste annually would have a positive impact on the environment.
- Universities are the training ground for tomorrow's industry leaders. Teaching and demonstrating awareness and elimination of hazardous waste in the university setting will speed its transition to the private sector.
- Certain sustainable material use cycles and flows discovered and implemented in zero (or near zero) hazardous waste emission university laboratories will be transferable to industry.
- Research and teaching - not profit - are the primary objectives of university labs. This enables the utilization of new environmentally friendly techniques and procedures whose initial cost and risk may prohibit industry.
- Many businesses have too much inertia and capital invested in traditional linear flow production schemes to make the dramatic paradigm shift towards cyclic thinking and design. This is not true in all cases (see above mention of Interface) so industry should continue to be pushed aggressively toward environmentally efficient production schemes. Nevertheless, making the switch in Universities may meet less resistance initially - until the synergistic benefits (reduced waste management costs, reduced material procurement costs, decreased liability to EPA, improved public relations, improved worker safety, etc.) start to be recognized by industry.
- The move toward zero (or near-zero) hazardous waste emission operations will require a mix of altruism, civic responsibility, financial health, credibility and intelligence. Universities provide a rare mix of all five characteristics, and can effectively demonstrate the various synergistic benefits of such operations.

As mentioned above, this paper presents a case study of issues pertaining to hazardous waste at the Massachusetts Institute of Technology. It will specifically focus on hazardous waste produced by the Chemistry department. While initiatives that improve the eco-efficiency of the Institute are discussed in detail - to illustrate tangible and relatively simple ways to reduce pollution at other universities - it is important to remember that simply “being less bad” should not be the ultimate goal of pollution prevention program. As such, the consideration and discussion of more radical initiatives is included to spur further movement toward sustainable, zero (or near-zero) hazardous waste emission laboratories.

V. MIT Hazardous Chemical Waste Production

In 1998, MIT was found to be in violation of 18 federal environmental regulations. The violations did not include any hazardous chemical leaks to the environment; instead they were associated with improper management (storage, handling, labeling) of hazardous waste containers, and the lack of an oil spill prevention plan.[17] According to the EPA:

> "It [was] clear that the violations stem from institutional problems – too much decentralization of responsibility, lack of clear lines for environmental compliance, deficienceies in training programs and lack of resources dedicated to environmental compliance".[18]

MIT agreed to pay a $150,000 fine and fund $400,000 in environmental projects to settle the issue. The EPA punishment has dramatically raised the environmental awareness of MIT's administration.

MIT produces around 15,000-20,000 containers of hazardous waste per year (the containers range in size from 500mL to 4L).[19] In order to reduce the risk of future liability associated with ground contamination, the majority of the Institute's hazardous waste is incinerated at off-campus facilities.[20] The vast majority of chemical waste produced at MIT is produced by the Chemistry Department. So far this year, the chemistry department has produced 47.8% of MIT's hazardous waste – which translates to about 8,500 containers per year (Figure 2). Thus, much as the chemical and petrochemical companies are the natural focus for industrial chemical waste reduction strategies, the Chemistry department is a logical focus for university hazardous waste

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[17] Beth Daley, Globe Staff, *The Boston Globe,* April 19, 2001, pg. B3.
[18] Mark Pratt, Associated Press Writer, *BC Cycle,* April 18, 2001.
[19] "2001 Semi-Annual MIT Hazardous Waste Removal", obtained from Jeffrey Bernard, Technical Assistant, MIT Environmental Health and Safety Office, December 3, 2001.
[20] Conversation with William Van Schalkwyk, MIT Assistant Director of Environmental Programs, November 30, 2001.

reduction schemes. Nevertheless, it is important to remember that all other departments combined produce an equal amount of hazardous waste.

The chemistry department provides the natural focus for waste reduction schemes, and the most hope for innovative and engaged participation in such schemes. Based on the motivation for this paper, it was natural to first assess first the role of Undergraduate Teaching Laboratories (UTLs) in MIT hazardous waste production. Like most universities, MIT has both teaching and research labs. The central and defining result of this project's early investigation revealed that, surprisingly (to me at least), <u>UTLs produce an almost insignificant amount of hazardous waste, on both the institute and department levels.</u> UTLs generate an estimated 20 containers of hazardous waster per semester.[21] This is only about .50% of total Chemistry Department hazardous waste, and about .22% of total MIT hazardous waste. To put this in perspective, UTLs generate about the same quantity of waste as the Audio/Visual department.

The bulk of the Chemistry Department's hazardous waste comes from research laboratories (about 145 containers per week, plus call ins). As such, it was important to come to terms with the fact that applying the Swiss model to MIT classrooms would not result in any direct, drastic reduction in overall Institute hazardous waste production.

Rather, incorporation of "Green Chemistry" and sustainability into the undergraduate curriculum, could only hope to yield benefits that are synergistic and less tangible:

- teaching sustainability and consciousness of waste to the future leaders of industry
- eliminating small amounts of pollution
- teaching personal responsibility to deal with a chemical's entire life-cycle
- demonstrating the capabilities of material cycles and closed loops

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[21] Conversation with Jeffrey Bernard, Technical Assistant, MIT Environmental Health and Safety Office, December 3, 2001. Jeff relayed estimated bottle counts for room 4-440, the storage location for the UTLs.

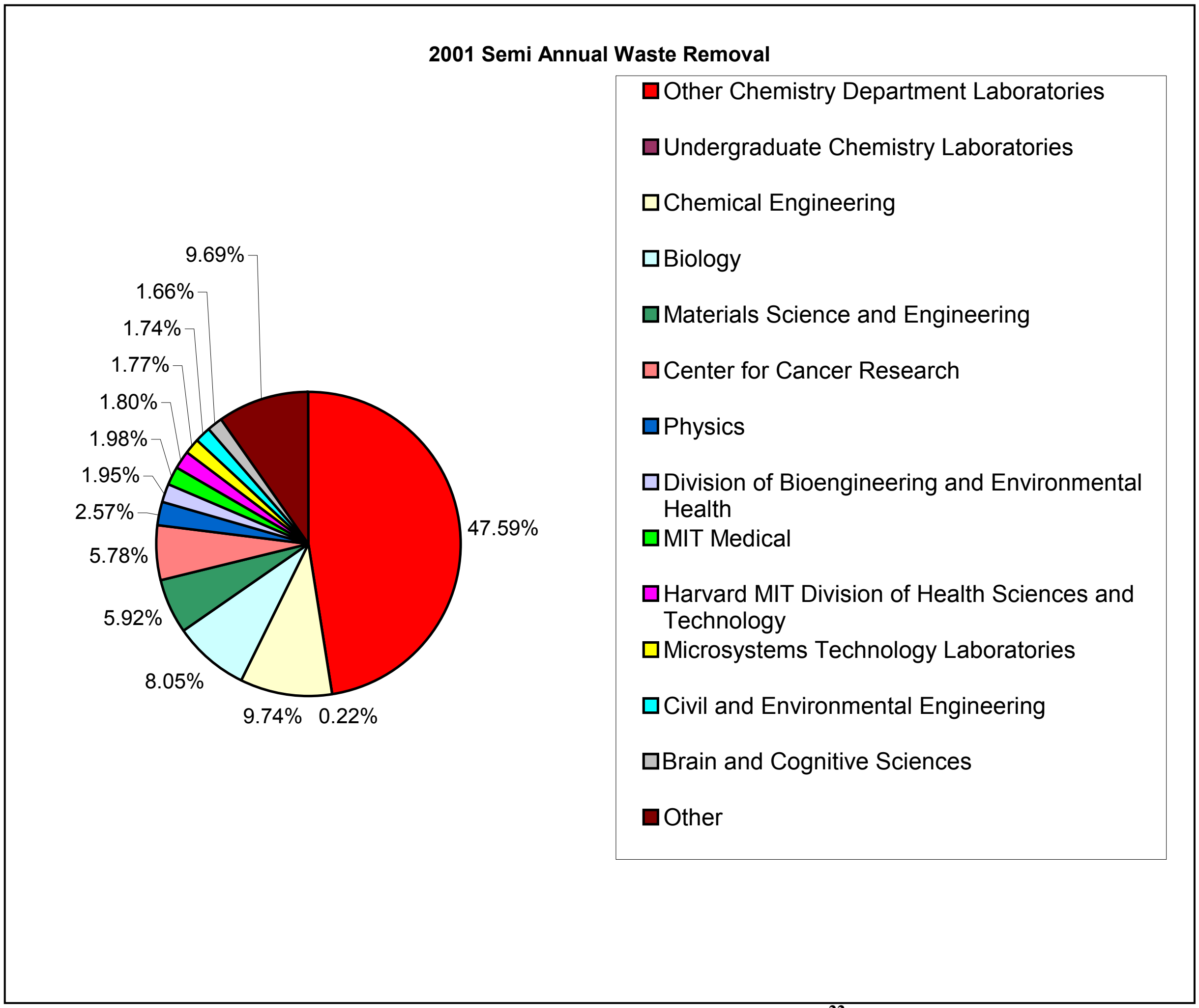

Figure 2. Hazardous Chemical Waste Production at MIT by department.[22]

Conversely, the production of hazardous waste in Chemistry Research Labs at MIT jumped to the forefront of importance and provides the most compelling case for both immediate and long-term intervention.

[22] Bernard, J. "2001 Semi-Annual MIT Hazardous Waste Removal".

VI. Initiatives in MIT Undergraduate Laboratories

Prior to coming to the realization that UTLs do not produce a significant portion of hazardous waste, I spent a good deal of time attempting to assess the applicability of the Swiss model at MIT, and familiarize myself with the "Green Chemistry" initiatives already underway here. The first person I spoke with was Professor Jeff Steinfeld, who had been referred to me as the champion of Green Chemistry at MIT. Professor Steinfeld gave me an overview of the various initiatives introduced in the MIT's Undergraduate Teaching Labs to minimize waste (Appendix A):

- **Elimination of Mercury:** Mercury is an extremely toxic substance often found in thermometers and vacuum gauges. Non-mercury containing equipment was bought as replacements.

- **Ionic Liquids:** As discussed above, volatile organic solvents pose significant health and waste management concerns. In a rather cutting-edge initiative (not employed in the Swiss model), MIT instituted the use of an ionic liquid solvent to replace the need for dichloromethane solvent in one experiment. As dichloromethane is an anesthetic, narcotic, and potential carcinogen (29,000 metric tons of which were released in 1994 by US Industry), this replacement seems clearly preferable. Further, ionic liquids have a very low volatility over normal temperature ranges, which makes their use as a solvent even more preferable. Even better, the reaction to create the ionic liquid is a solvent free reaction, which produces no waste. Indeed, ionic liquids are a relatively new phenomenon, but have generated quite an interest as a widely applicable "green solvent".[23]

- **Mathematical Titration:** Another clever and unique initiative employed in MIT's undergraduate lab is the use of mathematics to reduce chemical use. Standard titration experiments have well defined titration curves, which students use to assess the quantity of a given component in a mixture. By mathematically defining the titration curve for a given experiment, only a small portion of the titration reaction must be carried out, as the preliminary results of the partial titration reaction can be extrapolated to give the desired end result.

- **Water as Reaction Solvent:** MIT's undergraduate laboratory has explored "green" solvent selection. In addition to the use of ionic liquids described above, the use of water as a reaction solvent has in one experiment replaced 12L of ether/semester/100 students.

- **Internal Toxic Release Inventory:** Chemistry majors fill out waste inventory reports in all three experimental lab classes. Much like on the EPA mandated industry TRI sheets, the students document all the waste produced by their experiments, how it is disposed, and also give suggestions for waste reduction. These TRI sheets generate innovative suggestions for waste reduction, provide the potential for identification and quantification of excessive wastes, and force students to start considering the issues associated with chemical waste (Figure 2).

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[23] Stark, A., MacLean, B.L. and Singer, R.D. *J. Chem. Soc. Dalton Trans.,* 1999, pp. 63-66 and Welton, T. *Chem. Rev.* 1999, 99, pp 2071-2083.

- **Scale Reduction:** Experiments using an excessive amount of reactants have already been identified and reduced in scale. Comments on the student TRI sheets serve to remind and alert the lab managers when the experiment scale is deemed unnecessary.

VII. Institute Wide Initiatives for Hazardous Waste Reduction

As a pro-active response to (and part of the settlement of) the1998 EPA violations, MIT has overhauled its administration of environmental issues. The importance given by the administration to the newly created Office of Environmental Programs and Risk Management is gleaned from that fact that its director reports directly to the University Vice-President. In short, this office has been given the authority and resources to undertake significant environmental initiatives. Through the creation of councils that establish networks and dialogue between various departments and staff, a central environmental management software package, and task forces charges with undertaking specific environmental issues, the new administrative infrastructure has created the framework for institutional change (See Appendix B).

While this new management structure addresses a broad range of environmental issues, such as recycling, sustainable building requirements on campus, food composting, etc., specific attention has been paid to the issue of hazardous waste, particularly waste produced by research laboratories:

> **Purchasing Automation and Integration:** The creation of an automated chemical purchasing software package has the potential to reduce chemical waste at MIT. Aimed mainly at research laboratories, this system will have the automated ability to track the purchase, destination, and disposal of all most all chemicals flowing through MIT. In doing so, a great deal of the anonymity in chemical waste use on campus could disappear. Much as the transparency provided by industrial TRI sheets provides a point of leverage in forcing companies to reduce chemical waste, the release of detailed information on hazardous chemical use at MIT could spur reductions here. The program will also serve as a training guide to encourage proper legal handling of hazardous waste; it will include pop-up screens to alert the buyer of non-toxic alternatives whenever applicable; and it will create an internal MIT chemical marketplace to reduce redundant consumption while providing the potential for sustainable cyclic material flows within the Institute.
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> **Application for Lindbergh Grant:** Professor Steinfeld has submitted a proposal to rank the "high priority [toxic] chemicals that are widely used in a variety of research activities or operations" at MIT.[24] Notification of the award for this grant occurs in January; however, there are tentative plans to move forward with the project even if the grant funding does not come

[24] Steinfeld, J. "2002 Lindbergh Grant Application", pg. 3

through. The project is estimated to take about two years to complete, and once the high priority chemicals are assessed, reduction strategies can be put in place.

VIII. Future Suggestions/Conclusion

As discussed above, the original intent of this report was to investigate the feasibility of the "Green Chemistry" techniques described in the University of Zurich case study, as a starting point to reducing chemical hazardous waste at MIT, and beyond. One primary finding of the study is that UTLs do not produce a significant amount of hazardous waste.

Nevertheless, as described above, designing sustainable university laboratories are an important way to affect the larger problem of industrial chemical waste. UTL's can still harness student creativity and concern, while taking advantage of the educational setting to move closer towards the goal of sustainable laboratory design. In fact, precisely because such little amounts of hazardous waste are produced by UTL's, the transition is easier - they don't have very far to go.

Raising awareness among chemistry majors: It is easy to be unaware of the consequences of the American industrial complex. It seems that these days, college students are so focused on their schoolwork while on campus, that they are even less aware of the world around them. It is easy to imagine a developing chemistry major working so hard just to stay afloat for four year and being oblivious to the consequences of and issues surrounding the waste he/she is creating in lab and one day will create in industry. As such, it is vitally important to raise awareness among chemistry majors of the environmental issues surrounding chemical waste. In order achieve a greater level of awareness, I propose 4 simple initiatives targeting all chemistry students:

- Require students to watch a movie documenting the impacts of the chemical industry, such as "Trade Secrets". You could even include a counterpoint film by the chemical industry, so long as you get the students thinking seriously about the issues.
- Arrange one-day seminars about the effects of chemical waste by Professors in Environmental Engineering, Public Policy, or other related fields.
- Take a poll at the beginning of the semester to gauge the priority they give eliminating toxics and being environmentally responsible. Should the students show great interest, their values should be respected. Should they not show great interest, such a poll will start them thinking about the subject.
- Provide students information on chemical waste produced by theirs and other MIT laboratories in previous years. This will make the issue seem more tangible to them.

Establishment of a Sustainable Chemical Cycle Theory Class: Establishment of such classes is necessary to promote and encourage innovation and proliferation of these concepts. Teaching the concepts to policy makers is one thing, but teaching them to the actual scientists who will utilize them is of the utmost importance.

Design a curriculum network: The greatest contribution an undergraduate chemistry department could make to the environment is to provide a working model that utilizes sustainable chemical flows and cycles to create zero waste. Universities are remarkably well suited to this task because of the endless possibilities of material networks that could be established. Classes could recover their own wastes and regenerate reagents on site. Lower level classes could produce reagents for upper level classes. Upper level classes could be established to clean/purify wastes from other upper level classes. In fact, even interdepartmental connections between environmental engineering, chemical engineering, and biology could be established. The possibilities of taking a holistic approach to designing a sustainable curriculum are seemingly endless. It is not reasonable to assume that such courses would spontaneously replace the entrenched curriculum. Therefore, it may be reasonable to propose an alternate curriculum path for those professors and students interested in working on such a project. Eventually when the merits of this system are proven, it may overtake the standard linear curriculum.

Institute wide policies to address chemical waste from research laboratories are necessary to drastically reduce the 20,000 containers of hazardous waste produced by MIT every year. These policies, outlined below, will supplement the steps MIT has already taken toward reducing waste.

Make departments and labs pay for their own waste disposal: Currently, MIT pays all disposal costs for hazardous waste produced in its laboratories. With someone else paying the bill for their waste, there is no economic incentive for the waste producers to reduce their output. By making each entity responsible for its own waste management costs, there would be an incentive to reduce waste. Such a policy change would require grants and grace periods as the shift is made. It is important to note that the Office of Environmental Programs would be hesitant to make such a policy change, because of fears that labs would clandesitinely circumvent regulations in order to reduce disposal costs. This goes against the current trend toward the centralization of environmental management brought about by the EPA regulations. Nevertheless, the idea has its merits.

Rank labs on basis of hazardous waste production: The impetus behind such a policy change is clear and simple, and follows from the success of the EPA's TRI reports: nobody wants to be branded a hazardous waste polluter. By making data available on the worst polluting labs at MIT, there will be societal pressure on them to clean up. Making such rankings is within the capabilities of the MIT Office of Environmental Programs. Accurate and complete data correlating room number to hazardous waste production started to become recorded earlier this year (see Appendix C). Currently the raw data contains a correlation between room number and a person associated with that room. A cursory glance of the data showed that the position of the person correlated with each room and its waste varied considerably. Some rooms' waste is correlated with the lab safety officer, some with post-doc fellows, some with lab technicians, some with graduate students, and some with lab directors. In order to make the above policy effective, data should be collected and associated with the head of the lab it is coming from. This way, ultimate responsibility rests on the lab director, who has the power to make and change policy within his lab. Collecting such data would simply require some coordination with the waste pick-up contractors and the Office of Environmental Programs. In the future, with the automated chemical purchasing and tracking system, such data may be easily compiled. It should be transparent as well.

Create positive incentives for innovative waste reduction strategies: Since the administration is paying the cost of hazardous waste disposal, it stands to save money if these wastes are reduced. There is no reason why such savings could not just be passed along to the labs that have produced them by demonstrating reduced annual hazardous waste production. This would create a tangible positive incentive for the labs to reduce their waste. Further, the administration could subsidize student grants to winners of waste reduction strategy competitions and continue to encourage applications for environmental grants such as the Lindbergh grant pursued by Professor Steinfeld.

There are several barriers obstructing the way toward sustainable university laboratories. These include standard, but not fatal, obstacles to innovation - things like money (initial capital investment needed to upgrade facilities) and overcoming inertia and apathy. However, the very nature of the university environment renders these obstacles less foreboding than one would expect in industry.

More problematic are existing EPA regulations that prohibit waste treatment by facilities without permits. MIT does not have permits to treat chemical waste. As such, installing a sustainable curriculum may require legal negotiations with the EPA or the obtaining of permits. It is important to note that there is a pilot program at the University of Massachusetts, which has obtained the leeway necessary to undertake small-scale on-site waste treatment.[25]

Another serious barrier is the law of physics and chemistry. It is indeed true that some processes are irreversible, and some are inherently wasteful. Not all chemicals will fit neatly into cycles. Some processes are inherently wasteful. However, human ingenuity (coupled with sensitivity to environmental issues) can overcome these obstacles and find viable alternatives.

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[25] Conversation with William Van Schalkwyk, MIT Assistant Director of Environmental Programs, November 30, 2001.

The most troubling barrier in my view is bringing about the required paradigm shift on the part of many chemical teaching laboratory directors. Most teaching laboratories, especially here at MIT, have aspirations of running a “world-class” curriculum. To them, this might mean producing a crop of students skilled in the most cutting edge and difficult laboratory techniques that will prove useful in industry. In light of the pressing current problems associated with hazardous waste production in the United States, running a “world-class” laboratory has come to mean quite a different thing to me. To me, a “world-class” laboratory would exemplify the maximum potential of “Green Chemistry” and sustainable curriculum design. At some level you have to ask, what good is feeding industry what it wants when industry itself needs to be changed?