Preventing Future Brownfields

Engineering Solutions and Pollution Prevention Policies

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***Abstract*— A systems methodology for identifying, characterizing, and evaluating engineering solutions and policies that prevent the formation of brownfields is presented. Brownfields exist in very large numbers and pose serious environmental and health risks in developed countries around the world. As industries abandon unprofitable sites and development spreads to other parts of the globe, potential brownfield creation abounds which will further exacerbate the problem. Preventing the creation of brownfields in the first place should be a priority. However, it will depend on the availability of options (technology) and the incentives to implement them (policy). A retrospective look at the City of Kitchener, Ontario, Canada, shows that a $10,000 investment in prevention could have avoided $100,000+ of cleanup cost on former gas station sites. Similarly, leaking underground fuel tanks could be prevented in South Sudan with double-walled tanks and appropriate procedures for less than 2% of the cost of cleaning up fuel leaks. Additional health-related economic and social costs associated with consumption of hydrocarbon contaminated groundwater could also be avoided. Actual implementation of pollution prevention requires a systems approach. Our research focuses on enhancing the relationship between engineering and policymaking through systems thinking and providing practical decision making support tools to guide development in a sustainable manner.**

Keywords-brownfield; leaking underground storage tanks; pollution prevention; systems engineering; policy development

I. Introduction

Albert Einstein is quoted as saying, "Intellectuals solve problems; geniuses prevent them" [1]. Brownfields, which are a common eyesore in many parts of the industrialized world, pose a number of problems, which, if left unaddressed, may result in deteriorating socio-economic conditions and serious environmental and health risks to surrounding ecosystems and populations [2][3]. Governments, industry and researchers are working on innovative ways to remediate brownfields and redevelop underutilized lands for productive uses to the benefit of the environment, economy, and society [4][5][6]. However, as economies grow throughout the world and developing countries become increasingly industrialized, there is a need to learn from experience and to prevent the creation of brownfields in the first place. Consider this: a brownfield is the legacy of a polluting entity. Without access to, or record of, the site's history, which consists of past operations on a site, as well as its previous owners, accounting and accountability is difficult to determine. Before a site comes remotely close to being labeled a brownfield, a multitude of decisions and measures can be taken to protect the integrity of our land, air, and water. In order to do this, a systems engineering approach that embraces pollution prevention (P2) is presented for sustainable development practitioners and policymakers so that brownfields become things of the past. More than anything, however, people are needed to bring pollution prevention to the forefront and into practice.

Environmental problems are inherently complex because they tend to affect multiple stakeholders through the use of public goods, such as clean air and water, and their effects may span beyond human-made borders and through time with uncertain and emergent consequences. Preventing environmental problems is a matter of both technology and policy through which creative solutions are engineered and implemented according to the value systems of all stakeholders – present and future. Interconnecting engineering solutions and pollution prevention policies enhances sustainable development by encouraging system managers to minimize the creation of pollutants and wastes such that future generations are not burdened with costs of remediation and clean-up while present generations drain the capital gains of current development investments. Implementing these measures, however, is often met with technical and political challenges.

The purpose of this paper is to further interdisciplinary research between engineering and policymaking to support sustainable development and environmental management. In Section 2, the context of pollution prevention (P2) is laid out with a historical perspective and a view on its future directions. The underlying technology and policy interactions that influence the development and success of P2 strategies are explored. In Section 3, an integrative and adaptive methodology is proposed, based on a systems engineering approach, for identifying, characterizing, and evaluating engineering solutions and policies that prevent the formation of brownfields. Ultimately, such an approach would contribute to the broader goal of sustainability throughout the community and beyond the borders of the industrial plant. Section 4 presents case studies of hydrocarbon contamination in the City of Kitchener, Ontario, Canada, and in Sudan to show the practical use of this methodology.

This work was supported in part by the Natural Sciences and Engineering Research council (NSERC) of Canada through the project "Systems Engineering Approaches for Brownfield Redevelopment" (STPGP-336683-06) and Discovery Grants.

978-1-4244-3878-5/09/$25.00 ©2009 IEEE

II. Pollution Prevention (P2)

Pollution prevention, or cleaner production, is defined as "the use of processes, practices, materials, or energy that avoid or minimize the creation of pollutants and waste at the source" [7]. In relation to brownfields, P2 seeks to avoid their creation in the first place.

A. History and Development

Pollution prevention is by no means a new concept, but it has evolved due to advances in science, technology and society. In 1876, the UK parliament enacted the Rivers Pollution Prevention Act, which was an attempt to curb the deleterious consequences of the industrial revolution and urbanization [8]. With advances in waste treatment and recognizing that the large number of authorities involved in administering the law rendered the preventative measure ineffective, the statute was replaced with the Rivers (Prevention of Pollution) Act of 1951 [8]. However, as noted in the sitting of the UK House of Commons, this act would be more aptly called the "Rivers Pollution Act" as it was more akin to an attempt of defining under what conditions rivers may be polluted rather than requirements of stopping pollution altogether [8]. Nobody was advocating for real prevention as the only apparent way to stop polluting was to shut down industry. Nonetheless, environmental awareness spread.

In the US, the National Environmental Policy Act (NEPA) of 1970 advanced the movement. A procedure for full disclosure of environmental impacts of federal projects operationalized the government's commitment to environmental stewardship [9]. In the 1970s, "end-of-pipe" pollution control would be enforced. At best, this strategy was a compromise to resolve the conflict between industrialism and environmentalism. Industry would need to monitor its interfaces with the environment and would control, rather than prevent, the release of pollutants. Industry could basically continue business-as-usual with some additional costs in altering the tail end of its processes. Environmentalists would have to accept some level of pollution as an inevitable consequence of development. However, since the late 1970s and early 1980s, early visionaries saw that a fundamentally different approach was possible - true pollution prevention where waste and pollutants, instead of being created and then controlled, could be prevented where they originated [10]. Moving into the 1990s, governments realized that its single medium legislation simply shifted pollution from one part of the environment to another [11]. Some industries recognized the benefits of replacing materials and redesigning processes and products such that wastes were reduced or eliminated to reduce costs. P2 values were being institutionalized throughout the industrialized world, for example, in the US as the Pollution Prevention Act of 1990. Yet, as Hirschhorn [10] argues, the P2 revolution has yet to succeed as long as there are more people and power pushing for pollution control over prevention.

The gap between the ideal of pollution prevention and the reality of achieving it may have appeared to be slowly closing during the past century as our science, technology and the political will to protect the environment was increasing. However, to some such as Homer-Dixon [12][13], a general innovation gap appears to be increasing in the 21st century due to rising complexity as global environmental problems coupled with continuous economic growth and population pressures require new methods that are adaptive and complex. Higher demands on both technical and societal innovations in pollution prevention are likely to be imposed if it is to succeed. In order for P2 methods to have a higher change of adoption and success, P2 must build a stronger cohesiveness between policy and technology. In the next section, the technology and policy interactions in pollution prevention are discussed in order to promote synergistic relationships among scientists, engineers, managers, and policymakers.

B. Technology and Policy Interactions

Broadly speaking, technology is the product of science and engineering, while policy is the product of social and political processes. P2 requires both available technical solutions and supporting political environments in order to be carried out in practice with a high chance of success. In order to advance P2, one has to be aware of the interactions between technology and policy, which may be identified as key driving factors for a project. Some identified interactions are enablement and knowledge transfer. Young et al. [14] also lay out several models of research-policy relationships.

Different policies enable different paths of technology development and innovation. Since P2 is generally a voluntary course of action, appropriate incentives are needed in order to encourage research and investments into new technologies, materials, and processes that avoid producing pollution. Failing to factor in environmental costs in normal profit-loss economics, P2 may be erroneously viewed as a luxury, rather than a necessity [15]. Economic incentives may initially work, but returns may diminish over time. Incorporation of the P2 ethic into the values and culture of organizations and governments is likely to sustain the drive towards prevention. Hence, in order to enable P2 technology innovation, policy should enhance the value of P2 through both economic and social incentives. On the other hand, the lack of technology may weaken the impact and enforcement of a policy that tries to regulate pollution, as was the case of the Rivers Pollution Prevention Act and, to a certain extent, current environmental acts. No industry is perfectly in compliance with the regulations [16]. Technology enables policy compliance insofar as the objectives of the policy are reasonably achievable, though it is often a matter of using appropriate technology. In fact, P2 often results in meeting targets beyond compliance, though various regulation, education, incentive and development programs are initial drivers for pursing P2 [17].

To know what may be reasonably expected and what we need to strive for, knowledge transfer between policymakers and scientists/engineers is needed to close the gap between ideology and reality. Knowledge transfer is bi-directional. Communication is a key component in any relationship and to be understood both parties need to speak a common language and both perspectives need to be heard. In particular, for P2, risk communication to and from the political arena and the technical realm is an important interaction. Most controversies may be attributed to poor risk communication [18]. Essentially, undertaking prevention is based on the calculated risk of threats and consequences, which may be mitigated or avoided with a preventative measure. Informed decision making cannot take place in a multidisciplinary team without first understanding all of the different perspectives, which each member on a P2 project contributes. When some level of understanding has been reached, the stage may be set for interactive decision making. Finally, in order to move from talk to action, decisions need to be made and carried out. To open the dialogue and put P2 into practice with technical and societal innovations, an integrative and adaptive framework is proposed.

III. Systems Methodology

Brownfield prevention, like any other prevention program, involves technical and societal systems working within the environment characterized by interconnected natural systems. It is a system-of-systems challenge. A system-of-systems (SoS), by definition, involves complex adaptive systems and multiple participants [19], where the culmination of their actions and decisions leads to emergent behaviour. Risk, which is largely the basis for undertaking preventative measures, is increasingly harder to quantify as consequences and outcomes of emergent behaviour are unpredictable and the interconnectedness of systems leads to higher complexity. Integrative and adaptive systems methodologies are needed more than ever before to efficiently and effectively address SoS challenges, such as brownfields, their prevention, and the wider goal of sustainability.

A. Integrative and Adaptive Framework

An integrative and adaptive framework for pollution prevention programs is structured with multi-participant multi-objective decision making methods, complex adaptive system models, and risk management techniques. These tools and their processes facilitate systematic identification, characterization, and evaluation of different technologies and policies, contributing valuable insights to decision making. The goals of this framework are to communicate different facets of the defined problem and to develop solutions that are, among other location-specific objectives, robust and resilient to changes such that negative consequences are avoided or mitigated. As in any organization and government body, time and resources are limited, which requires that the tools of the framework be implemented in a timely fashion with minimal data. Moreover, the framework should not be biased towards any singular interest. The following discussion outlines a systems approach within an integrative and adaptive framework for practicing P2.

Identification of possible engineering solutions and pollution prevention policies flows from the definition and understanding of circumstances that lead to problems. This task is crucial and requires integrated thinking. Sustainable development practitioners seek out perspectives from all stakeholders extracting information on values and risk attitudes in everyday language. Using these perceptions and documented scientific observations, a system model may enhance common understanding and expose interdependencies among parts of the system. Francis [20] suggests using complex open system models in Participatory Integrated Assessments (PIAs) to support interactive discourses on sustainability. A well-defined problem generally leads to well-defined solutions. Although root causes of problems are not so easily defined, problem definitions are nonetheless helpful at generating hypotheses. Testing hypotheses with a system model may point out potential root causes and lead to associated solutions. In the case of brownfield formation, substances, which may have been waste or at one time useful products, are released or thought to be released into the environment. Possible P2 options are not only means to eliminate waste at the source, but also insurance policies to ensure that useful substances do not escape into the environment to become pollutants.

Characterization is an important step to validate hypotheses with evidence that is unbiased and logical. While non-experts may have an intuitive understanding of the system's behaviour, third-party specialists are necessarily consulted to understand the system's properties and dynamics which are used to subsequently predict future outcomes of proposed solutions and policies. Specifically, studies on transport pathways, ecological and biological effects, and socioeconomic impacts of brownfield contaminants are a base of knowledge. At this stage, objectives and risk factors are determined using information gained from analyzing stakeholders' values and risk attitudes and quantified or qualified with information gained from expert knowledge. Characterizing technology and policy alternatives with objectives and risk factors that are meaningful to stakeholders keeps them engaged. In this task, it is important to acknowledge uncertainty, missing information and assumptions.

Finally, evaluation of different strategies, which are combinations of potential technology and policy options, is performed using criteria, which are also determined by stakeholders' values and risk attitudes. A multi-criteria decision matrix provides a snapshot comparison of the available strategies. In order to evaluate robustness (resistance to change) and resiliency (recovery after disturbance), system responses to changes in uncertain variables, different assumptions and new information are simulated to generate an array of plausible future scenarios. The system response may be obtained via complex adaptive system simulations. Along with these results, technology and policy options can be iteratively designed using risk management techniques to handle unpredictable events, such as spills and leaks. All that this framework consists of thus far is information gathering, planning and analysis. If all goes well, the process likely leads to undisputed timely decisions and actions. However, technology and policy interactions in implementing P2, which are to be expected when dealing with societal-technical systems, can be the difference between a successful project and one that never gets considered.

B. A Much Needed Paradigm Shift

To effectively achieve the broader goal of achieving community sustainability with P2, what is ultimately required is a paradigm shift from single-media reductionism and end-of-pipe control to whole systems change. That whole systems change involves not only producers, for whom traditional P2 methods are designed, but also consumers for whom new P2 tools that affect the delivery of people, good and services can be brought to bear [16]. The original vision of pollution prevention had always advocated for both. It calls for technical and societal innovations that create a world that is fundamentally different from the status quo.

IV. CASE STUDIES ON HYDROCARBON CONTAMINATION

Petrol stations, or gas stations in the US and Canada, consist of underground storage tanks containing hydrocarbon products, such as gasoline and diesel. Spills and leaks from storage tank systems have contaminated many sites in the US and Canada, resulting in the formation of brownfields nation-wide. In the US, between 0.8 and 3.5 million single-walled underground tanks were used to contain petroleum and of these, 30 - 40 % failed the EPA's 0.1 gallon/hour tightness test [21]. Soluble parts of gasoline can dissolve in water thus contaminating groundwater if a leak comes into contact with the water table as shown in Fig. 1. Just one liter of gasoline could render one million liters of potable water unfit for human consumption [22]. Contaminants, such as benzene, toluene, ethylbenzene, xylenes (BTEX), and methyl tertiary-butyl ether (MTBE) [23], migrate with the groundwater and may contaminate the soil as vapors. As petrol stations become more commonplace in developing countries, potential hydrocarbon contamination should be an area of concern, for which pollution prevention methods need to be part of the sustainable development ethos. To illustrate the need for a systems approach to implement P2 engineering solutions and policies concurrently, two case studies are presented. A retrospective study on gas stations in the City of Kitchener provides hindsight to the brownfield problem and its costs. Lessons learned can then be applied to the prospective study on Sudan with foresight into potential risks and consequences of hydrocarbon contamination.

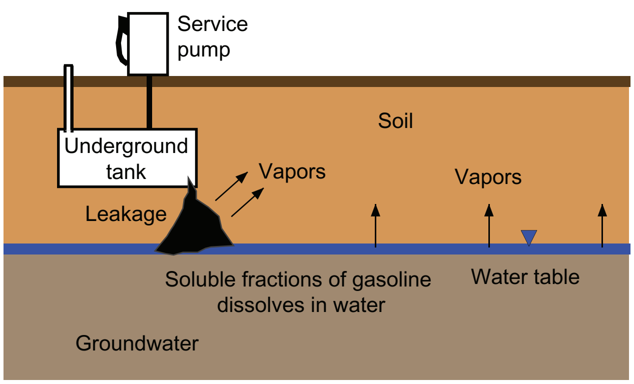

Figure 1. How tank leakage can contaminate soil and groundwater (adapted from [22]).

A. *Retrospective Study on City of Kitchener*

Kitchener gets most of its drinking water from groundwater sources. The city has listed 16 brownfield sites on former gas stations, which are eyesores on prime real estate (see Fig. 2) and pose potentially high risks of contaminants migrating through the soil to adjacent properties and sources of groundwater [24]. As part of a pilot project, the city helped to develop a redevelopment framework for former service stations in the province of Ontario which can be easily accessed online [25]. While site remediation to property specific standards (PSS) rather than generic standards may have the potential to decrease costs, approximate cost estimates of available soil and groundwater remediation and risk management technologies

Figure 2. Brownfield site on former gas station, 115 Union Blvd, Kitchener, Ontario, surrounded by commercial and residential zones.

for leaking underground tanks are on the order of hundreds of thousands of dollars [25]. These high costs and the immense experience of underground storage tank leakage in North America have resulted in regulations, comprehensive guidelines, and best practices on preventing releases. In this section, a retrospective look at how P2 options could have helped the City of Kitchener avoid its gas station brownfield problem is discussed.

The problem of leaky tanks is a relatively small issue in the grand scheme of sustainability, but since closed and abandoned gas stations are the most common type of brownfield in Ontario [24], it would be prudent to incorporate its prevention into planning considerations wherever storage tanks for petroleum products are used. For owners, product leaks translate directly to loss of sales and land value. Nearby residents have relevant health and safety concerns. Governments, who have main jurisdiction over the protection of the environment, will ultimately have to transfer the costs of clean-up to the public if the polluter cannot pay. Private owners, the community and the public have a shared benefit if leaks are prevented in the first place. Ensuring that these stakeholders are involved in the planning and implementation of P2 is an important first step for sustainable solutions.

A useful P2 tool is a centralized inventory of usage and emissions of toxic substances. Recently, Ontario passed legislation, the Toxics Reduction Act 2009, to compel companies to record, report and plan to reduce their use of regulated chemicals [26]. Environment Canada also maintains the National Pollutant Release Inventory [27]. In conjunction with regulations, financial incentives to encourage companies to do assessments and educational programs that train people to prepare plans correctly are likely to encourage industry to implement P2 [17]. For storage tank systems, the environmental code of practice devised by the Canadian Council of Ministers of the Environment includes registration, and technical requirements which can be adopted by the authority having jurisdiction [28]. As a P2 measure, the City of Kitchener, as part of its brownfield inventorying efforts, may also consider including provisions to have all underground storage tank systems in its jurisdiction registered and assessed as needed. Similarly, financial and educational incentives to have private owners voluntarily comply would enhance the ease of information gathering. It is worth mentioning that, from experience, having private owners voluntarily comply rather than forced is likely to result in "beyond compliance." Under strict regulations, private owners may only meet the bare minimum, or may even risk the costs of noncompliance if enforcement is weak. On the other hand, incentives for prevention acknowledge that eventually everyone pays, but disasters averted, everyone pays less.

Eliminating waste at the source can be interpreted at different levels of change. An obvious solution to the problem is to prevent the leak. Implementing technical enhancements such as corrosion protection, secondary containment, and monitoring and leak detection are minimum standards now in North America. These measures reduce the risk of leakage, but the potential is always there. Changing the composition of gasoline, such as the phasing out of methyl tertiary-butyl ether (MTBE) which was originally used to replace lead, may eliminate one problem but more than likely will replace it with another. Replacing the fuel altogether with electricity is possible. Better Place™ is on a mission to create an electric refueling network with battery-swap stations that replaces a car's spent battery pack with a fully charged one [29]. The electric car is one of many transit options and its lifecycle should also be scrutinized for its disposal of battery packs. Further up the community scale, eliminating society's need for conveniently stored petrol products in neighborhoods calls for deeper understanding and consideration of the way people live their lives. New models of sustainability can lead to different ways of meeting our needs with integrated transit and land-use planning. For this, complex open systems models, as mentioned by Francis [20], would be useful to understand the interconnections among people, goods and services. Building up a sustainability model for the City of Kitchener will be undertaken with further research to support the aforementioned systems methodology. As a simple first step here, we consider the minimalist solution of having double walled tanks instead of single walled tanks to reduce the risk of leaks. Retrospectively, a $10,000 investment could have avoided $100,000+ of likely remediation and redevelopment costs.

B. Prospective Study on Sudan

Civil war in Sudan, mainly between the militarily powerful North and the oil-rich South, ravaged the country for approximately 50 years until a peace treaty was signed in 2005. As a result of the prolonged war, South Sudan was left with virtually no infrastructure. Currently, the South is rapidly developing as South Sudanese refugees repopulate the region. Transportation infrastructure (roads and fuel stations, see Fig. 3) is a high priority of the Southern government. It appears, however, that the new underground storage tanks for fuel are single-walled steel tanks. The high risk of leakage, as manifested in North America, leads to concern for Sudanese people being subjected to the negative consequences of brownfield formation thirty years in the future. Environmentally, contaminants would migrate through soil and groundwater polluting land, water, and air. Economically-speaking, it is unlikely that private owners or the government could bear the high costs of remediation, unlike the industrial world, where knowledge and technologies are also created and more easily available. Finally, if hydrocarbon contamination migrates into borewells, where most Sudanese obtain their domestic water, the social health impacts of sickness and fatalities are daunting [30].

Figure 3. Fuel station in Kajo Keji, South Sudan.

The South Sudan government is cognizant of risks that petrol stations pose to the public. In March 2009, it adopted regulations for ten states of South Sudan to be implemented immediately to avoid the loss of life and properties from unsafe operations at petrol stations [31]. All stations erected near public institutions such as schools, churches and airports are to be decommissioned and move to more appropriate locations. New policies for waste management and fire safety are also on the horizon. The government is in the process of creating a solid foundation for its country. Pollution prevention, which is not widespread nor explicitly on the development agenda in Africa, is likely the best hope for environmental improvement and provides much cheaper options than waste management and treatment [17]. The main challenges are coordinating, funding and maintaining P2 projects from conception to follow-up. Champions are needed to lead and to gather stakeholders to efficiently identify, characterize and evaluate P2 opportunities. A large hurdle is getting stakeholders to focus on the prevention of future catastrophes, while their minds are inundated with present needs such as clean water, feeding one's family, and living day-to-day with no savings and ineligibility for credit. Without a vision, financing for P2 is nonexistent. Without ownership, support for P2 is unattainable. As in the case of the City of Kitchener, the community, government and private owners share the benefits of preventing hydrocarbon contamination and should each be involved in planning and implementation to share the vision and ownership. For South Sudan, who enjoys cooperation with Kenya and other foreign entities, it is also important to share the P2 vision with other stakeholders in the oil industry so that they may also take responsibility for the benefits which they reap. South Sudan may quickly learn to leverage their resource-wealth against the risks of environmental conflicts.

Using the systems methodology, P2 options for South Sudan can be systematically devised to yield higher chances of success. For example, on a visit to Sudan in November 2008, one of the authors met with Zamba Duku, Speaker of the

House for Central Equatoria, to share knowledge on the risks of single-walled tanks. A simple technical solution would be to replace them with double-walled tanks, which costs 2% of the potential clean-up costs if a leak occurs. As with most sustainable development challenges in Africa, however, technical solutions are not sufficient. Hence, the proposed framework seeks to provide a methodological approach to integrate the issues of coordination, financing, and continuous improvement of technology and policy using adaptive thinking. The political, economic and cultural climate of South Sudan differentiates its systemic policy issues from those of the City of Kitchener, which a systems methodology should be able to accommodate. On the other hand, the technological issues are the same, which is why knowledge transfers from North America to Africa and vice versa is possible and important. To aid decision making for all key decision makers, further research will be done to identify, characterize and evaluate potential P2 engineering solutions and supporting policies.

V. Conclusions

Engineering solutions and pollution prevention policies are interconnected components of a sustainable development framework, in which proponents should utilize a systems approach. Case studies on the City of Kitchener and South Sudan show potential cost savings (economic, environmental, and social) with pollution prevention. Sustainable development practitioners are encouraged to seek out P2 opportunities and to apply the proposed integrative and adaptive framework to bring P2 into practice.

Acknowledgment

The authors would like to thank F. Granek, Ontario Centre of Environmental Technology Advancement and Canadian Centre for Pollution Prevention (C2P2), as well as, T. Boutilier, City of Kitchener, for providing insights and information.

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