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Sustainable Development in Future Process Design and Analysis Education*

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A key role of engineers in the transition to more sustainable activities is likely to remain that of seeking to achieve pollution prevention and energy efficiency in manufacturing/production activities. A fundamental concept that has proven useful in teaching pollution prevention is that of 'intrinsic' vs. 'extrinsic' wastes. The same concept may be amenable to promotion of energy efficiency.

INTRODUCTION

CIVILIZATION appears to be on the brink of a Sustainable Revolution. The scale of the perceived changes warrant calling it the third global revolution, the first two being the Agricultural Revolution and the Industrial Revolution. This paper attempts to look into the effect of this upcoming revolution on the future process design education (from a chemical engineering perspective) and to postulate some responsible and credible pathways. The educational needs of the Sustainable Revolution are likely to be met by the broadest spectrum of educators; while engineering will play an important part in these future changes, future societies needs are likely to require the cooperation of the broad spectrum of disciplines. The authorship of this paper does reflect the long-standing partnership between the University of Tennessee, DuPont and Eastman Chemicals in responsible engineering education [2–5].

BACKGROUND TO SUSTAINABLE DEVELOPMENT

Several definitions of sustainable development are presented below. Two definitions presented below are thought to reasonably represent current thinking.

Sustainability is the nascent doctrine that economic growth and development must take place, and be maintained over time, within the limits set by ecology in the broadest sense—by the interrelations of human beings and their works, the biosphere and the physical and chemical laws that govern it. The doctrine of sustainability holds too that the spread of a reasonable level of prosperity and security to the less developed nations is essential to protecting ecological balance and hence essential to the continued prosperity of the wealthy nations. It follows that environmental protection and economic development are complementary rather than antagonistic processes [8]. Sustainable development is defined as [7]:

> [The] socioeconomic development that can be sustained over the long term so that the needs of the present generation are met without compromising the ability of future generations to meet their needs; the process of improving the quality of human populations without exceeding the assimilative capacity of the environment or outpacing the rate at which resources are being replenished.

This definition presents a complete but complicated set of goals for human beings and their activities.

Previous major changes for human beings, the Agricultural Revolution and the Industrial Revolution, were probably gradual, spontaneous and largely unconscious. The Sustainability Revolution will likely be a fully conscious operation, hopefully guided by the best science available. Educating society to value sustainable products and processes would greatly expedite this movement.

Much of the need for sustainable planning is motivated by the increasing world population,

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now doubling approximately every 40 years. Demands for food, energy and resources are also rising and great disparity in the quality of human life is apparent. Phillips [7] estimated that, at the 1996 rate of consumption, oil reserves will last about 44 years, natural gas reserves will last about 60 years, and coal will be available for about 300 more years. Phillips also estimated that reserves of several critical metals (copper, lead, mercury, nickel, tin and zinc) will last from 38 to 119 years; reserves of aluminum and iron are higher, 270 and 247 years respectively. Other resources such as certain fisheries, forests, fresh water stores and agricultural lands are showing signs of nonsustainable use. Waste handling and treatment is of continuing concern. Other environmental problems include global climate change, stratospheric ozone depletion, air quality, land use, ecological health and human health.

DESIGNING FOR SUSTAINABILITY

The global situation can easily be viewed as overwhelming. The point of this paper is on responsibly dealing with the needs to translate sustainability concepts into the future design of industrial processes. In general, the engineering curriculum must deal with the application of science and mathematics to the utilization of energy and the conversion of materials; perhaps a broader perspective is needed to meet current and emerging challenges. A dictionary definition of engineering is the application of science and mathematics by which the properties of matter and the sources of energy in nature are made useful to man in structures, machines, products, systems and processes [10]. A key phrase in this definition of engineering is that the efforts of engineers be useful to man; this suggests the need to consider the concerns of a number of stakeholders in our activities. Woolard, a former CEO of DuPont says [9]:

> For a sustainable process to proceed, it has to be good for the environment, good for people, and good for business. The reality is that companies cannot take time out from making money and growing our businesses in order to convert to sustainable processes. The adoption of sustainability has to run concurrently with corporate performance that meets standards of business success, consumer satisfaction, and shareholder expectations in a modern market economy. This means that although the idea is revolutionary, its implementation has to be evolutionary.

In a recent report, CEOs of DuPont and Procter & Gamble, identify markets as the primary link to improving and revolutionizing the activities that are at the heart of the interrelationship between production and consumption [6]:

> As the world society approaches a balance between economic, environmental and social sustainability, markets are transparent, stimulate innovation and are effective in their role as catalyst for change toward a better quality of life for everyone.

In the teaching of process design and analysis, we are largely preparing our students to provide continuous improvement for existing manufacturing/production facilities or to design similar-purpose facilities for the future. A simplified manufacturing/production process is shown in Fig. 1. These processes utilize energy to convert raw materials to products. Waste materials may be unreacted raw materials or by-products and may be referred to as emissions. The constraints on these processes are subject to the policies of the parent organizations and the dynamics of the marketplace, both of which are likely to change over time.

Pollution prevention and energy conservation

Regardless of the process constraints the primary role of engineers has and will continue to be the efficient conversion of:

(1) raw materials to products
(2) efficient energy utilization
(3) control of emissions.

Items (1) and (3) are referred to as pollution prevention. Certainly an understanding of the global environmental situation will be useful as a responsible world citizen and in understanding the direction of future changes in the marketplace and policy, but engineers have primary responsibility of achieving pollution prevention and energy efficiency in their organizations.

Four drivers for incorporation of pollution prevention and energy efficiency into industrial waste management strategy are:

1. *Cost savings* (e.g. recovery of a valuable raw material or reduction in waste management or energy costs).
2. *Safety and health* (e.g. prevention of an emission which could have safety or health effects on employees or the local community. These emissions must be reduced to regulatory levels. Regulations ensure that health is not impacted

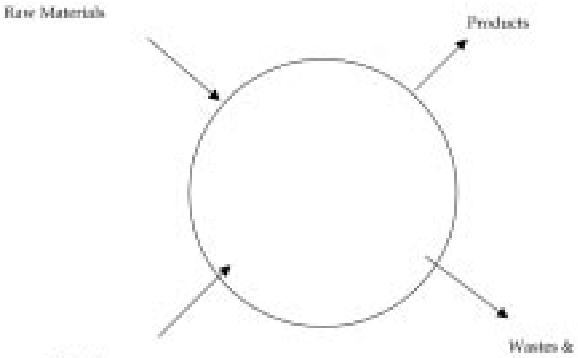

Fig. 1. Simplified production/manufacturing process.

and that all industries are playing by the same rules and incurring the same costs),

3. *Societal needs* (e.g. prevention of emissions that may have global or cumulative effects, such as greenhouse gases. In this case, regulations are needed to ensure that all industry is treated fairly worldwide. Global treaties are needed, such as the Kyoto Protocol).
4. Public relations (e.g. it is sometimes difficult to quantify in ordinary economics but the goodwill of our communities is very valuable).

RESULTS OF EDUCATION IN SUSTAINABLE DEVELOPMENT

A key role of engineers in the transition to more sustainable activities is likely to remain that of seeking to achieve pollution prevention and energy efficiency in manufacturing /production activities. A fundamental concept that has proven useful in teaching pollution prevention is that of 'intrinsic' versus 'extrinsic' wastes. The same concept may be amenable to promotion of energy efficiency. Intrinsic wastes are inherent to the fundamental process configuration, while extrinsic wastes are associated with the auxiliary aspects of the process. Most wastes are somewhat in between totally intrinsic and totally extrinsic. The primary categories listed from most intrinsic to most extrinsic are [1]:

- unreacted raw materials
- impurities in the reactants
- undesirable by-products
- spent auxiliary materials: catalyst, oils, solvents, etc.
- off-specification materials
- maintenance waste and materials
- material generated during startup and shutdown
- materials from process upsets and spills
- materials from product and waste handling sampling, storage, or treatment
- fugitive emissions.

The intrinsic waste streams from production/ manufacturing facilities utilizing similar process configuration will be similar; the extrinsic waste streams from their operation may differ greatly, depending on local operating procedures.

The ongoing need for sustainable development

Typical progression in the incorporation of pollution prevention into an industry's waste management strategy usually begins with a pollution prevention audit and employee training followed by progression through three phases of pollution prevention activities. Phase I activities are operations-oriented usually focusing on extrinsic wastes; these commonsense activities include good housekeeping, inventory control, waste separation, and simple recycling. Phase I activities often involve very little capital investment and tend to produce high return on investment (ROI). Phase II activities are equipment-oriented activities usually focusing on extrinsic wastes; these activities involve the addition of new equipment and/or the modification of existing equipment. The ROI for Phase II activities is typically less than that of Phase I activities and may involve including less tangible economic incentives such as long-term liability, public relations, etc., to improve the economic justification for the activity. Phase III activities are process-oriented, usually focusing on reduction of intrinsic wastes through fundamental process changes, changes in raw materials or catalysts, or reformulation of the product. The ROI for Phase III project is typically lower than that of Phase I or Phase II activities; introduction of Phase III activities are more likely to occur when a process unit is being replaced or a new unit installed.

As pollution prevention is becoming more ingrained in business culture, the above progression may evolve into a cycle where revisiting Phase I and Phase II concepts is a part of the continual improvement cycle.

The broader aspects of sustainable development

A great deal of attention has been placed on the design and operation of production/manufacturing facilities. Other relevant thoughts are [1]:

- The size and complexity of production facilities typically may increase as more of the by-products are processed into products. Recently the trend seems to be that of involving third party processors for by-product production and handling as industries seek to concentrate on core processes; in any case the extended family of facilities is likely to become more complicated. Examples of this at the DuPont Chattanooga Plant include third-party production of nitrogen, utilization of the city wastewater treatment rather than operating an on-site facility, and off-site recovery and recycle of filter media, polymer waste and waste fiber.
- Effective information and control systems aid in pollution prevention by effectively tracing routinely generated wastes, monitoring and controlling the process so that wastes from process upsets are minimized, process optimization, and optimal scheduling of maintenance activities.
- Effective pollution prevention requires involvement at all levels. Employees must be dedicated, rewarded, and trained.
- Research and development contributes to pollution prevention through identifying new processes or modifying existing processes to produce less waste, identification of new separation technology, and identifying sources contributing to waste production or impeding effective recycle operations.
- Close cooperation between the customer and suppliers of equipment and raw materials offers opportunities to further pollution

prevention. An example of this was cited above for recovery and recycle of filter media by the vendor to the DuPont Chattanooga plant.

- Many industrial customers are demanding environmental responsibility from their suppliers.
- A successful pollution prevention program requires support and commitment from all levels within the firm and must involve top management.

One final relevant thought that has been more clearly recognized after the events of September 11, 2001 is that any complete pollution prevention plan must also protect society against possible man-made catastrophic events by applying increased site security measures and inherently fail-safe designs.

CONCLUSIONS

A key role of engineers in the transition to more sustainable activities is likely to remain that of seeking to achieve pollution prevention and energy efficiency in manufacturing /production activities. A fundamental concept that has proven useful in teaching pollution prevention is that of 'intrinsic' vs 'extrinsic' wastes. The same concept may be amenable to promotion of energy efficiency. The feasibility issues for promotion of pollution prevention (and energy efficiency) are closely related to the category of the activity (i.e., Phase I, II or III) and the general acceptance of this approach. Most of the focus here is on pollution prevention but the concepts presented should largely apply to energy efficiency.

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