Chemical Engineering industry Transition towards Sustainability

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ABSTRACT

The past decade has seen vast changes in both chemical industry and chemical engineering profession for example what was once a vibrant industry in some countries are now mere memories of yesteryears. Similarly the current chemical engineering workforce is undergoing many challenges that have affected the sector from pollution control, CO_2, NOx SOx emissions to labour shortages to an economic downturn. So what are the Implications for chemical engineering? Why has it lost its shine? Will chemical engineering become a seasonal profession, at the mercy of commodity prices? Can Chemical Engineering afford to live in isolation, and must it consider interactions amongst industrial processes, human and ecological systems. At the present rates, i.e. lack of skilled labour and dwindling interest from students studying degree level (or above) presents the biggest challenge for chemical engineering. This article investigates the nature of transition required to assist chemical engineering towards sustainability. The purpose of this study is to assist the chemical "industry" in defining the transition by developing awareness, knowledge, and ability to minimize the environmental impact of the chemical manufacturing processes towards sustainability. We argue that the chemical engineering profession is uniquely placed to support in sustainability and the industry and professionals need to move away from the present philosophy of optimizing the existing process to a new generation of novel processes that would eventually lead to more equity in prosperity and stable economical situations worldwide. It remains to be seen whether these old-established 'invisible` barriers will be overcome in the future or the professional formation of a contemporary chemical engineer will remain halfway between paradigms of technocracy with this mind set. For this reason sustainability in chemical engineering was once confined to research needs however now it is to be the "new frontiers".

INTRODUCTION TO CHEMICAL ENGINEERING

Energy is perhaps among the biggest issues in sustainability. Global warming and climate change are of increasing concern as it is more widely realized that our planet does not provide an infinite capacity for absorbing human industrialization in the 21st century. In its short history, chemical engineering has moved far beyond the bulk production of commodity chemicals that first motivated the discipline's development (Stouffer *et al.*, 2008). Chemical Engineers need to have an understanding of these issues so that they will be able to design products and systems that integrate sustainability framework it is widely accepted that Present-day thinking has led away from previously accepted practices such as end of the line measures for example dilute the pollutant or dump it in a sufficiently remote inaccessible place was acceptable, where as nowadays products and systems are designed to preventive or minimize the pollutants. Chemical engineering and its products have a significant impact on all of our lives. Chemical engineers are involved in the design and management of many industrial processes that help feed, clothe us, keep us warm, mobile and healthy these include Pharmaceuticals, biotechnology, food and drink, metals, plastics, energy and water. Consequently with the aid of chemical engineers the "age of oil" has laid the foundation for unprecedented economic growth. However, there are downsides to this activity since it consumes finite resources and the generation of waste products. If we review history the 18th century rise of the British Empire was fuelled by the Industrial Revolution, which was in turn powered and to some degree symbolized by the heavy use of coal. Modern Germany's late-19th century industrial expansion and its subsequent imperial aspirations were likewise supplied and characterized by massive coal consumption. The 20th century has been labelled "the age of oil," At the close of the 20th century, however, a new energy paradigm, forged by technological advances, resource and environmental constraints and socioeconomic demands, has begun to emerge (Flavin and Dunn, 1999). Thus the contribution of chemical engineers and the engineering profession to economic growth and in turn the consumption of natural resources has been highlighted, rendering the sustainability a central engineering issue. In the context of this paper, "sustainability" is as per (Brundtland, 1987) report. To establish a discussion on sustainability in chemical engineering one would ask, How do I/we as engineers contribute towards sustainability for example by helping the victims of the Asian tsunami, Australian drought, the extreme poverty of so many of our fellow humans face daily in our region, East Timor, Solomon islands, Maldives, Malawi, and the disappearing islands. These are some questions the industry and engineers alike are likely to encounter. (Miller *et al.*, 1998) asked whether humanity has the social and ecological capacity to keep on advancing and inventing new tools new products and new ways of organising life. Furthermore how would we deal with the concepts of Preservation versus change, conservatism versus dynamism, incrementalism versus radicalism these are the dividing lines of the sustainability debate as we reached not only a new century but a new millennium. What will the costs and the risks are for the environment? What does it all mean for our traditions? Who will oversee it? Governments or global institutions? what is the respective role in this transitions (Hasna, 2009a) given that all the mentioned factors are intertwined, Figure 1 depicts the interaction and relationships that exist between government, industry and the public. The role of government is to legislate for the public good, and though it will foster economic growth, it must also ensure that workers, the general public and the natural environment are adequately protected. Because of the many accidents and disasters which have occurred since the industrial revolution, public and media attention has become much more focused on environmental issues. The industries that came under scrutiny initially were those in the chemical process and heavy industry sectors; however, environmental issues are now a matter of concern for all (Young *et al.*, 1997).

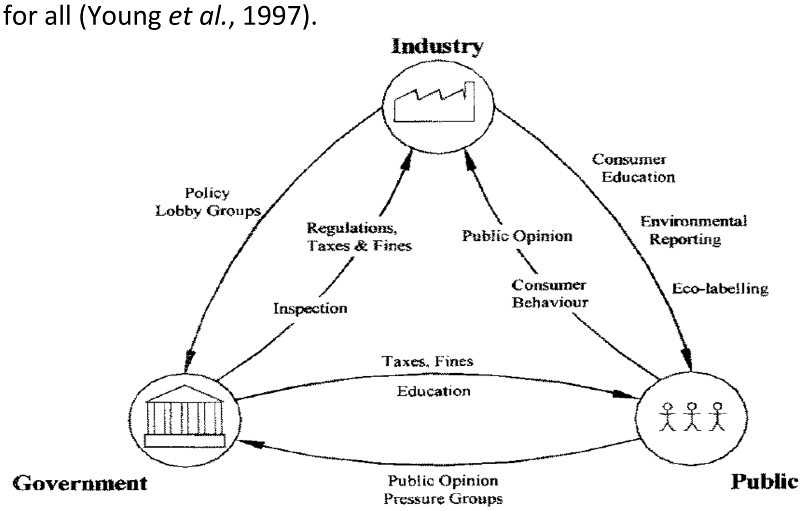

Figure 1: public government & industry on environmental issues (Young, 1997)

The Chemical Industry

The scale of the global chemical industry is enormous: in 2003, the total value of global production exceeded US$1.7 trillion (Erera *et al.*, 2005). There are more than 80,000 chemicals registered for use in the United States, and an estimated 2,000 new ones introduced each year (National Toxicology Program, 2009). According to (Anastas, 1994) the chemical industry is the major source of toxic pollutant release in the United States.The chemical industries labelled it as 'dirty' by definition, the dirty image is significantly tied to public perceptions of its business operation and product (Natori and O'Young, 1996; Albrecht, 1998; Vangelis and Devashish, 1998; Freemantle, 2002; Milne and Patten, 2002; Adams, 2004; Phillimore and Bell, 2005) according to (Lancaster, 2002) the Image of the Chemical Industry is often perceived by the public in the United Kingdom as: Dirty, Secretive, Patchy knowledge of what we do, Motivated by profit, We only improve because we are forced to, The industry is unloved and disliked in comparison with all industries except nuclear and tobacco. The public perception is also mirrored in Australian where The Loy Yang A, Hazelwood and Yallourn W power stations, all in the Latrobe Valley, were found to be among the highest-emitting plants in the country (Morton, 2009).

Technology Society and Engineers

Technology driven knowledge society and knowledge economy have become common terms in our twenty first century vocabulary whilst globalization has deepened the economical interdependence of countries and simultaneously caused a borderless mega competition (Hasna, 2009b). The (FIDIC, 2002) International Federation of Consulting Engineers states that engineers are uniquely positioned to provide leadership in implementing sustainable development. Because of their knowledge and skills and the central role that they play in the development of society, chemical engineers have a tremendous responsibility in the implementation of sustainable development. In addition, the (WFEO, 1997) World Federation of Engineering Organizations, it states that professional engineers provide innovative technically excellent and cost effective solutions to society's problems and are largely responsible for the high quality of life enjoyed by the world's developed countries. The increasing globalisation of technology, communications and commerce, the growth of regionalism (Europe, the Americas, and the Asia Pacific region), an increase in religious and ethnic tensions around the world, threats to our environment (Sutton, 2007). finally the successful introduction of inventions in society resulted in increase in prosperity of Western societies during the 20th century; hence technological developments and innovation played a key role in the growth of Western economies (Vollenbroek, 2002). likewise the past decade has also seen many technological innovations in energy efficiencies, despite the paradox of innovation and regulation (since the former is concerned with re-writing the rules and replacing the incumbent products and processes specified by the latter), both innovation and regulation are required to move the industry toward a more sustainable future (Dewick and Miozzo, 2002). finally, as cites and large metropolis centers struggle with climate change and fresh water supply society technology and engineering are tightly netted, for example for a large city as Melbourne Victoria chemical engineers are on the mend supplying technology for membrane Filtration or reverse osmosis for water Desalination plants.

THE AUSTRALIAN CHEMICAL INDUSTRY OVERVIEW

The Chemicals and Plastics industry is a diverse manufacturing sector comprising of base and feedstock products, speciality and refined chemicals, intermediate goods and components as well as finished products. It plays an important role in manufacturing, with 70% of its outputs used as essential inputs to other manufacturing and industrial sectors (automotive, building and construction, packaging, medical, agriculture and mineral processing) (Productivity Commission, 2008). By 1985 its turnover (including plastics, paint and pharmaceuticals) was 10,840 million dollars, its added value 3,923 million dollars and it employed 83,630 people (Industries Assistance Commission Report, 1986). It is also one of the country's key strategic and enabling industries, on which other industries depend (Australian Academy of Technological Sciences and Engineering, 1988).

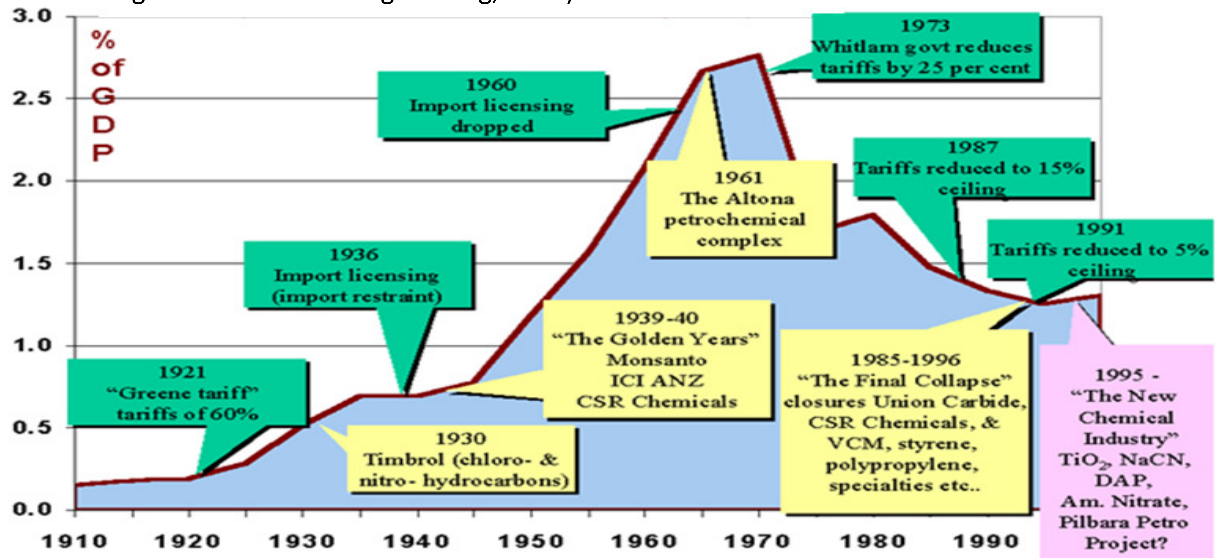

Figure 2: Australia's chemical industry 1905 -1995. Value added as % GDP, (Van Santen, 1998)

In 1986 investment was estimated to have exceeded 2500 million, it employed 10,000 people it assisted the export revenue, the industry accounts for 21 percent of research done in manufacturing sector (ACIC, 1986). Peaking in the mid 1970s, after three-quarters of a decade growing strongly to represent 3 per cent of GDP, the importance of the chemical industry collapsed to just one-half in just two decades. With the reduction in tariffs and the undoing of protectionism in late 1980s came a decline. In 2004/05 the Annual turnover was over $30 billion or 9% of total manufacturing. The industry employed over 82 thousand people or about 8% of the total manufacturing industry workforce. It added about $9 billion in value or about 9% of total value added by manufacturing. However, annual imports of about $14 billion make up 9% of the total manufacturing sector's import bill. Furthermore, imports have grown at an average annual rate of 3.4% in the three years to 2004/05. Thus, even with annual exports of around $4 billion, there is a significant balance of trade deficit (Australian Government, 2004).

SUSTAINABILITY ANALYSIS

The decline of the chemical or manufacturing industries in OECD countries and the shift in manufacturing to offshore countries mainly Southeast Asian developing countries in particular India and China hence altering the distribution of wealth from the traditional Western developed countries to developing countries. The relocation of polluting or unsafe chemical processes or the migration of "dirty" industries from developed countries to underdeveloped (Menezesa and Antunes, 2005). These mentioned together with renewable energy, potable water, safe food, and clean air are part of the societal sustainability challenges chemical engineers in Australia and abroad will inevitably engage during professional practice and it also raises questions concerning the ground rules of engineer's accountability and contribution to society.

The major conundrum today for chemical engineers is the question whether they are motivated by profit margins, technical advancement or upholding sustainability in our work ethics? Hence, it is worth wondering whether the society is on course for further dramatic social and economic change and whether such changes as they do take place can be steered to benefit all of human kind i.e. sustainability and growth. On a local scale understanding the wider international challenges facing Australian chemical engineering industry as a whole, is part of the professional practice. A number of notable scholars have reviewed chemical engineering and sustainability (Haile, 1999; Lange, 2002; Lempert *et al.*, 2003; Nissen, 2003; Romero-Hernandez, 2004; Tsoka *et al.*, 2004; Abraham, 2005; Grassian, 2007; Poliakoff and Licence, 2007; García-Serna *et al.*, 2007). It has been widely reported that sustainability is still approached as environmental compliance issues for decades; on the other hand it is recognized as one of the key challenges for the industry. It is now widely accepted that this can only be achieved by balancing all three dimensions of sustainability and the industry is already working actively towards this goal (Azapagic, 2004b).

the disposition of Ecological utopia Ecotopians (Callenbach, 1975) in the chemical industry is not one of rejection but rather one of careful selection on the basis of sustainability (Sheldon, 2008). These concepts carry further by the industry mantra of reduce, reuse, and recycle. furthermore, the international institution of chemical engineers (IChemE, 2007) detailed within six thematic areas; seen by members in terms of priority the survey lists as follows;

1. Sustainability and Sustainable Chemical Technology
2. Health, Safety, Environment and Public Perception of Risk
3. Energy – Securing Reliable and Affordable Supplies in the Near Term
4. Food and Drink
5. Water
6. Bioprocess and Biosystems Engineering

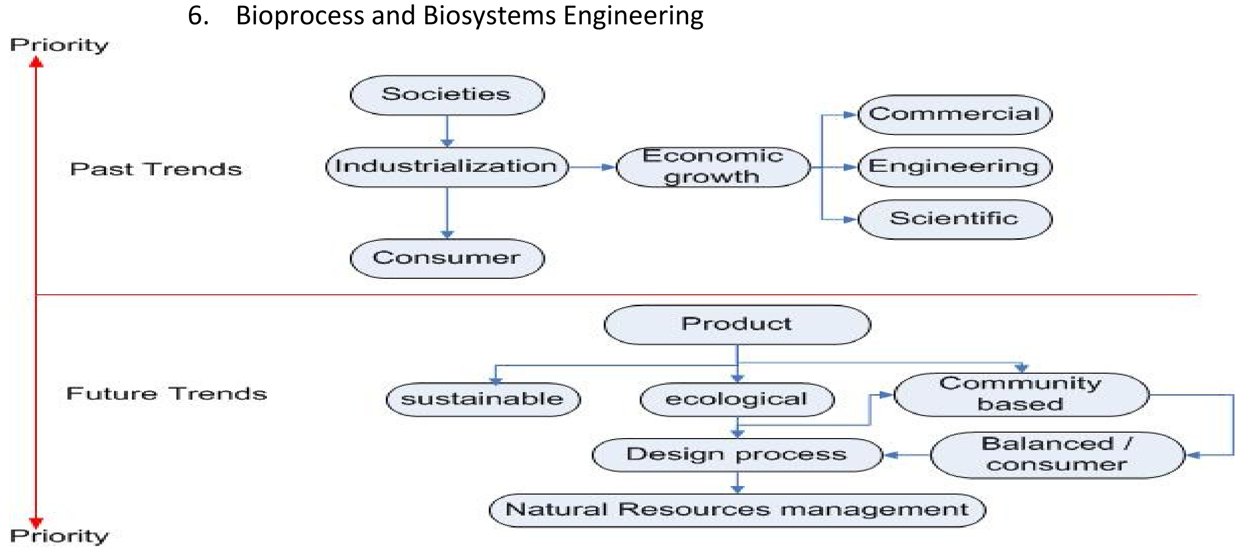

Figure 3: Past and Future trend in Engineering Designs

Chemical engineers subscribe to sustainability, according to (Furlong, 2004) the process industry commitment to the environmental and social components of sustainable development lags behind that of their employees. on four types of tools needed for building the sustainable systems reported by (Sikdar, 2007b; Sikdar, 2007a). Depending on the scope of an objective, one of the four or all four types might be employed in designing cleaner technologies. These are

1. Metrics tools; for measuring progress towards sustainability,
2. Analytical tools; for problem identification, problem analysis, and decision making for design,
3. Process tools; for designing unit operations and processes, and
4. Economic tools; for assessing the incentives for cleaner practice.

The scope of this research will limit discussion on item 3 and 4. Highlighting the changing nature of the profession is illustrated in a simple example of past and present trend in product development shown in Figure 3, where priority has shifted from consumer to satisfying the management of natural resources. Gone are the days were the motor industry used to promote the petrol guzzling 5 litre V8's and income new-age ,fuel efficient 1.5 litre motor vehicles.

Sustainability Metrics

Chemical Industry has traditionally been using only standard financial indicators to track their business effectiveness (Krajnc and Glavic, 2003) nowadays, due to demands from various parties (such as customers, suppliers, employees, national regulators, banks, insurance companies, shareholders, trade associations, local community), sustainability reports are emerging as a new trend in corporate reporting, integrating into one report the elements of financial, environmental, and social facets of the company (Global Reporting Initiative, 2002). Sustainability reports usually introduce a set of indicators that can be used to measure sustainability performance of a company. They translate sustainability issues into (usually) quantifiable measures of economic, environmental, and social performance with the ultimate aim of helping address the key sustainability concerns (Azapagic, 2004a) and to provide information on how the company contributes to sustainable development (Azapagic and Perdan, 2000).

A definite need has been identified to develop a comprehensive framework of sustainability criteria that focus on the performance of the industry sector and more specifically the sustainability assessment of companies. Dozens of indicators have been suggested for use in determining improvements made to chemical process, a manufacturing site, or a manufacturing enterprise (Sikdar, 2003). Important developments for the issue of sustainability reporting were the foundation of the World Business Council for Sustainable Development (UNEP, 1997), the foundation of the (Global Reporting Initiative, 2002) and the development of standards for environmental management systems, such as the ISO 14000 and EMAS standards (OECD, 2001). One of significant studies on sustainability metrics was sponsored by the Centre for Waste Reduction Technologies (CWRT) of (AIChE, 2004) for evaluating process alternatives. The other significant effort was made under the auspices of the (IChemE., 2002) in the U.K. In this effort, the indicators are specifically grouped into environmental, economic and social categories.

Veleva and Ellenbecker (2001) discussed the indicators of sustainable production, including their dimensions and desirable qualities. Decision-making processes encompass uncertainty in particularly in the state of natural systems and the impact of human activities upon natural systems. Decisions will always involve a certain amount of risk and uncertainty (Dovers and Handmer, 1995). Directly addressing the causes of such uncertainty through a variety of tools and precautionary measures such as indicators and risk assessment will reduce the level of uncertainty over time. Ecological foot printing, LCA, green engineering and sustainability have been discussed numerously in literature. For instance the 12 Principles of Green Engineering provide a framework for designing new materials, products, processes, and systems that are benign to human health and the environment. However a design based on the 12 Principles goes not beyond baseline engineering quality and safety specifications to sustainability factors, which are considered fundamental factors from the earliest stages of design of a material, product, process, building, or a system (Zimmerman, 2006).

Mimicking nature

Next Generation Environmental Technologies focuses on the redesign, at the molecular level, of manufacturing processes and products, with the aim of reducing or eliminating the use of hazardous materials (Lempert *et al.*, 2003). The most notable example of sustainability and resilience is probably "Nature". Hence learning from nature is one method of achieving the transition of chemical industry to sustainability by mimicking nature. Mimicking of bio-processes (biomimicry) is a new frontier in chemical engineering. The following is a list of the some of the developments on that front; Thermal processes in desalination plants mimic the natural process of producing rain. Condensing steam is used to supply the latent heat needed to vaporize water (Abu Arabi, 2007). The architecture of the lung uses minimal entropy generation, which is equivalent to the highest thermodynamic efficiency for air transport (Gheorghiu *et al.*, 2005), Such fractal structures of channels are effective fluid distributors and collectors, connecting a huge volume and surface area to a single point. This concept led us to propose a fluid distributor, the so-called fractal injector, which distributes gas or liquid uniformly over a large reactor volume from a single inlet (Coppens, 2005). The fluid leaves the injector via outlets at the deepest generation (the "twigs"), which are equidistant to the inlet, resulting in equal pressure drops from the inlet to each of the outlets, and uniform flow. The low pressure drop saves energy. In a small reactor, the distributor only has one or two generations of branching tubes. In a larger reactor, generations are added, conserving the size of the outlets and the distance in between. This differs from conventional reactor design, in which larger tubes are used to distribute fluid over larger reactor vessels, with often empirically determined outlet position(s) and added baffles or mixers to compensate for scale-dependence (Coppens, 2008).

In addition, the chemical industry has led a number of sustainable commercial productions of chemicals using Metabolic pathway engineering (Chotani *et al.*, 2000), a rapidly developing technology Metabolic engineering to channel that resource into desirable building blocks with great potential to impact dramatically the development of the bio-based economy (DOE, 1998). For example Aromatic compounds provide some of the first examples of chemical production using microorganisms through the use of pathway engineering such as the natural end products of the aromatic amino acid pathway, tryptophan.

Finally, there are a number of barriers involved in switching to sustainable practices, these are categorized as technical and non technical. Nontechnical barriers include slow turnover of existing equipment, higher upfront costs, slow return on investment, limited incentives, inflexible regulations, and customers' demand that sustainable alternatives must also be superior to existing products (Satterfield *et al.*, 2009). However many of which cannot be fixed simply by improving pollution abatement costs, technology and disruptive changes. In terms sustainability transition in chemical engineering industry it is evident in tertiary education where it is not uncommon for environmental courses and others find way in chemical engineering undergraduate programs (Gadala-Maria, 2002; Boyle, 2004; Yu *et al.*, 2008) Micro/nano processing, Alternative (renewable) energy, Health safety and Environment, Water Pollution Control, Air Pollution Control, Hazardous Solids Waste Processing, cleaner production, Life cycle analysis, green chemistry and engineering, industrial ecology and sustainable development; Waste audit and inventory, and pollution prevention options for unit operations; Environmental impact assessments: LCA assessment, total cost analysis and environmental systems analysis; Eco-industrial parks: material and energy exchange and integration, reduce/recycle/reuse of wastes and by-products (Bi, 2005). These courses have promoted sustainability as educational priorities fully embed its values into the chemical engineers training.

Validation of the Transition

At the present time Chemical industry proactive position is evident to promote sustainability, as the reality of the changing world around us. This position is required to prevent the chemical engineering profession being caught by extreme swings (Batterham, 2003). According to Einstein, and problems cannot be solved at the same level of thinking that lead to their creation. If so, problems arising from "old" design thinking cannot be solved using "old" engineering thinking. A "new" engineering concept of sustainability cannot be derived from the design engineering of the "old" belief system that is at the root of most sustainability issues. It must build from the ground up, starting with a new belief system. since Chemical engineers are primarily interested in process systems engineering in which the systems approach is employed in the design and operation of chemical processing plants (Perkins, 2002). The chemical industry is now applying technical expertise of natural resilience to a number of sustainable manufacturing areas, as it is widely acknowledged that end-of-pipe approach typically adds cost and operational burden.

Switching to more sustainable processes, practices, and products within the context of conventional business practices involves some barriers. The (National Academy of Sciences, 2005) has referred to it as Grand Challenges for Sustainability, as depicted in **Figure 4**, large arrows address the transition from current thinking to the ideal vision for the chemical industry over the next 100 years. In addition innovation systems and technological transitions were addressed by the outcome of the American Chemical Society (ACS) and American Institute of Chemical Engineers (AIChE) workshop that explored the nontechnical barriers and incentives to industrial implementation of sustainable technologies and practices (Satterfield *et al.*, 2009), are listed as follows;

1. Establish a Clear, Measurable, Actionable, and Universally Accessible Definition of Sustainability
2. Create and Communicate Better Information for Better Decision-Making
3. Tear Down Silos and Build Cross-Functional Efforts
4. Make Sustainability a Top Priority; Reframe Sustainability As an Opportunity, Investment, and Pathway to Innovation
5. Develop Forward-Thinking, Collaborative Regulations or Incentives with the Capability to Adapt
6.

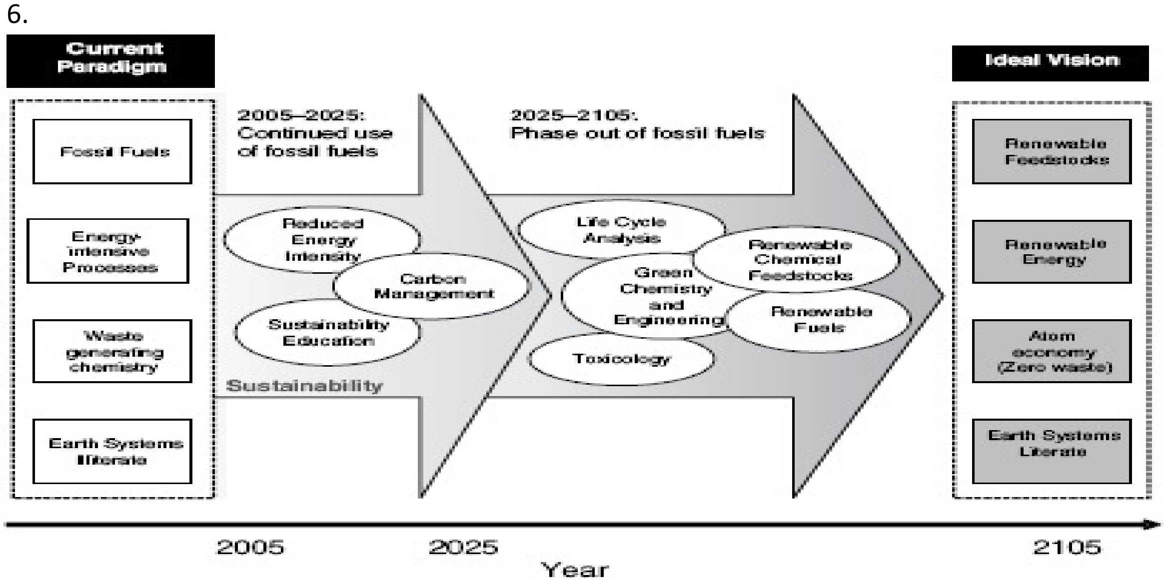

Figure 4: The Grand Challenges (ovals) for Sustainability (National Academy of Sciences, 2005)

CONCLUSION

In this paper, I have presented a view of the Chemical engineering industry changes and the pursuit of sustainable development. The progress is inextricably linked through their involvement in a diverse range of industries to achieve holistic aspects of sustainability. We have witnessed the engineering profession as whole and in particular chemical engineering evolve by the birth of numerous sub-disciplines within chemical engineering, during this same period the market has changed significantly. Chemical engineers are integral to the delivery of a sustainable society and have a paramount importance in global warming since the chemical processes, unit operations, drying, distillation, separation, extraction, evaporation, absorption, etc Separation, Sequestration, and Utilization of Carbon Dioxide is a core component of their daily work. however, it is remarkable that most sustainability discussion in literature are dominated by no engineers or professions on the periphery to engineering, one of the key points this paper hopes to have highlighted is the need to remove the silo philosophy and include engineers in these discussions. Over the last decade there has been a great swing in the chemical engineering culture especially towards clean and green technologies. furthermore, with the advent of IEAust Engineers Australia sustainability Character (2007) and IChemE, The Institution of Chemical Engineers Sustainability Performa, and AIChE, Waste Reduction Technologies studies it appears that the chemical engineering profession has started the discussion and is on course to integrate sustainability into daily practices. From an institutional perspective similar principles were reflected in national and international regulations and agreements. For example, in Australia these include the principles of ecologically sustainable development as outlined in the Intergovernmental Agreement on the Environment (IGAE) which was signed by the Heads of Australian Governments in May 1992. While humanity has an unprecedented opportunity to succour, chemical engineers are a key driving force for integrating sustainability. Thus presenting opportunities for innovation, superior product development, and cost savings.

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