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Industrialization is a desirable state to achieve for undeveloped countries as it improves the general standard of living for the local population through increased wealth. However traditional routes to industrialization typically involve the burning of fossil fuels adding CO_2 to the atmosphere. Resource consumption in industrial processes is also currently unsustainable as the raw material is not recovered at the end of a products life. With these points in mind a project is proposed to use new sustainable and environmentally friendly technologies to develop a route to industrialization for undeveloped nations.

Introduction

In the early 19th century Charles Babbage surveyed the efficiency of the new technology of machines and manufacturing techniques such as assembly line production compared to the traditional method of hand crafting by single artisans. He was able to show by direct comparison that these new technologies, now associated with an industrialized economy, are able to more efficiently use labour and process raw materials into finished goods (Babbage, 1835). Modern developments in manufacturing such as lean manufacturing reduce waste to a minimum (Womack & Jones, 2003). In a world where resource scarcity is becoming increasingly important (Cohen, 2007) it is vital to start addressing resource consumption on a global scale and begin working towards more sustainable use. Taking an estimate of the worlds available raw materials and assuming world wide consumption at 50% of the average United States consumption rate per capita gives approximately 20 years before resources run out (Cohen, 2007). With many nations still developing if this is not addressed then either our resource base will run out or developed nations will have to prevent undeveloped nations from developing and hence impose a lower standard of living on these people.

An additional concern is that nations currently developing are still doing so via a route crudely similar to that undertaken in the 18th and 19th century during the first industrial revolution. Namely this is by burning large amounts of fossil fuels to supply energy to a growing economy. An excellent case for this is the rising CO_2 emissions by China in the last decade. China has now become the highest producer of

CO_2 emissions. Similar trends have been seen in India but without as dramatic increase (Raupach et al., 2007). It is now accepted that these rising CO_2 emissions from fossil fuels could have a dangerous impact on the climate and hence CO_2 emissions need to be reduced to an acceptable level (Hoffert et al., 2002). Again this provides a significant problem for developing nations.

This paper will examine the idea of an environmentally friendly method for an undeveloped nation to reach an industrialized state. In this examination the primary goals and limitations will be outlined. Further to this a more in depth study of technologies and methods that might be used to achieve these goals are outlined along with areas where existing technologies are missing. Not only is this important for the developing nations but it is also important for the developed nations. Currently, undeveloped nations and developing nations provide only 41% of global CO2 emissions and have provided only 23% of global emissions since the first industrial revolution (Raupach et al., 2007). Developed nations therefore provide a significant portion of the global CO_2 emissions while only accounting for approximately 20% of the worlds population. Although numerous environmentally friendly manufacturing techniques are being developed few will see quick uptake into industry as there is little incentive for a company to scrap its current industrial capital in favour of a green alternative. Social conscience is causing companies to offer green alternatives but without strong economic competition from environmentally friendly products or legislation it is possible that industry in developed nations will not reduce CO_2 emissions fast enough to avoid significant impact on the climate. By developing a route to industrialization for undeveloped countries it could be possible to troubleshoot the emerging green manufacturing technologies and implement them in an integrated way without having to integrate with existing infrastructure and technologies. This would provide competitive green alternative products that would provide a strong economic incentive to companies in developed nations to adopt the new green manufacturing technologies. Additionally as the technologies would then be established it would also be easier for implementation.

Scope and Limitations

The scope of this project is to define a path that an undeveloped nation might take to achieve an industrialized state without significantly impacting the environment in a negative way. Taking the three sector classification system of an economy as outlined by Colin Clark in 1957 and Jean Fourastiè in 1966 (Binder, Jänicke, & Petschow, 2001) one can say that an undeveloped country is characterized by a primary sector economy (farming, livestock breeding, exploitation of mineral resources). The move towards an industrialized state is historically characterized by an expansion of the secondary sector (manufacturing) and subsequently the tertiary sector (service). In order for the secondary sector to expand quickly (within a normal lifetime) the labour force must be freed up from subsistence living. As such an effective starting point could be to address the seven indicators for poverty outlined by Gordon 2005 (see Table 1). The improvement of the efficiency of agriculture will free up labour. This labour can then be used in expanding the secondary and tertiary sectors to support the new agricultural process and to produce products and infrastructure required to address the need for safe drinking water, sanitation and shelter. By addressing these factors you also ensure that your labour force remains effective for continued development.

Indicator	Minimum level to be above poverty
Food	Average Body Mass Index above 16
Safe Drinking Water	Not sourced directly from rivers or ponds and be within 15 min walk from any home
Sanitation Facilities	Toilets must be accessible in or near the home
Shelter	Home must not have more than 4 people living in them per room and floors are not dirt, mud or clay
Health	Treatment available for serious illness or pregnancy
Education	School is available for everyone to be able to learn to read
Information	All people must have access to an information source (newspaper, radio, TV, computer or telephone)

Table 1: Indicators of poverty (Gordon, 2005).

A free and capable labour force alone will not result in industrialization. In addition to the labour force a supply of raw materials to be processed into goods must be established. Once the efficiency of agriculture for food is improved it is then important to start introducing industrial crops that will provide sustainable raw materials for industry. Initially these could take the form of crops to be processed for energy needs. Later crops for plastics, fibres, resins and more complex chemical species can be introduced according to the local environment. These crops need to be analysed for their sustainability. A number of frameworks exist, the helix of sustainability demonstrates the life cycle analysis approach, analysis in terms of being carbon neutral is currently the standard for environmentally sustainable products and an alternative novel method that could be used is in terms of being energy neutral. For the economy of a nation to be energy neutral it would need to balance the total energy lost within the economy with the total energy captured from the sun within the nation. If this is balanced and all processes in the economy utilize sustainable cycles then the industrial output of the nation can carry on indefinitely.

Currently this paper has not outlined any limitations on what the project aims to achieve. It is reasonable to assume that once the required technology and infrastructure are in place the economy is then capable of sustained development without further guidance or input. As such once a stable food supply is achieved, raw materials are available for manufacturing and the necessary tertiary sectors are available to maintain the technology in use the “revolution” phase of the industrialization process is over and continued growth is possible without further intervention.

Enabling Technologies

The bulk of the work this project entails is surveying existing sustainable and environmentally friendly technology and determining ways to integrate them with each other to form larger systems. The implementation and integration must also be examined from the minimum existing infrastructure viewpoint as well. The following sections will discuss existing technology and research that is already known to the author and ways that they might be integrated to form a complete system.

The Cycle Concept

In sustainability the concept of following a cycle is of significant importance. If the flow of energy and mass in an economy is cyclical then all waste becomes the raw materials for the next generation of products. This means the cycle can carry on indefinitely. The formalization of this concept is embodied in the helix of sustainability (Kirwan, Tucker, & Johnson, 2003). The helix of sustainability is a concept that can help traditional manufacturing processes become more sustainable by mapping its models of raw material use and re-use onto those of nature. It is a total systems approach and should be central to the implementation and integration of the new environmentally friendly technologies so that the entire economy is operating as close to a closed cycle as possible. It should be noted that by closed cycle this does not assume zero loss, but simply a zero net loss in energy such that the loss is balanced with the gain from solar input.

In order to implement the helix of sustainability to the total economic plan each step must first be subjected to life cycle analysis (ISO14040, 2006; ISO14044, 2006). By doing this the minimum required support infrastructure and raw materials can be determined as can a quantitative measure of the waste streams. This then provides the necessary data to integrate these waste streams into new processes, potentially undeveloped, to produce either new products or new raw materials that can be fed back into other processes.

Basic Needs

As outlined above the first stage of development is the addressing of the basic needs of the labour force in order to free their time from subsistence to industrial production. As much of the labour will be occupied by agriculture the introduction of new agricultural techniques and equipment is a vital first step. One such example of this is what is known as “organoponicos” which is a combination of organic farming and hydroponics developed in cuba (Ewing, 2008). The technology was developed in response to a lack of industrial fertilizers and as such has developed techniques that could be applied to countries where the cost of importing, handling and transporting these chemicals would prohibit implementation.

The most useful development from the organoponico concept is the isolation of nitrogen fixing bacteria (*Azotobacter chroococcum*) which allows farmers to enrich their soil without environmentally unfriendly nitrogen fertilizers. Additionally a concept that can assist in the initial phase of agriculture improvement is the development of more advanced and efficient animal traction agriculture methods. This culminates in a “multi-plow” for use with draft animals that can be used for plowing, harrowing, ridging, tilling, sowing, covering, hilling and adapted for other operations. Further by surveying the local soil and performing crop trials it was possible to reduce the energy input and improve crop yields creating a sustainable and secure food supply (Gersper, Rodríguez-Barbosa, & Orlando, 1993).

In the talk by Michael Pollan he discusses the idea of intensive organic farming by synergistic effects between species. This variant of permaculture allows the production of vast amounts of food (claimed from 100 acres in a year, 40,000 pounds of beef, 30,000 pounds of pork, 25,000 dozen eggs, 20,000 chickens, 1000 turkeys, 1000 rabbits and more). The details of this specific farm are not relevant as any

implementation requires a case study for the local agricultural environment but there are some important points that this concept demonstrates. Specifically by using these synergistic effects the production rate quoted above was done with minimal technology and resulted in the improvement of soil quality rather than depletion (Pollan, 2007).

Beyond the supply of food, clean drinking water is also of vital importance to ensure the health of the labour force. Concepts such as solar water distillation (Foster, Amos, & Eby, 2005) are ideal as an initial technology to develop and implement as there is no need for an energy infrastructure and the equipment required is low cost. Another concept that could be applied is the use of a flow of water and standard PVC style plumbing fittings to build a device that will selectively filter sand to a specific grade. This sand can then be used as a filter to remove coarse material from water making it more suitable for use in solar water distillation (Lyons, Pankhurst, Scott, Tweedie, & Staiger, 2006).

Raw Materials

In order for the development of the local economy beyond the basic needs of survival and into an industrialized state a number of sustainable materials that suit the environmental criteria must be identified and undergo full characterization. This will allow planning for some agriculture to switch to industrial crops as food crops are gown more efficiently that will provide the raw materials to the developing secondary industry. These raw materials will either be natural such as bamboo as a structural material, a material that is extracted from the crop such as zein or hemp fibre or undergo processing to modify an extract to result in bio-origin materials such as polyurethanes.

Bamboo, a relative of grass, grows as a natural composite tube formed from cellulose fibres in a lignin-hemicellulose matrix. Thanks to its high void fraction it is very light for its structural strength (Wegst & Ashby, 2004). It holds the record for the fastest growing plant at approximately 120 cm in a 24-hour period (Farrelly, 1984) making it ideal as an industrial crop. Evaluation of the tensile properties of bamboo without nodes found that it was comparable to structural steels when stressed along the fibre axis (Lima, Willrich, Barbosa, Rosa, & Cunha, 2008). Bamboo has a long history of use as a structural material in Asia (Fu, 1993) and with proper testing and characterization to standardize its properties it could be used as a sustainable construction material.

The use of natural fibres in composites has a long history but often lacks optimization studies so often the composite shows poor performance. Hemp is an efficient fibre crop, with yields of over 3 tonnes per hectare of bast fibre (Olsen, 2004). Using a crop origin fibre such as hemp and crop origin resin it is possible to create environmentally friendly composite articles to replace traditional composites in current product designs (Tucker & Johnson, 2004). Both bamboo and hemp display very high values of specific modulus (E/ρ) and specific strength (σ_f/ρ) demonstrating the value for use as structural materials (Wegst & Ashby, 2004).

Zein is the primary storage protein in corn. It can be extracted via an aqueous alcohol solvent and can be used to form fibres or films. Relatively pure zein has a glass

transition temperature of 165^{o}C while its thermal degradation temperature is around 320^{o}C. Hence the as extracted material can also be processed using standard thermoplastic techniques producing a tough plastic article. Thanks to its amino acid composition it is insoluble in water though is still bio-degradable. It should be noted that problems with solvent recovery and high energy input are still being addressed but membrane technology offers a potential solution (Shukla & Cheryan, 2001).

The crop origin polyurethanes involve the chemical modification of oil extracted from a number of crops. The work by Coles 2008 also demonstrates the effectiveness of using a synthetic method to produce oil samples and optimize industrial processing of the oils without undertaking lengthy and expensive crop trials (3-5 years to determine if crop based oil is suitable). This method allows the selection of crops for their industrial potential rather than for food optimization (S. R. Coles et al., 2008). Polyurethanes from plant oils is an example of a crop origin resin that could be used to make composites.

Waste Stream Processing

Many of the above materials result in agricultural waste streams, typically with high cellulose content. In order to stay in line with the helix of sustainability it is important to ensure that methods for processing these waste streams into useful materials are developed. The development of both a number of specialized techniques and robust general techniques for processing this waste into useful materials would form a useful toolbox. This can then be applied to any new materials production process that is to be introduced into the economy to quickly and efficiently determine how to best integrate it. Potential technologies range from bioreactors/biodigesters to simple techniques of producing clean burning fuel for cooking and heat from a rapid reuptake carbon source.

The use of a bioreactor typically is aimed at lignocellulosic ethanol for use as an energy fuel. These reactors can take raw agricultural waste and digest the cellulose and lignin to produce sugars which can subsequently be fermented to produce ethanol (Black and Veatch Limited, 2008). As ethanol functions well in traditional combustion engines it would serve as a useful industry to develop in order to provide fuel for agricultural machinery that would further increase crop yields. Beyond that work is currently being done on the biorefinery concept (Fletcher, 2007) which differs from traditional bioreactors as it aims to extract not only raw fuels but additional useful molecules that can be used as feed stocks for further chemical reactions. Using this process the breakdown products of lignin/hemi cellulose are taken and useful molecules such as phenolics are extracted before further processing (S. Coles, 2008).

The processing of waste streams doesn't need to require a high level of capital and infrastructure though as demonstrated in a talk by Amy Smith. Taking a combination of agricultural waste left over from food extraction and combining it with a binder chosen from local ingredients Smith was able to demonstrate the manufacture of clean burning solid fuel that could be used for cooking or home heating (Smith, 2006). This fuel replaced coal obtained from local forests. This method provides the required combustible fuel without sourcing it from fossil fuels or from long term carbon sinks such as trees.

Further Development

Although the previous discussion was by no means exhaustive of the current available environmentally friendly technologies there are areas where the author is unaware of simple proposed solutions. Support infrastructure for industry such as the large scale generation of power, environmentally friendly transportation of raw materials and finished goods and sustainable infrastructure for the urbanized population required to support the developing secondary sector are such areas. Additionally the technologies mentioned in the precious section have been developed in isolation of each other. The most significant work that needs to be done to enable a route to industrialization to be developed is finding ways to integrate all the new green technologies into a larger system that may require novel support infrastructure.

Further Technical Research

In the case of power generation it is not necessarily a case of there being no possible technologies but more a case of technology that is accessible to an undeveloped country. Studies that examine the use of low cost materials to produce sustainable energy need to be undertaken such as those being done by local people within these countries (Kamkwamba, 2007). Much can be done using solar heat but many industrial processes that are optimized will require some electrical energy input. As such using life cycle analysis there needs to be studies undertaken to look at how an energy infrastructure can be developed. It is possible that initially power generation should be isolated forming small scale generation networks which can later be linked to provide a large scale distributed generation network. This would prevent the redundancy of established power generation capital and would allow for energy to be captured whenever the opportunity presents itself when a new industrial process is implemented.

Additionally transport infrastructure needs to be examined. It was shown by Braschkat et al. that the energy taken to produce a loaf of bread and transport it to distribution points was typically equivalent to the energy typically expended if one were to drive to the distribution point and purchase only the single loaf (Braschkat, Patyk, Quirin, & Reinhardt, 2003). This demonstrates the need for finding ways to minimize the energy consumption for personal transport. It has been shown that in a typical car approximately 6% of the energy from burning the fuel goes into accelerating the car and less than 1% goes into moving the driver. On top of this as much as 75% of the fuel used is caused by needing to shift the weight of the vehicle. This shows that designing lighter, smaller vehicles immediately provides energy savings is an important goal in developing environmentally friendly personal transport (Lovins, Datta, Bustnes, Koomey, & Glasgow, 2005).

Implementation

Initially the Industrial Revolution was driven by innovation bringing new technologies, shifting people from subsistence farming to developing secondary sector industries in cities. With the innovation coming from an external source (the product of this research) the key driver would be education. Specifically this will involve the transfer of knowledge into the nation and subsequently from person to person. In order for the development to stay green one needs to focus the education around the cycle concept of sustainability and consciousness of environmental impact. By instilling these values in the local social and economic systems present an

environmentally friendly mindset can be developed. Beyond the education an additional area that must be addressed is how to handle the funding of new capital in the developing nations. Care must be taken to avoid exploitation of the local people yet retain flexibility to make investment attractive.

Summary

This paper has presented an argument for the industrialization of undeveloped nations and an argument for developing a route that is environmentally friendly for doing so. It has outlined a rough structure that this route should follow. A number of potential technologies are proposed as possible candidates for implementation in this industrialization route and their value is reviewed. One major area of needed research has been outlined, namely the integration of these different technologies and the design of the support infrastructure for the new industries. Additional points are raised on the difficulties of the implementation of any route that is developed.

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