Journal of Basic and Applied Engineering Research
p-ISSN: 2350-0077; e-ISSN: 2350-0255; Volume 3, Issue 12; October-December, 2016, pp. 1046-1051

http://www.krishisanskriti.org/Publication.html

Drivers for Changing the Way We Convert Energy to Usable Form and their Relevance in Automotive Research

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Abstract—*In the recent times there has been a paradigm shift in the ways we convert energy to usable form. From the setting up of hydro power plants to governmental incentives for rooftop solar power plants and from increasing taxes on diesel based vehicles to concessions on electric drive vehicles all epitomize this shift. The fundamental question which arises is that what are the reasons for this inconvenient shift from well-established technologies and methods to newer, unfamiliar and in most cases costlier alternatives? These reasons are the driving force for this change and consequently the cornerstone of the approach taken by the researchers to obviate the problems associated with present methods. This article contains information about whether this approach should be based upon the scarcity of fossil fuels or on the global warming or on the ecological impacts of extracting fossil fuels and the consequences of each of them. It is discussed whether or not the fossil fuels are actually scarce, if not then what else drives us towards renewables and what is the relevance of this change in automotive research. Then the effectiveness of the electric/hybrid vehicles is analyzed theoretically, establishing the prerequisites and conditions for their success on both environmental and economic parameters. Finally some of the other possible solutions for reducing the collateral damage caused by the transportation sector are considered along with their future scope.*

1. INTRODUCTION

Population and development indices of the world in general and Asia in particular have been increasing continuously and consequently so are the demands for energy. Even if we consider a time frame as short as the last ten years in a country like India it's quite evident that both the population and the range of activities that consume electrical power have increased. Just by looking around us for a couple of minutes numerous examples can be seen. Capacity of the batteries of our phones have increased to up to 5000mAh from 1000mAh and moreover we are recharging them more frequently, power windows of the cars have made the manual handle-operated windows seem obsolete, the simple doors are being replaced by sensor equipped sliding doors, so are the taps. One very noticeable occurrence which truly exemplifies this is the comprehensive wipe out of the manually pulled rickshaws by the electric rickshaws at least within the Delhi-NCR region. Simultaneously the population of India has increased from 1.12 billion in 2006[1] to 1.33 billion in 2016[2]. Thus there has been an increase in both the number of users of energy and the per capita usage and this increase is in addition to the comparatively enormous amounts of energy that the developed nations continue to consume perpetually.

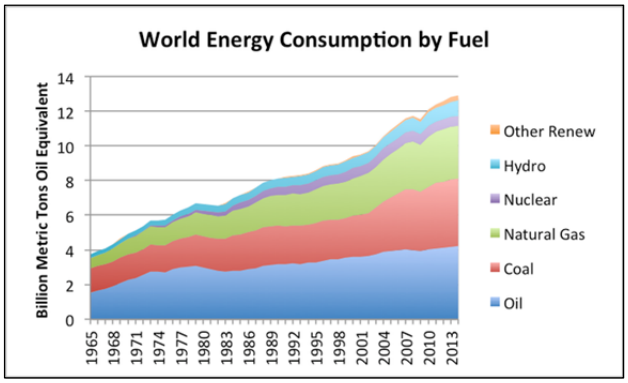

Fig. 1: World Energy Consumption by Type of Source/Fuel (1965-2013) [3]

Two very noticeable things from the Fig. are that the consumption is ever increasing and that the contribution of renewable sources (apart from hydro sources) is just about 1-2% of the total energy consumption. Thus given the tremendous potential that they possess developing renewables is our safest option to meet the future demands. But the biggest dilemma that the community of researchers faces is whether to develop renewables as a supplement to fossil fuels or as their replacement.

2. ARE FOSSIL FUELS SCARCE?

For a common man this question may seem a bit rhetorical but the truth is actually quite different. The ratio of the global proven reserves to global production in 2015 is 40 years for oil, 62 years for natural gas and 224 years for coal [3]. Now the interesting thing is that this ratio takes into consideration

neither the increase in consumption in the coming years nor the possibility of discovery of new fossil fuels and methods. This ratio only takes into consideration what may be called as traditional sources of fossil fuels and traditional methods of production. But in the last decade alternative fossil fuels feed stocks such as oil sand, oil shale and methane hydrates have come to our knowledge. These are those sources which have not been yet utilized for the production of fossil fuels. Considering North America alone there is a total of about 3.3 trillion barrels of oil equivalent of energy in oil sands located at Athabasca in Canada and the southern states of the USA which could meet the global demand for oil for over 80 more years at the present consumption rate. Additionally the oil shale present in the Rocky Mountains, USA possesses over 2.1 trillion barrels of oil equivalent of energy. Also located off the eastern coast of the USA on the ocean floor are methane hydrates which possess over 56 trillion barrels of oil equivalent of energy and thus these alone can meet the global oil demand for the next 1500 years and the total global energy demand for the next 300 years [9]. The word 'scarce' as defined by the Oxford dictionary refers to something which is insufficient for demand and fossil fuels though are non-renewable but clearly aren't scarce as far as foreseeable future is concerned. Thus scarcity of fossil fuels is not one of the drivers for shifting to renewable sources. Contrary to what one may think this doesn't allow even for their continuous let alone indiscriminate use, neither it is a favorable scenario and in fact it may be the biggest deterrent to the aforementioned shift to renewables.

3. REAL DRIVERS FOR THE SHIFT

Global Warming in the present world is no longer an uncertainty, it's definitive, it's measurable and it's real.

For about half a million years before 1950 the carbon dioxide levels had never risen over 320ppm [4] whereas the levels at the end of 2010 almost touched 400ppm.

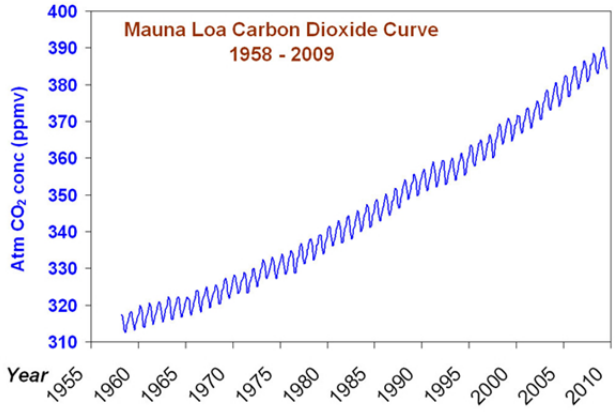

Fig. 2: Changes in the concentration of CO2 over time in the Earth's atmosphere [4]

This increase is analogous to the increase in the global energy consumption. Fossil fuels are basically hydrocarbons and every hydrocarbon on complete combustion results in the formation of a molecule of carbon dioxide for each atom of carbon present in it. Since we have been deriving over eighty-five percent of our energy requirements from fossil fuels the increase in atmospheric carbon dioxide levels is an inevitable consequence.

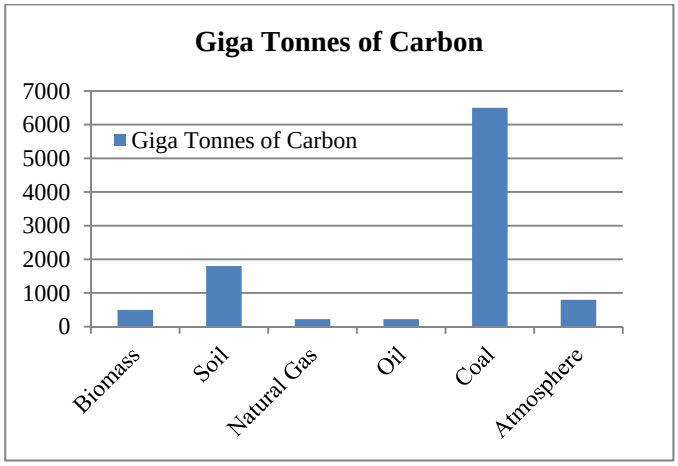

Fig. 3: Amount of Carbon present on Earth by source [5]

Fig. 3 shows the amount of carbon present on Earth in various forms. We can see that most of the carbon is in the form of coal and that a comparatively very less amount is present in the atmosphere. If we are to consume all of the natural gas, oil and coal then it would mean converting all the carbon occuring in these forms to atmospheric carbon. Bringing the alternative sources of fossil fuels into consideration Fig. 3 transmutes to

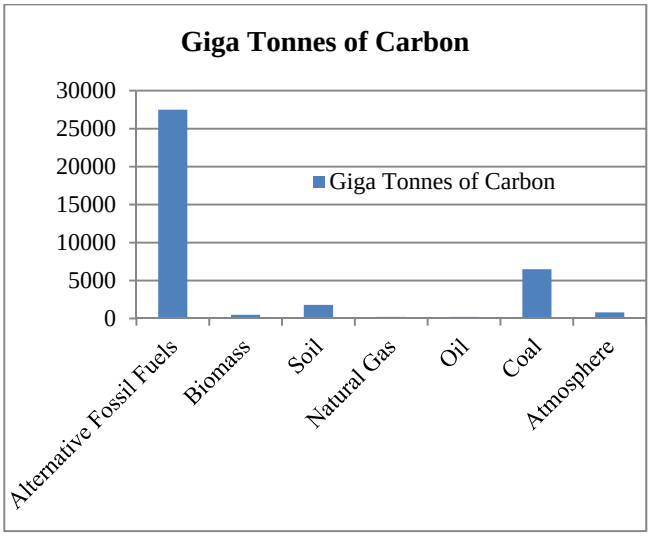

Fig. 4: Amount of Carbon present on Earth by source [5, 9]

Now let us suppose that at any hypothetical point in future we end up consuming all of oil, natural gas, coal and half of the alternative fossil fuels

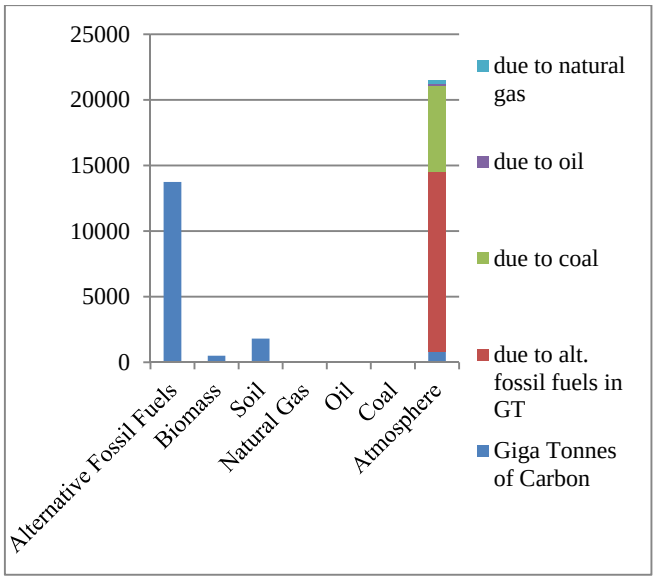

Fig. 5: Amount of Carbon present on Earth by source at a hypothetical point in future

A planet having such enormous amounts of atmospheric carbon would be extremely different from the planet which we call Earth. In practical terms we would not survive even if we consume half of the coal reserves let alone having access to alternative fossil fuels. This again validates the point that fossil fuels are not scarce as far as mankind is concerned and mankind will not be around to see the day when the fossil fuels get exhausted. In simple words it means that they are quite extensive but are not supposed to be consumed. Thus the approach followed by the researchers becomes of paramount importance and it is very crucial that the alternative fossil fuels, despite of the vast potential they have, should be left undisturbed.

4. IMPORTANCE OF RESEARCH APPROACH

Outcome of every research project is contingent on the driving force for the initiation of the project. Projects with similar objectives can result in quite varied outcomes if the drivers used are different. This can be demonstrated by discussing a number of projects each with the objective of finding ways to meet the future energy demands but with different drivers. A project which is driven by the scarcity of fossil fuels will try to meet the objective by discovering new sources of fossil fuels or by improving the efficiency of energy production methods, the one driven by the ecological and monetary costs of extracting alternative/traditional fossil fuels will proceed by inventing new technologies and techniques which can be used with minimum ecological invasion and at economical costs. Only the project driven by the requirement of minimizing the environmental impact caused by energy production will proceed by discovering and inventing environment friendly methods of energy production from renewable sources. Thus it is vital that correct drivers are used as the research based on wrong drivers is not only a waste of time, money and material but also can prove to be extremely dangerous.

5. DANGERS ASSOCIATED WITH WRONG DRIVERS

The most unfortunate and dangerous thing about the present world is that it is propelled by the cost equations and not by the scientific equations. It makes the current situation a market competition between fossil fuels and renewables which the latter are losing pretty badly. One prediction is that with the depleting reserves the prices of fossil fuels will increase and renewables will start winning. Now what if someday new methods are developed which make it possible to use alternative fossil fuel stocks with minimum impact on local ecology and at very low monetary costs? This will significantly lower the prices of fossil fuels and the position of renewables will further exacerbate. That's why it was pointed out earlier that the fact that fossil fuels aren't scarce may be the worst thing that could have happened. This means that one of the factors that could have made renewables popular in the market is non-existent. It makes it indispensable to identify that we have to develop nonpolluting renewables not to supplement fossil fuels but to replace them and not because fossil fuels are scarce or because of the ecological and economic costs associated with their extraction but because they are not environment friendly. We need to be absolutely clear in our approach. One scientific breakthrough in the wrong direction and the renewables (and ultimately the mankind) may lose this competition once and forever.

6. THE PARADOX

It's already discussed that any improvement in the efficiency of fossil fuel based methods will serve as an impediment to the commercial success of renewables. On the other hand over eighty five percent of the global energy demand is being met through fossil fuels and even with our best possible efforts it may take decades for a comprehensive shift. So discontinuing these improvements will be counter progressive on all parameters. The situation leads to paradox but fortunately it can be solved. First of all, the alternative fossil fuels should be declared inaccessible and all the information should be kept confidential by the international organizations and national governments. This will impose the scarcity factor again and will ensure that we have only 50 years of fossil fuel use. Secondly improvements in the present methods of fossil fuel extraction and combustion processes should continue but the amount of fuel saved should not translate into monetary savings of the final customer. This can be done by periodically regulating the prices corresponding to improvements in efficiency and the profit generated by these improvements should be solely used for developing renewables. This can be

very effective as it will turn the paradox on its head i.e. the greater the improvements in traditional methods the greater will be the funds generated for renewables. Governmental control will definitely be required to achieve this. Obviously promoting the renewables itself will be the most effective way forward. Giving them significant space in the annual budget, providing incentives and rewards to the people who use them, promoting small scale private installations of renewable energy power plants are just few ways to expedite the shift.

7. RELEVANCE IN AUTOMOTIVE RESEARCH

The following figures provide information about the percentage of greenhouse gas emissions that can be attributed to the transportation sector which is 14% globally and as we move our analysis to a more developed nation i.e. the USA the share of transportation sector increases to 26%. This shows that as a country gets more developed the emissions per unit of energy produced may decrease for other sectors due to advancements in technology but not for transportation.

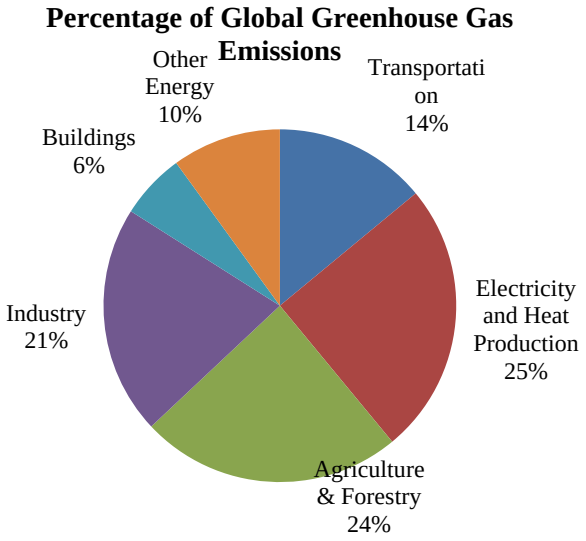

Fig. 6: Percentage of Global Greenhouse Gas Emissions by Sector [6]

This thing is quite visible as generally the more developed a country is the more powerful are the vehicles used by the masses and since almost the entire transportation sector derives energy from oil through internal combustion engines thus more powerful vehicle implies a less fuel efficient vehicle. [There are some exceptions especially Norway which has decided to ban all fossil fuel tank based cars from 2025]. This shows that there is something inherently wrong with the conventional vehicles and there is an urgent need for the vehicles which provide the maximum efficiency over a larger range of power and speed. The hybrid and all-electric vehicles are a step in this direction. Additionally it may be highlighted that an all-electric vehicle has zero tank to wheel emissions which is a very promising quality.

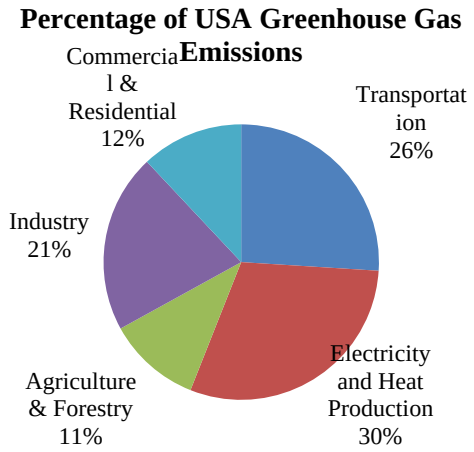

Fig. 7: Percentage of USA Greenhouse Gas Emissions by Sector [7]

Also if we assume that the alternative fossil fuels will not be accessed it brings back scarcity into the equation leaving less than 30 years to make the transportation sector free from oil. The other promising concepts that are under research include hydrogen fuel cell based vehicles, hydrogen internal combustion engine based vehicles and solar powered vehicles. The point of mention is that all these vehicles generate energy on board and thus need not to be energized externally. But these concepts need to be developed further and beginning has to be made from electric/hybrid vehicles. It will not be a huge problem to switch to fuel cell or solar powered vehicles in future as they also use electricity as the source of propulsion.

8. PREREQUISITES FOR THE SUCCESS OF ELECTRIC VEHICLES

Electric/Hybrid vehicles have problems of their own. Huge initial investment, less cabin space, high charging times, lack of related infrastructure and low distance range are just some of them. In spite of all these, these vehicles need to be given a chance for the simple reason that we don't have other options. Therefore it is imperative to ensure that these are better than the conventional vehicles on environmental as well as economical parameters.

Electric Vehicles may have zero tailpipe or tank to wheel emissions but this alone doesn't make them emission free. To be termed so, the electricity used for charging the batteries must be produced from renewable and environment friendly sources. But at the same time it doesn't mean that electric vehicles wouldn't be beneficial in a country where majority of power is produced from coal. First of all it will be helpful in preparing the country for the day when renewables take over the majority of power production and secondly it's more convenient to improve the efficiency and decrease the emissions from stationary power generation as compared to power generation onboard moving vehicles. The techniques

like combining Rankine and gas power cycles along with cogeneration resulting up to 90% efficiency are well established. Running costs of electric vehicles qs expected are pretty low as compared to conventional vehicles. Even the few commercially successful hybrid vehicles have been found to return a fuel economy about 2.5 times of the corresponding conventional vehicles. But where these vehicles loose decisively is the huge initial costs associated with them. If ever a hybrid version of Maruti Suzuki Alto is produced then it may cost around 6-8 lakh rupees and not a very encouraging number of customers may eventually buy it when they can buy Honda Amaze with the same amount. This is why huge governmental subsidies as high as 30-50% especially in the initial years become a prerequisite for their commercial success. The principle to keep in mind though is that to wipe out conventional vehicles from the market, electric/hybrid vehicles must be more economical than them but we are developing these not because they can be more economical but because they have the potential to create a future where transportation sector has zero emissions.

9. SAVINGS FROM VEHICLE ELECTRIFICATION AND ROLE OF HYBRID VEHICLES

To improve the fuel economy of a vehicle even by 10%, it takes millions of dollars and years of research and all of this translates to nothing whenever a vehicle is stuck in a traffic jam while idling. Another major loss occurs whenever the brakes are applied which convert the kinetic energy (high grade) of the vehicle ultimately to heat energy (low grade). Even with mild degree of hybridization it is possible to achieve automatic starting/stopping of the engine while idling and to recover braking energy through recuperative braking. This can result in significant amount of savings especially in mega cities. Hybrid vehicles especially the plug-in hybrid vehicles will have an influential role to play in next couple of decades. Their existence eliminates the paradox which was discussed earlier. If somehow their costs are reduced and they occupy an appreciable share in the market then the improvements in the efficiency of conventional powertrains and electric powertrains will become complementary instead of competitive. An improvement in any of these will improve the overall efficiency of the vehicle.

According to a study it was found that mean daily trip for a private car is 43.53km while the median being 34.73 km [8]. Even keeping in mind the various regional and other differences it is safe to assume that a great majority of users travel less than 100km on any given day. Most of the present hybrid vehicles are capable of providing all electric range of over 100km after being charged overnight. Thus it can be construed that internal combustion engine would be required only for once in a while long trips. This point is validated by our past experiences with CNG-petrol dual fuel vehicles in the Delhi-NCR region where due to the easy availability of CNG, petrol is used only in cases of emergency. Thus hybrid vehicles will remarkably reduce our dependency over oil and provide us time and money to shift to environment friendly renewables for generating electricity and to set up the required infrastructure allowing for a convenient shift to all electric vehicles.

10. OTHER ALTERNATIVE PROPULSION SYSTEMS

Current research focuses upon Hydrogen Fuel Cell based vehicles and Hydrogen IC Engine based vehicles. The most auspicious thing about hydrogen as a fuel is that the natural emissions after combustion include only water which is neither a pollutant nor a contributor to global warming at any concentration. Additionally the gravimetric energy density of hydrogen is best amongst the known fuels i.e. 33.3 KWh/kg for pure substance. But there are some very fundamental issues that need to be solved before these vehicles can be produced commercially. First of all hydrogen doesn't naturally occur in the amounts which can permit its extensive usage as a fuel and therefore it will need to be produced commercially. The method of production will require energy as an input for example in case of electrolysis we require electricity which again brings us back to the method of electricity generation. Additionally the volumetric energy density of hydrogen is extremely poor. The following Fig. compares the gravimetric and volumetric energy densities of the commonly used fuels/batteries.

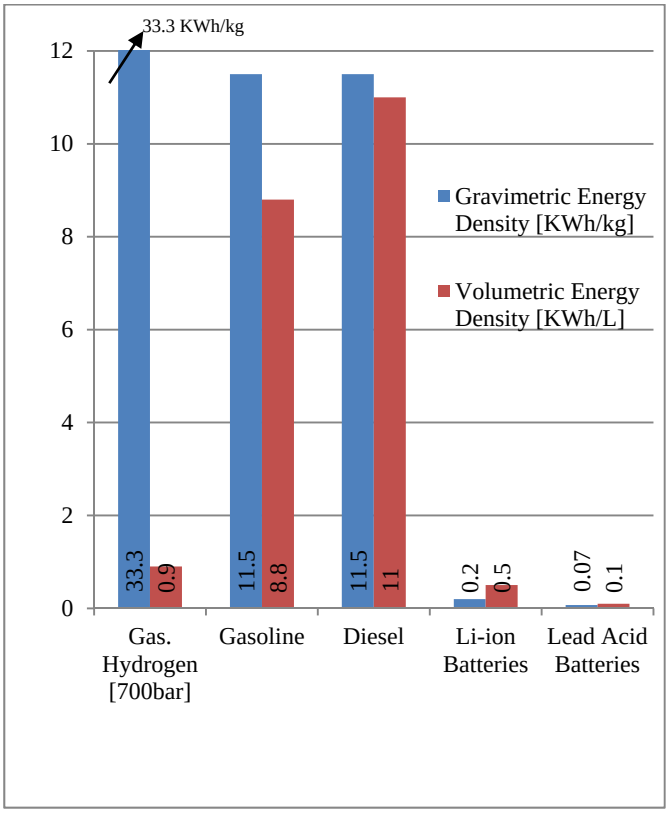

Fig. 8: Gravimetric and Volumetric Energy Densities of Common Fuels/Batteries. [9-10]

Thus sufficient research is required before the hydrogen based vehicles become commercial and the start has to be made by switching to hybrid vehicles first.

11. CONCLUSION

It is evident that substantial reductions in emissions from transportation sector can only be possible if first the emissions from power generation sector are reduced substantially and for that to happen the drivers for eliminating the problems associated with energy demand and consumption must be chosen wisely. It must be strictly understood that environment friendly renewables should be developed not to supplement fossil fuels but to completely replace them under a time bound mission. The International community must ensure that scarcity of fossil fuels is maintained. Also the national governments must fortify these alternative technologies in their competition against established technologies. All the economic and business factors must be regulated so that they don't act against them.

Though it seems really difficult but the encouraging thing is that considerable reductions in emissions of both pollutants and greenhouse gases are possible. We just need to be clear in what kind of a future we want.

12. ACKNOWLEDGEMENTS

This work could have been possible only because of the valuable information and perspective provided in the University of Michigan's online course-'Introduction to Thermodynamics: Transferring Energy from Here to There'. I would like to express my sincere gratitude to Margaret Wooldridge, Arthur F. Thurnau Professor at the Mechanical Department of University of Michigan for being a source of motivation during the online program. I would also like to acknowledge the role of Coursera which presented me with the opportunity to be enrolled in the program. I want to specially thank Dr. Rajinder Kumar Soni, Professor, DeenbandhuChhoturam University of Science and Technology for constantly supporting, motivating and blessing me with relevant information.

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