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Energy Efficiency: An Engineering Pathway towards Sustainability

A. M. Hasna

Abstract**—**Today global warming, climate change and energy supply are of greater concern as it is widely realized that the planet earth does not provide an infinite capacity for absorbing human industrialization in the 21st century. The aim of this paper is to analyze upstream and downstream electricity production in selected case studies: a coal power plant, a pump system and a microwave oven covering and consumption to explore the position of energy efficiency in engineering sustainability. Collectively, the analysis presents energy efficiency as a major pathway towards sustainability that requires an inclusive and a holistic supply chain response in the engineering design process.

Keywords**—**Sustainability, technology, efficiency, engineering, energy.

I. INTRODUCTION

ENERGY supports industrialization and guarantees technological progress. Industrialization is stimulated by societal pursuit of higher standards of living, thus taking a toll on the planet's ecological system, and consequently natural resources. Actually consumption of natural resource is facilitated by engineers and the engineering profession, whom in turn convert natural resources for the end-user in the form of consumer ready products. In this capacity engineers are positioned at the forefront of the mission. For this reason engineers and the profession have a crucial role to play in sustainability. Engineers could contribute by consuming fewer resources and designing technology that is energy efficient. However, can sustainability be achieved solely via energy efficiency? This realm of thought germinates numerous unrequited issues. For example, efficiency and sustainability mean different things to different people, and thus is it unreasonable for engineers to focus on the efficiency component of technology to achieve sustainability? The term "technology" in this context implies any technical system that can result in and/or be well-described in terms of a process by which humans modify nature to meet their needs and wants. As engineers in society let us examine our professional relationship with sustainability, how do we contribute towards sustainability? Detonating, is it an engineer's responsibility? Or is it some else's job? What is sustainability? Definitions of sustainability abound, is it the most oft-cited? What are the imperatives for sustainability? According to [2-6] the role of engineers in society is changing, placing new pressures and demands on engineering education. What are the key drivers of change towards sustainability principles? The role of engineering education in sustainability movement is a growth area, literature is rich with citation [7-23].Most citations refer to an approach of eliminating stereotypical notions of engineers about sustainability [24]. The new broader roles for engineers occur in emerging engineering disciplines "sustainability," innovation, and entrepreneurship [25], in interdisciplinary activity, and consequently in the protection of health, safety and the environment. According to [25], engineering graduates are needed to serve society, not only in the traditional technical capacities which they need to master well, but increasingly in non-technical leadership capacities. What time frame of sustainability should we settle on? The magnitude of the engineering sciences and technology in driving sustainable economic and social development and addressing the reduction of poverty has been emphasized at numerous international conventions. To name a few: the World Conference on Science in 1999, the World Engineers' Convention in 2000, the Johannesburg World Summit on Sustainable Development in 2002, World Engineers Convention 2004, Engineers Shape the Sustainable Future 2008, and Engineering: Innovation with Social Responsibility. Almost all of the mentioned meetings and literature communicate the eight United Nations' Millennium Development Goals (MDG) in one form or another. Hence from an engineer's standpoint we are particularly interested in the 21 quantifiable targets that are measured by 60 indicators. Most of these indicators relate to energy; therefore, let us review energy in perspective.

II. ENERGY AND EFFICIENCY

Energy sources of various kinds heat and power human development, but also put at risk the quality and longer-term viability of the biosphere as a result of unwanted, "second-order" effects [26]. The five primary energy commodities of petroleum, coal, natural gas, nuclear power and renewable products make up the complex energy market. Primary energy is needed for the provision of electricity. Electricity is not a primary energy source, but rather an "energy carrier": zero mass, travels near the speed of light, and, for all practical purposes, it can't be stored. Electricity is the quintessence of the modern way of life [27]. Energy consumption is a global predicament [28-35].To demonstrate the magnitude of the energy dependencies of modern society, for instance, the U.S. president [36] coupled energy with national security, as lack

Abdallah M. Hasna is the Chair of the Department of Chemical and Mechanical Engineering, Abu Dhabi Men's College, Higher Colleges of Technology, Abu Dhabi, United Arab Emirates (phone: 971-2-404-8390; fax: 971-2-445-1571; e-mail: ahasna@hct.ac.ae).

of energy creates economic vulnerability. Similarly energy consumption per person determines the level of the development of nations, despite the fact that with it comes with some known environmental problems such as global warming and air pollution [37]. Energy is an economic "good," and thus energy supplies will need to be expanded to meet emerging demands if living standards are to be improved and developing countries are to achieve prosperity [38]. Traditionally in the 1970s, the focus was conventional pollution; in the 80s it was acid rain; and in the 90s, it has fluctuated between transported pollutants and submicron particles. At the beginning of the new decade, attention had moved to carbon emissions [39]. Consequently steam power plants driven by fossil fuels contribute to climate change and greenhouse gases, CO_2 in particular. Definitional ambiguities allow no clear distinction between energy conservation and Energy Efficiency. Energy conservation is the act of conserving. For engineers Energy Efficiency means doing more (and often better) with less—the opposite of simply doing less or worse or without [40]. The conversion of energy from one form to another is often coupled with efficiency. So let us consider the physical science that governs energy conversion. The laws of thermodynamics state that energy can be neither created nor destroyed, but only transformed. The total amount of energy in a closed system does not change. Temperature is a measure of the average kinetic energy of atoms or molecules, and no natural process is perfectly efficient. No energy conversion process can be 100% efficient; there will always be some heat that escapes. Heat is the lowest form of energy. All energy eventually ends up as heat or infra red radiation, hence the knowledge of efficiency of energy utilization through fundamental insights can lead to creative sustainable solutions. Efficiency is defined as the ratio of work done by an organism or machine to the amount of food or fuel consumed and the energy expended. To engineers the definition of general "efficiency" is physical ratio, that is output/input, as described by [41] in equation (1) where η is efficiency:

$$\eta = \frac{useful\ energy\ out}{energy\ in} \tag{1}$$

However to economists; "efficiency" means a monetary output/input ratio. Economics underpin our energy generation. Consequently steam power plants powered by fossil fuels contribute to greenhouse gases, CO_2 in particular. Let us review the useful energy conversion of coal-fired electricity generation technology, where energy efficiency is the focus of global debate.

III. ENERGY AND COST

Climate change is a global environmental problem that requires global cooperation and greater scientific consensus to reduce carbon emissions and consequently the planet's energy footprint. For this reason, research into alternative energy is a growth industry. Let us review the renewable energy alternatives available as shown in Fig. 1. Generally renewable or alternative energy relies on a variety of power generation sources which are electrical power derived from renewable resources, wind, and solar energy. The major deterrent remains the financial drawbacks that are cost per kilowatt-hour for renewable energy.

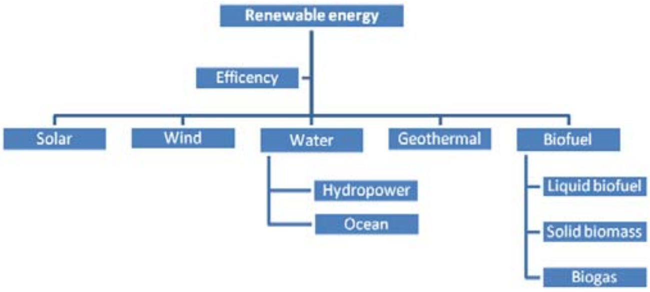

Fig. 1 Renewable energy alternatives

Coal is the most abundant fossil fuel in the United States, providing over 50% of domestically produced electricity, and amounts to a $200 billion industry. A key component to keeping coal attractively priced is continued technological advancement. The costs of generating electricity deemed dependable supply according to [39, 42-45] are summarized in TABLE I , which illustrates the present day costs of generating electricity from different types of technology. Therefore the cost of generating electricity, in terms of a unit cost (cents per kWh), delivered at the boundary of the power station site for coal is 4 ¢/kWh. It is not the cleanest but certainly the cheapest and deemed as dependable or firm supply. In this instance, low efficiency has consequences including $C0_2$ pollution, not to mention other greenhouse emitting fuels. Let us review electricity generation technology where energy efficiency is the focus of debate.

TABLE I
COST OF GENERATING ELECTRICITY

Technology	Current energy cost	
	All costs are in US$-cent per kilowatt-hour	
	¢/kWh	$/GJ
Biomass energy		
Electricity	3–12	
Heat	1–6	
Ethanol		8–25
Bio-diesel		15-25
Wind electricity	4–8	
Solar		
photovoltaic electricity	25–160	
thermal electricity	12–34	
Low-temperature solar heat	2–25	
Hydro energy		
Large	2–10	
Small	2–12	
Geothermal energy		
Electricity	2–10	
Heat	0.5–5	
Marine energy		
Tidal	8–15	
Wave	10–30	
Tidal stream/Current	10–25	
OTEC	15–40	
Coal plant		
Pulverised fuel (PF) steam plant	3-4	
Circulating fluidized-bed combustion (CFBC)	3-4	

IV. CASE STUDY DESCRIPTION

The case study described below is one of a series of three case studies with a similar theme of "energy efficiency." The first section includes a brief process description, followed by analysis and discussion.

A. *Case study 1: Coal-fired Electric Power Plant*

The basic components of a simplified fossil fuel coal power plant are shown schematically in Fig. 2. To facilitate efficiency analysis, the overall plant is broken down into three subsystems identified A to C in a simple flow chart. The focus of this case study is in section B: Power Generation where energy conversion from heat to work occurs in a typical thermal coal-fired electric power plant. Components of a thermal power plant are the incoming coal-handling system, water treatment plant, boiler feed water arrangement, flame control system, re-heater, super-heater, economizer, steam turbines, and turbo-generators with auxiliaries.

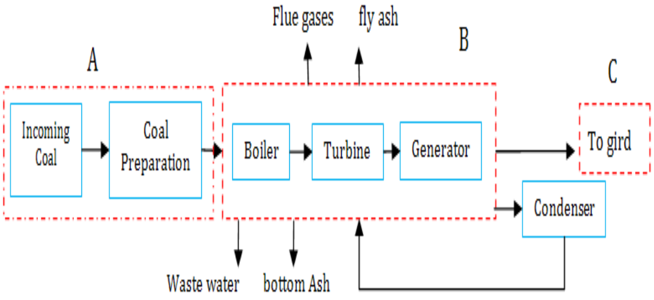

Fig. 2 Process chain of electricity generation from coal to electricity

B. *Case study 2: Industrial Pump Systems*

Motors produce useful work by causing a shaft to rotate. The electric motor draws either single or three phase power from the mains to drive the pump. The drive train, or transmission, connects the motor shaft to the pump where the transmission transfers virtually almost 100% of the power from the motor to the pump. Therefore the pump assembly with a throttle moves the fluid to the required level.

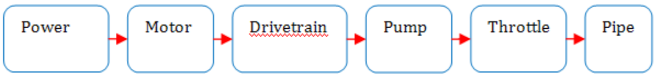

Fig. 3 Industrial pumping system

C. *Case Study 3: Microwave Oven*

The microwave oven consists of the line or supply voltage as shown in Fig. 12.

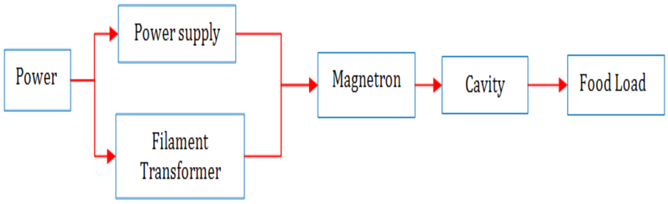

Fig. 4 Typical microwave oven

The alternating current (AC) is stepped up to thousands of volts (high voltage), the high AC voltage is stepped up to an even higher DC voltage, and then converts the DC power to generate microwave energy. The microwave energy is generated using the nucleus of the high-voltage system, the magnetron tube, which is a diode-type electron tube that is used to produce the required 2450 MHz of microwave energy.

V. ANALYSIS

To better understand the promise of efficiency in sustainability it is helpful to first know how it fits in the global scheme of things. The following section examines three case studies: coal power plants, a pump system and a microwave oven individually to establish their fitness for energy efficiency upstream and downstream.

A. *Analysis: Coal-fired Electric Power Plant*

The typical operation of a coal power station would begin by the coal initially shipped to the power plant by rail car. At first coal may contain trace amounts of chemicals which are usually accounted for under the EPA's Toxics Release Inventory (TRI) program. The objectives of the Coal Preparation plant are to remove impurities and produce consistent fuel products within specified ash, sulphur and moisture contents. Recognizing the importance of the Rankin and Carnot cycles (pressure-volume and temperature-entropy studies) in thermal steam plants, this analysis is limited to ascertain an approximation for conversion efficiency under normal operating conditions. The Boiler produces steam (thermal power) which is then transformed using a turbine into rotational energy; however, not all thermal energy can be transformed into mechanical power. This means that some of the energy of the coal that is used to heat the steam is lost. The typical boiler losses are most significant in terms of heat loss in evaporation, heat loss as the specific heat of water from combustion, and heat loss due to combustibles (unbumt carbon) in the fly ash. In addition, the turbine efficiency is directly affected by boiler where any changes in the heat distribution in the boiler due to changes in gas flows, or the effects of ash emissivity and slagging on heat absorption may result in reduced turbine efficiency because of reduced steam temperature. Naturally there are other inefficiencies linked to the operations such as coal handling equipment, pulverizing mills, fans, ash handling equipment, and the flue gas cleaning plant. Therefore, if we consider the simple material balance shown in Fig. 5, where 48 percent of the energy is waste heat, the figures are beyond belief.

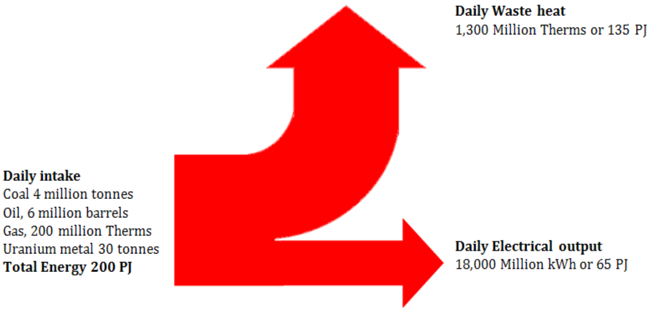

Fig. 5 Energy Flow for the world's thermal power-stations [46]

Coal properties have a large impact on both the thermal efficiency of the power plants and the specific CO_2 emissions from the plants. According to the second law of thermodynamics, the conversion efficiency is reported on thermal efficiencies between 30% and 40% [46, 47]. The efficiency of Australian coal power stations has risen over time. According to the [48] [49], the national average thermal efficiencies was 33.3% and [50] reported on a state of the art plant in Japan that reached a maximum of 44.2% , whereas the European commission had published similar data with some improved efficiencies nearing 2004 displayed in Fig. *10* . This energy efficiency improvement has been due to a combination of factors including the closure of old inefficient plants, improvements in existing technologies, installation of new, more efficient technologies, often combined with a switch to fuels with a better generating efficiency, such as from coal power plants to high-efficiency combined cycle gas-turbines. In analyzing the coal power plant, it is appropriate to point out that historically coal fired plants have always had the biggest market share. The vast majority of electricity production is generated in coal fired plants [51], as illustrated in *Fig.* 7.

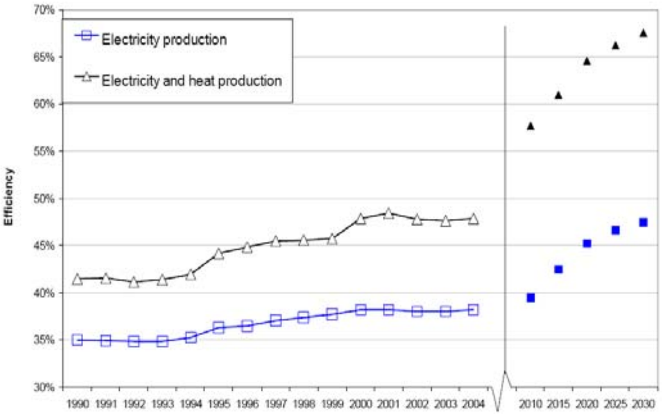

Fig. 6 Efficiency of conventional thermal electricity [52]

As a result, we have seen that the majority of electricity generation is produced using fossil fuels, coal in particular, with associated environmental impacts such as greenhouse gas emissions and wastes. In order to understand conversion efficiencies, some properties of the energy supply chain need to be elucidated.

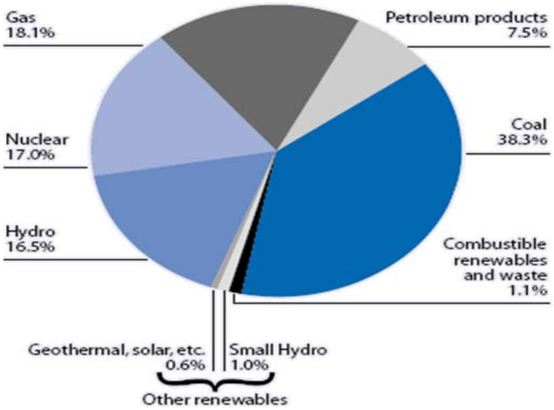

Fig. 7 World electricity production by source [53]

Technology interaction with the environment and the end-user are schematically represented in Fig. *9*, whereas the demands of the end user are translated into functional criteria that must be fulfilled by the technology for the coal power plant. For that reason technology is included as part of the four dimensions of sustainability. Hence to make greater energy efficiency and cleaner energy, technology remains the centerpiece of systems design needed for a rapidly developing world. Referring to the energy supply chain from natural resources listed in Fig. 8, the link between natural resources, end user and technology is that it provides satisfaction of human needs. This satisfaction has benefits and inherent conversion efficiency. Improving conversion efficiency to seamlessly achieve sustainability in one sense is a contradiction. The concept of technological rationality improves conversion efficiency by developing more advanced technology. We beg the question was sporadic development and consumption not a problem to begin with? This oxymoron states that the very mean of improving conversion efficiency is by consuming more, which is self-contradictory. Therefore, to achieve satisfaction of human needs through the aid of technology with existing legacy is a perennial mandate.

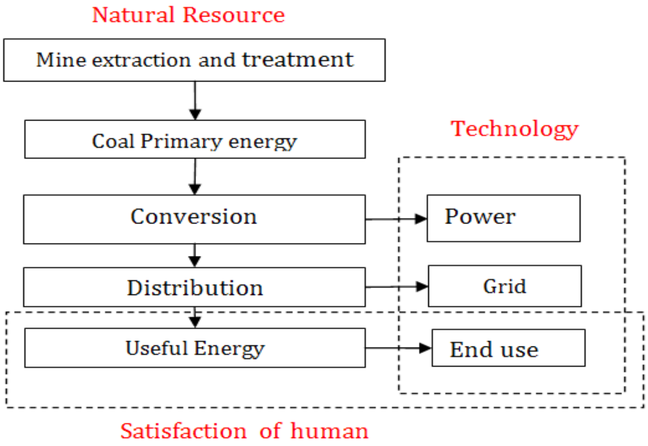

Fig. 8 Conversion chain thermal power from coal to end user

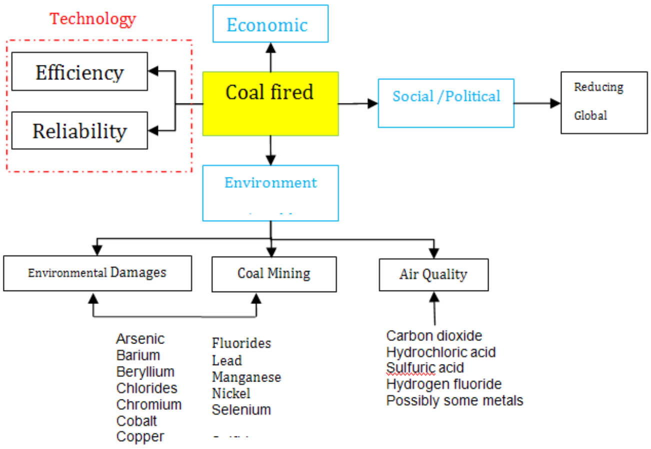

Fig. 9 Analysis of coal fired power station

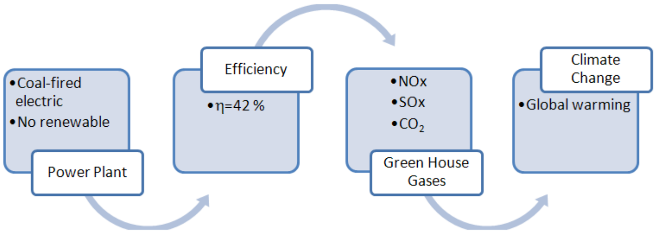

Fig. 10 Energy conversion chains

A few researchers have tackled the idea of design intention for example [54] reported on technological design being divorced from the context of the use of products. He gave examples of big dams feeding leaking pipes and electricity generating stations pumping heat into the atmosphere when electricity is mainly used for heating, as examples of halfway technology. There are several lingering challenges particularly in conversion efficiency that must be overcome before any sustainability potential can be realized. As shown in Fig. 10 the energy conversion of the coal plant, consecutively efficiency, is tied into climate change and consequently sustainability. According to [55] coal is at a crossroad, either resolving its environmental challenges and regaining its competitive edge, or suffering a possibly precipitous decline with ratification of the Kyoto Protocol.

B. *Analysis: Industrial Pump Systems*

Pumps are used to deliver liquids through piping systems. On a typical industrial site, pumping is the largest application of motors, and motors use three-quarters of all industrial electricity [56] [57]. Therefore, pumping is a key area to target for energy efficiency. Fig. 11 illustrates a flowchart of a typical pump chain of energy conversions (i.e. the conversion efficiency of primary into secondary energy) the energy loss data adapted [40] and [58].

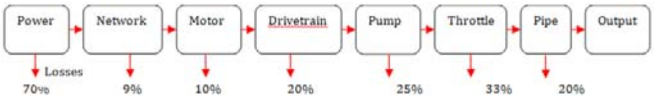

Fig. 11 Industrial pump system

In the energy conversion efficiency for a pumping system, listed in Fig. 11, which starts upstream at the power station where the primary energy, 100 units of fuel, progresses at various stages to reach the motor and is then piped downstream, we see the conversion chain losses. The effectiveness of the conversion process is characterized by primary into secondary energy plus the delivery efficiency from secondary to end user. A number of known losses contribute to the distribution efficiency of delivering secondary energy from the point of conversion to the point of end-use. For example,

(a) The motor converts electricity input into torque and the remainder is lost due to heat and vibration. The effectiveness of the pump conversion process is characterized by the motor efficiency which is a ration of mechanical output to electrical energy input;

$$\eta_{motor} = \frac{mechanical\ power\ output}{electrical\ energy\ input} \qquad (2)$$

(b) The inevitable energy losses due to mechanical friction and the turbulence created in the fluid as it passes through it [59] causing more power requirement to drive the pump than the amount that eventually gets delivered to the fluid [60] . The degree of perfection of the conversion process between the mechanical work supplied and the mechanical energy of the fluid is expressed by the pump efficiency [61] .

$$\eta_{pump} = \frac{mechanical\ energy\ increase\ of\ the\ fluid}{mechanical\ energy\ input} \qquad (3)$$

The energy savings possible through properly matching pump specifications to the system requirements. These potential savings are compared to those attainable through the use of high efficiency motors and improved pump efficiency.

(c) Over-design--it is common practice to add approximately 10% to the estimated frictional losses of a pipe work system design, then to specify pumps based on the elevated figure, resulting in oversized pumps. This practice allows for any fall-off in pump efficiency through wear, and to allow for any pipe work fouling which may occur as the system ages [56] . Finally the energy cost is the highest component of the total life cycle cost of the industrial pump. Therefore, minimizing the energy by increasing efficiency is a major goal towards sustainability.

C. *Analysis: Microwave Oven*

According to the American Council for an Energy-Efficient Economy and [60], cooking in a microwave oven reduces energy use by about two-thirds of the energy used for conventional cooking. However, if we review the energy consumption stages of a typical microwave oven, the power drawn from the wall is deduced using equation (4), where I, is current and V, is line voltage.

$$P = IV \qquad (4)$$

Using the data listed in Fig. 12, P= 1595 where V=120 V and I=13.3 amperes (A), this power is known as the oven power; however, the output power using load test is about 700W; hence, the efficiency of power transfer would be 700/1595 =0.44 or 44%. The conversion efficiency at various stages of the process, Fig. 12, clearly show the efficiency of magnetron which is a major component of the appliance comprises a large percentage of power losses at 35% of energy in yielding it, a not so efficient process. Nowadays, microwave ovens have increased the overall microwave oven efficiency; however, it is still around 44 per cent [62] and 54 percent [63].

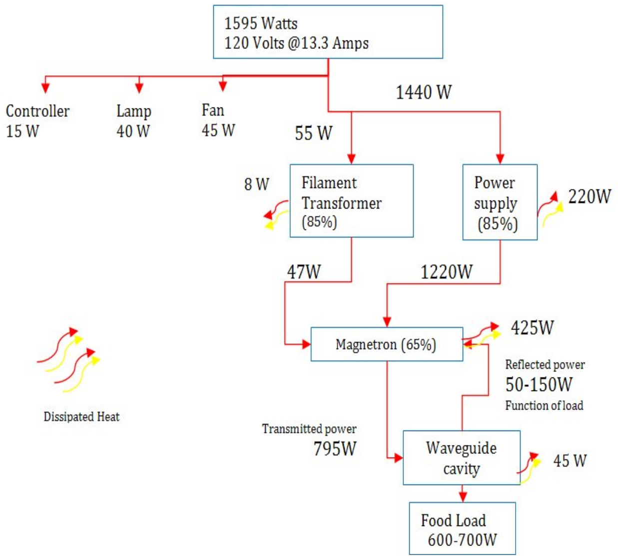

Fig. 12 Efficiency of microwave oven

Finally, if the efficiency of the power plant supplying the energy and its distribution network and the microwave oven are added together, the end user energy conversion efficiency would reach a figure above 70% in losses. Hence, the efficiency of a cooking appliance represents a fraction of the energy supplied to the appliance that is transferred to the food and this resembles our energy consumption legacy.

VI. DISCUSSION

The significance of efficiency in society is colossal as it determines the real output or productivity of technology. For example, the 46% drop in U.S. energy intensity (primary energy consumption per dollar of real GDP) during 1975–2005 represented by 2005 an effective energy "source" 2.1x as big as U.S. oil consumption. The conclusion of the analysis listed in TABLE, demonstrates technical efficiency.

TABLE II
EFFICIENCY SUMMARY

	Power plant	Pump system	Microwave oven
Efficiency	44.2 % from primary	9.5% from primary	44 % from secondary

Hence, with the relevance of this topic to today's society to the ever-increasing earth population, engineers have a paramount role to be play in sustainability. The link between natural resources, energy and engineering can be explained by the impact equation. Where from it early beginnings the "IPAT' equation developed and proposed by [64] and [65] also termed the sustainability equation [66] [67] recognized the impact of a human population on the environment, where (P) is the population's size, (A) affluence and (T) technology

$$I = P \times A \times T \tag{5}$$

Due to the complexity in estimating A and T, per capita energy or economic consumption per person, normally measured by GDP per capita is employed as a surrogate for their product. [68] and [69] report on equating T with impact per unit of economic activity. As a product of the above constraints equation (6) developed into using a simple relation adapted from the IPAT Eq. (5) where Environmental degradation = population × consumption per person × environmental damage inflicted by the technologies used to supply per unit of consumption. Through the above equations technology, population, environment and efficiency are interrelated. We can also see from all three case studies the technical energy successively applied along the chain of energy conversions chain contains at least three efficiencies, efficiency the product of efficiencies: (1) conversion efficiency of primary into secondary energy (upstream), (2)distribution efficiency of delivering that secondary energy from the point of conversion to the point of end-use, (3)end-use efficiency of converting the delivered secondary energy into such desired energy services as hot pumping water or zapping your dinner in the microwave (downstream).

However it is astonishing how technology is not a major criterion in sustainability assessments (Hasna, 2008). [70] identified technology as an important determinant of Sustainability. In addition [71] found that technology influences energy consumption. [72] found that technology is an important source of reduction potentials for energy consumption. [73] examined the relations between total energy consumption and wealth creation and between electricity generation and wealth creation and recommended that the benefits of electricity generation are at least of the same order of magnitude as economic development itself. The relationship between energy consumption and the gross national product (GNP) of countries has become such a commonly understood concept that figures in U.S. dollars per tonne of oil equivalent (toe) are quoted as world development indicators by the United Nations. Global oil prices have been steadily increasing for more than a decade. However, the huge run-up in oil prices over the last several years, reaching a peak of close to U.S. $140 per barrel in summer 2008, has given energy companies a big incentive to find new ways of harvesting unconventional oil [35] . Although the sharp run-up in price through June of 2008 to $140/barrel price in the summer of 2008 might be consistent with a newly calculated scarcity rent, the $60/barrel in November of 2008, a dramatic price collapse in the fall, is more difficult to reconcile. However, the recent fall out caused by the credit crunch has yielded falling energy prices a concern for energy efficiency as it is difficult to entice energy efficiency with oil prices below $40 a barrel. The concept of energy return on investment is introduced as a major driving force in our economy, and data are provided which show a marked decline in energy return on investment for all our principal fuels in recent decades [74]. Under current economic conditions lower prices generally lead to increased consumption, reducing the net savings from efficiency. If greater efficiency reduces the global demand for oil, prices will fall. However, cost is an important factor as it is estimated that oil prices have to be above about $65 a barrel for renewable energy to become price competitive. The unit cost of utilized energy is inversely proportional to the efficiency and it is determined from

$$\text{Cost of utilized energy} = \frac{\text{Cost of energy input}}{\eta} \tag{6}$$

Today most major car companies are taking steps to lighten their vehicles while improving their quality, to improve the efficiency of existing types of engine while reducing their unwanted exhaust emissions. But Efficiency has its drawback: the world has been successful in the past in increasing energy efficiency in many sectors. For example, the United States introduced fuel-economy standards in the transportation sector that were implemented in 1978, in which the fuel efficiency of new cars and trucks rose quickly but it has since leveled off [75]. Whether this leveling off is due to the fall in oil prices is hard to state; however, it is plausible. For example, the hypothetical efficiency,η curve illustrated in Fig. *13* reveals energy consumption trends over the past 35 years such as the extinction of petrol guzzlers. The three major North American automakers General Motors, Ford, and Chrysler, also known as the "U.S. Big Three, are all now producing smaller and smaller cars. Gone are the days of the 1970s, the most powerful years of the muscle-car era, in with the new small four cylinder cars. However, it takes a long time—fifteen to twenty years to replace the on-road vehicle fleet [75]. Changes in fuel economy standards, even if made today, would not be fully felt until 2025. There are many factors responsible for changes in crude oil prices, Fig. *13*, shows energy prices influenced by embargo, revolution, war, financial crisis, undersupply and oversupply. However, along with the elevated oil prices, increases in other commodities like steam coal and coking coal directly affect electricity generation. The graph demonstrates the nominal price of oil trends over the past the 35 years. It clearly demonstrates that energy is based on supply and demand, primarily cost driven, that is affected by political and social progress.

A	Arab Oil Embargo	G	Rising Demand
B	Iranian Revolution	H	9/11 Attacks
C	ran-Iraq War	I	Iraq War and Venezuela Strike
D	Iraq Invades Kuwait	J	Hurricane Ivan in Gulf of Mexico
E	OPEC Cuts Quotas;	K	Inventory Build up
F	asiian financial crisis	L	Hurricanes Dennis, Katrina and Rita in Gulf of Mexico

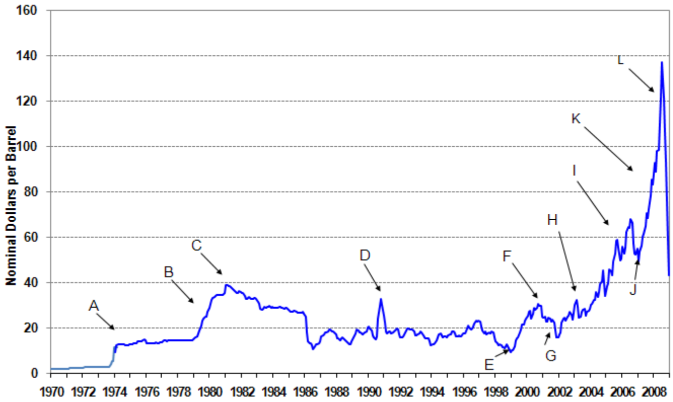

Fig. 13 Graph of oil prices over the last 35 years [76] [77]

The U.S. Department of Energy was created in response to the 1973 oil embargo. Hence, engineers are also influenced by these external conditions and therefore how we tend to lend our services to develop technology is equally affected by the mentioned conditions that also bind with the spheres of influence, i.e. social, economic, ecological and global, for example since the first oil crises nearly 35 years ago, a quiet but dramatic revolution in energy conservation has swept the industrialized world, reducing the projected increase in atmospheric pollutants and in large part producing the world oil glut. However, theoretical potential for efficiency gains upstream or downstream is governed by the maximum permitted by the laws of physics. The world has saved far more energy (since 1973) through improved efficiency than it has gained from all new sources [78]. Each kWh of electricity conserved saves 0.4 kg of coal and 1.0 kg of CO$_2$ and 15 g of SO$_2$ from a coal power plant. According to [79], the whole economy is less than 10% as energy-efficient as the laws of physics permit. This is perhaps what [80] described as forms that badly fit their context. Fitness is the relation of mutual acceptability between domains. In a problem of design we want to satisfy mutual demands which the two make on one another. We want to put the context and the form into effortless contact or frictionless coexistence.

VII. CONCLUSION

We believe that the greatest potential for transformative change towards sustainability may lie in improving conversion efficiencies. Finally, how can engineers play a positive role in sustainability? Unquestionably the engineering profession can make significant contributions via improvements of technical efficiencies, by providing more with the same amount of energy consumed is generally the least expensive, most benign deployable pathway to work towards sustainability. Hence, Energy efficiency needs to gain attention and respect in the engineering profession, since engineers are capable of producing radically different process changes to limit the consumption of primary resources. So one might ask why energy efficiency? Energy efficiency buys time. Time is a precious asset since it permits the refinement of robust renewable energy development and more importantly it postpones natural resource depletion to facilitate the future path, which will not be a continuation of the historical past, thus forging ahead a pathway towards sustainability through energy efficiency. Reconciling the conflicts between economic growth and technology is a key challenge in terms of securing long-term sustainability. Therefore Sustainability pathway needs to be economically viable, ecologically sound; sensitive, socially responsible and culturally appropriate together with the implementation of a strategy of energy efficiency, also by recognizing we need to create behavioral changes.

As a concluding remark a question is posed what are the risks in focusing too strongly on technology for its own ends and in not adequately applying energy efficiency to meet the needs of an expanding population which is expecting a higher quality of life since the development of technology provides innovation and economic success. We argue that society is driven by growth and growth is determined by successive technology. Thus technological change compliments societal change and hence a subset of sustainability. Therefore, we propose technology efficiency criterion be also included as one of the measures towards achieving sustainability.

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Abdallah M. Hasna is the Chair of the Department of Chemical and Mechanical Engineering, Abu Dhabi Men's College, Higher Colleges of Technology, Abu Dhabi, United Arab Emirates, he holds PhD in manufacturing from Swinburne University of Technology, Graduate, Certificate in Higher Education (Deakin), Graduate Certificate in Management, (SUT) BE, Chemical (RMIT).

He has 15 years' experience as process engineer, held senior positions in the chemical and process industry, most notably water flocculation systems in the Australian mining industry, plantation timber moulding, fuel cell power generation for air independent propulsion with DSTO, sacrificial corrosion protection for the green river project, paperboard manufacturing, and developed a microwave corrugator with Visy Industries., previously he held a Senior lecturer position affiliated with the Department of Sustainability, at Central Queensland University.

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