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Energy Engineering, an Emerging Discipline

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Abstract—**Energy engineering is one of the more recent emerging engineering disciplines. It is a multidisciplinary field requiring an integration of physics, math, and chemistry with economic and environmental engineering. Energy engineers discover new energy sources to reduce dependency on fossil fuels that their use is detrimental to the environment. They find the most efficient and sustainable ways to operate buildings and manufacturing processes. This includes suggesting energy efficient measures to reduce heating, cooling, and lighting energy consumption of buildings. This paper provides an overview of the history of energy generation and the current state of energy supply and consumption around the world to bring to light the need for energy engineering discipline. Typical duties and work activities of energy engineers are discussed to identify the body of knowledge required for the discipline. Curriculum of several engineering schools that offer the degree in energy engineering are reviewed to show the type of courses offered.**

I. Introduction

Improving energy efficiency and substituting fossil fuel based-energies are essential elements of sustainable development. Worldwide, 13,371 million tonnes of oil equivalent (Mtoe) total primary energy (TPE) was produced in 2012. Coal, oil, and natural gas accounted for 81.7% of global TPE supply (Figure 1). At the same time, these three energy sources accounted for 99% of the 31,734 million tonnes of CO_2 emissions from fuels (Figure 2). Reducing greenhouse gas emissions and ecological footprint are directly dependent on the sources of energy and energy technologies. Therefore, a systematic transition from traditional energy concepts and practices to new energy principles is necessary. Energy engineering education and training have a central role in facilitating this transition.

Energy engineering is one of the recent engineering disciplines that is emerging. It is a multidisciplinary field that incorporates technical fields of study such as physics, mathematics, chemistry, and engineering economics; as well as engineering fields such as mechanical, electrical, and environmental engineering. Energy engineers play important roles in sustainable development and solving complex energy related problems by working on projects designed to reduce energy consumption and cost, and advance renewable resource technologies. Energy engineers discover new energy sources to reduce dependency on fossil fuels that have detrimental effects on the environment. They find the most efficient and sustainable manufacturing processes and ways to operate buildings. They also suggest energy efficient measures to reduce heating, cooling, and lighting energy consumption of buildings.

This paper provides an overview of the typical duties and work activities of energy engineers to identify the body of knowledge required for the discipline. Curriculum of several engineering schools that offer a degree in energy engineering are reviewed to show the types of courses offered.

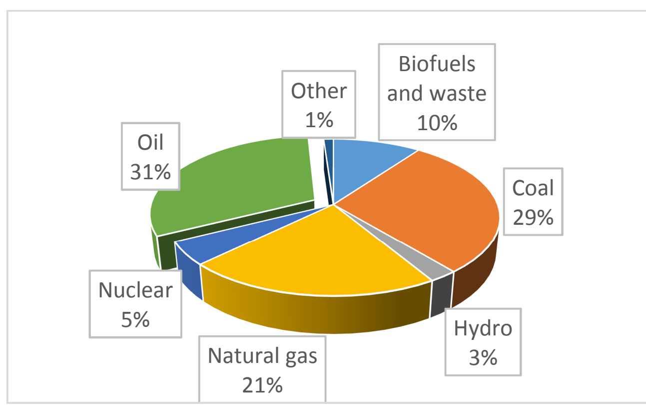

Figure 1. 2012 fuel shares of TPES (Total Primary Energy Supply) - Adapted from [1]

Note 1: Peat and oil shale are aggregated with coal.
Note 2: Other includes geothermal, solar, wind, heat, etc.

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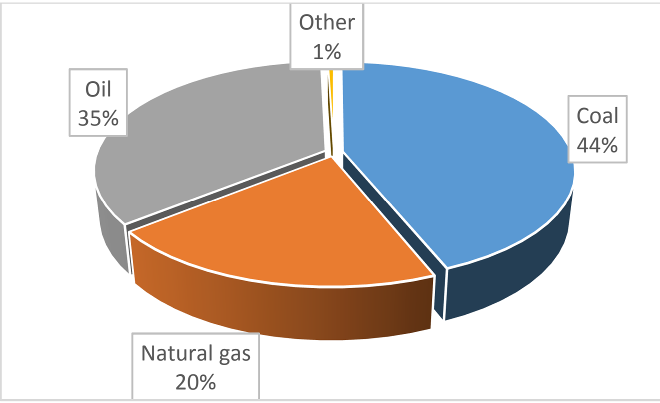

Figure 2. 2012 fuel shares ofCO_2 emissions - Adapted from [1]

II. Background

Energy is categorized into major types of primary and secondary energies. Primary energy is directly from environment and secondary energy is the outcome of primary energy conversion to other forms such as electricity, fuels, and petroleum products. Measuring primary and secondary energy is very important for calculating energy loss during transformation. Primary energy can be classified into the following three categories [2]:

1. Non-renewable energy (fossil fuels) such as oil, coal, natural gas, and nuclear fuel;
2. Renewable energy such as biomass, solar, wind, geothermal, and hydropower; and
3. Waste

Figure 3 shows the history and projection trends of primary global energy consumption by fuel type. Although in 2040, petroleum, coal, and natural gas are projected to remain as the dominant energy sources; the share of petroleum and other liquid fuels is expected to decrease; and shares of natural gas and renewables are expected to increase [3].

Renewable energy is among the key areas of sustainable development. Renewable energy decreases our dependency on fossil-fuel based energy; and it decreases greenhouse gas emissions coming from fossil fuels.Release of carbon dioxide (CO_2) from fossil fuel consumption to the atmosphere is one of the major causes of climate change, the key environmental challenge facing humanity today. The climate change can increase or decrease rainfall, influence agricultural crop yields, affect human health, cause changes to forests and other ecosystems, or even impact the energy supply. Therefore, increasing the share of renewable energy has environmental, social, and economic benefits for societies.

Over the past decade, due to the evolution of renewable energy technologies, the production and capacity of renewable energies have increased substantially and their cost has had downward trends. The share of modern renewable energies (hydro, wind, solar and biofuels)from global final energy consumption was 5.4 percent in 2006[4].Based on REN21's 2014 report, total renewable energy accounted for 19 percent of global final energy consumption in 2012. Both modern renewables, as well as traditional biomass, contributed about equal parts to the global energy supply [5].Worldwide investments in renewable technologies amounted to more than US$ 214 billion in 2013 [5].

Improving energy efficiency is another emerging area in the energy industry. Improving energy efficiency focuses on enhancing the performance of systems (motor systems, boilers, HVAC, lighting, appliances, and equipment) in different sectors such as the built environment, transportation, and energy utilities.

Based on the aforementioned statistics, it is projected that the share of renewable energy from primary and final energy consumption increases steadily. Another arising opportunity in the energy industry is that a wide range of potential job opportunities in the areas of renewable energy and improving energy efficiency are being created; however, these jobs

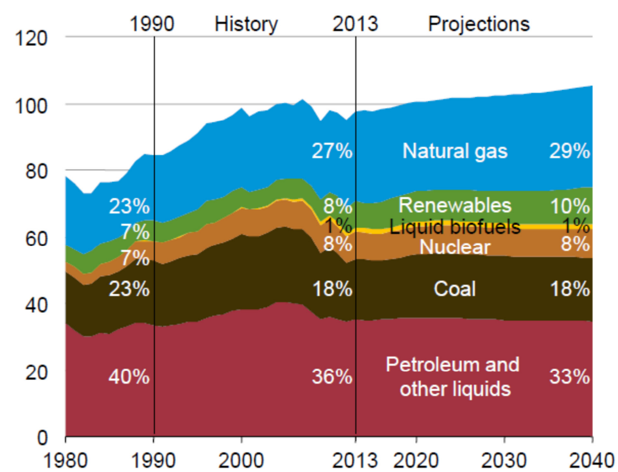

Figure 3. Primary global energy consumption by fuel (1980-2040) Adapted from [3]

require special competencies and skillsets that are not readily available. Engineering education and training systems can play important roles in developing required skills of prospective employees in the energy industry. The expansion of energy engineering and energy certification programs can be seen as steps towards addressing the increasing needs of the renewable energy and energy efficiency job market.

It should be noted that in 1997, an important conference was held with the participation of the United Nations Environment Program (UNEP), World Federation of Engineering Organizations (WFEO), World Business Council for Sustainable Development (WBCSD), and the École des Ponts Paris Tech (ENPC) on engineering education and training for sustainable development [6]. The conference highlighted the fact that engineering education has a critical role in enhancing knowledge and skills necessary to solve energy problems and supporting future economic [7].

III. Energy Production and Consumption in Iran

According to the Oil & Gas Journal, as of January 2015 Iran has an estimated 158 billion barrels of proved crude oil reserves, representing almost 10% of the world's crude oil reserves [8]. Iran is also the second-largest proved natural gas reserve holder in the world, behind Russia. Iran has an estimated 32.42 trillion cubic meters of natural gas and holds 17% of the world's proved natural gas reserves and more than one-third of reserves held by the Organization of the Petroleum Exporting Countries (OPEC)[8].

Iran's primary energy consumption has grown by almost 50% since 2004 [8]. It consumed almost 244 million tons oil equivalent (Mtoe) of primary energy in 2013. Due to abundance of oil and gas products, these two fossil fuels accounted for 98% of energy consumption(Figure 4). Iran is heavily reliant on energy-intensive industries for domestic economic production and export. It also has a high dependence on oil products to meet primary energy needs and for its petrochemical and metal industries [9]. Energy consumption per capita in Iran has increased 5 times in 35 years and gasoline consumption is increasing at an annual rate of 8-10%. If this trend continues in the next two decades, Iran's oil consumption will be more than its current production [10].

Renewable energy in Iran has been neglected for a long time. By 2003 there was slight improvement in the share of renewable energies in total primary energy supply. The share of hydropower increased to 1.8%, with the share of wood and traditional biomass increasing to 0.18% and non-hydro renewable energy to 0.004% [9]. Iranplans to add 5,000 megawatts of renewable wind and solar power to its grid by 2018. Several projects for 1,300 megawatts are either underway or have been signed [11].

In 2013, Iran generated almost 224 billion kilowatt-hours (kWh) of electricity, of which 92% was from fossil-fuel sources (Figure 5). Hydropower, nuclear, and non-hydro renewables make up the remaining fuel sources used to generate electricity in Iran. Iran exported 11 billion kWh of electricity in 2012 to Armenia, Pakistan, Turkey, Iraq, and Afghanistan, and imported 3.9 billion kWh of electricity from Azerbaijan and Armenia under swap agreements [8].

In spite of its low Gross Domestic Product (GDP), Iran is the 7th highest carbon emission-intensive country in the world(after China, US, India, Russia, Japan, and Germany). Total CO_2 emissions in 1990 were 211 million metric ton (MMT), which increased rapidly at an average annual rate of 5.1 percent to 572 MMT by 2010 (Table 1). Per capita carbon emission in 1990 was 3.7 metric ton (MT), 12 percent less than the global average of 4.2 MT. This figure increased to 7.7 MT by 2010, 57 percent higher than the global average (Table 1). Iran's high levels of CO2 emissions primarily results from high levels of energy consumption per capita, energy-intensive industries, and inefficient energy use throughout the country.

IV. Job Opportunities for Energy Engineers

With the increasing demand to utilize and manage energy sources more effectively and develop more efficient techniques to generate green energy, energy engineers have diverse work opportunities in the industry. They can work in the public or private sectors and in the areas of energy management, photovoltaic engineering, hybrid / electric transportation, renewable energy, sustainability, environmental compliance, energy generation, energy consumption / transmission, or fuels engineering.

In 2014, the Association of Energy Engineers (AEE) conducted a survey regarding job potentials and salary data in the energy industry. The survey had 2,967 participants from the energy industry. According to the results, 66.1 percent of the participants believed that there is a shortage of energy management professionals in the industry and 61.6 percent of them agreed that there will be a shortage of qualified professionals in the energy efficiency and renewable energy fields within the next five years. Figure6 shows the base salary distribution of the participants. The average salary of the participants was $98,847 [12].

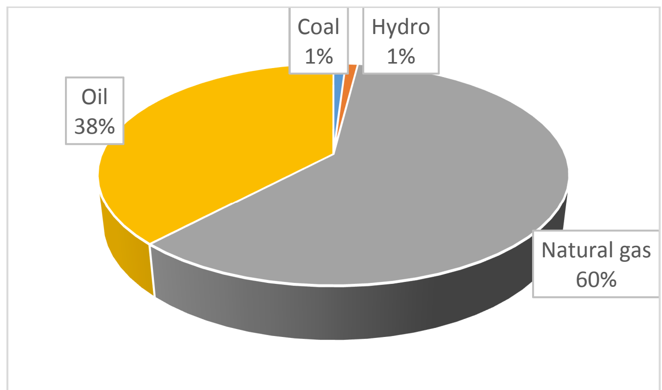

Figure 4. Total energy consumption in Iran, by type (2013)- Adapted from [13]

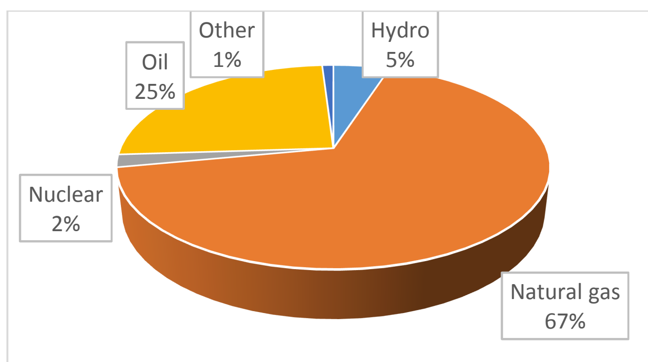

Figure 5. Iran's electricity generation capacity, by fuel, 2013 – Adapted from [8]

Table 1. Carbon dioxide emissions in 1990 and 2010 for Iran and neighboring countries –Adapted from [14]

	GDP per unit of energy use		Carbon Dioxide Emissions			
			Total		Per Capita	
	2011 PPP $ per kilogram of oil		MMT		Metric Tons	
Country	**1990**	**2010**	**1990**	**2010**	**1990**	**2010**
Afghanistan			2.677	8.471	0.2	0.3
Iran	7.7	6.1	211	572	3.7	7.7
Iraq			53	111	3.0	3.6
Pakistan			69	163	0.6	0.9
Saudi Arabia			218	533	13.4	19.6
Turkey	10.9	11.4	146	298	2.7	4.1
World	5.5	7.2	22,201	33,516	4.2	4.9

Energy professionals are responsible to decrease our dependency on fossil fuels by finding solutions that consume energy resources more efficiently and by developing newenergy resources.

The duties of energy engineers are different based on the sectors they are involved in. Some oftheirgeneral tasks include [15]:

- Advancing energy technology and management of energy;
- Designing, developing, and building renewable energy technologies such as wind, solar, hydro, and geothermal;
- Connecting renewable energy systems with the existing power systems;
- Designing and selecting equipment;
- Contributing to develop energy efficiency measures for different sectors;
- Monitoring and evaluating new technologies or applications, and developing performance indicators;
- Contributing to research studies focused on sustainable energy and new energy methods and technologies;
- Addressing societies' energy needs and demands;
- Addressing critical issues of various energy sectors including extraction, production, and conversion;
- Addressing safety issues related to renewable and non-renewable energy production; and
- Advancing automobile fuel engines.

V. ENERGY ENGINEERING PROGRAMS

In this section, the curriculum of three energy engineering programs are described to introduce the body of knowledge required for this emerging discipline.

The curriculum of energy engineering degree in the Department of Energy and Mineral Engineering at Penn State University is classified into six major categories including [15]:

1. Basic engineering courses which are common with the traditional engineering disciplines;
2. Fundamental energy engineering principles such as material and energy balances, thermodynamics, fluid mechanics, heat and mass transfer operations, and physical and chemical processing as applied to energy industries;
3. Renewable/sustainable energy principles;
4. Basic chemistry of fuels - coal, petroleum, natural gas and biomass; combustion; petroleum and natural gas processing; electrochemical;
5. Energy conversion; and energy conversion processes including chemical, nuclear, biological and catalytic; and
6. Miscellaneous elective courses such as green energy engineering and environmental compliance, and air pollutants from combustion sources.

Berkeley Engineering offers a variety of courses for the undergraduate program in energy engineering. The recommended courses for the first two years include basic and fundamental engineering courses such as chemistry, mathematics- calculus, physics for scientists and Engineers,

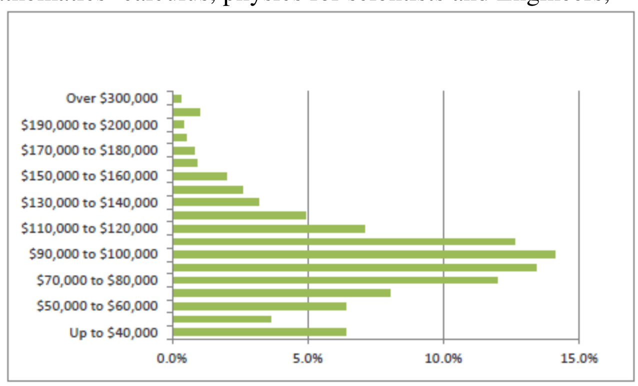

Figure 6. Base salary distribution of the survey's participants Adapted from [12]

energy and society, linear algebra, and multivariable calculus. The courses offered by Berkeley engineering in the third and fourth years of undergraduate program are more specialized (or energy focused),including introduction to electric power systems, heat transfer, materials in energy technologies, humanities/social science course, nuclear power engineering, air pollutant emissions and control, climate change mitigation or geography, fundamentals of photovoltaic devices, and sustainability course [16].

Energy engineering at the Ohio University is offered in the Russ College of Engineering and Technology,Department of Mechanical Engineering. The Ohio University divides the curriculum in the following three sections [17]:

1. *Engineering Fundamental Requirements*
   It includes basic engineering courses such as engineering graphics fundamentals, programming , basic electrical engineering I, engineering thermodynamics, engineering economy, mass and energy balances I, principles of microeconomics;
2. *Energy Engineering Core Requirements*

Some of the offered courses in this section includes: basics of environmental engineering, economics of energy, introduction to electric power system engineering and analysis, programmable logic controllers, introduction to energy engineering, fuels conversion engineering and technology public policy, energy engineering senior design, heat and fluid transport, energy engineering and management; and

3. *Technical Electives*
   The courses include but are not limited to solar design, solar cell and photovoltaics, power station engineering, atmospheric chemistry , atmospheric pollution control, fundamentals of nuclear engineering, and power station engineering.

The energy engineering is a multidisciplinary majorthat not only addresses basic and fundamental concepts of energy engineering, but also focuses on clean energy, sustainability and the environmental and social dimensions of the major. This range of concepts should properly be covered in energy engineering curriculum to ensure students gain an appropriate depth of knowledge in their field.

In addition to energy engineering programs, a wide variety of certificates focused on recent energy concepts are available for professionals to continue their education in new emerging fields. Some of the certificates that are available in different categories of the energy industry include [12]:

1. Certified Energy Manager (CEM®)
2. Energy Manager in Training (EMIT™)
3. Certified Energy Auditor (CEA™)
4. Certified Sustainable Development Professional (CSDP®)
5. Certified Green Building Engineer (GBE®)
6. Business Energy Professional (BEP®)
7. Certified Lighting Efficiency Professional (CLEP™)
8. Certified Power Quality Professional (CPQ®)
9. Certified Building Commissioning Professional (CBCP®)
10. Distributed Generation Certified Professional (DGCP™)
11. Certified Measurement & Verification Professional (CMVP®)
12. Certified Energy Procurement Professional (CEP®)
13. Certified Indoor Air Quality Professional (CIAQP™)
14. Certified GeoExchange Designer (CGD®)
15. Certified Carbon Reduction Manager (CRM®)
16. Certified Building Energy Simulation (BESA™)
17. Certified in the Use of RETScreen® (CRU™)
18. Certified High Performance Building Professional (HPB™)
19. Certified Building Energy & Sustainability Technician (BEST™)
20. Government Operator of High Performance Buildings (GOHP™)
21. Certified Energy Efficiency Practitioner (EEP™)

VI. Conclusion

The energy industry is in the transition process from fuel-based technologies to renewable and energy efficiency technologies. This transition faces new challenges as well a great potential for job opportunities requiring a special set of skills and competencies in energy engineering. Energy engineering as a multidisciplinary field of knowledge is one of the most recent disciplines that has emerged to address the new training requirements of the energy industry. After completing an energy engineering program, energy engineers are expected to be able to address the challenges of new sources of energies and technologies. These challenges may have different dimensions such as policies, cost, and technical aspects, and they usually require discovering new sources of energy and finding the most efficient and sustainable ways to operate buildings and manufacturing processes.

This paper provided a brief history of the energy sources and statistics, and presented some of the job opportunities and typical duties that energy engineers will have in the energy market. It also explored the curriculum of some of the engineering schools that offer a degree in energy engineering to introduce the body of knowledge required for this emerging discipline.

References

[1] Energy InternationalAgency. 2014. Key World Energy Statistics.
[2] Demirel, Yaşar. 2012. Energy: Production, Conversion, Storage, Conservation, and Coupling; Springer Science & Business Media.
[3] U.S. Energy Information Administration (EIA). 2015. The Annual Energy Outlook 2015.
[4] Bringezu, S., H. Schütz, M. O'Brien, L. Kauppi, RW Howarth, and J. McNeely. 2009. "TowardsSustainable Production and use of Resources:Assessing Biofuels."
[5] REN 21. 2014. Renewable 2014- Global Statistics Report: Renewable energy Policy Network for 21 Century.
[6] UNEP, WFEO, WBCSD, ENPC. 1997. Engineering education and training for sustainable development. Report of the joint UNEP, WFEO, WBCSD, ENPC Conference. Paris, France, 24–26 September 1997.
[7] Desha, Cheryl J. and Karlson Charlie Hargroves. 2010. "Surveying the State of Higher Educationin Energy Efficiency, in Australian EngineeringCurriculum." Journal of Cleaner Production 18 (7): 652-658.
[8] U.S. Energy Information Administration (EIA). International energy data and analysis, http://www.eia.gov/beta/international/analysis.cfm?iso=IRN
[9] Sabetghadam, M., "Energy and Sustainable Development in Iran," in Sustainable Energy Watch. 2006, HELIO International.
[10] Ghazinoory, S., "Cleaner production in Iran: necessities and priorities." Journal of Cleaner Production, 2005. 13(8): p. 755-762.
[11] Press TV, "Iran joins water turbine manufacturer's club," July 23, 2015 http://presstv.com/Detail/2015/07/23/421482/iran-electricity-turbine-power-
[12] The Association of Energy Engineering. 2014. Energy Management Jobs Report 2014: Relevant Trends, Opportunities, Projections& Resources http://www.aeecenter.org/files/reports/2014EnergyManagementJobs.pdf
[13] BP Statistical Review of World Energy 2014
[14] World Development Indicators, the World Bank, 2015
[15] Penn State- College of Earth and Mineral Sciences. "Energy Engineering- Career Opportunities."2015, http://www.eme.psu.edu/eneng/degree.
[16] Berkeley Engineering. "Energy Engineering."2015, engineeringscience.berkeley.edu/energy-engineering/
[17] Ohio University. "Energy Engineering."2015, http://catalogs.ohio.edu/preview_program.php?catoid=45&poid=11687.