 doi:10.20944/preprints202205.0283.v1

*Article*

# Energy Economics in the GCC: A Synergistic Product of Engineering and Economics at Missouri S&T

**Joseph D. Smith [1], Greg Gelles [2] and Yishu Zhou [3,*]**

[1] Chem and Biochem Eng, Laufer Endowed Energy Chair, Missouri Univ of Sci and Tech, USA, smithjose@mst.edu
[2] Economics., Chancellor's Prof, Missouri Univ of Sci and Tech, USA, gelles@mst.edu
[3] Economics., Assistant Prof, Missouri Univ of Sci and Tech, USA, yishuz@mst.edu
*Correspondence: yishuz@mst.edu

**Abstract:** Issues related to safe and abundant energy production have been prominent in recent years. This is particularly true when society considers how to increase the quality of life by providing low-cost energy to citizens. A significant concern of the Gulf Cooperation Council (GCC) relates to the environmental effects of energy production and energy use associated with climate change. Efforts to reduce fossil fuel use and increase the use of renewable energy, together with the price volatility of fossil fuels, have seriously impacted the economics of many of the oil-producing countries, particularly the Gulf States, which has led to efforts to make their economies more diverse and less dependent on oil production.

**Keywords:** energy policy; energy economics; renewable energy; fossil energy; nuclear energy; hybrid energy; teaching

## 1. Introduction

The question of how the Gulf States can expand their economies to reduce economic dependence on oil production is an engineering question, an economic question, and ultimately an issue of information and education. The collaboration between engineering and economics focuses on the importance of economic diversification in energy and how to reduce dependence on oil while making GCC economies more resilient to oil price shocks.

The authors of this paper reacted to this broad energy debate several years ago by developing a course in Energy Economics at the Missouri University of Science and Technology (Missouri S&T) that provides a deeper understanding of the energy issues discussed above. Our approach has been to link the scholarly disciplines of engineering and economics to provide an educational system to inform college students about the core energy issues being debated worldwide. This course encourages open discussion about energy policies countries may consider pursuing to bring the most significant benefit to their citizens. This course is available online and can quickly be adopted by universities in the Gulf States.

Underlying our teaching approach to energy economics is a firm belief that engineering and economics are synergistic disciplines that together combine the ideas of new technologies with a framework for understanding whether these technologies will be quality-of-life enhancing. We believe a collaborative approach to teaching energy economics will yield a more informed debate on the best directions to take in energy production and use policies. Our class presents informed subject matter on all forms of energy production including fossil, nuclear, renewables, and bio-energy. We have provided study abroad opportunities that focus on energy issues in Dubai and Oman. We also take our energy economics students on field trips to solar microgrids, nuclear reactors, and biofuel plants. The class is divided into groups that are assigned a current energy-related topic on which they conduct detailed research to produce a final report and oral presentation for the class.

 doi:10.20944/preprints202205.0283.v1

During a previous U.S. Presidential election, a prominent U.S. newspaper ran an advertisement showing pictures of the two final candidates and included a headline stating: "***Energy, Bigger than Both of Them***". A key component of educating the future workforce is providing an unbiased view of energy from an economic viewpoint. Economists teach to ask "does the benefit outweigh the cost?" In Energy Economics we use these criteria when discussing renewable energy (i.e., wind, solar, biomass), fossil energy (coal, natural gas, petroleum) and nuclear energy. We examine several serious energy related questions including:

1. 1. How can we provide a supply of clean secure energy to a world with more than 9 billion people (see **Error! Reference source not found.**)?
2. 2. How can a country best support its economic activity with available energy resources?
3. 3. How can a world dependent on fossil energy evolve to reduce climate impact?

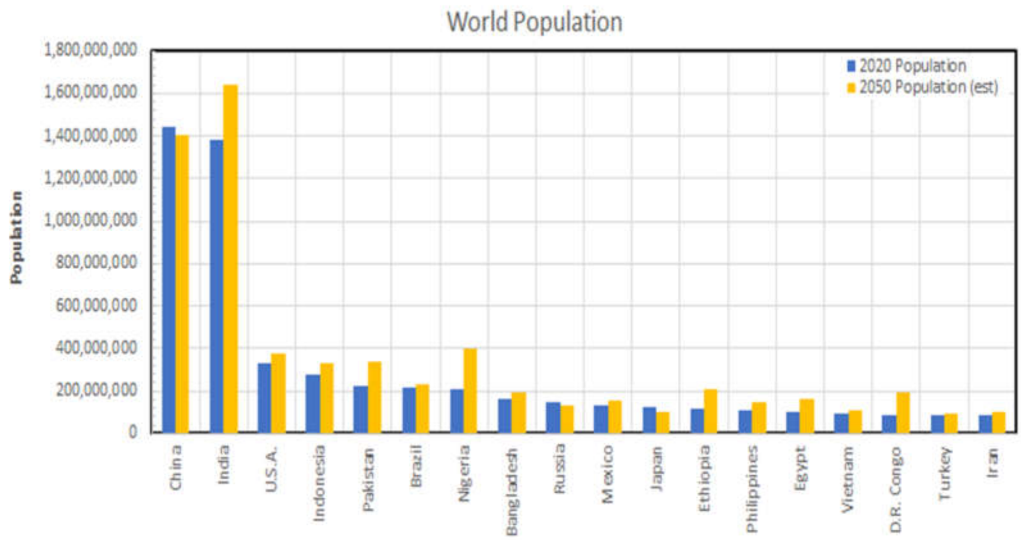


**Figure 1.** World Population estimates for 2050.

The topics addressed in the Energy Economics course needs little introduction. Every day we are bombarded with news reports dealing with energy and natural resources. Familiar issues include: high gasoline prices, wind versus coal energy, fossil fuels impact on global climate change, air and water pollution, oil spills, energy production and consumption, and nuclear waste to name a few. We address each of these issues during classroom lectures and discussions.

The Energy Economics course examines issues of particular significance to Gulf countries concerning oil and natural gas markets and associated electricity generation. The theory of perfect competition is discussed as it relates to energy markets, the economic theory behind market failures, and the reasons energy markets are subject to government regulation. We also discuss a critical issue in the GCC relating public policy to energy production. Further, we compare the efficiency of various energy forms and discuss possible energy policies that can be applied in the GCC. With this information, we believe students become better equipped with the necessary background to make informed decisions as they move into the workforce.

This class is designed for both the economist and engineer. Therefore, it is taught collaboratively by an engineering professor with a background in Chemical and Nuclear Engineering and an Economics Professor with a background in energy and experience in the GCC. Our course textbook is Energy for Future Presidents-the science behind the headlines by Richard Muller[1]. We also use selected readings from various journals and technical reports that examine general energy-related issues. The collaborative teaching approach for this course gives it an experimental flavor which we enhance with outside visits to nearby energy production/use facilities.

## 2. Course Contents and Requirements

The Energy Economics course is designed to help students learn about key issues in the GCC related to various forms of energy and the political/social externalities[2] associated with each. Specific learning objectives for the course are shown in **Error! Not a valid bookmark self-reference.**.

**Table 1.** Energy Economics Learning Objectives.

| # | Learning Objective |
|---|---|
| 1 | Learn and apply economic principles to assess economic sustainability for energy resources, |
| 2 | Learn and apply Life Cycle Analysis methodology to assess environmental sustainability of energy resources, |
| 3 | Learn how to use the GREET software to conduct sustainability assessments, |
| 4 | Examine multiple forms of energy to understand limitations related to each energy resource, |
| 5 | Consider the evidence for climate change and discuss the impact fossil fuels play in this issue, |
| 6 | Work in a team environment to conduct an techno-economic analysis of a selected energy technology, |
| 7 | Demonstrate understanding of the principles discussed in class through a written report from the group project |

Students are assigned to read selected materials available from online sources related to the learning objectives designed to support in-class discussions (see **Error! Reference source not found.**)

[1] https://www.amazon.com/Energy-Future-Presidents-Science-Headlines/dp/0393345106

[2] Defined as a side effect or consequence of an industrial or commercial activity that affects other parties without this being reflected in the cost of the goods or services involved, such as the pollination of surrounding crops by bees kept for honey.

***Table 2.*** Outside Reading Topics to Supplement In-class Discussion.

| # | Topical Area for Outside Reading |
|---|---|
| 1 | Energy demand and supply |
| 2 | Competitive energy markets and problems of market failures |
| 3 | Government policies designed to correct for price inefficiencies |
| 4 | The issue of scarcity rent |
| 5 | Global Warming and Climate Change |
| 6 | Natural Gas, Shale Oil, and Fracking |
| 7 | Solar Energy, Wind Energy and Energy Storage |
| 8 | Nuclear Energy including Fusion Energy |
| 9 | Biofuels |
| 10 | Tidal/ Wave Power, Hydrogen Fuel, and Geothermal Energy |

In addition to classroom lectures, students are assigned to work in groups to complete a major research project with a written final report and an oral presentation. This activity is considered the course final exam. Students are given a list of potential research topics to consider (see **Error! Reference source not found.**). They may also select a topic of their own if desired.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 May 2022 doi:10.20944/preprints202205.0283.v1

**Table 3.** Research Topics for the Major Class Project.

| # | Research Topics for Major Project |
|---|---|
| 1 | Examine in detail the renewable energy policy in Massachusetts. Provide a summary of the policy; what does the policy contain; what has been the impact in prices and how does it compare to other renewable energy policies? |
| 2 | There now appear to be two functioning cellulosic ethanol plants in the United States. Both appear to be using corn stover to produce alcohol. What is the future of cellulosic ethanol production in the world? Can these processes produce ethanol efficiently? |
| 3 | Perform a policy analysis of the global warming issue. What are the theories on both sides of the question? Is there any validity to sunspot theory? |
| 4 | Do an analysis of the technical and economic issues related to hybrid energy vehicles. For instance, consider the following: Natural gas vehicles; Plug in electric vehicles; and fuel cell vehicles among others. |
| 5 | Do an economic and technical analysis of small modular nuclear reactors (SMRS). Are they cost efficient? What are their advantages and disadvantages? Are SMRS the future for advancing nuclear's share of electricity production. |
| 6 | Do a technical and economic analysis of deriving energy from fusion. What are the different technologies? Look in particular at new technology discussed by McQuire, 2007 MIT PhD dissertation. |
| 7 | What is the impact of cheap energy on the world economy? Consider short and long-run. What impacts might cheap energy have on carbon emissions and global warming? |
| 8 | How serious a problem is energy poverty? Analyze whether we can we alleviate energy poverty without increased use of fossil fuels? |
| 9 | Analyze whether replacing ethanol production from corn with butanol would increase efficiency. What are butanol's advantages and disadvantages of as a fuel over ethanol? |
| 10 | One solution that some economists have suggested as a way of accounting for the social external costs of fossil fuels has been carbon taxes or cap and trade. The carbon tax was used for many years as an environmental policy in Australia. The EU established a cap and trade policy, which had serious problems but may still exist. Examine the theory behind their initiatives, analyze their effectiveness to-date, and make policy prescription based on your analysis. |
| 11 | Several years ago, an article appeared in Scientific American advocating the construction of a 60,000-square mile project of photovoltaic collectors and concentrated solar thermal units in the Western U.S. with the purpose of producing one-half of the U.S. electricity consumption. Since the article was written, fossil fuel prices have dropped dramatically but at the same time photovoltaic efficiencies have improved. Is this project, or something similar, viable for energy production in the U.S.? Consider the technical challenges and the economic issues. |
| 12 | Perform an environmental and economic analysis of oil and gas fracking. Fracking has been a successful energy producing technology in the United States. What are chances of its success in other countries and economies? |
| 13 | Analyze the issues surrounding carbon sequestration versus carbon utilization. |
| 14 | Explore current policy related to microgrids and conduct a LCA for a microgrid in a large urban market and a small rural market with multiple energy resources (e.g., solar, wind, biomass, nuclear, coal, gas) available in each market according to the location of the microgrid implementation. |

Lastly, students take several field trips to observe operating energy-related technologies. Two popular field trips with students include visiting a regional bioethanol plant and an operating solar microgrid. This approach could also be applied to classes taught in the GCC.

The bioethanol plant in Laddonia, Missouri (see Figure 2) produces approximately 60 million gallons of ethanol plus corn oil, animal feed, CO2, and electricity per year. Students see firsthand how this bioethanol plant has hybridized its production to generate multiple bi-products that improve its economic performance. Ethanol produced by this plant is blended with petroleum to meet U.S. regulations requiring 10% ethanol in all gasoline. Class members tour the plant after an introductory presentation by the plant manager. This introductory presentation provides facts about how much water and energy are required to produce a gallon of bioethanol and the current corn yield (bushels per acre), both significant factors affecting bioethanol price.

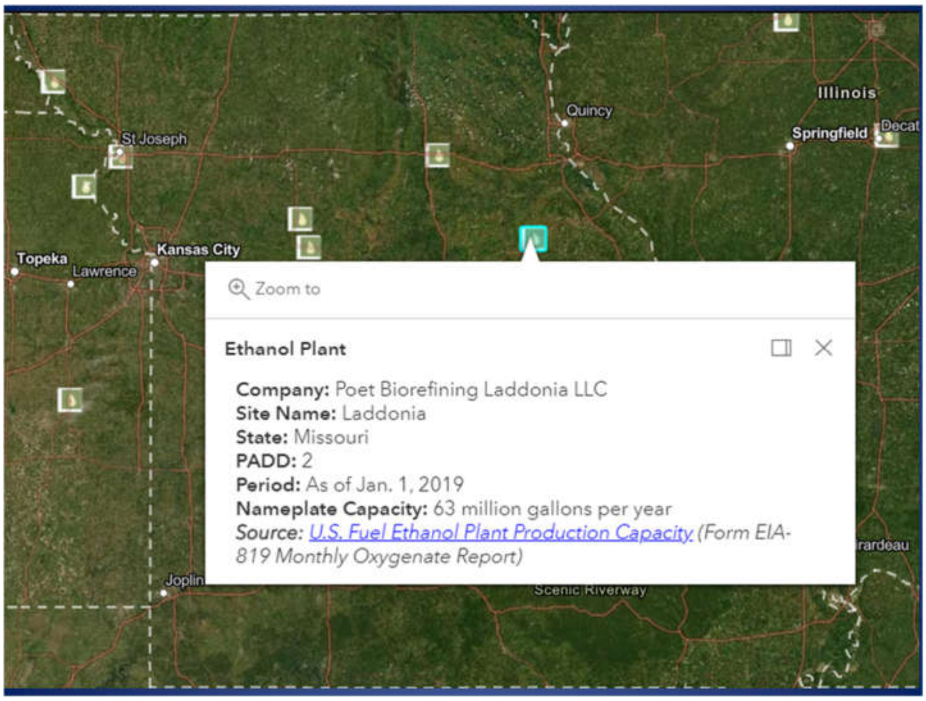


**Figure 2.** POET Bioethanol plant in Laddonia, Missouri (USA).

The class also visits the Missouri S&T solar microgrid (see **Error! Reference source not found.**). This microgrid includes 6 homes originally constructed as part of the U.S. Solar Decathalon. Students and faculty live in these homes and generate a "real-time" load profile used to analyze energy use and grid control and operation in residential settings. This research is available to public utilities and governmental agencies to study next-generation grid design and cyber-security.


**Figure 3.** Missouri S&T Solar Microgrid and EcoVillage composed of homes built for the U.S. Solar Decathalon[3].

A primary goal of our course is to provide an in-depth analysis of issues related to energy economics as pertains to production and use and to expose student to current energy policy relevant to their location. To encourage participation, students must keep a classroom journal containing their ideas and perceptions gained from outside readings

[3] For a description of the Solar Microgrid located at the Missouri University of Science and Technology, see https://cree.mst.edu/laboratories/

and in-class lectures. Journals are collected and reviewed twice during the course and represent the mid-term exam.

**3. An Example: Nuclear Hybrid Energy and Process Sustainability**

A grand challenge the GCC and the world must face over the next thirty years is related to energy security. Economic activity in the GCC is directly tied to a secure low-cost energy supply. The world population, currently approximately 7.8 billion people, will grow to more than 9 billion by 2050, with most population growth in developing countries (see **Error! Reference source not found.**).

In recent years, the United States has found new energy resources, including, most notably, natural gas and oil from shale rock deposits. Ten years ago, the U.S. was mainly concerned with its energy supply and its increasing dependence on foreign energy sources. Today, we discuss the possibility that the United States will become energy independent based on shale gas/oil resources and increasing renewable energy. A key GCC energy policy issue has become "how to move beyond oil to renewable energy." Together, both policy discussions can be addressed with a hybrid energy system.

A novel concept discussed in class that students find interesting is related to hybrid energy systems as a way to transition from dependence on fossil fuels to reducing carbon footprint. During class, we discussed recent work related to a Nuclear-Hybrid Energy system (see **Error! Reference source not found.**). The International Atomic Energy Agency (IAEA) has identified Small Modular Nuclear Reactors (SMRs) as having improved manufacturing economics, safer, and less proliferation risk. As illustrated by an analysis of a coal-wind-nuclear hybrid system using an advanced pressurized circulating fluid bed reactor to burn coal with oxygenated combustion air and a high-temperature co-electrolysis unit integrated with an SMR – for heat and wind machines/solar PV panels - for electricity [Buchheit, 2015]. A dynamic process model was used to examine how the system handles the variability of wind energy combined with nuclear power to meet a dynamic load profile with reduced carbon emissions and improved economic performance (see **Error! Reference source not found.**).

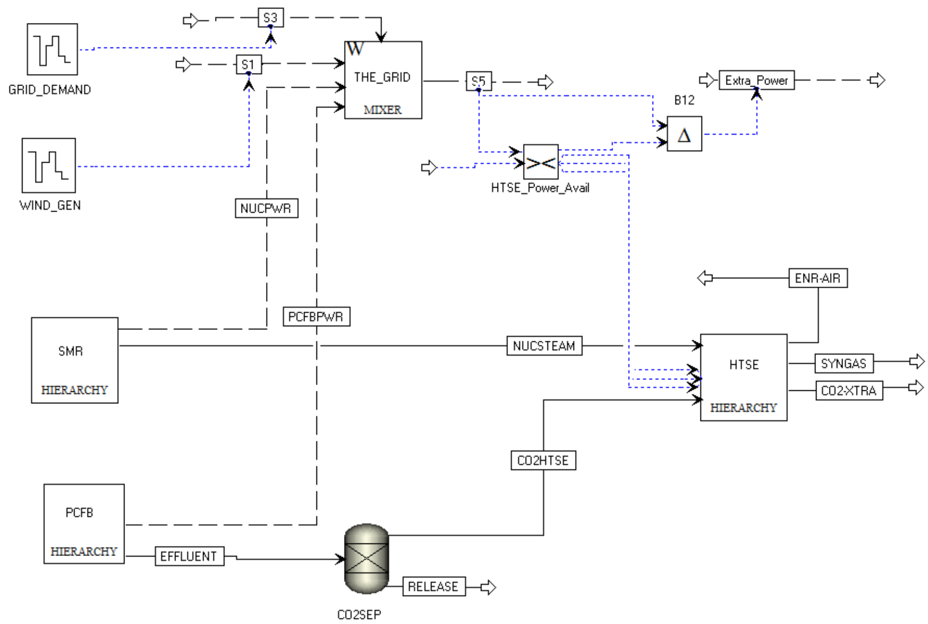


**Figure 4.** Coal-Wind-Nuclear hybrid energy system to produce low-carbon electric power plus chemicals or fuels [Buchheit et al., 2016].

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 May 2022 doi:10.20944/preprints202205.0283.v1

**Table 4.** Cost Analysis of Coal-Wind-Nuclear Hybrid Energy System [Buchheit, 2015].

| Cost Source | Conventional Coal (Reference Case) | Hybrid Energy (No HTSE) | Base Hybrid System (Levelized Cost) | 10% Hybrid (No HTSE) | 10% Hybrid |
|---|---|---|---|---|---|
| Conventional Coal | $336.40 | - | - | - | - |
| PCFB (Advanced Coal) | - | $198.80 | $198.80 | $68.00 | $68.00 |
| Advanced Nuclear | - | $176.00 | $176.00 | $46.40 | $46.40 |
| Wind | $10.90 | $10,871.00 | $10.90 | $10.90 | $10.90 |
| Advanced Combustion Turbine | $16.80 | $16.80 | $16.80 | $16.80 | $16.80 |
| Solid Oxide Fuel Cell | - | - | $21.00 | - | $21.00 |
| Hybridized Capital Cost | - | - | - | $234.30 | $234.30 |
| $15/Metric ton CO2 | $678.90 | $330.40 | $303.60 | $330.40 | $303.60 |
| $30/Metric ton CO2 | $1,357.80 | $660.70 | $607.10 | $660.70 | $607.10 |
| Total Cost | $364.10 | $402.40 | $423.40 | $376.40 | $397.40 |
| Total Cost + $15 tax | $1,043.00 | $732.80 | $727.00 | $706.70 | $701.00 |
| Total Cost + $30 tax | $1,721.90 | $1,063.10 | $1,030.60 | $1,037.10 | $1,004.50 |

This analysis included a complete life cycle analysis (LCA) using the GREET[4] software package to evaluate the sustainability of the proposed energy system. In our class, we teach students about LCA to assess system sustainability and how to use GREET. This approach applies to how GCC countries might integrate more renewable energy into their future energy production to reduce carbon emissions while maintaining economic activity.

## 4. Discussion

A grand challenge we as a society face is how to provide clean, sustainable, secure energy to a growing population, including the GCC countries, with minimum impact on the climate that supports economic development. The collaborative approach to teaching students in the GCC about various energy forms and the associated externalities will help them integrate into the workforce to make more informed decisions regarding energy policy. Completely replacing fossil energy with renewable solar and wind in the GCC would have a significant economic impact on the regional economies that may cause political unrest. Imposing a Carbon Tax on the oil and gas industry in the GCC, which currently primarily uses fossil energy to generate process heat to refine petroleum products, would seriously impact the geopolitical landscape in the GCC. Installing next-generation hybrid energy systems promises to increase profitability and efficiency while reducing the carbon footprint of generating stations. Concepts taught in the Energy Economics class taught by engineering faculty collaborating with economics faculty is one way to help the GCC prepare as they migrate from fossil to renewable energy. The multi-disciplinary approach to presenting a holistic picture of providing clean, sustainable, secure energy to a growing population may help avoid regional conflicts related to energy supplies. This approach may also positively impact global energy poverty while protecting our climate from the adverse effects of global warming.

**Author Contributions:** Conceptualization, J.S. and G.G.; methodology, J.S.; software, J.S.; validation, J.S., G.G., and Y.Z..; formal analysis, J.S.; investigation, J.S.; resources, G.G. and Y.Z.; data curation, J.S.; writing—original draft preparation.

**Conflicts of Interest:** The authors declare no conflict of interest.

[4] See https://greet.es.anl.gov/index.php

 doi:10.20944/preprints202205.0283.v1

**References**

1. Buchheit, K.L. "Process Design, Dynamics, and Techno-Economic Analysis of a Sustainable Coal, Wind, and Small Modular Nuclear Reactor Hybrid Energy System," *Doctoral Dissertation*, Department of Chemical and Biochemical Engineering, Missouri University of Science and Technology, Rolla, Missouri (2015).
2. Buchheit, K.L., Smith, J.D., Guntupalli, Chen, C. (2016) "Techno-Economic Analysis of a Sustainable Coal, Wind, and Nuclear Hybrid Energy System," *Energy Fuels*, 30 (12) 10721–10729. https://doi.org/10.1021/acs.energyfuels.6b02113.