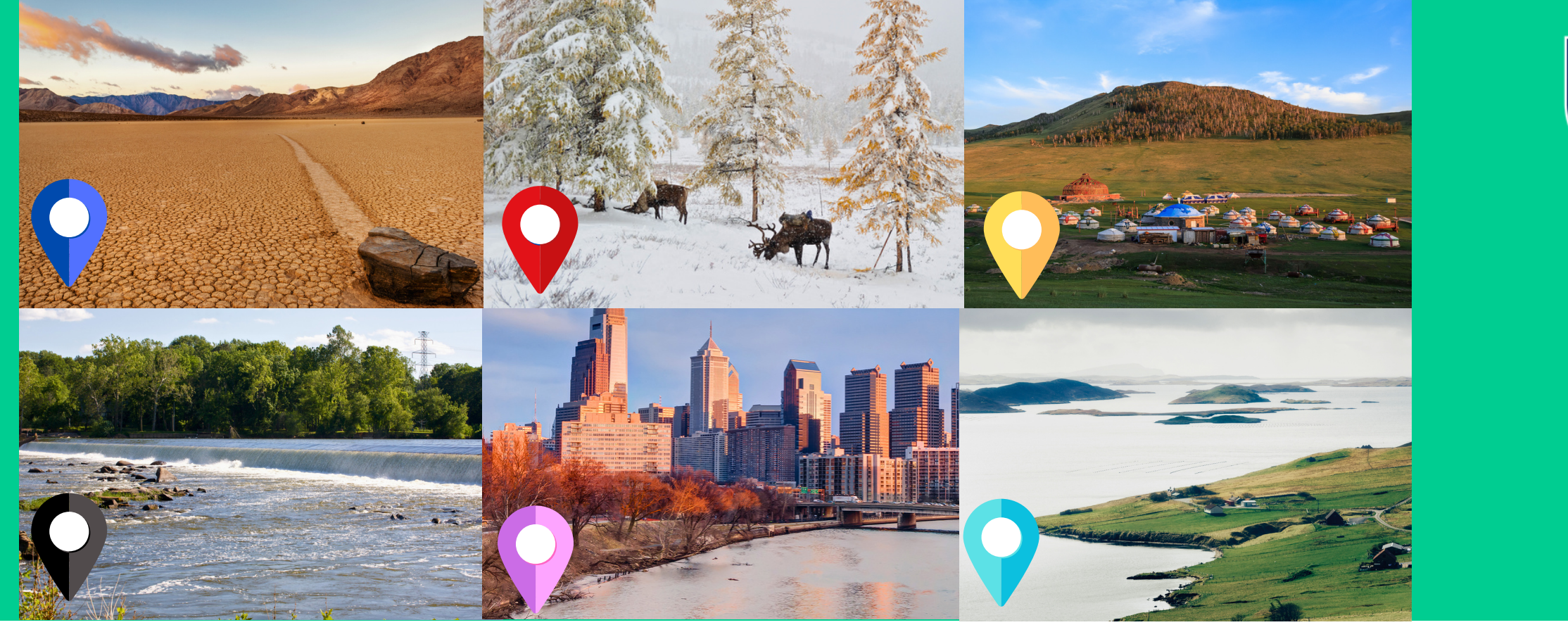
- MOJAVE DESERT, CA, USA
- YAKUTIA, RUSSIA (REMOTE)
- YANGTZE RIVER, CHINA
- PHILADELPHIA, PA, USA
- HOHOT, MONGOLIA, CHINA (REMOTE)
- SHETLAND ISLANDS, UK (REMOTE)

# WHY ARE WE STILL BUILDING FOSSIL FUEL PLANTS?

Rohan Daswani, Dr. Jane Dmochowski
ENVS 3100: Environmental Case Studies



Penn
University of Pennsylvania

## 1. INTRODUCTION

We know that carbon emissions are primarily responsible for global warming and climate change; however, we have highly efficient renewable technologies at our disposal that deliver electricity at cheaper rates than coal or gas power plants, so why aren't they being deployed on a broader scale? In this case study, we will understand the multitude of factors that go into deciding what energy generation methods we use. The results of this case study are very open-ended and dependent on the location being considered; however, we will conduct a fruitful debate to decide the best action moving forward. Data-driven statistics will aid our decision-making process and should clear up any hesitance or doubts.

## 3. DISCUSSION

Electricity generation consumes 38% of the US's primary energy needs. (EIA) Further, it is the second largest contributor to greenhouse gas emissions, contributing 25%, only slightly less than transportation at 28%. (2021, EPA)

After calculating the cost of providing energy through different utilities, renewable energy will emerge as cheaper than coal or natural gas. As such, the question arises: why haven't we ultimately switched to these renewables? The main problem is the storage of electricity. There is currently no efficient method to store electricity at scale. Further, solar and wind are non-dispatchable. Solar power can only be generated during the day and given the issue of storing electric energy, energy demand throughout the night must be met through other sources. Wind energy is also highly variable. Natural gas and hydroelectric plants enable us to quickly meet demand during peak loads. Baseload utilities should have a low cost per kWh of capacity (LCOE), and the expensive utilities will rarely be turned on, only when demand is at the highest. There are minute-to-minute bidding wars for electricity, meaning prices skyrocket during peak demand.

**Interesting Facts:**
During the 2021 Texan freeze, 1kWh rose to $900. The average cost is only $0.03/kWh. It is estimated that at least 20% of electricity generation can be replaced with wind/solar without impeding the demand curve.

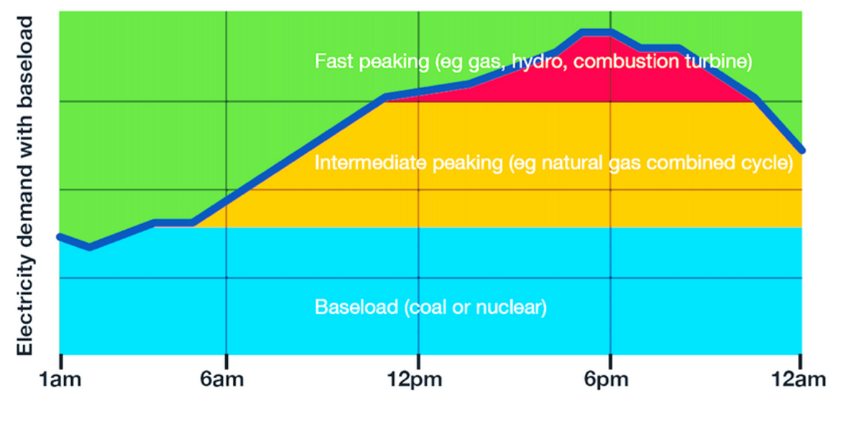
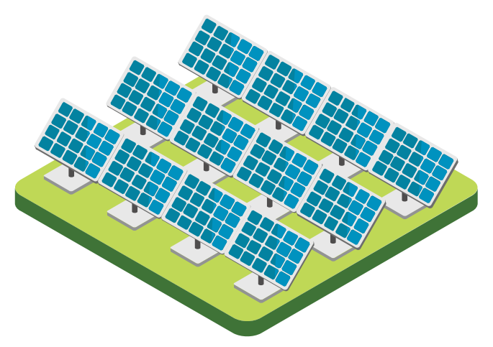


Figure 1: Daily Electricity Demand, EnergyPost

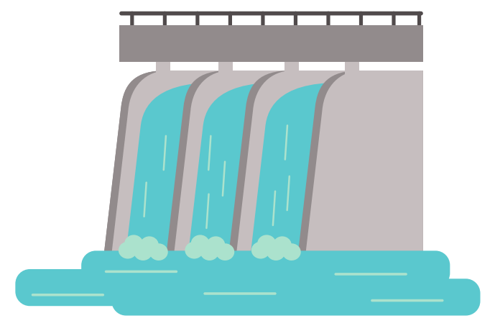
## 2. ELECTRICITY GENERATION

### 1 Solar Energy



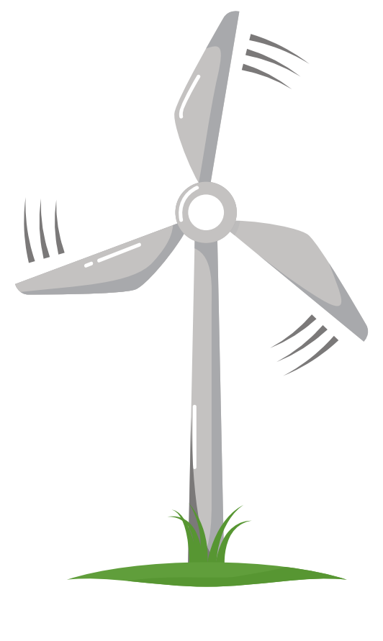
- **Dependent on solar flux**, only available during the day.
- No fuel costs, No emissions.
- Low maintenance costs.
- High capital costs & large land coverage required; but, can integrate onto rooftops.

### 2 Hydroelectricty



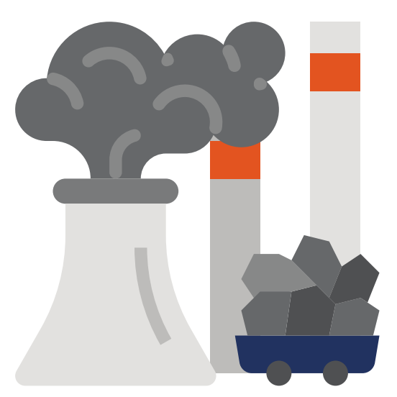
- Damaging to local ecosystem.
- No fuel costs, No emissions.
- **Dispatchable**; however, dependent on water.
- Low maintenance costs.
- High capital costs.
- **Often causes large floods**.

### 3 Wind Energy



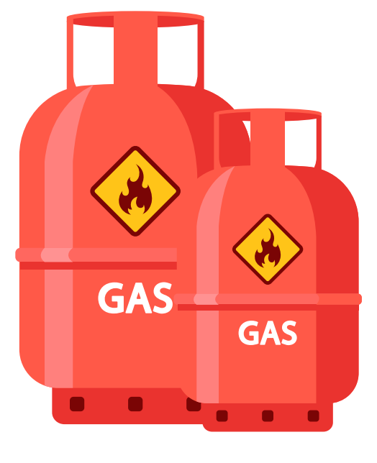
- Highly variable output.
- No fuel costs, No emissions.
- **Moderate maintenance costs, and risk to birds.**
- Obstructs views and is noisy.
- Mid to high capital costs.
- Onshore or offshore.
- More consistent at night.

### 4 Coal Power Plant



- Coal emits **88** kg$CO_2$ / GJ (EIA).
- Low dispatchability.
- Coal costs **$2.88**/GJ (EIA).
- High capital costs.
- Old plants are less efficient and require high maintenance.
- **Great for baseload power.**

### 5 Natural Gas (NG) Plant



- NG emits **51** kg$CO_2$ / GJ (EIA).
- Moderate dispatchability.
- NG costs **$2.24** / GJ (EIA).
- Moderate capital costs.
- Works well combined with coal to meet peaking power.
- **Ideal for baseload power.**

### 6 Nuclear Plant

- Very **low $CO_2$ emissions.**
- Low dispatchability.
- Fuel costs **$1.70**/ GJ (2022, EIA).
- Highest capital costs.
- Highest maintenance cost due to safety considerations.
- Problems dealing with **nuclear waste or nuclear disaster.**

## 4. DATA & ANALYSIS

Many worry about nuclear power and how nuclear waste will be dealt with; however, a properly functioning nuclear plant emits less radiation than coal-powered plants. Coal contains radioactive elements released upon burning. In functioning plants, nuclear waste is safely contained.

Although Hydro may reduce emissions, we must balance its other associated risks. Dams may affect water temperature, quality, sediment flow, local ecology, etc. Large projects often require displacing locals, and failures lead to mass floodings.

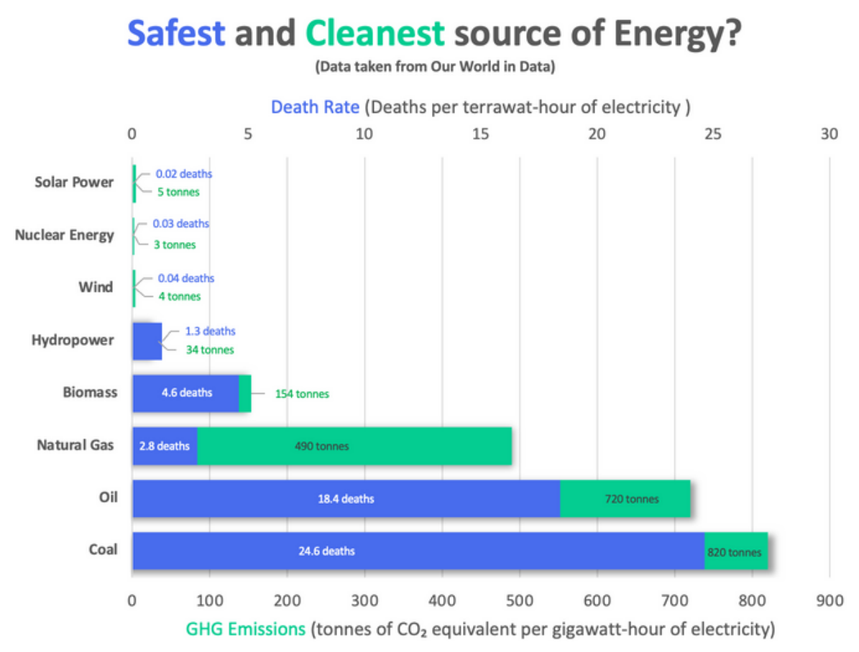


Figure 3: Deaths from accidents and pollution per TWh compared against GHG emissions, Rohan Daswani

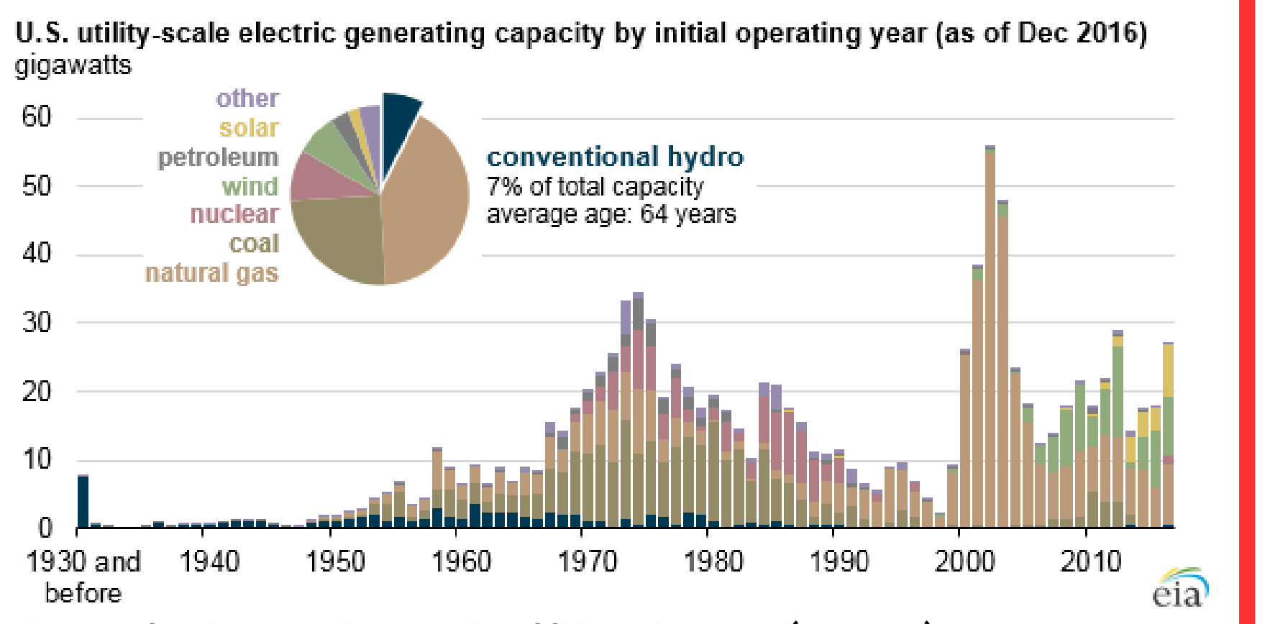


Figure 4: Electric generation capacity additions since 1930 (2017, EIA)

Considering capacity additions from 1930 to 2016, coal and nuclear have become less economically attractive to developers. The fracking boom in the early 2000s is largely credited for a more sustainable shift to NG. However, NG additions also decreased due to a push for sustainable energy. Technological advancements have made photovoltaics and offshore wind more economically viable and efficient. Although hydro has the added benefit of being dispatchable, environmental concerns have phased out their development. Looking at planned capacity additions in 2023, the push for renewables is clear. Nuclear power is slowly re-emerging with advancements, such as small modular reactors that can reliably provide power to remote communities. Given the issue of storing electricity on a large scale, developers have also started working on battery storage for the grid.

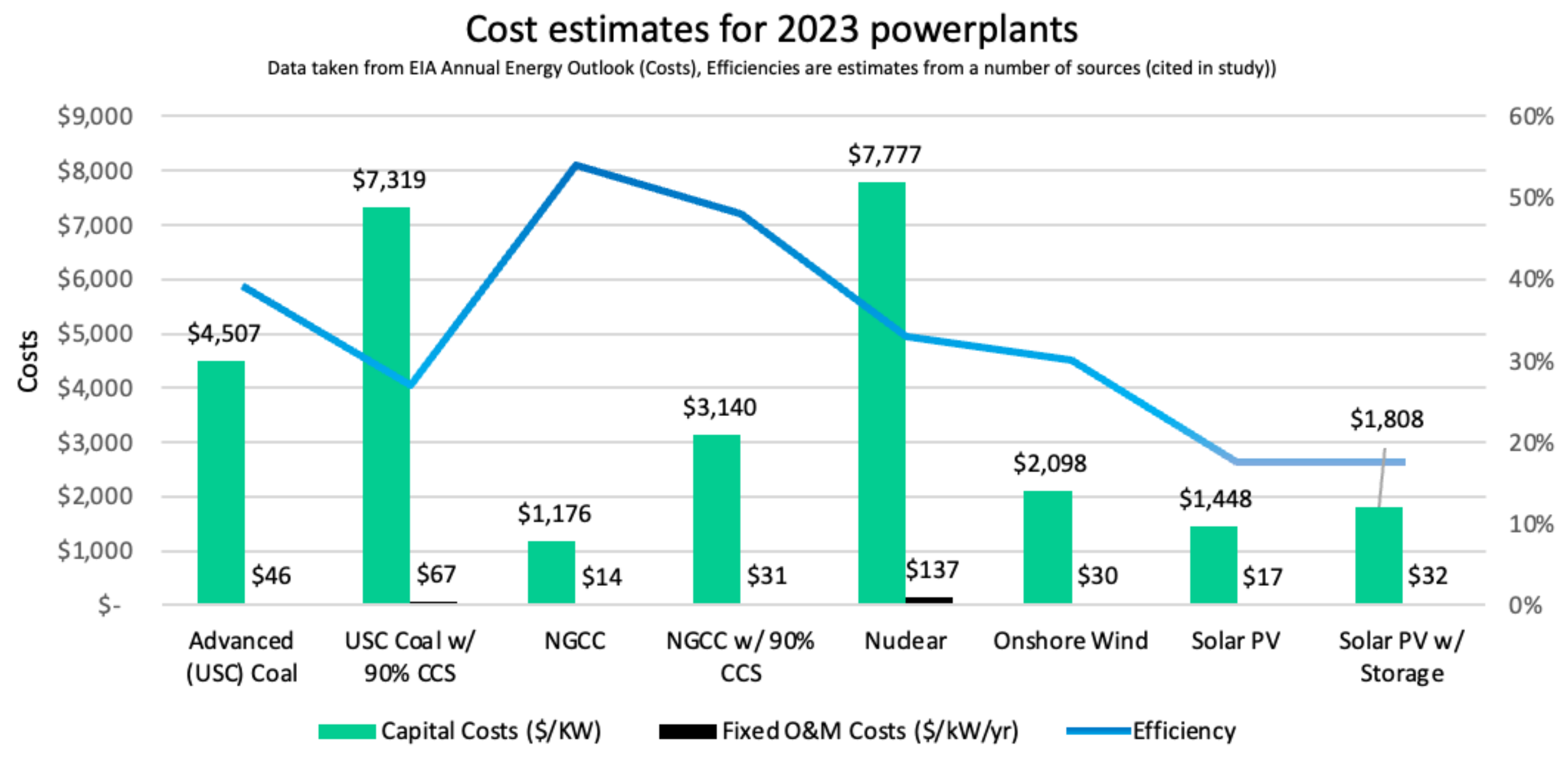


Figure 2: Cost estimates for different utilities, Rohan Daswani

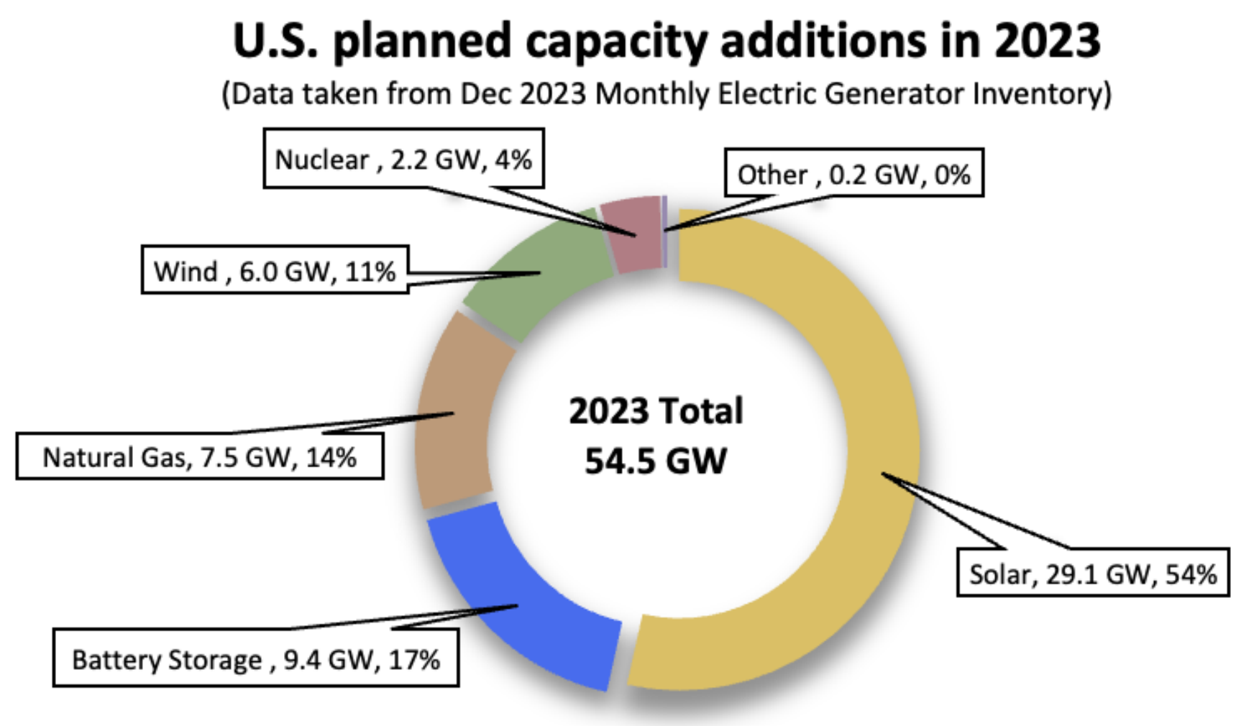
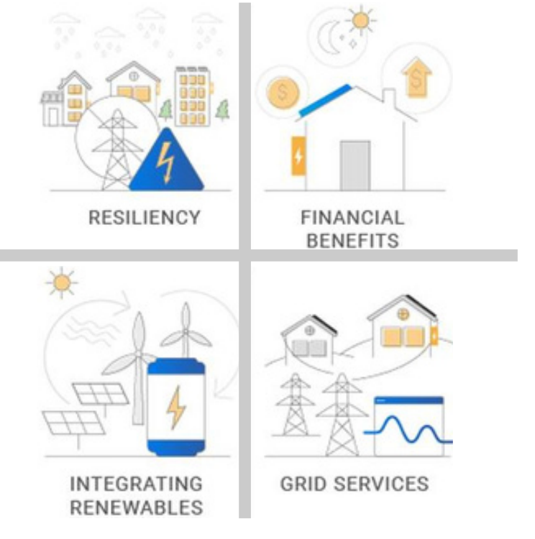


Figure 5: Planned capacity additions in 2023, Rohan Daswani

Figure 6: Storage benefits, Energy Sage



## 5. CASE & CONCLUSIONS

Unlike traditional case studies, this lesson exposes students to various electricity generation methods. After learning about the needs of consumers, students consider the viability of different utilities and debate what makes them appropriate. Below is a table of some key considerations.

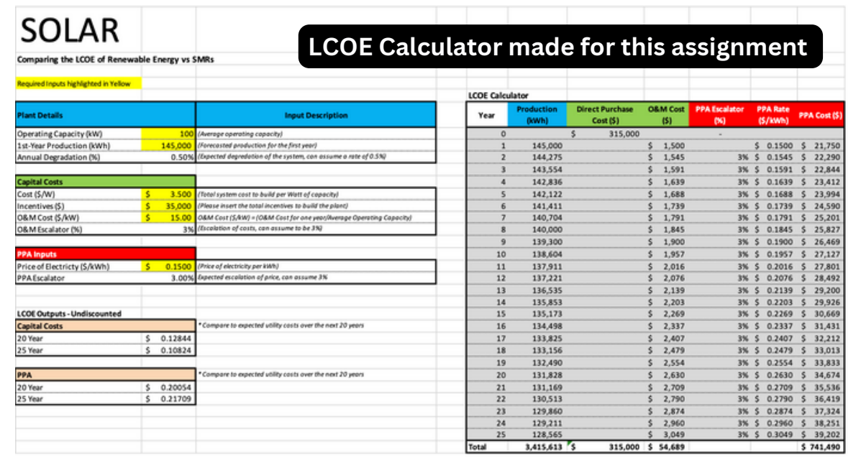
| | | |
|---|---|---|
| **Mojave Desert, CA**<br>• Site of Ivanpah plant.<br>• High solar irradiance.<br>• Vast, open area.<br>• Close proximity to existing infrastructure.<br>• Home to desert wildlife.<br>• High incentives for renewable energy. | **Yakutia Russia**<br>• Nuclear is intended.<br>• Remote location, no connection to the grid.<br>• Extreme climate.<br>• Independence from power lines required.<br>• Steady, reliable output is required. | **Hohot, Inner Mongolia**<br>• Site of Tuoketuo Station, the largest coal plant.<br>• Proximity to coal mines.<br>• Moderate infrastructure and transportation links<br>• Flat terrain, steady wind<br>• High altitude and steady sunshine |
| **Yangtze River, China**<br>• Site of Three Gorges, the largest hydroelectric power plant worldwide.<br>• Significant flow rate<br>• Prone to flooding<br>• Rich local ecology<br>• Displacement concerns<br>• Proximity to grid | **Philadelphia, PA, USA**<br>• Urban Location leading to air pollution concerns.<br>• Proximity to Marcellus Shale formation<br>• Strong Infrastructure<br>• Focus on sustainability<br>• Highly variable climate<br>• 2nd largest nuclear state | **Shetland Islands, UK**<br>• Remote Archipelago off scotland.<br>• Strong winds and wave power potential<br>• Limited connection to the UK power grid.<br>• Unique biodiversity and environment |

Students will assume their utility provides 100% of the electricity needs. Although results are open-ended, students must consider sustainability, cost, efficiency, environmental damage, and more. Students must inform their decisions using their LCOE calculations and consider all stakeholders involved.

## 6. HOW THE CASE WILL BE TAUGHT

### 1 Pre-Class Calculations and Questions

Before class, students are expected to fill out an **Excel spreadsheet** to obtain the required statistics. Students will also answer **reflection questions** from the case study. An LCOE template will be provided, and students must search for required inputs, fix the broken nuclear energy tab, and learn data analysis skills.



LCOE Calculator made for this assignment

SOLAR
Comparing the LCOE of Renewable Energy vs SMRs
Required Inputs highlighted in Yellow

| Plant Details | | Input Description |
|---|---|---|
| Operating Capacity (kW) | 100 | (Average operating capacity) |
| 1st-Year Production (kWh) | 145,000 | (Forecasted production for the first year) |
| Annual Degradation (%) | 0.50% | (Expected degradation of the system, can assume a rate of 0.5%) |
| **Capital Costs** | | |
| Cost ($/W) | $ 3.500 | (Total system cost to build per Watt of capacity) |
| Incentives ($) | $ 35,000 | (Please insert the total incentives to build the plant) |
| O&M Cost ($/kW) | $ 15.00 | O&M Cost ($/kW) = (O&M Cost for one year/Average Operating Capacity) |
| O&M Escalator (%) | 3% | (Escalation of costs, can assume to be 3%) |
| **PPA Inputs** | | |
| Price of Electricty ($/kWh) | $ 0.1500 | (Price of electricity per kWh) |
| PPA Escalator | 3.00% | Expected escalation of price, can assume 3% |

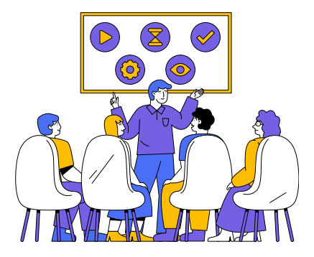
LCOE Outputs - Undiscounted

| Capital Costs | | |
|---|---|---|
| 20 Year | $ 0.12844 | *Compare to expected utility costs over the next 20 years |
| 25 Year | $ 0.10824 | |

| PPA | | |
|---|---|---|
| 20 Year | $ 0.20054 | *Compare to expected utility costs over the next 20 years |
| 25 Year | $ 0.21709 | |

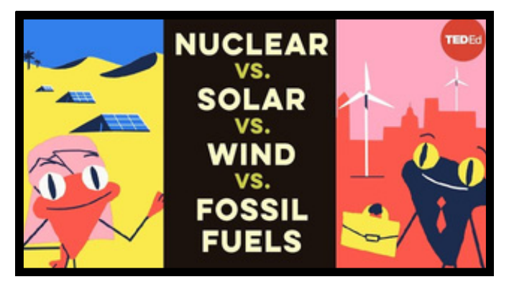
LCOE Calculator

| Year | Production (kWh) | Direct Purchase Cost ($) | O&M Cost ($) | PPA Escalator (%) | PPA Rate ($/kWh) | PPA Cost ($) |
|---|---|---|---|---|---|---|
| 0 | | $ 315,000 | | - | | |
| 1 | 145,000 | | $ 1,500 | | $ 0.1500 | $ 21,750 |
| 2 | 144,275 | | $ 1,545 | 3% | $ 0.1545 | $ 22,290 |
| 3 | 143,554 | | $ 1,591 | 3% | $ 0.1591 | $ 22,844 |
| 4 | 142,836 | | $ 1,639 | 3% | $ 0.1639 | $ 23,412 |
| 5 | 142,122 | | $ 1,688 | 3% | $ 0.1688 | $ 23,994 |
| 6 | 141,411 | | $ 1,739 | 3% | $ 0.1739 | $ 24,590 |
| 7 | 140,704 | | $ 1,791 | 3% | $ 0.1791 | $ 25,201 |
| 8 | 140,000 | | $ 1,845 | 3% | $ 0.1845 | $ 25,827 |
| 9 | 139,300 | | $ 1,900 | 3% | $ 0.1900 | $ 26,469 |
| 10 | 138,604 | | $ 1,957 | 3% | $ 0.1957 | $ 27,127 |
| 11 | 137,911 | | $ 2,016 | 3% | $ 0.2016 | $ 27,801 |
| 12 | 137,221 | | $ 2,076 | 3% | $ 0.2076 | $ 28,492 |
| 13 | 136,535 | | $ 2,139 | 3% | $ 0.2139 | $ 29,200 |
| 14 | 135,853 | | $ 2,203 | 3% | $ 0.2203 | $ 29,926 |
| 15 | 135,173 | | $ 2,269 | 3% | $ 0.2269 | $ 30,669 |
| 16 | 134,498 | | $ 2,337 | 3% | $ 0.2337 | $ 31,431 |
| 17 | 133,825 | | $ 2,407 | 3% | $ 0.2407 | $ 32,212 |
| 18 | 133,156 | | $ 2,479 | 3% | $ 0.2479 | $ 33,013 |
| 19 | 132,490 | | $ 2,554 | 3% | $ 0.2554 | $ 33,833 |
| 20 | 131,828 | | $ 2,630 | 3% | $ 0.2630 | $ 34,674 |
| 21 | 131,169 | | $ 2,709 | 3% | $ 0.2709 | $ 35,536 |
| 22 | 130,513 | | $ 2,790 | 3% | $ 0.2790 | $ 36,419 |
| 23 | 129,860 | | $ 2,874 | 3% | $ 0.2874 | $ 37,324 |
| 24 | 129,211 | | $ 2,960 | 3% | $ 0.2960 | $ 38,251 |
| 25 | 128,565 | | $ 3,049 | 3% | $ 0.3049 | $ 39,202 |
| Total | 3,415,613 | $ 315,000 | $ 54,689 | | | $ 741,490 |



### 2 In-class lecture and Introduction

In class, we will learn about US energy needs; I will start with a **short video** detailing each form of energy generation.



TED-Ed Video: "How much land does it take to power the world?"
https://www.youtube.com/watch?v=DW0jTe80kmM&ab_channel=TED-Ed

After the video, the class will **reflect on what they learned**. I will then walk through the case and provide the EIA data. Students will answer questions from this data, learning to **transform raw data into useful statistics.**

### 3 Collaboration and assigning utilities.

Students are split into groups of 4-5 people. Students will then compare LCOE calculations, correcting mistakes. They will then calculate an **average LCOE for each utility**. Following this, groups will be presented with the case study and **debate internally** about which utilities would best suit which location, considering LCOE, environmental impact, feasibility, and other concerns. Finally, each group will be given **2 minutes to explain their decisions** to the class.

### 4 Class discussion and Reflection

After hearing all pitches, the class will **vote on a utility** for each location. I will then finally reveal the intended utility for each location. As a class, we'll discuss the **benefits and drawbacks of each utility**. Some locations, such as Yakutia and Mongolia, should be more unexpected than others like using solar in the desert. Finally, students will submit two sentences on **how the energy transition should occur**, shifting to what utility, and for what reason. Some answers will be read aloud.

## 7. REFERENCES