7-2 Final Project

Research Paper

Energy Mix

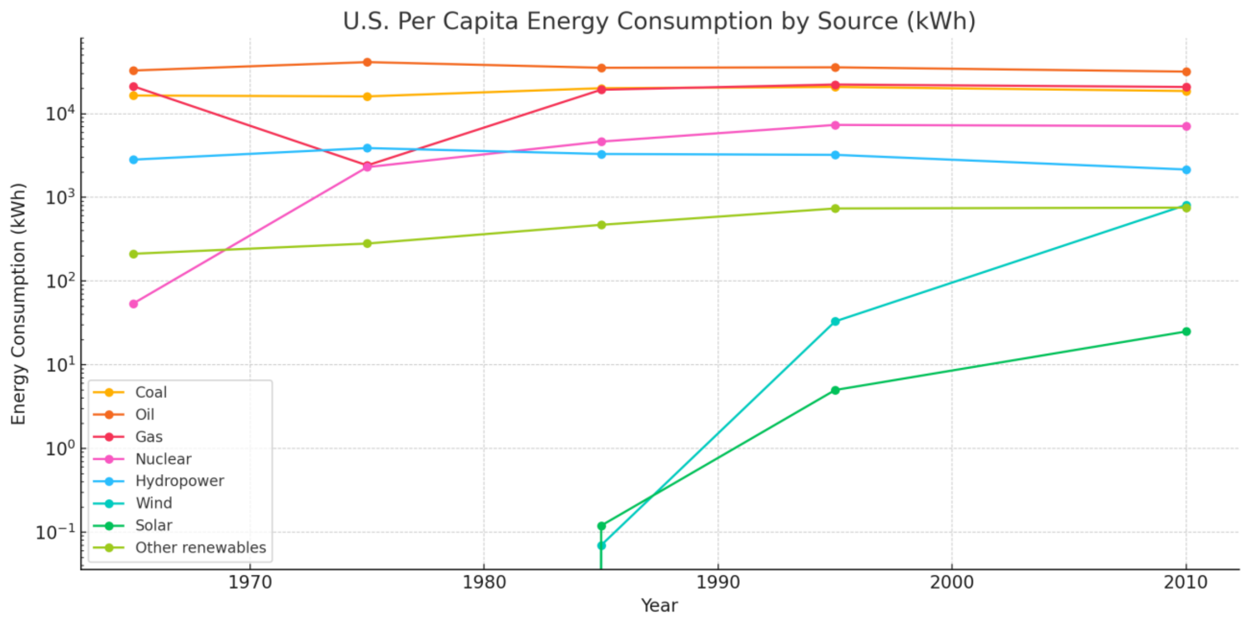
Historical Energy Mix

From 1885 to 1950, coal was the primary fuel source for energy production in the United States, driven by its abundance, low cost, and suitability for powering steam engines and electricity generation in an industrializing economy (EIA, 2024). In 1950, petroleum-based fuels overtook coal to become the dominant source of energy, a transition fueled by post–World War II economic growth, mass adoption of automobiles, and the expansion of highway infrastructure. Petroleum, however, was used primarily for transportation rather than electricity generation (EIA, 2024). Since that shift, coal has been used mainly for electricity production, alongside natural gas, which rose to become the second-largest energy source in 1958 due to its cleaner combustion, expanding pipeline networks, and technological advances in extraction (EIA, 2024).

In the 1980s, ethanol-blended gasoline and biodiesel-blended diesel entered the U.S. energy mix, promoted by agricultural policy incentives and a desire to reduce dependence on imported oil (EIA, 2024; Reisser et al., 2018). By the mid-1990s, wind and solar power began to register measurable contributions, aided by falling technology costs, federal and state tax incentives, and growing environmental awareness. Since then, renewable sources such as solar, wind, and hydropower have steadily increased their share of electricity generation, supported by continued technological improvements, climate policy measures, and shifting market economics in favor of low-carbon energy (Reisser et al., 2018).

Data from Our World in Data (n.d.) illustrates how the U.S. energy mix evolved from 1965 to 2010, measured in per capita kilowatt-hours (kWh):

Year	**Coal**	**Oil**	**Gas**	**Nuclear**	**Hydropower**	**Wind**	**Solar**	**Other renewables**
1965	16479	32784	21257	54	2824	0.0	0.0	212
1975	16088	41299	2411	2301	3881	0.0	0.0	281
1985	20134	35336	19320	4641	3300	0.07	0.12	470
1995	20853	35793	22295	7341	3223	33.0	5.0	737
2010	18647	31803	20838	7111	2153	811.0	25.0	754



Current Energy Mix

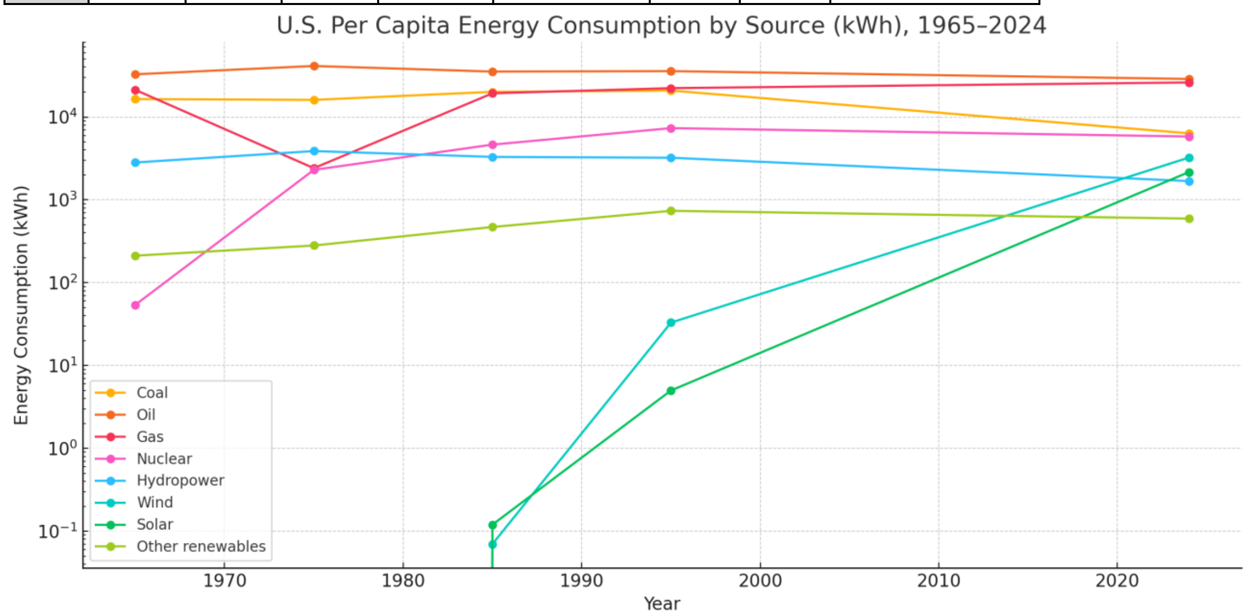
Since 2010, the U.S. energy mix has undergone significant changes. Coal consumption has steadily declined, while natural gas use has increased, making it one of the leading energy sources. Renewable energy—particularly wind and solar—has expanded rapidly, surpassing coal in total consumption. Hydropower remains in use but has experienced a modest decline. Despite these shifts, petroleum continues to be the most consumed energy source overall (EIA, 2024; Our World in Data, n.d.).

In 2016, biofuels became the most consumed renewable energy source in the United States, overtaking wood combustion (EIA, 2024). By 2022, biodiesel consumption had surpassed that of petroleum diesel, reflecting a growing reliance on renewable fuels (EIA, 2024).

In 2023, the United States consumed 94 quadrillion British thermal units (quads) of energy. Of this total, fossil fuels accounted for 83%, while non-fossil fuel sources made up the remaining 17% (EIA, 2024). That same year, renewable energy consumption exceeded that of coal, although petroleum remained the dominant energy source (EIA, 2023).

The following table presents the 2024 U.S. energy mix, measured in kilowatt-hours (kWh) per capita (Our World in Data, n.d.):

Year	**Coal**	**Oil**	**Gas**	**Nuclear**	**Hydropower**	**Wind**	**Solar**	**Other renewables**
2024	6356	28801	26118	5812	1685	3234	2162	594



Issues

One of the primary concerns with the current energy mix in the United States is that the most widely used fuels—petroleum, coal, and natural gas—emit greenhouse gases and other pollutants into the atmosphere. These emissions degrade air quality and negatively impact the health and well-being of communities located near the sources of pollution. Importantly, it is not only fossil fuels that contribute to these issues; even renewable sources such as wood combustion can emit greenhouse gases and particulate matter that exacerbates air pollution and climate change. Moreover, fossil fuels are non-renewable. Once depleted, they cannot be replenished, making them unsustainable for long-term energy security (Reisser et al., 2018).

Petroleum is a major driver of environmental degradation and climate change. Gasoline and diesel, the primary fuels derived from petroleum, are among the largest contributors to greenhouse gas emissions due to their widespread use in transportation. In addition to CO_2, the combustion of these fuels releases other harmful pollutants that contribute to smog, air pollution, and acid rain (Reisser et al., 2018). Petroleum extraction also poses environmental risks. Oil reservoirs often contain large volumes of contaminated water, which must either be reinjected underground or treated before disposal. Improper handling can lead to water pollution and ecosystem disruption. Furthermore, spills and leaks from drilling sites or pipelines can have devastating effects on local environments, especially aquatic ecosystems (Reisser et al., 2018).

Coal presents some of the most severe environmental and health risks across its lifecycle. It contains toxic elements such as sulfur, phosphorus, and mercury, which contribute to both air and water pollution. When burned, coal releases substantial amounts of CO_2—one of the leading causes of global warming—along with ash and fine particulates that degrade air quality in surrounding communities (Reisser et al., 2018). The process of coal extraction, particularly strip mining, can cause extensive ecological destruction. This method disturbs large areas of land and introduces sediment and chemicals into nearby waterways. Underground coal mining brings additional hazards. Methane, a highly potent greenhouse gas—roughly 20 times more heat-absorbing than CO_2 per unit—is vented from underground mines to reduce explosion risks (Reisser et al., 2018). Despite these precautions, miners remain exposed to coal dust, which can lead to Black Lung Disease, a chronic and often fatal respiratory condition (Reisser et al., 2018).

Natural gas is often considered a cleaner alternative to coal and oil, but it is still a significant contributor to climate change. While burning natural gas emits roughly half the CO_2 of coal per megawatt-hour, it is far from emissions-free (Reisser et al., 2018). Moreover, natural gas production and distribution systems are prone to methane leaks. Methane is a greenhouse gas many times more potent than CO_2, meaning that poorly maintained pipelines and wells can offset the climate benefits of using natural gas over coal. In some cases, methane leaks from natural gas infrastructure can contribute more to atmospheric warming than coal combustion itself (Reisser et al., 2018).

Environmental concerns also arise from the extraction process, especially with hydraulic fracturing (fracking). Fracking can lead to groundwater contamination and increased seismic activity, often linked to the high-pressure injection of wastewater into the ground. While many of these risks can be minimized with proper regulation and oversight, lax enforcement and poor operational practices continue to result in environmental damage (Reisser et al., 2018).

Proposed Mix

2050

Today, the U.S. electrical grid relies on a diverse mix of power generation sources, including coal, natural gas, nuclear, solar, wind, hydroelectric, and biofuels. Currently, power generation and distribution are primarily managed by private companies and municipal utilities. As the nation transitions toward a more carbon-neutral energy mix, there is an opportunity to reevaluate the centralized energy model in favor of a decentralized approach (EIA, 2024).

In a decentralized model, single-family homes, multi-family residences, and businesses would install rooftop solar panels paired with on-site battery storage systems to meet local energy needs when solar generation is unavailable. Excess energy could be exported to the grid, while surplus grid electricity could recharge distributed batteries. This localized generation and storage system could serve as an alternative to large-scale grid storage infrastructure. Residential and commercial solar deployments would both power local batteries and contribute electricity back to the grid. This decentralized model could account for approximately 18% of the total energy mix.

Grid-scale solar, wind, and nuclear projects could provide an additional 24% of the nation's energy needs. However, expanding nuclear energy requires addressing several challenges. First, the United States must implement a long-term solution for storing spent nuclear fuel, such as a geologically stable site like Yucca Mountain or salt domes in southwestern Kansas (Reisser et al., 2018). Public acceptance will be necessary through informed consent. Second, nuclear regulations must be updated to reflect best practices in plant design and safety. Third, uranium-235 (U-235), the primary fuel for nuclear fission, is finite. Recycling spent nuclear fuel to recover remaining U-235 can extend its availability while future technologies are developed (Reisser et al., 2018).

Geothermal energy and electricity from biomass could supply approximately 2% of the energy mix. Geothermal energy is best suited for regions with high geothermal gradients, such as the American West, and should avoid impacting protected lands (Reisser et al., 2018). Biomass, such as methane recovered from landfills, offers a low-carbon energy source. Capturing and burning methane significantly reduces net emissions compared to allowing it to enter the atmosphere.

The transportation sector could transition primarily to ethanol, biodiesel, and electric vehicles, which together could represent approximately 56% of the total energy mix. Ethanol and biodiesel offer lower-emission, domestically produced alternatives to petroleum-based fuels and are compatible with existing vehicles. This reduces the financial burden on consumers while transitioning to electric vehicles (EVs). As EV costs decline and infrastructure improves, electric vehicles will become more widespread. Since they are powered by electricity, the cleaner the grid becomes, the greater the emissions reduction benefits of EVs.

Based on the projected transition to cleaner, domestic energy sources, the proposed 2050 U.S. energy mix would consist of approximately 18% from decentralized rooftop solar with battery storage, 24% from grid-scale solar, wind, and nuclear, and 2% from geothermal and landfill-based biomass energy. The remaining 56% would come from transportation energy sources, including ethanol, biodiesel, and electric vehicles. This mix reflects a shift away from fossil fuels and emphasizes renewable generation, distributed storage, and sustainable fuels while maintaining energy reliability and security.

Justification

A major challenge of grid-scale wind and solar power is their intermittency, as they do not produce electricity consistently. Additionally, the U.S. lacks widespread grid-scale energy storage. Shifting energy storage closer to consumers has several benefits. Many household and business devices operate on direct current (DC), while the grid provides alternating current (AC). Converting AC to DC results in energy loss – typically 5 – 10% (Sinopoli, 2012). On-site battery storage allows power to be delivered directly as DC, improving efficiency.

On-site batteries also reduce the impact of brownouts and blackouts, providing backup power during outages or generation shortfalls. This localized buffering supports grid reliability and can help stabilize supply during peak demand.

The electrical grid will remain essential, especially as electricity demand continues to grow. For example, data centers supporting artificial intelligence (AI) are projected to require 1,065 terawatt-hours (TWh) annually by 2030, nearly double the 536 TWh required by traditional data centers in 2025 (Deloitte Insights, 2024). Meeting this demand will require the grid to produce as much carbon-neutral energy as possible.

Nuclear energy must remain a key component of the future energy mix. As a zero-emission baseload source, nuclear can reliably support high-demand infrastructure like data centers. Wind and solar will remain critical and cost-effective, and their intermittency can be offset through distributed storage. During periods of overproduction, excess energy can be stored in residential and commercial batteries for later use.

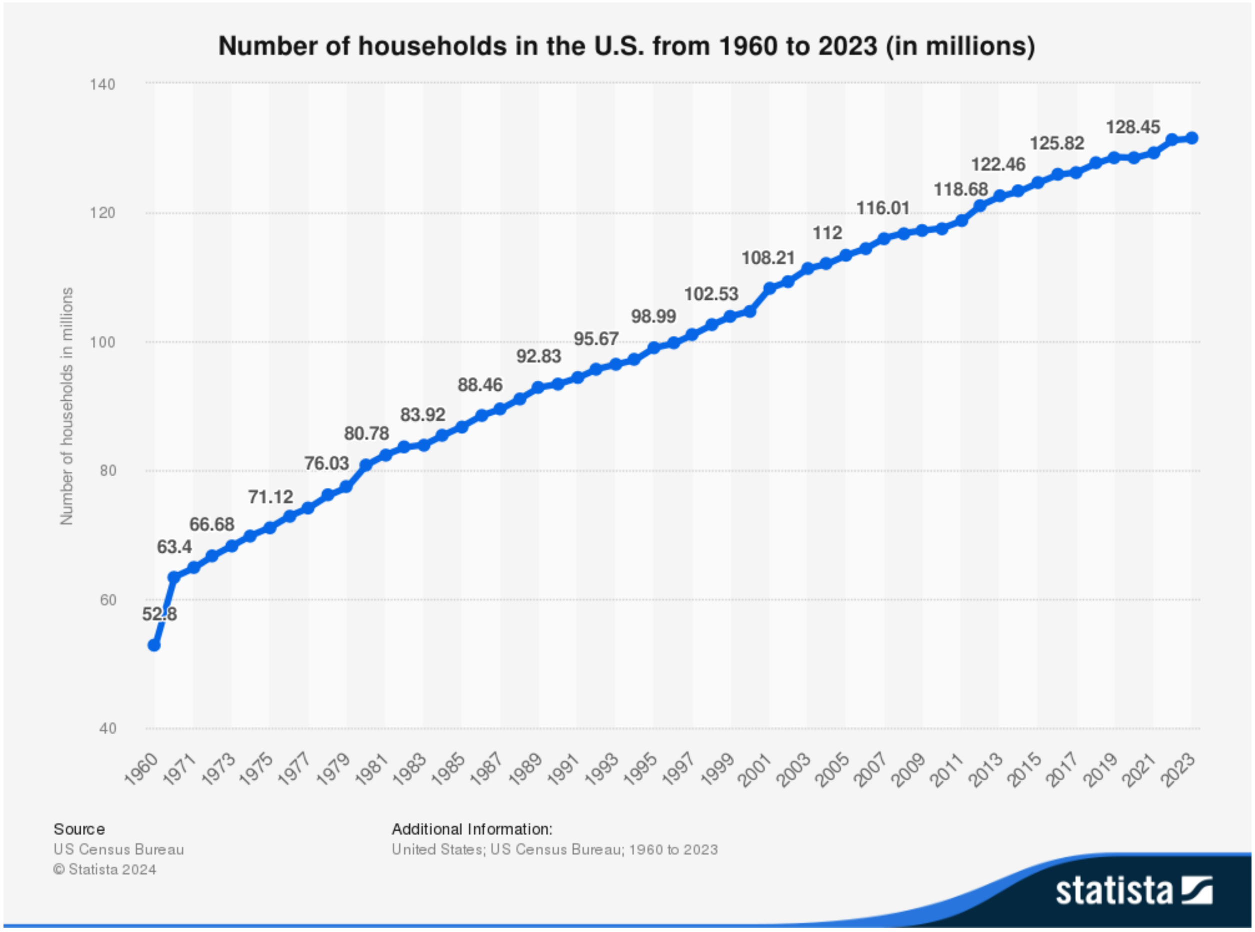
Geothermal energy provides clean, continuous power when deployed in geologically suitable regions. Biomass derived from landfill methane offers a climate-friendly transitional energy source by capturing and utilizing emissions that would otherwise contribute to atmospheric greenhouse gases. In 2018, 12% of the 292 million tons of solid waste generated in the United States was converted to biomass (EIA, 2024). This highlights significant potential for expanding waste-to-energy initiatives nationwide.

Ethanol and biodiesel are immediately usable, lower-emission alternatives to petroleum fuels. Their compatibility with existing internal combustion vehicles helps preserve consumer investments while transitioning to cleaner technologies. As EV adoption grows, cleaner electricity will enhance their emissions offset potential, directly linking transportation decarbonization to electricity generation.

Pathway

Home and business-scale energy storage systems are already commercially viable. Redirecting investments from centralized storage development to expanding adoption of distributed battery storage would support the transition to a decentralized model and improve overall energy resilience.

As of 2023, there are 128.45 million households in the United States (Korhonen, 2024). Using data from Statista, a regression model predicts that there will be approximately 212 million households by 2050. According to the National Renewable Energy Laboratory (NREL), the cost of a residential solar installation is $2.70 per watt, which includes all hardware and labor costs (NREL, n.d.). If the average household requires 15 kW of solar capacity, the total installation cost would be $40,500 per household. Installing solar for all 212 million households—based on 2050 household predictions and 2024 solar cost estimates—would total approximately $8.586 trillion. However, the true cost would likely be lower due to the economies of scale that would come from deploying such systems nationwide. According to the Tesla website, the cost of a 15 kW solar system paired with a Powerwall battery is approximately $36,000 today, providing both solar generation and integrated energy storage (Telsa, n.d.).



Nuclear energy remains a public concern, largely due to well-publicized accidents like Three Mile Island, Fukushima, and Chernobyl. Overcoming public skepticism requires broad public education on nuclear safety, regulatory oversight, and operational safeguards. The development of permanent storage facilities for spent nuclear fuel must be prioritized. Without such facilities, the continued operation and expansion of nuclear power will be politically and technically constrained.

Landfills across the country would need to upgrade infrastructure to capture methane emissions and connect to nearby power plants through dedicated pipelines. Regulations should be enacted to monitor methane leakage and require timely maintenance.

To avoid contributing to food price volatility, ethanol production should move away from corn and instead focus on sugarcane and cellulosic sources such as agricultural residues and grasses. This would allow biofuel production to expand sustainably without displacing food crops.

Socially, public awareness campaigns will be needed to promote the benefits of home energy systems, EV adoption, and biofuel usage. Politically, governments should extend tax incentives, streamline permitting for clean energy projects, and enforce renewable fuel standards. Infrastructure investments should focus on grid modernization, distributed energy integration, and rural energy access.

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