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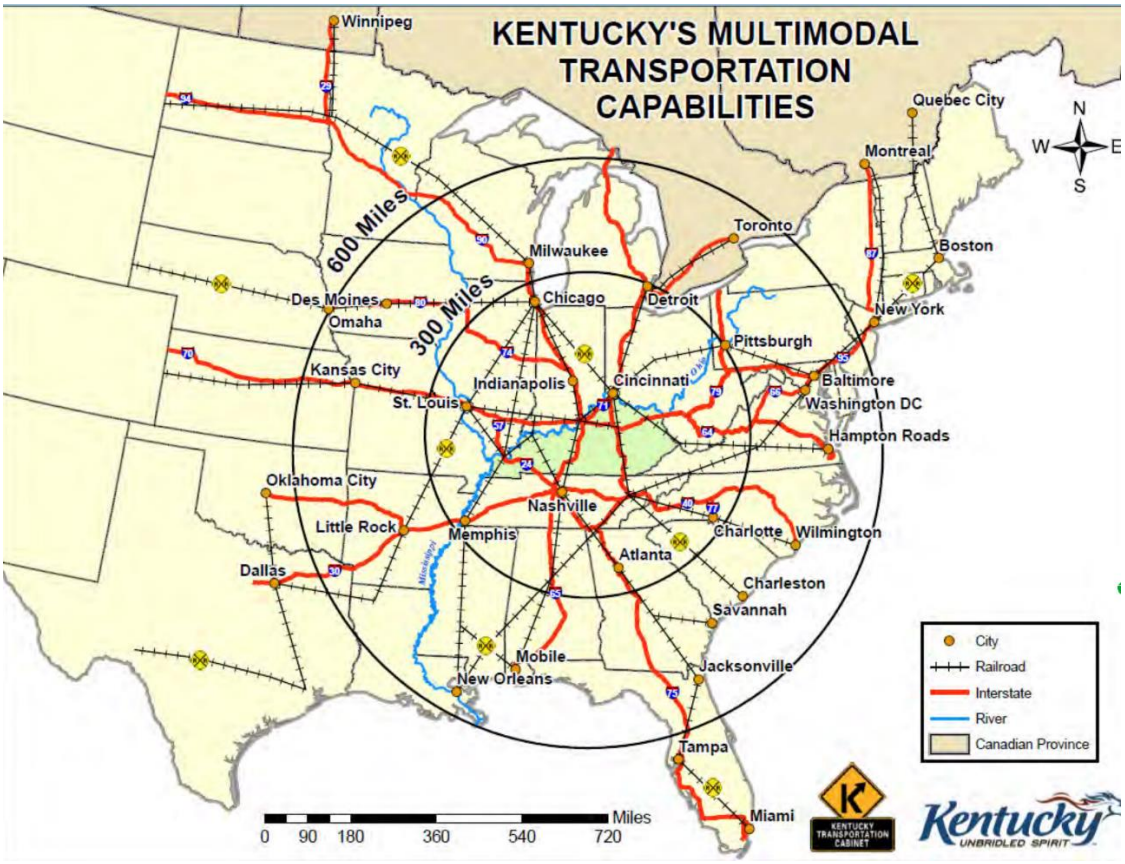
Regional Hydrogen Production, Resources, and Infrastructure

With over 65% of the nation's population within 600 miles of Kentucky, a regional hydrogen hub in Kentucky meets several criteria from a site suitability perspective. Kentucky has long supported the nation as a manufacturing and energy hub. Kentucky's gross domestic product or GDP was $215,399,000,000 in 2019 according to BEA data and represents 1.00% of US GDP which makes Kentucky the 28th largest state economy in the nation. While COVID 19 presented significant challenges to Kentucky's economy as with the nation, the Commonwealth is positioned to build back better for a better Kentucky and retain our dominance as the economic pulse of the nation. Looking forward, Kentucky is ready to manufacture the products for a sustainable economy, provide the fuels including hydrogen for a new energy economy, build the next-generation energy infrastructure, and develop and retain the workforce for tomorrow.

With a diverse energy resource supply including both fossil and renewable, Kentucky's energy infrastructure connects north-south and east to west. Ideally situated geographically, Kentucky offers several opportunities to build off of our existing heritage, workforce energy resources, and infrastructure to develop a robust regional hydrogen ecosystem serving the east and southeast as well as connecting across the United States.

From a multimodal transportation capabilities assessment, Kentucky's businesses and infrastructure move the commodities and resources to fuel the nation and hydrogen is a natural addition to the resource mix fueling the economy.



In addition to transportation, Kentucky has the following energy infrastructure to support, enhance, or expand for hydrogen distribution and transport. This infrastructure is illustrated on the maps following.

- 6,769 miles of natural gas pipelines,
- 18,834 miles of natural gas distribution pipelines,
- 13,000 miles of electricity transmission lines,
- Over 800 miles of crude and petroleum product pipelines,
- Deep saline formations,
- Oil and natural gas reservoirs, and
- Underground natural gas storage areas.

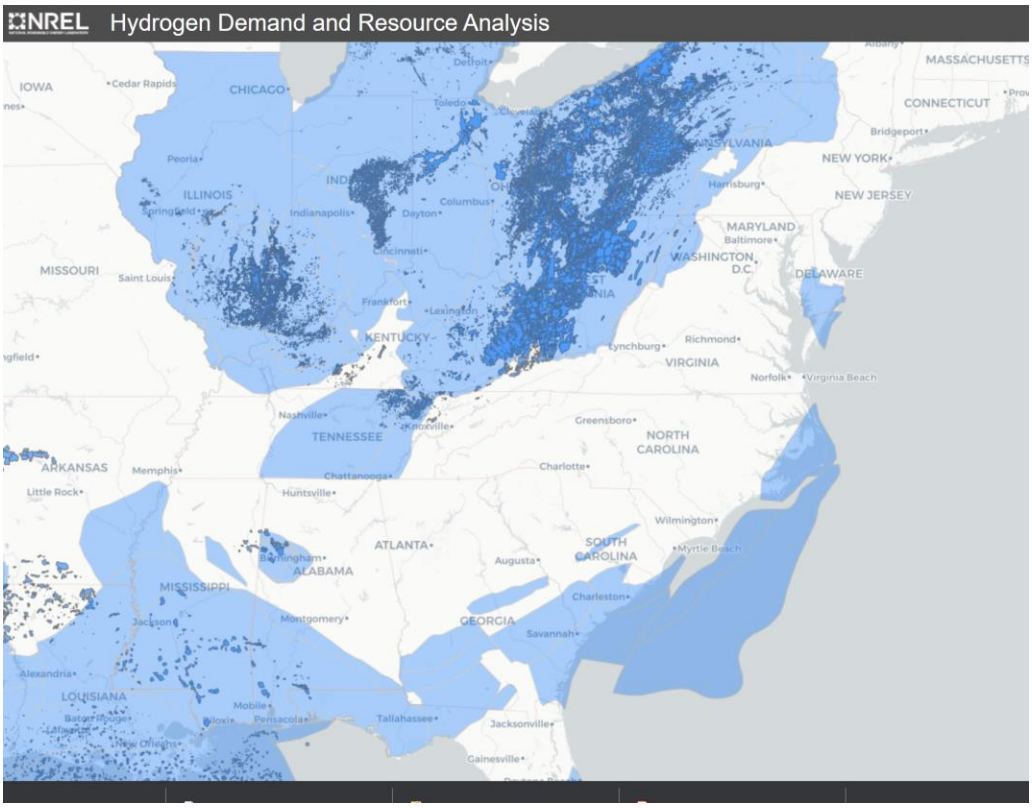


Figure 1: Saline Formations and Oil and Gas Reservoirs for CO2 Sequestration

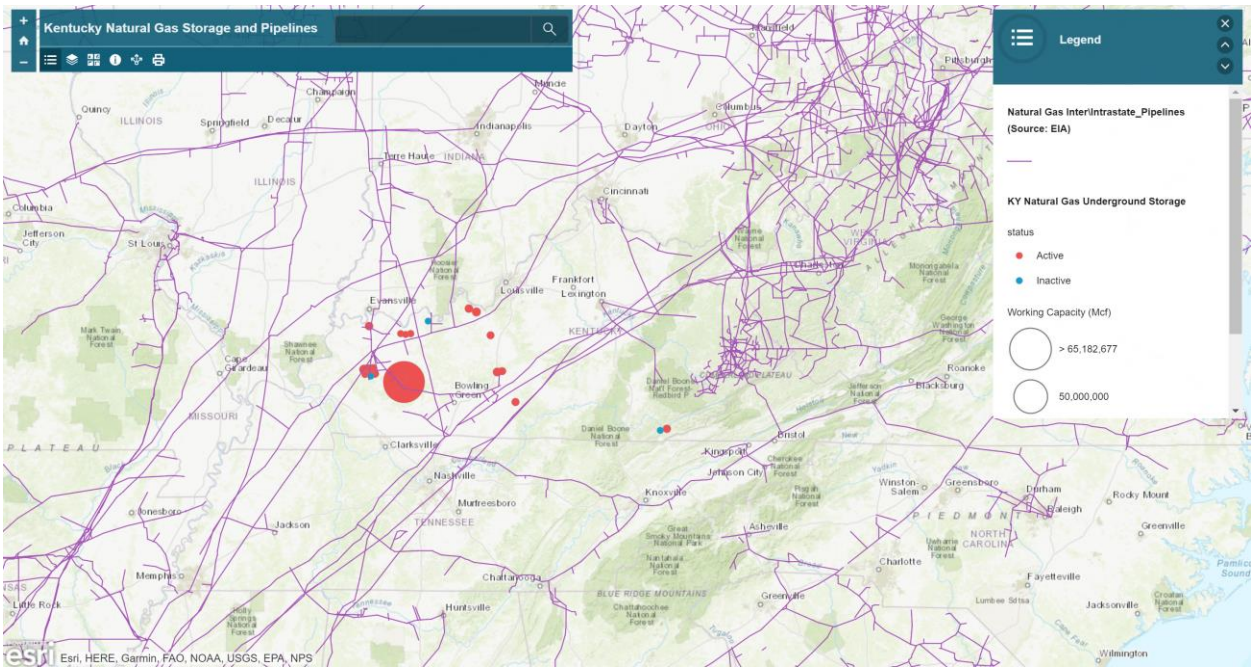


Figure 2: Natural Gas Infrastructure and Storage Locations

Carbon Sequestration Potential

Kentucky is not immune to the fact that our fossil resources necessitate the deployment of carbon capture utilization and sequestration (CCUS) in order to meet the needs of consumers for low or zero carbon fuels and to harness the benefit of our natural resources and existing infrastructure. The Kentucky Geological Survey (KGS) houses the Kentucky Consortium on Carbon Storage. Building on the work conducted in 2007 at the direction of the Kentucky General Assembly, KGS researchers have expertise in regional subsurface geology, reservoir analysis, seismic interpretation, geochemistry, and coal geology. The research from 2007 sets the foundation for low or zero carbon hydrogen generation in Kentucky given the results that Deep wells proved that there are both reservoir rocks, and overlying confining rocks at suitable depths for permanent CO2 storage in eastern and western Kentucky.

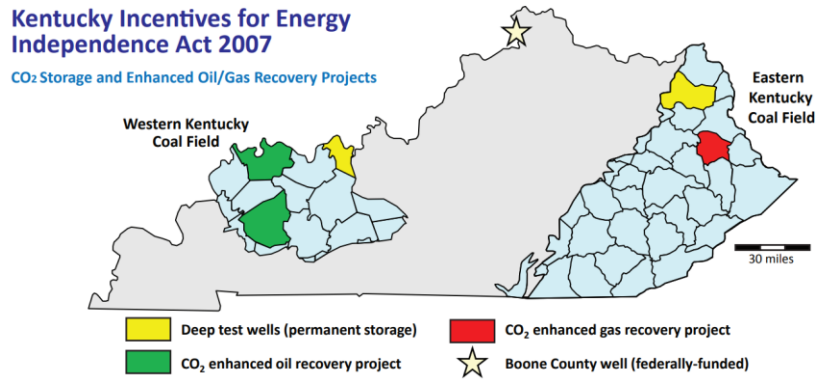


Figure 3: Funded CO2 Storage Research Projects in Kentucky

According the National Renewable Energy Laboratory (NREL) Hydrogen Demand and Resource Analysis, Kentucky is well position to draw upon both fossil and renewable resources for hydrogen production potential and can lead the southeastern states in development and distribution.

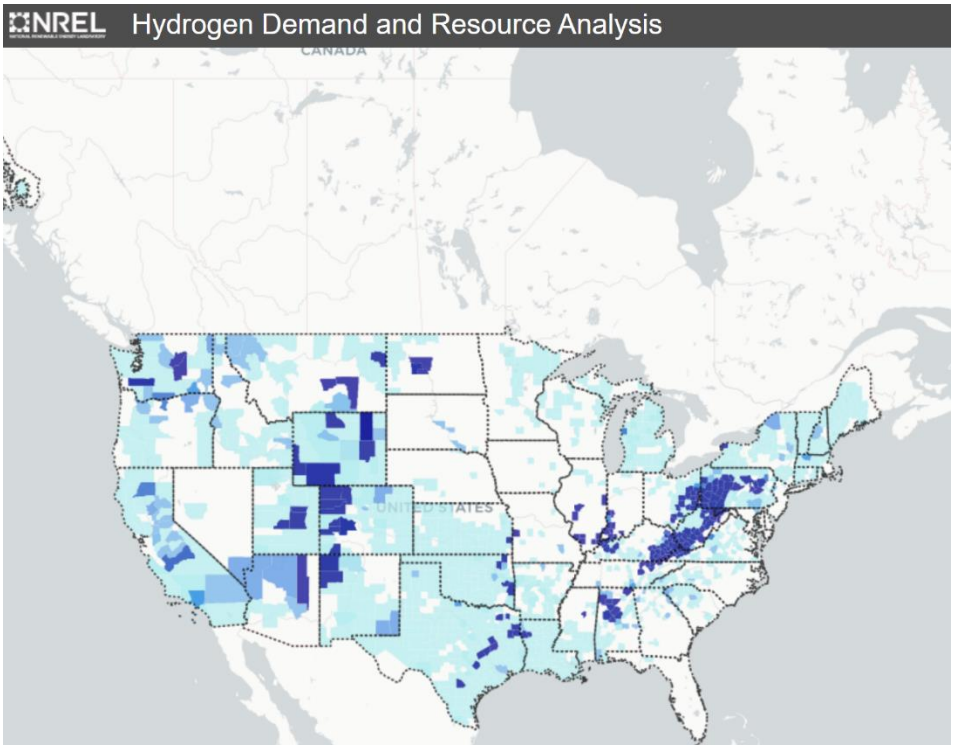


Figure 4: H2 Production Potential from 100% coal utilization, 30% natural gas utilization, and 30% hydro utilization

Looking a bit deeper at the county level production potential for all resources fossil and renewable, we see that there are areas of Kentucky that are well-positioned to support regional hydrogen development, ***particularly western, southcentral, and eastern Kentucky***.

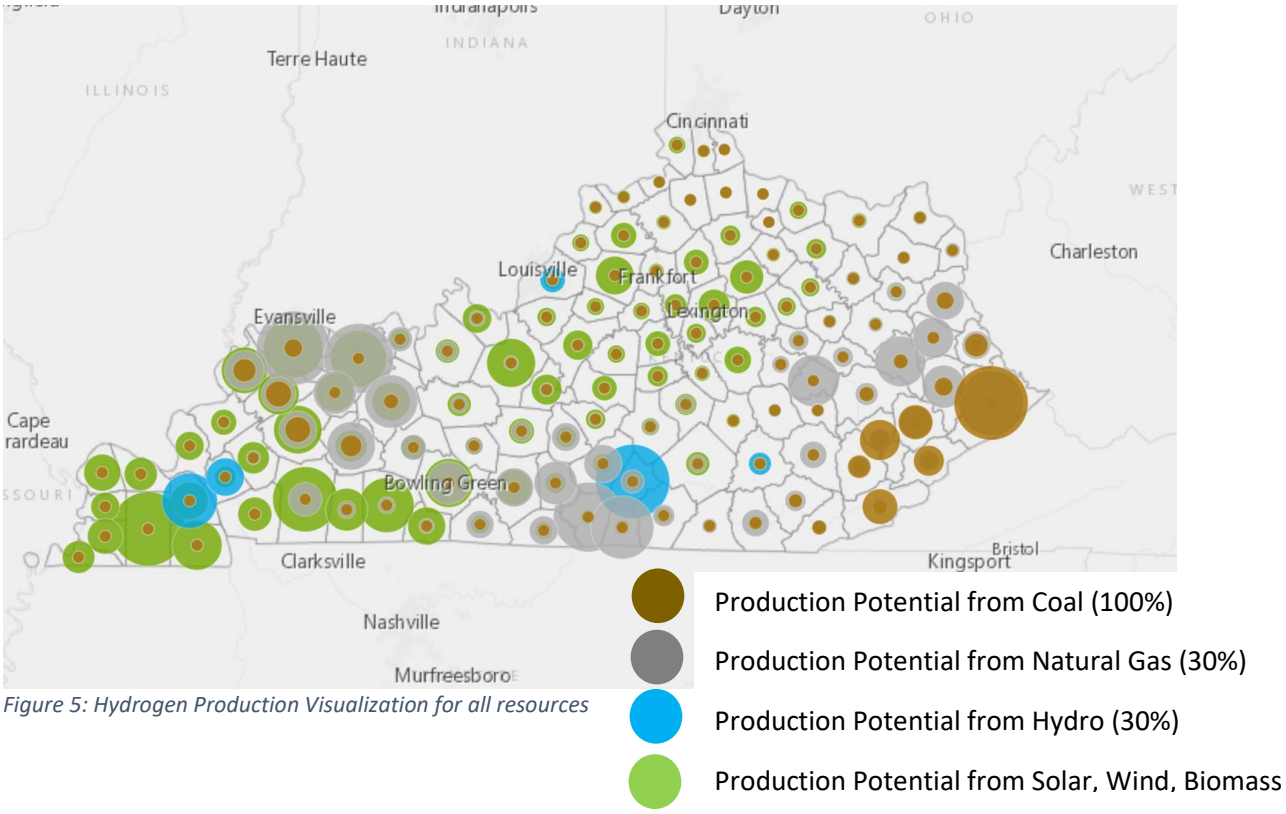


Figure 5: Hydrogen Production Visualization for all resources

Table of Kentucky Hydrogen Production Potential (source NREL Hydra)

Resource Type	*Average Production Potential*	*Maximum Production Potential*	*Units*
H2 from 100% Coal Utilization	*119,078*	*3.4 million*	*Tonnes/yr*
H2 from 30% Natual Gas Utilization	*1.382*	*9.2*	*Tonnes/yr*
H2 from 30% Hydro Utilization	*5,780*	*12,000*	*Tonnes/yr*
H2 from Biomass, Solar and Wind	*312,371*	*1.75 million*	*Tonnes/Yr*

Recent Energy Resource Development Trends In Kentucky

Utility-scale solar generation is experiencing a large growth from 2019 in Kentucky. There are approximately 27 merchant or independent utility-scale solar cases pending approval with the Kentucky Public Service Commission representing over 3,000 MW of installed capacity. Many of these are looking for potential off-takers or integrated project development opportunities.

In addition, Kentucky is blessed with abundant hydro resources with the oldest hydroelectric facility dating back to 1925. Therefore, it is no surprise that there are 12 pending hydroelectric

projects representing ~80 MW of capacity and 1 pump storage project at 500 MW of capacity. These projects are pending at FERC and also looking for offtake development opportunities.

In addition, from a renewable natural gas perspective, the EPA's Landfill Methane Outreach Project (LMOP) identified 10 candidate landfills for landfill gas recovery projects that could support fuel cell and hydrogen production.

Kentucky also anticipates partnering with the Kentucky Geological Survey in 2021 and 2022 to characterize methane gas recovery potential from coal mine ventilation.

Specific Kentucky Site Selection Information for Hydrogen Production

According to the Cabinet for Economic Development, Kentucky has 41 shovel-ready sites located in Opportunity Zones. Opportunity zones are economically distressed communities where new investments, under certain conditions, may be eligible for preferential tax treatment.

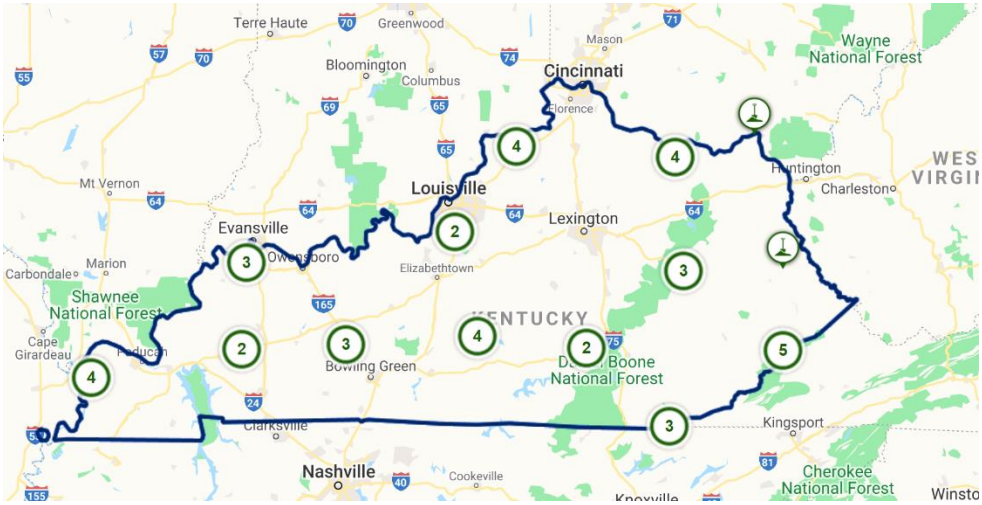


Figure 6: Shovel Ready Locations in Opportunity Zones

DOE's Paducah Gaseous Diffusion Site

The Paducah Gaseous Diffusion Plant (PGDP) was constructed in 1952 to produce enriched uranium, initially for the nation's nuclear weapons program and later for nuclear fuel for commercial power plants. The plant is owned by the Department of Energy (DOE), which oversees environmental cleanup activities at the site, including environmental remediation, waste management, depleted uranium conversion, and decontamination and decommissioning.

Ideally situated with infrastructure access, the DOE site offers a prime redevelopment opportunity for hydrogen production development. According to DOE's site future use, a combination of industrial and recreational use is considered as the most likely future scenario

for the site. DOE continues to look for opportunities for productive use of the PGDP facilities and property.

Kentucky's Brownfield Opportunities

Housed in the Kentucky Energy and Environment Cabinet, Kentucky's Brownfield program provides significant redevelopment potential. There are an estimated 8,000 brownfield sites in the Bluegrass state, and the Kentucky Brownfield Program is working to get those properties back into productive use. In addition, the Cabinet for Economic Development lists several secondary sites for consideration. These sites are categorized as secondary sites because they do not meet the cabinet's criteria for primary sites, but are available for business location and expansion projects. In some cases, the designation is due to environmental concerns. In summary, Kentucky is well-positioned to identify brownfield opportunities to revitalize underutilized properties for hydrogen demonstration and expansion projects.

Kentucky Decommissioned Power Plants

As Kentucky's power plant generation fuel mix has changed, some of Kentucky's utilities have decided to retire and decommission certain plants. These sites with their infrastructure offer opportunities to be re-envisioned for energy storage and hydrogen production potential.

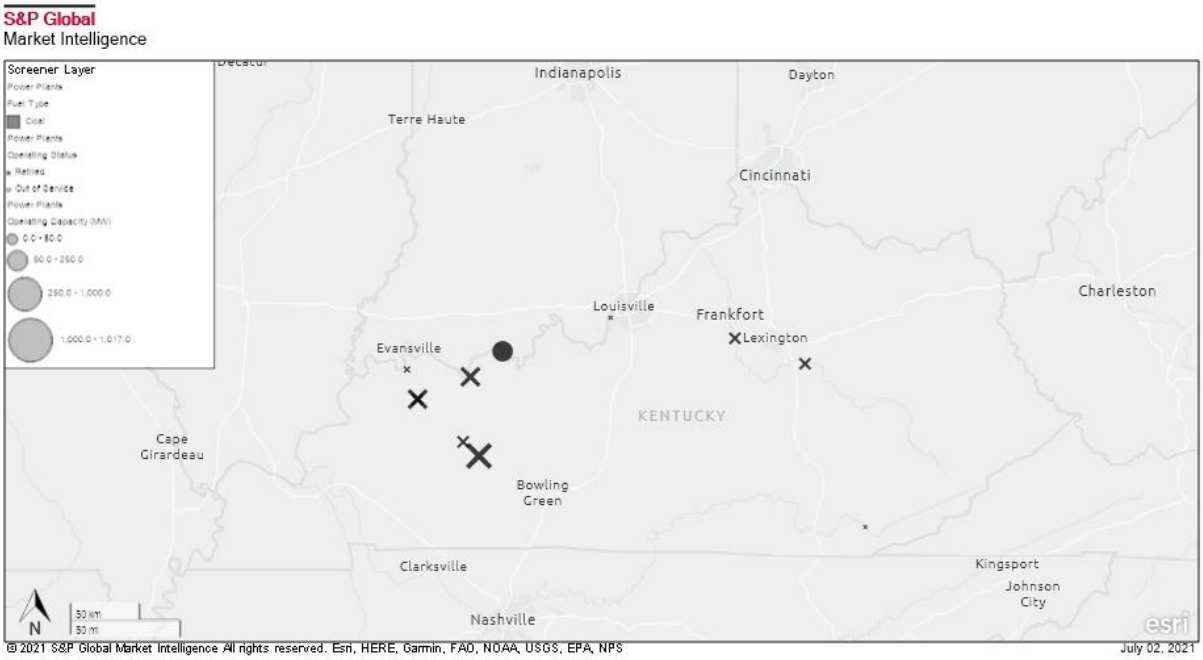


Figure 7: Retired Coal Fired Generation Plants

In addition, the Tennessee Valley Authority announced the retirement of Shawnee power plant in Western Kentucky and several Kentucky regulated utilities in their recent Integrated Resource Plan filings indicate sustainability or carbon reduction objectives. The average age of

Kentucky's coal fired power plant fleet is around 47 years with a life expectancy of around 60 years.

End Users for Hydrogen in the Region and Value Proposition

When looking at the production cost of hydrogen, Kentucky is a prime location for lower cost hydrogen production and a leader for the Southeast. Kentucky has counties in both the east and western portions of the state than can support **industrial electrolysis for less than $5/kg.**

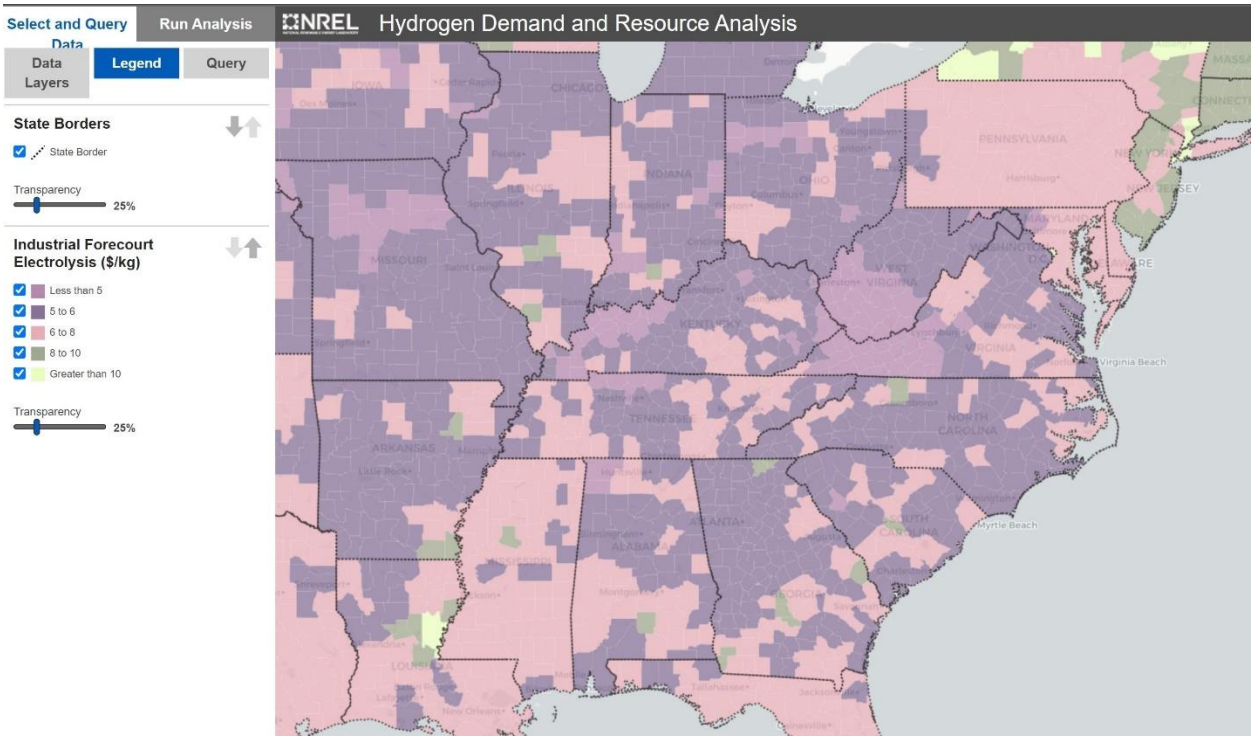


Figure 8L Hydra Production Cost Estimates

From a demand perspective, Kentucky's strong industrial, automotive, aviation, and chemical manufacturing base means the demand is present here to meet production as well. According to IEA, hydrogen use today is dominated by industry, namely: oil refining, ammonia production, methanol production, and steel production.

- Kentucky is home to two petroleum refineries and the associated infrastructure, including Marathon Petroleum.
- Kentucky is the #1 producer of cars, light trucks, and SUVs per capita.
    - Toyota Motor Manufacturing in Georgetown represents the largest manufacturing plant for Toyota. Toyota is a leader in hydrogen car innovation, production, and has active demonstration projects in California. In addition, Toyota has set goals for carbon reductions that depend on hydrogen.
- Located at the center of a 34-state distribution area in the eastern United States, Kentucky has more than 540 logistics and distribution facilities.

- Kentucky is home to 79 aerospace related facilities including GE Aviation.
    - General Electric's Aviation Production Facility is located in Madisonville, KY. In a recent article, GE Aviation expressed that, "GE Aviation is playing its role to achieve the industry's challenge to halve carbon emissions by 2050". GE also recently announced Rise (Revolutionary Innovation for Sustainable Engines) development program of its engine joint venture with Safran, CFM International. The CFM Rise hybrid electric advanced open fan demonstrator would run on either 100 percent sustainable aviation fuel (SAF) or liquid hydrogen.
- Kentucky is a world air cargo leader with three international air shipping hubs operated by Amazon, DHL, and UPS. Amazon has announced zero-carbon goals that will depend on sustainable aviation fuels and hydrogen.
    - Kentucky consumes over 16 million barrels at $1.3 billion in fuel expenditures according to EIA.
- Kentucky currently has 43 steel and iron production companies operating and 185 aluminum related facilities. Recently, Nucor Steel announced expansion in Brandenburg, Kentucky and the steel industry is anticipated to need hydrogen to meet the growing demand for low or zero-carbon steel.
- Over 230 metals-related facilities operate in Kentucky, employing approximately 25,000 people. Since 2019, 40-plus new-location and expansion projects have been announced in the state's metals industry, creating nearly $2.5 billion in new investment and 2,000-plus projected new jobs.
- There are over 210 chemical manufacturing companies in Kentucky that exported $743 million in basic chemicals.
- Kentucky's pro-business climate provides a number of incentives for businesses. The Kentucky Economic Development Finance Authority (KEDFA), established within the Cabinet for Economic Development, encourages economic development, business expansion, job creation, and provides financial support through an array of financial assistance and tax credit programs.
  Eligible operations include:
    - manufacturing,
    - non-retail service or technology activities,
    - agribusiness,
    - headquarters operations,
    - hospital operations,
    - coal severing and processing,
    - alternative fuel, gasification,
    - energy-efficient alternative fuels,
    - renewable energy production, or carbon dioxide transmission pipelines

Helping businesses in this way furthers the Commonwealth's goals of achieving long-term economic growth and employment opportunities for its citizens.

When looking at consumer demand locations, those same locations overlap with those areas of Kentucky that are ideal locations for production as well.

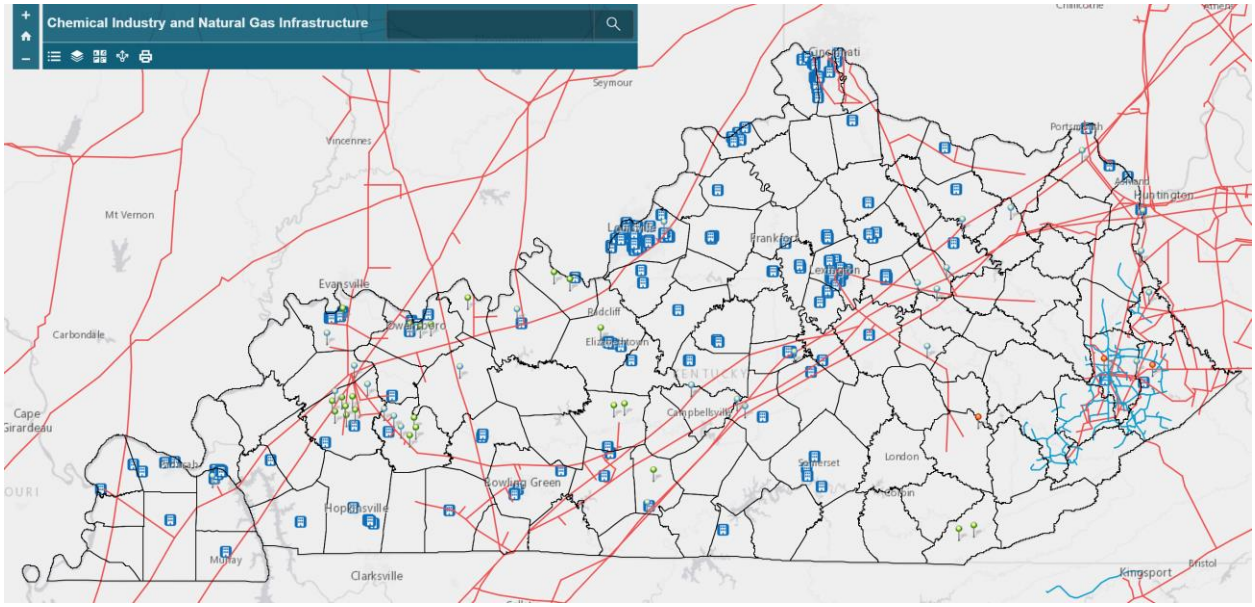


Figure 9: Ky Chemical Industries and NG Infrastructure

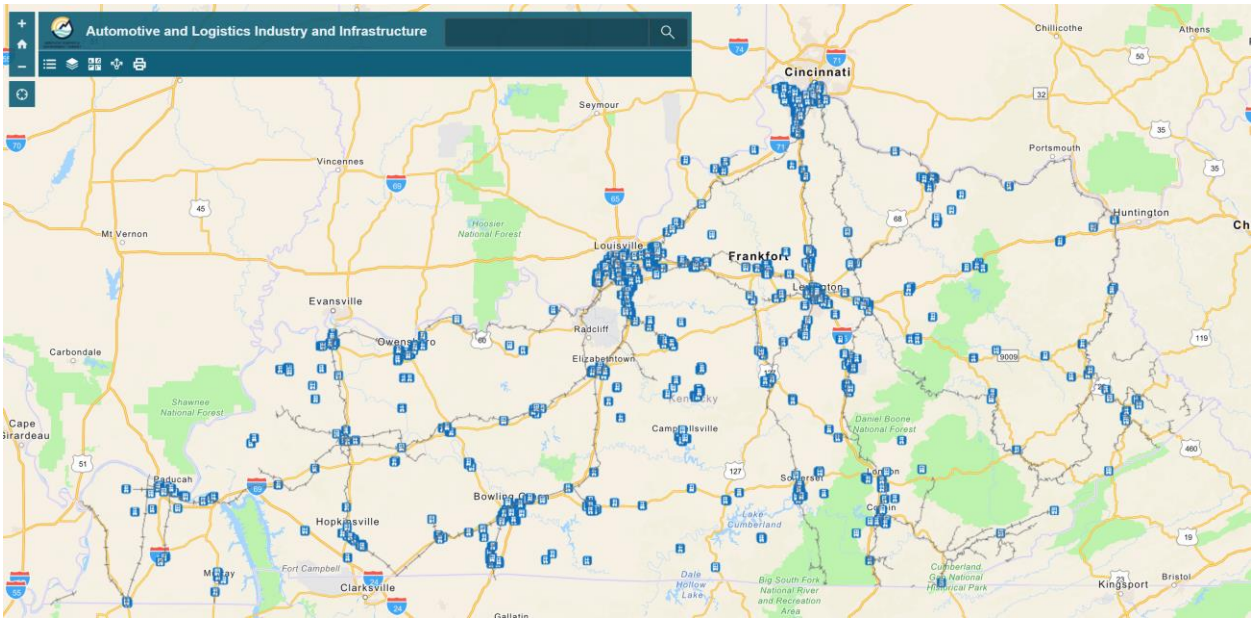


Figure 10: Ky Automotive and Logistics Industries

Referencing the 2006 study by NREL, even among the Southeast and neighboring states, Kentucky is positioned to support a southeast regional hydrogen ecosystem and hub.

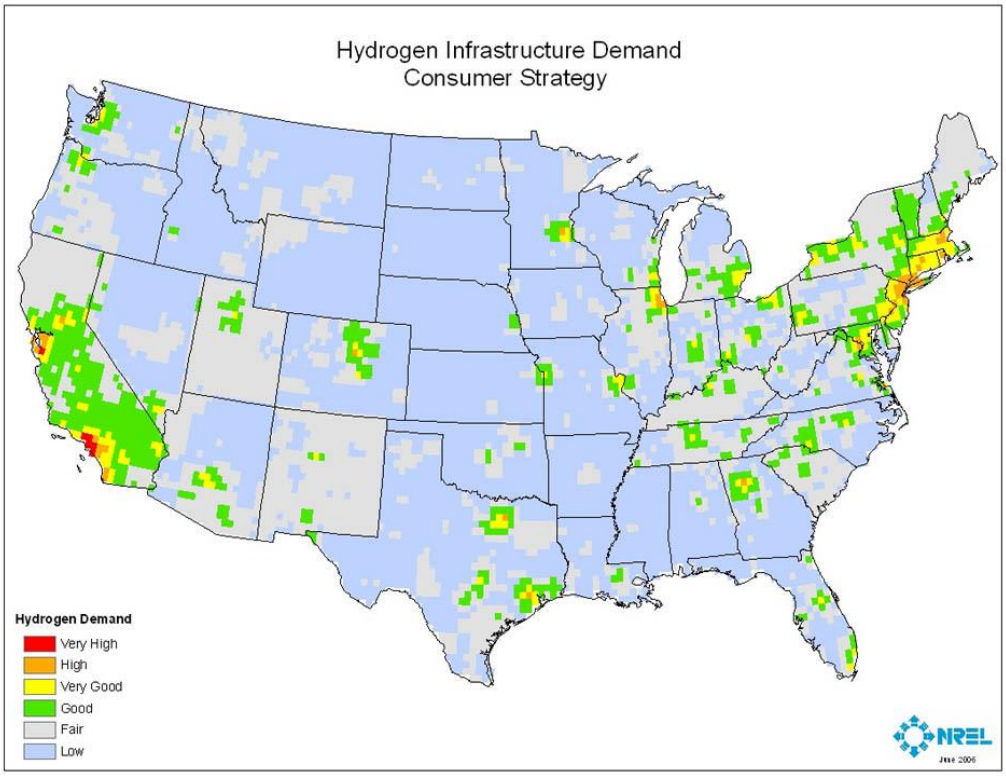
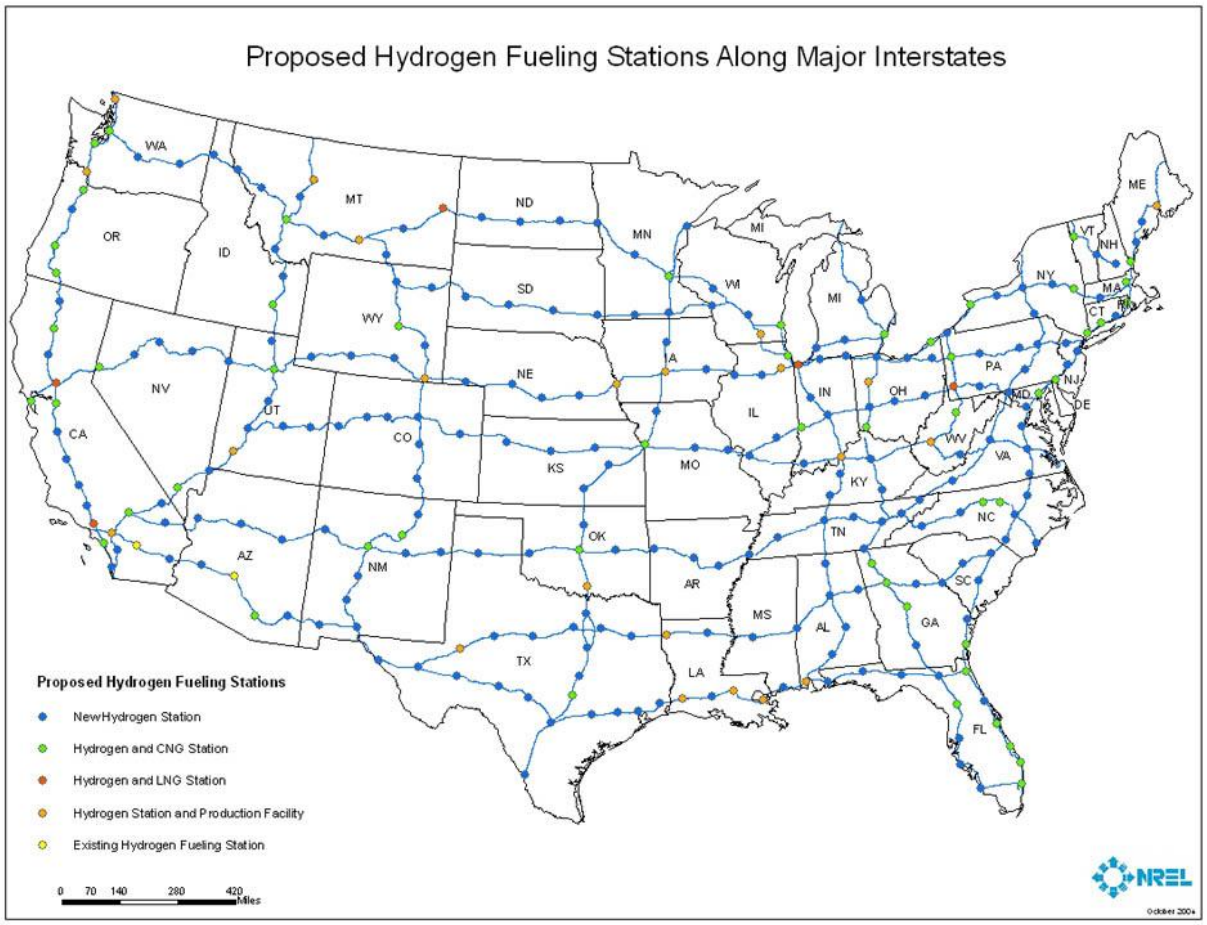


Figure 11: Hydrogen infrastructure demand map

Hydrogen Fuels Infrastructure to Support Freight Truck Networks

In order to support Kentucky's robust freight network, NREL estimates that Kentucky is positioned to support the deployment of several hydrogen refueling stations. Again, the map illustrates Kentucky's importance to connect north to south and east to west.



Hydrogen for Grid Resilience

In 2020, the Kentucky Office of Energy Policy in partnership with the Smart Electric Power Alliance released the Kentucky Regional Microgrid for Resilience Study. The study found that Kentucky has 558 ideal sites for nanogrids and a dozen potential sites for regional community microgrids. The Kentucky Regional Microgrids for Resilience Study was designed to help utilities, local and state governments, and industry stakeholders move from planning microgrids to building them. Hydrogen fuel cells could play an essential role in critical facility energy resilience by being incorporated into nano and microgrid development projects.

Greenhouse Gas (GHG) and Pollutant Reduction Potential

According to EIA's state energy profile for Kentucky, in 2019, about 73% of Kentucky's electricity net generation was coal-fired, the fourth-largest share of any state after West Virginia, Wyoming, and Missouri. Kentucky's natural gas-fired electricity generation reached a record 14.8 million megawatt hours in 2019, and accounted for about one-fifth of the state's net generation.

In terms of consumption, Kentucky's transportation and industrial sectors account for the largest share of energy consumption at 64.5%.

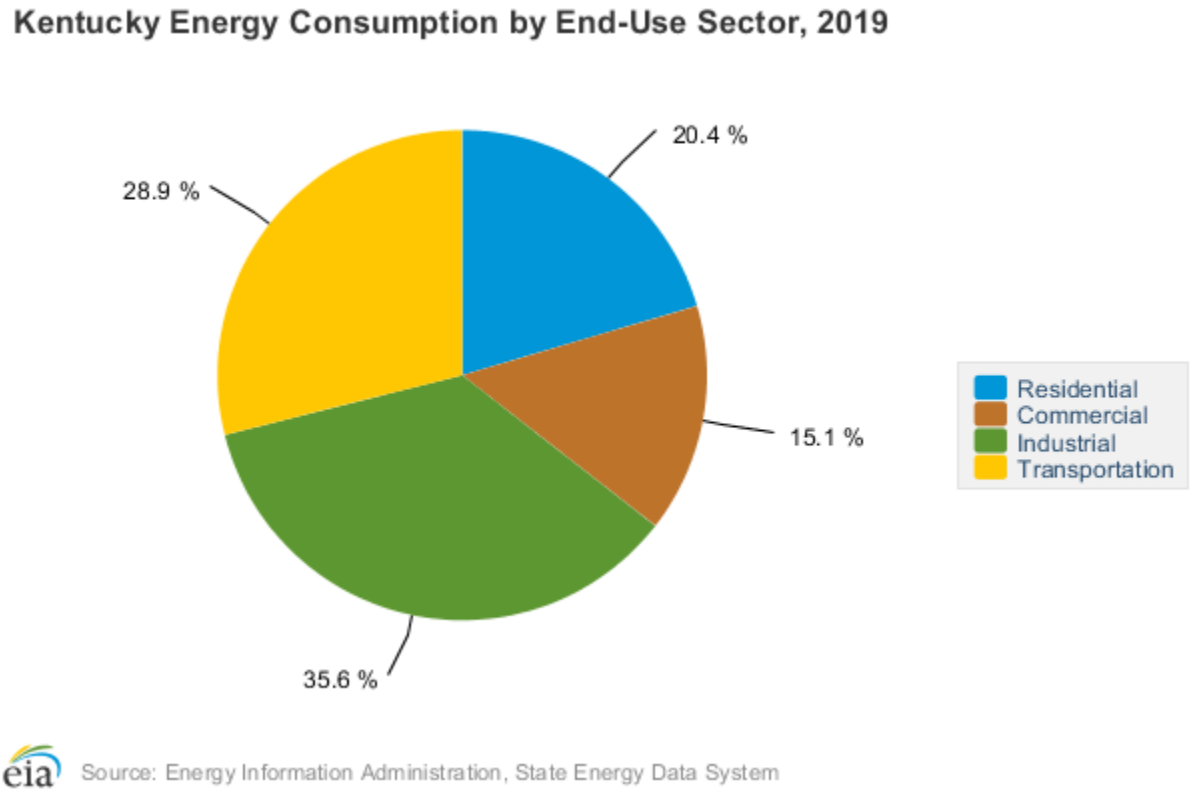


Figure 12: Kentucky Energy Consumption from EIA

In terms of emissions, according to EIA, in 2018, Kentucky produced over 120 million metric tons of CO2 emissions. The power sector accounts for 55% of those emissions, followed by the transportation sector at 28%, and the industrial sector at 11%. With the decline in the reliance on coal for power production, Kentucky's natural gas electric generation has grown to 23% of net generation and is expected to grow with more plants retiring and assuming natural gas prices remain low. The reliance on gas presents yet another opportunity for hydrogen consumption in Kentucky.

Consequently, hydrogen deployment for transportation including aviation and large freight and distribution is a key to emission reductions long term. While Kentucky's power sector transitions to including more natural gas, the opportunities for blending hydrogen into our natural gas infrastructure represent significant emission reduction potential.

Diversity, Equity, Inclusion, Jobs, and Environmental Justice

Around April 13, 1750, Dr. Thomas Walker was the first recorded person to discover and use coal in Kentucky. In 1820, the first commercial mine, known as the "McLean drift bank" opened in Kentucky, near the Green River and Paradise in Muhlenberg County; and Kentuckians

have been mining coal ever since. As a result of the decline in coal as a power production fuel, many of the communities in Kentucky are experiencing deep suffering having been reliant on coal for hundreds of years.

The map below highlights Kentucky's two coal-producing basins in blue (Illinois and Central Appalachian) along with locations of each of Kentucky's coal power plants and a 25-mile radius around those plants (representing commuting distances). As illustrated, almost all counties in Kentucky have experienced adverse economic impacts from the decline in coal; however, the counties in western and eastern Kentucky have experienced the most dramatic impacts.

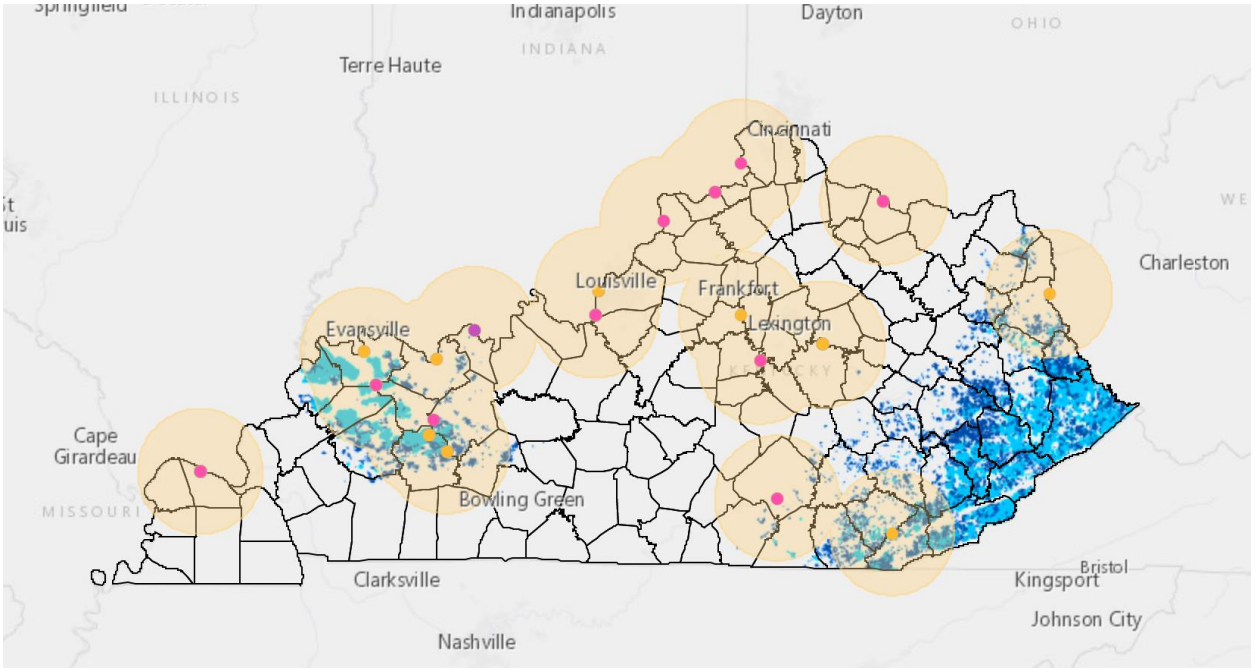


Figure 13: Coal Impacted Communities

Data from the University of Michigan's Multidimensional Index of Deep Disadvantage, shows there are 13 counties in Kentucky that are classified as most disadvantaged with **8 of those counties making the top 100 most disadvantaged counties in the nation**.

Looking at the map above and now taking a look at poverty status, there is an almost exact overlap of those counties that are directly experiencing the decline in the reliance on coal and the populations in those counties' poverty status. The map below represents the percent of the population whose income in the past 12 months is below the poverty level

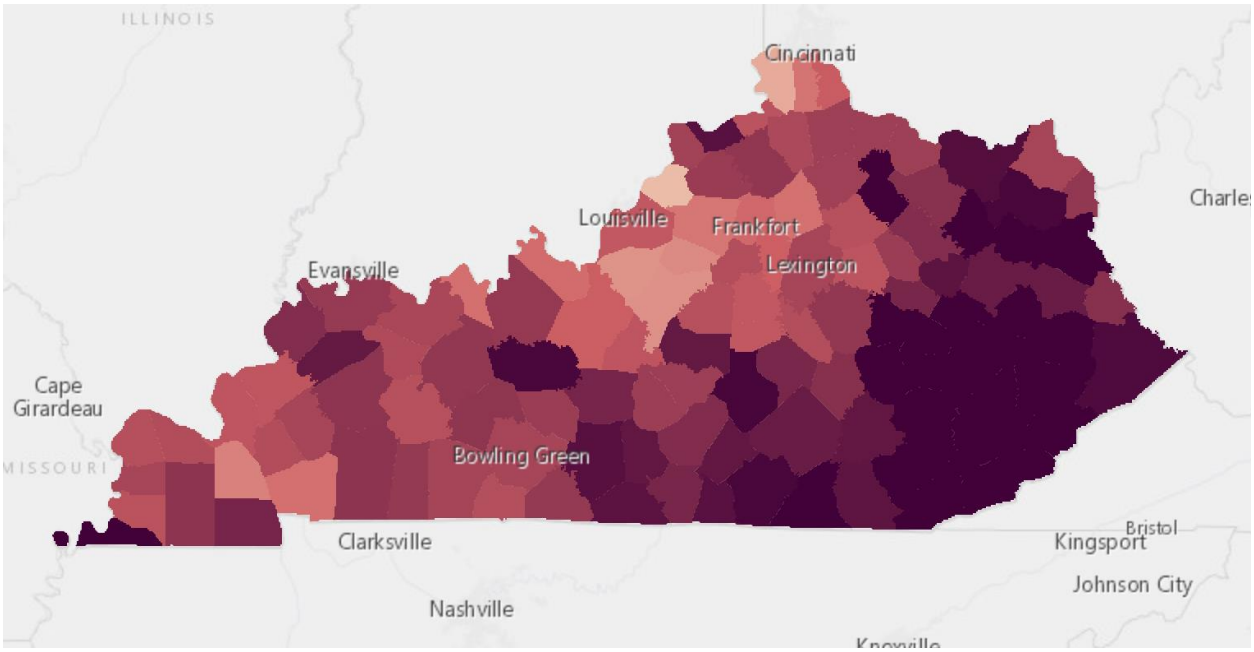


Figure 14; ACS Poverty Status Variable by County

For hydrogen demonstration and development in Kentucky, these areas represent ideal locations due to their history as energy producing regions and the associated infrastructure not to mention the workforce in these areas. It is also not surprising that these areas represent areas where hydrogen production is also most feasible.

From a labor perspective, looking at unemployment rates below, the Kentucky Center for Statistics Labor report also reinforces the workforce availability in these areas. Data from the Kentucky Energy Employment Report shows that Kentucky has an average concentration of energy employment, with 42,797 Traditional Energy workers statewide (representing 1.3 percent of all U.S. Traditional Energy jobs). Of these Traditional Energy workers, 5,043 are in Electric Power Generation, 15,817 are in Fuels, and 21,937 are in Transmission, Distribution, and Storage. The Traditional Energy sector in Kentucky is 2.2 percent of total state employment (compared to 2.3 percent of national employment). Kentucky has an additional 26,221 jobs in Energy Efficiency (1.1 percent of all U.S. Energy Efficiency jobs) and 83,060 jobs in Motor Vehicles (3.2 percent of all U.S. Motor Vehicle jobs).

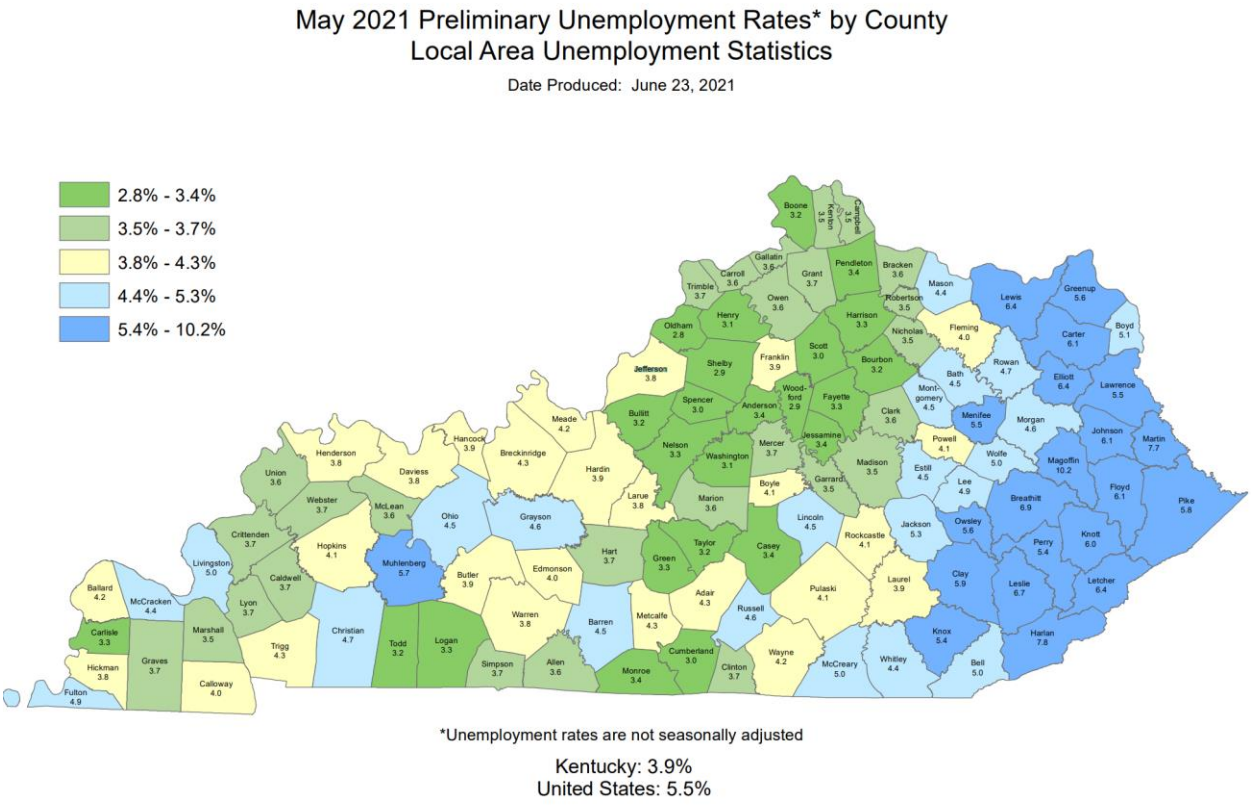


Figure 15: Kentucky Center for Statistics Unemployment Report

In addition, Kentucky's energy and manufacturing sectors are well-positioned to expand to include hydrogen jobs and workforce training needs to meet the hydrogen demand. The Kentucky Federation for Advanced Manufacturing Education (KY FAME) is a partnership of regional manufacturers whose purpose is to implement career pathway, apprenticeship-style educational programs that will create a pipeline of highly skilled workers.

The Kentucky Community and Technical College System (KCTCS) is also positioned to rapidly deploy workforce solutions to meet the hydrogen industry needs in Kentucky. KCTCS is a critical piece of workforce infrastructure in the Commonwealth. With 16 independently accredited colleges across 70 campuses, KCTCS is within a 30-minute drive of ninety percent of Kentucky's population. Regardless of where businesses and industries locate in the Commonwealth, the benefits of this system are available and accessible.

KCTCS also offers the Work Ready Kentucky Scholarship (WRKS), which helps Kentuckians who have not yet earned an associate's degree, afford an industry-recognized certificate or diploma. Certifications or diplomas must fall into Kentucky's top demand industry sectors (Advanced Manufacturing, Transportation & Logistics, Construction/Skilled Trades, IT/Business Services & Healthcare).

Kentucky's rich history in the energy sector makes our workforce aptly suited for hydrogen production jobs. KCTCS is equipped to train, upskill and reskill Kentucky's workers to meet the demands of our energy future.

The statewide system of colleges provides anytime, anyplace customized training and support services for business and industry, that:

- develop a better workforce with the knowledge and skills for the jobs of the future.
- assist the Commonwealth of Kentucky in competing for and sustaining businesses and industries that thrive on innovative ideas and technologies.
- provide Kentucky workers with world-class transferable, portable skills.
- increase the productivity of Kentucky's workforce.
- improve the employability of Kentucky citizens.
- strengthen and improve state and local economies.

Science and Innovation Needs and Challenges

Hydrogen presents an opportunity to bring together a number of science and innovation resources in Kentucky.

- The *University of Kentucky Center for Applied Energy Research* investigates energy technologies to improve the environment. Researchers contribute to technically-sound policies related to fossil and renewable energy. **Laboratory 2** – *43,000 sq. ft.* – The first LEED-certified research lab at UK Lab 2 is home to CAER's renewable energy research programs. Biofuels, organic electronics, and battery R&D labs are housed in this space. The Center's carbon research group – working to turn coal into carbon fiber – also utilizes space in Lab 2.
- The *University of Louisville Conn Center for Renewable Energy Research* conducts and facilitates R&D on potentially commercializable renewable energy and energy efficiency technologies. The Conn Center also houses solar fuels research that targets hydrogen production. The Conn Center is striving to develop new and promising approaches in the field of solar fuels. This effort includes the study of novel photoactive semiconductors and surface preparations to make efficient photoelectrodes for fully integrated solar water-splitting systems. The center is also researching the design of electrolyzers to reduce carbon dioxide into useful hydrocarbon fuels efficiently and with high yield. New photovoltaic technologies specifically designed to drive a desirable electrolysis reaction are under investigation as well. Each of these research thrusts is dedicated to lowering the ultimate cost of solar fuels production.
- *Kentucky Science and Technology Corporation* is a private, nonprofit corporation committed to the advancement of science, technology and innovative economic development founded on Kentucky know-how. KSTC is a fast-paced leader with a

reputation for developing and managing creative initiatives in education, economic competitiveness and scientific research.

However, while Kentucky is positioned well from a science and innovation resource perspective, the largest challenge is not technological or innovation but rather technical assistance from DOE and the National Laboratories coupled with federal prioritization of Kentucky for funding and private sector investment through demonstration, commercialization, and development programs.

DOE's technical assistance and funding need to facilitate a comprehensive hydrogen ecosystem in Kentucky that can integrate into other regional systems.

This ecosystem must successfully deploy demonstration and commercialization opportunities in five areas:

1. Manufacturing to support the supply chain for hydrogen production development;
2. Production from both fossil (with CCUS) and renewable resources;
3. Transportation projects utilizing existing and new infrastructure;
4. Fueling infrastructure to enhance Kentucky's freight dominance; and
5. Utilization by the power sector, industry, and aviation

Summary

Given Kentucky's energy and manufacturing landscape today and building on our history as a fuel and energy hub, there are five potential locations to deploy a diverse hydrogen ecosystem in Kentucky creating a regional hydrogen hub for the southeast and connecting north to south, east to west. In addition, two prime hydrogen influencers exist in Kentucky: Amazon Prime Air Hub and Toyota Motor Manufacturing.

- Paducah (Renewable Hydrogen Production)
- Owensboro (Hydrogen Storage and Transport)
- Corbin (Hydrogen Fueling)
- Pikeville (Fossil with CCS Hydrogen Production)
- Ashland (Hydrogen Utilization, Fueling, and Transport)

See map below for more details

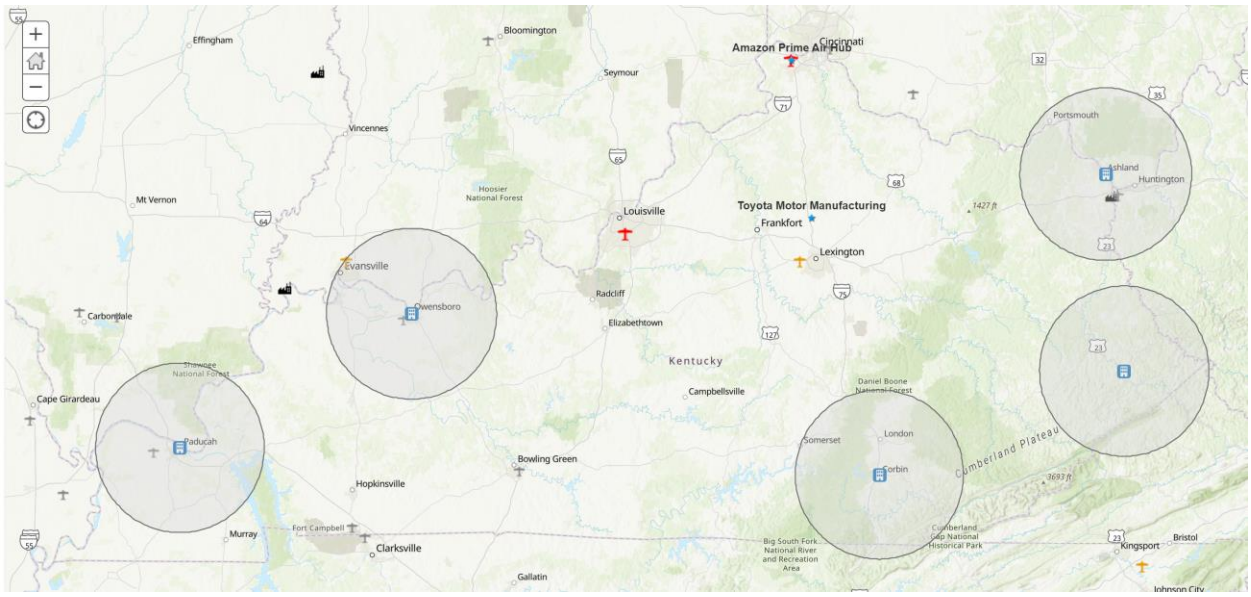


Figure 16: Proposed Hydrogen Deployment Locations