Gas Turbines, Hydrogen, and the Evolving U.S. Energy Sector

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Key Domestic Discussion Points

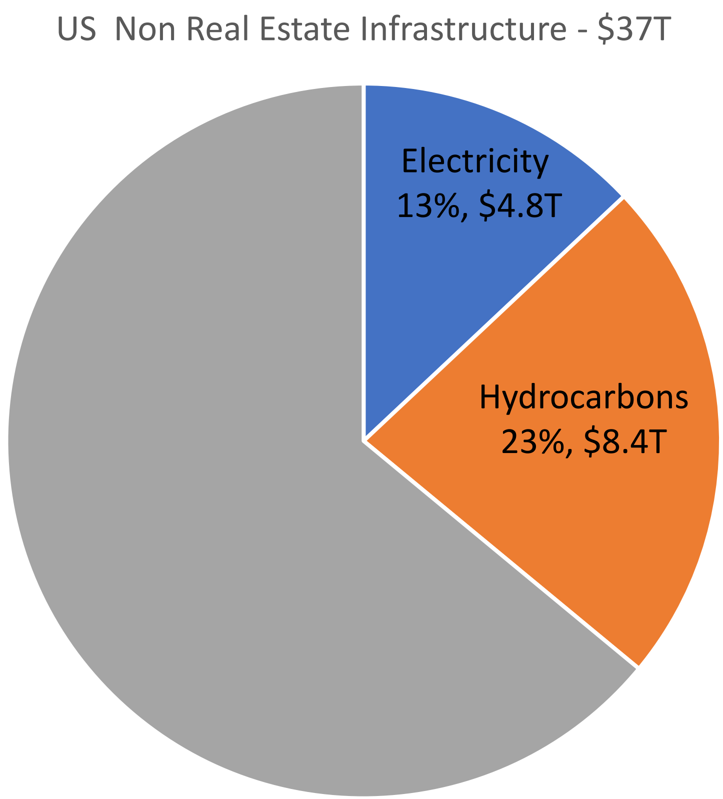
- Economics, Cost, Jobs
- Category Pollutant and Carbon Emissions
- Energy Imports/Exports, Energy Security, and Global Interactions
- Equity and justice

Domestic Snapshot- Past, Present, and Future

US Energy System

Energy
Sources

Renewable:
Nuclear
Fossil Fuel:



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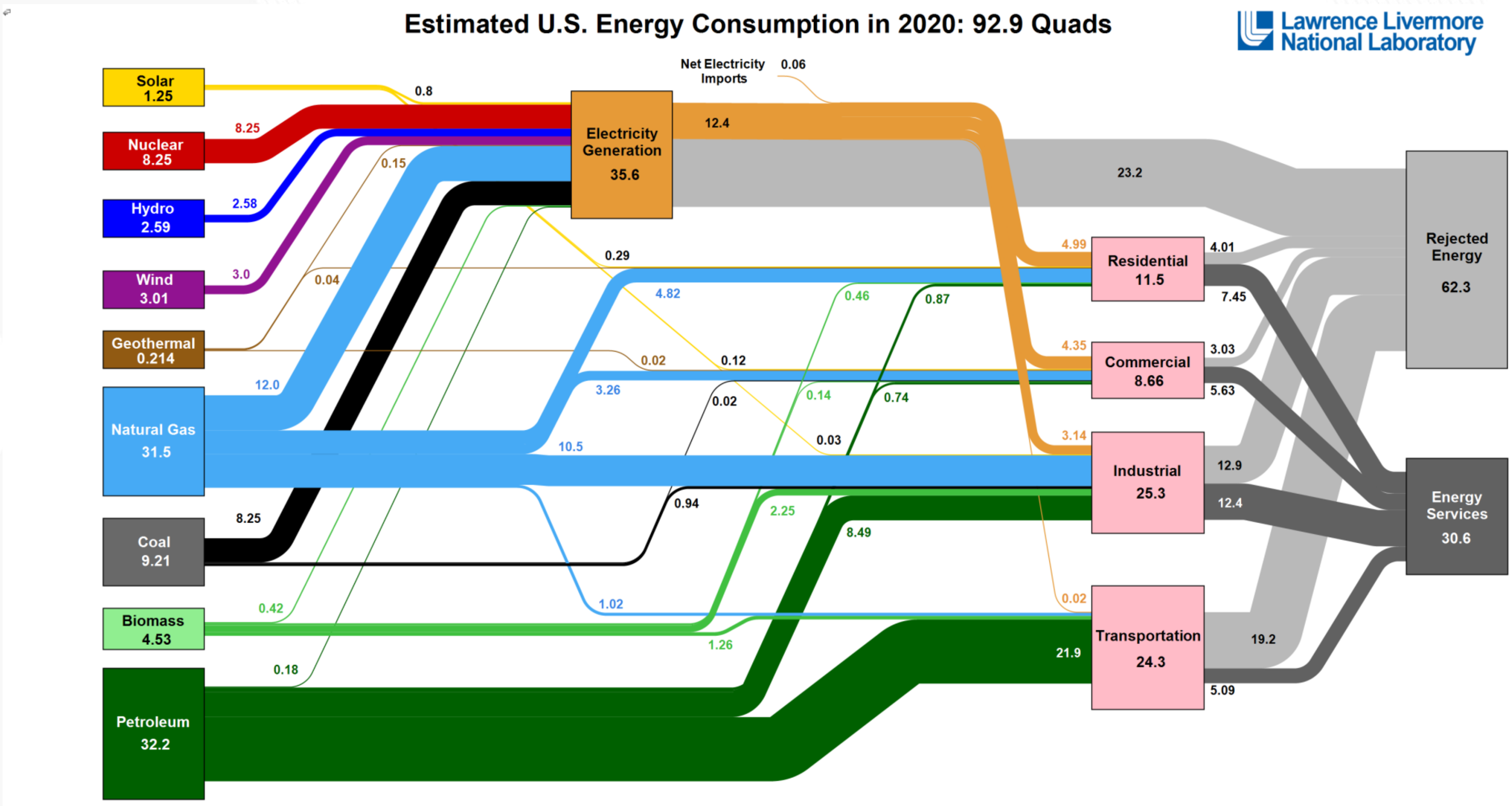
ıdustrial
ısportation
3uildings

R. Simmons, “*Valuation of U.S. Infrastructure Assets…. *”
https://epicenter.energy.gatech.edu/studies/

U.S. Energy System – Supply View



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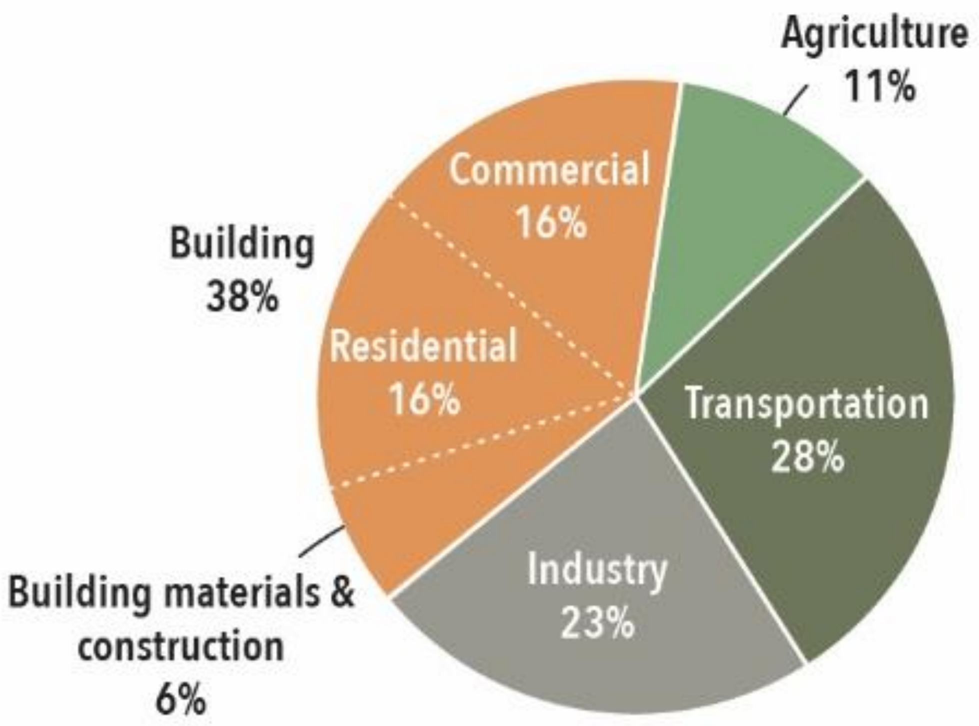
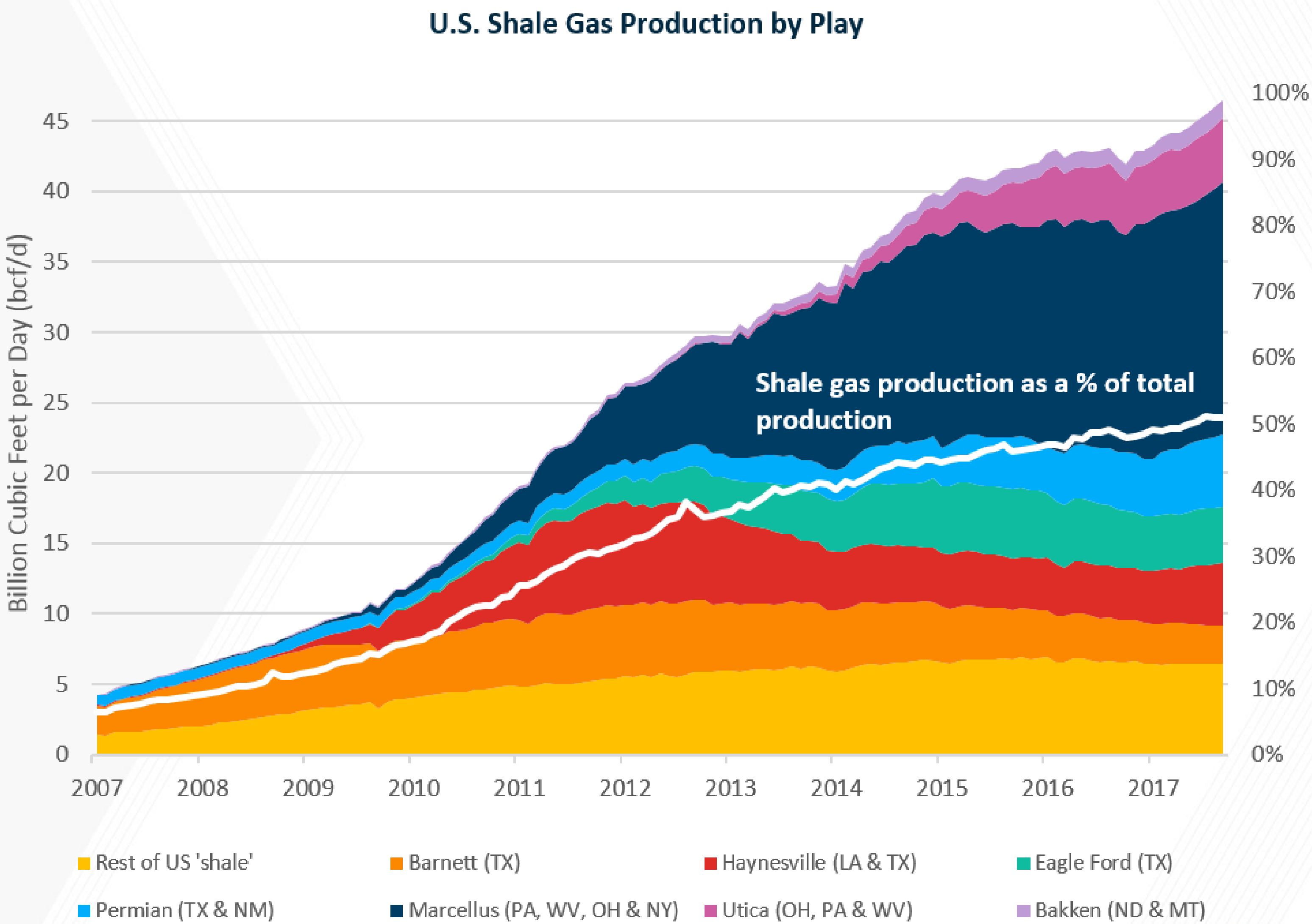
U.S. Energy System – End Use View



Fully Assigning GHG Emissions to End Use Sectors for Decarbonization Policy & Action

Created 2020 by Carnegie Mellon Center for Building Performance and Diagnostics, based on Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2018, US EPA; Röck at al., 2020

U.S. Natural Gas Production

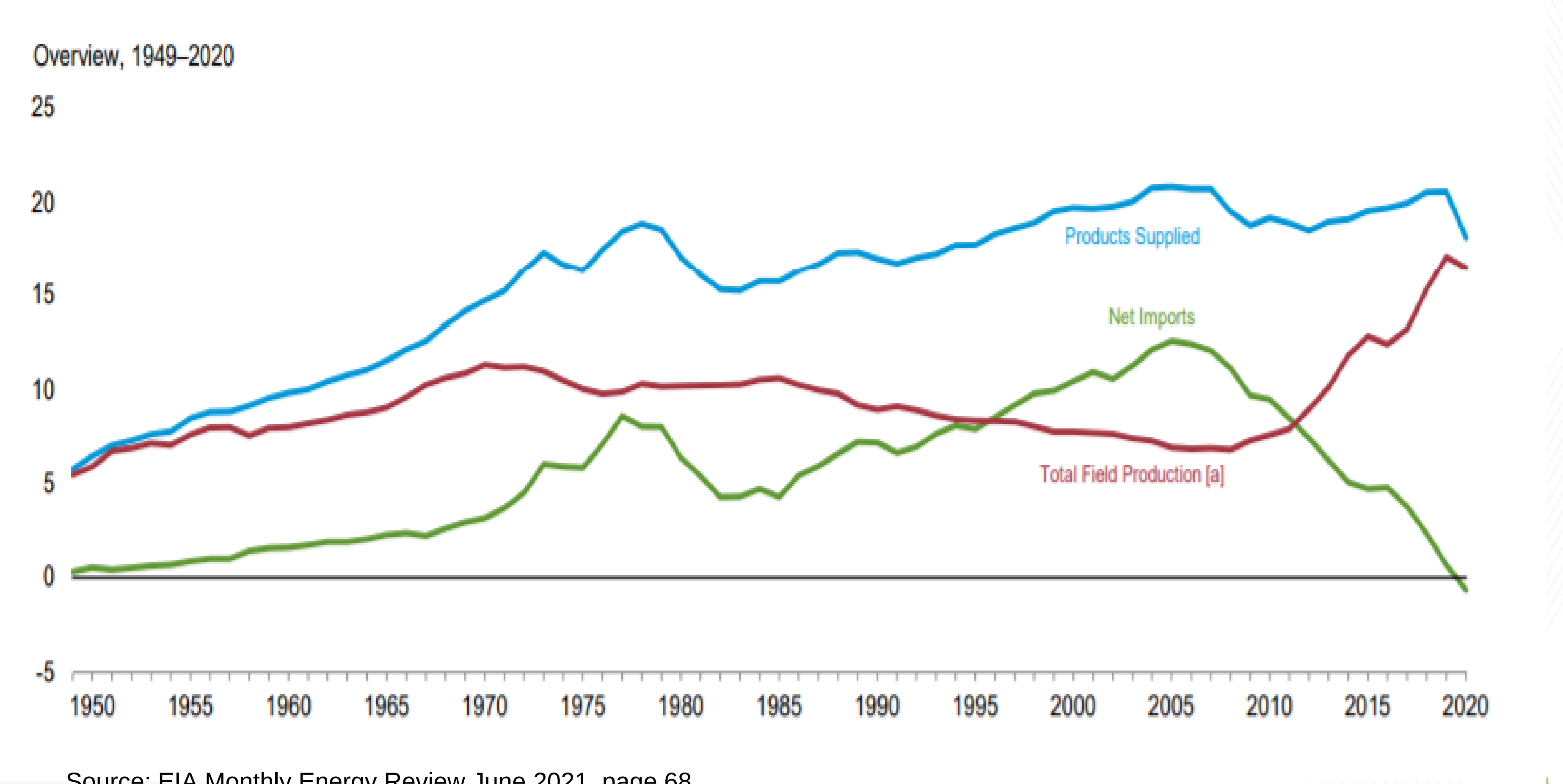


Center for Strategic and International Studies | Energy and National Security Program
Source: Adapted from U.S. Energy Information Administration Data (October 2017).

https://www.csis.org/features/us-natural-gas-global-economy

U.S. Petroleum Production

Million Barrels Per Day



Source: EIA Monthly Energy Review,June 2021, page 68
eia.gov/totalenergy/data/monthly/pdf/mer.pdf

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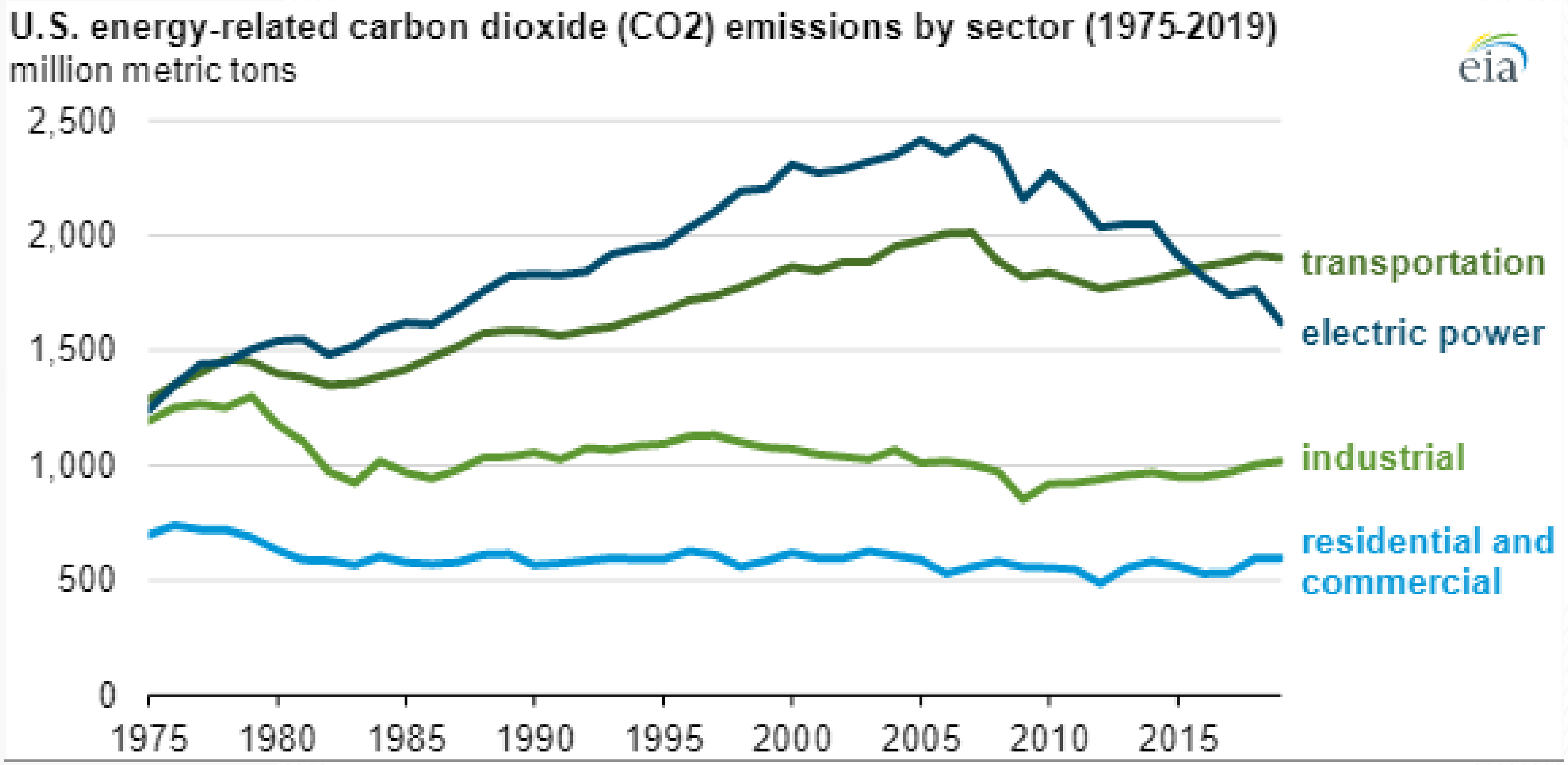
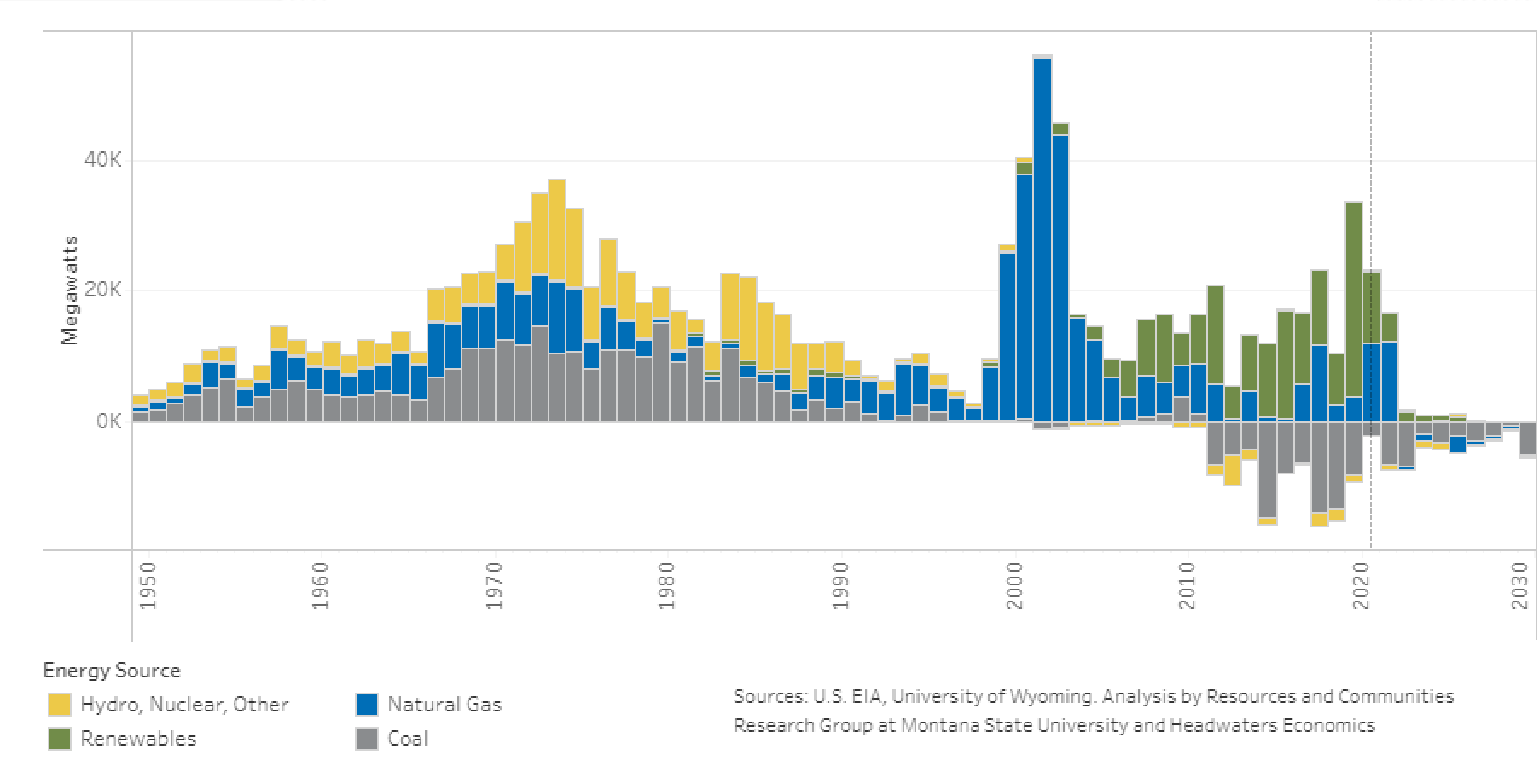
U.S. CO2 Production by Sector



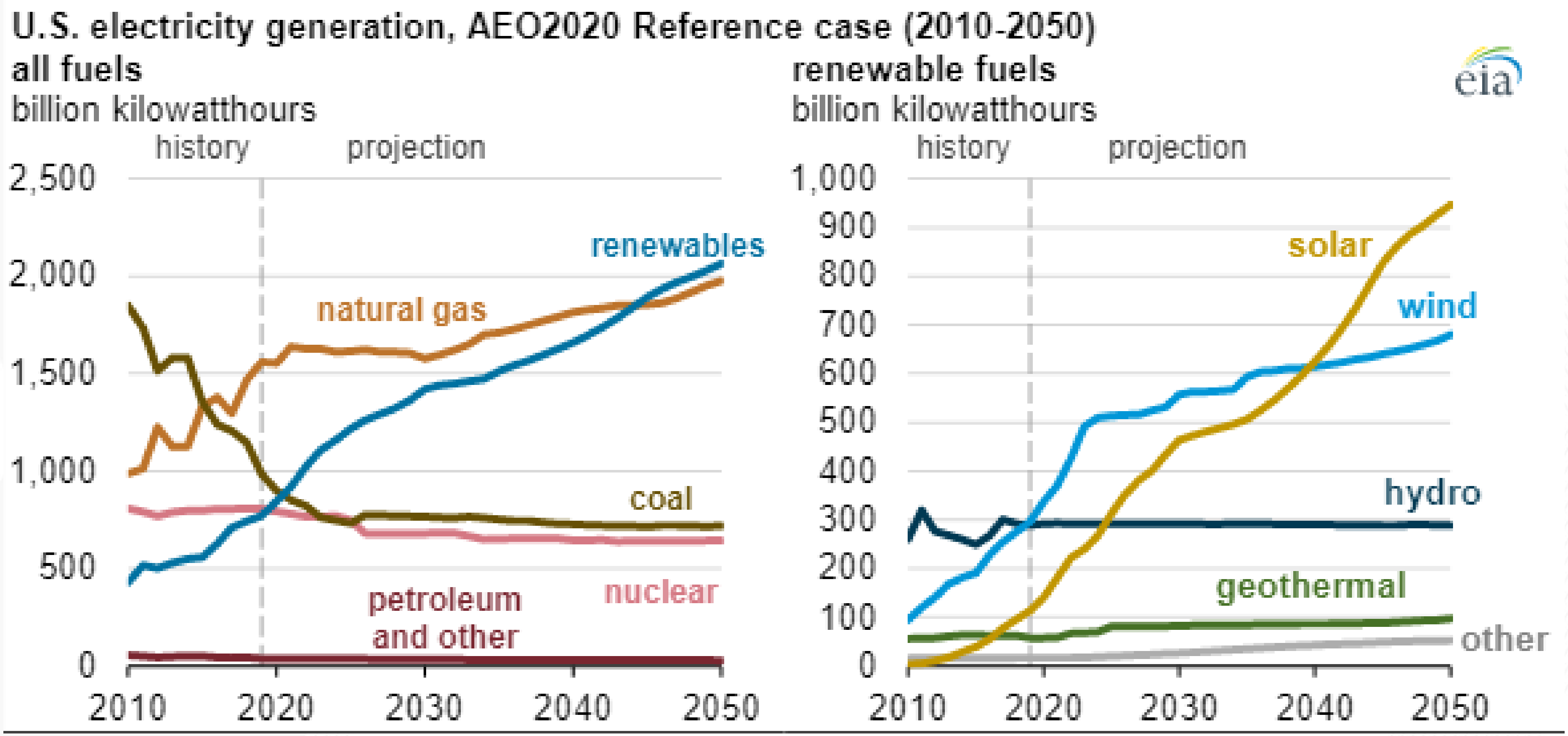
Source: eia.gov/todayinenergy/detail.php?id=43615
Date: May 5, 2020

Electricity Summary – New Capacity



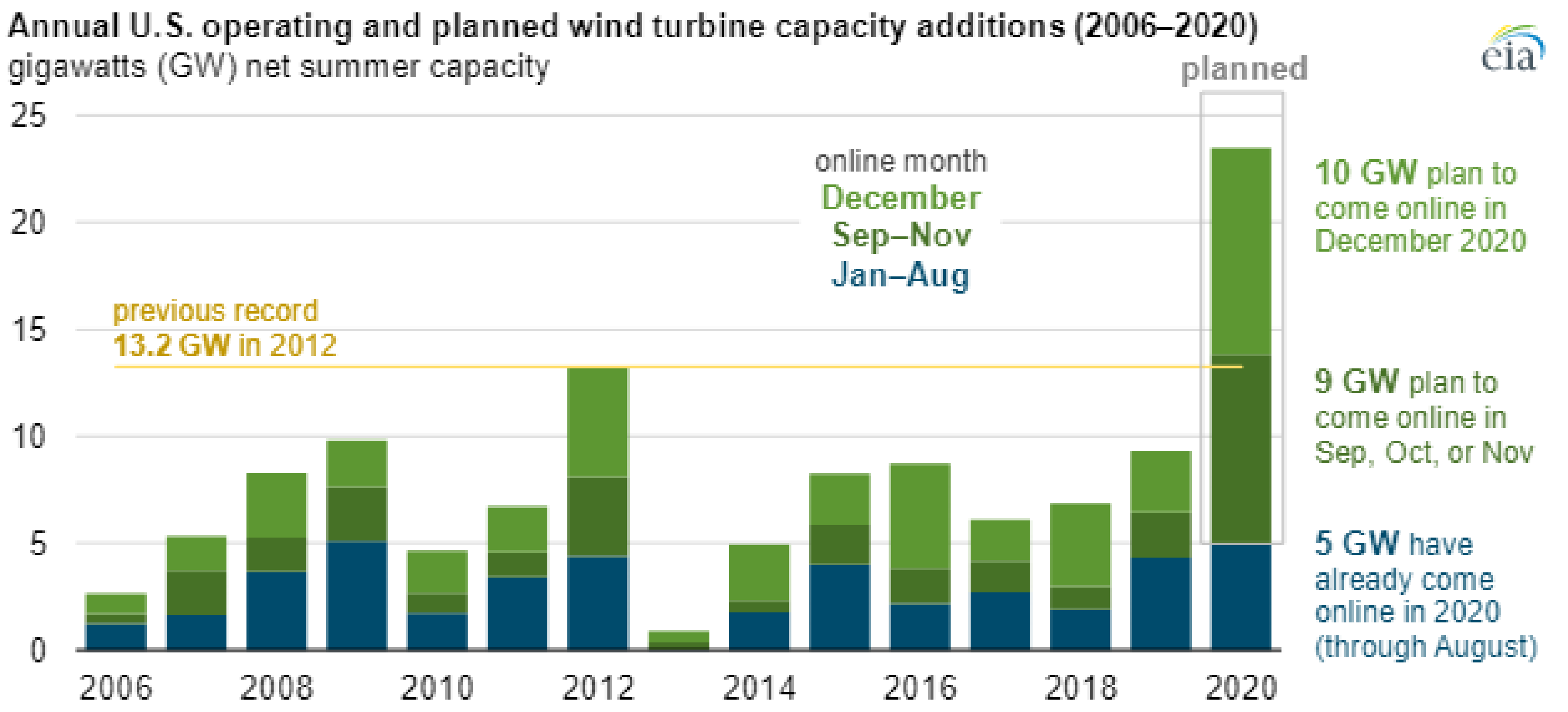
https://headwaterseconomics.org/economic-development/evolution-electricity-generation/

Electricity Summary



Source: eia.gov/todayinenergy/detail.php?id=42655
Date: Jan. 30, 2020

Electricity - Wind

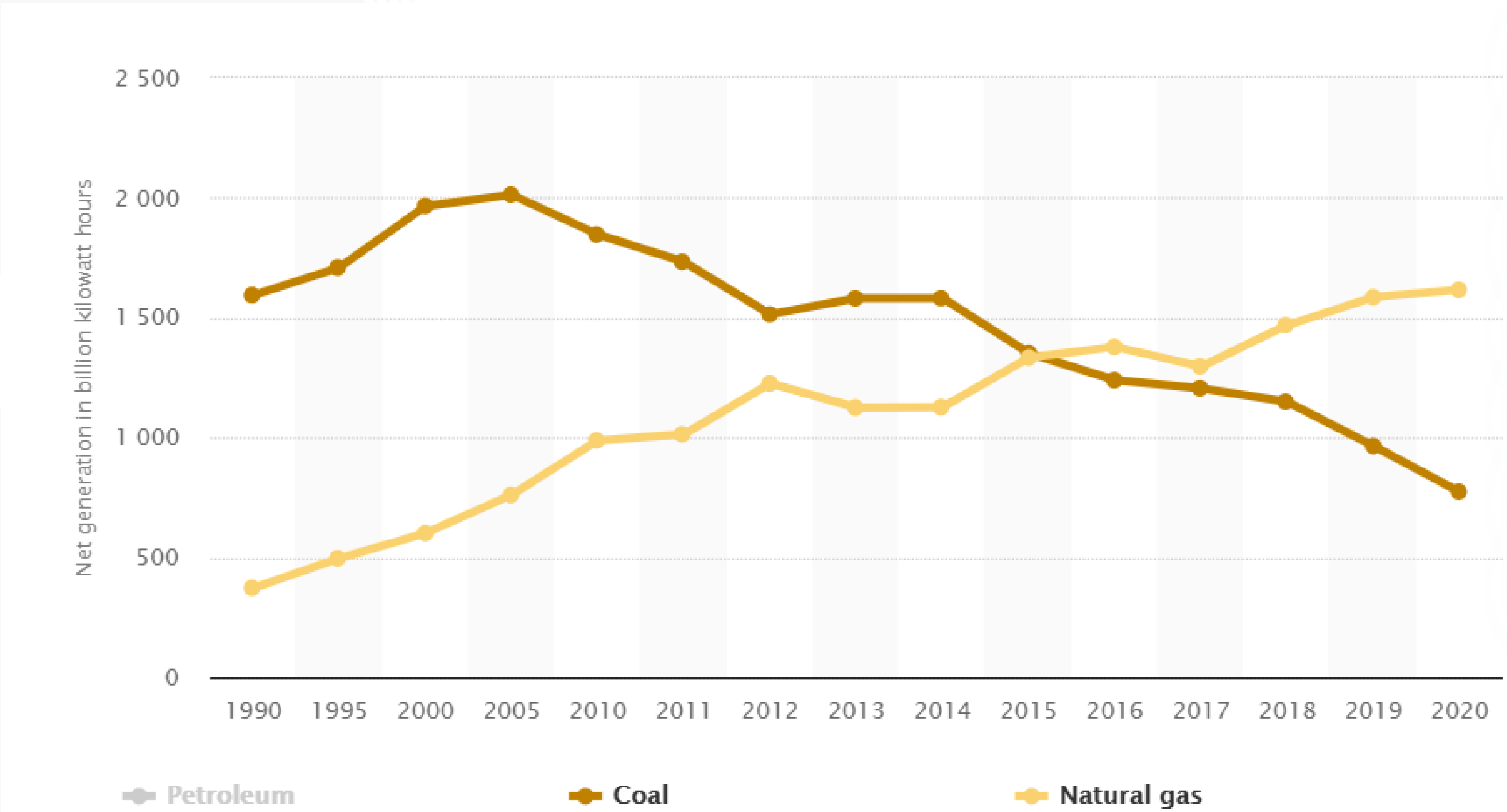


eia.gov/todayinenergy/detail.php?id=45856
Date: Nov. 12, 2020

- Total wind turbine capacity as of Dec. 31, 2020 is 118 GW
- Wind accounts for 8.4% of electricity generation in 2020
- ERCOT Wind penetration record: 54% (October 27, 2017)

Electricity – Natural Gas

- ~44% of US electricity (March, 2021)



Source: statista.com/statistics/220174/total-us-electricity-net-generation-by-fuel/
Date: March 2021

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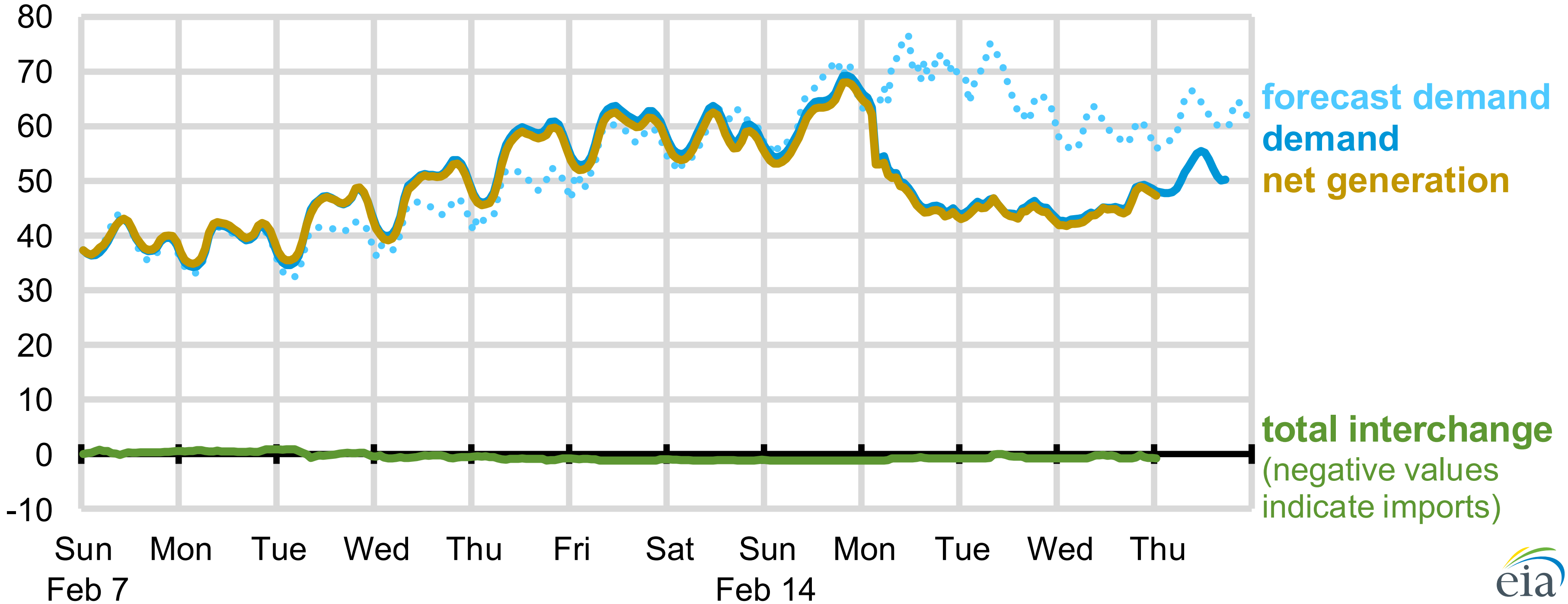
Revisiting Texas…

Hourly electricity demand, net generation, and total interchange (Feb 7–Feb 18, 2021)
Electric Reliability Council of Texas, Inc (ERCOT)
gigawatts



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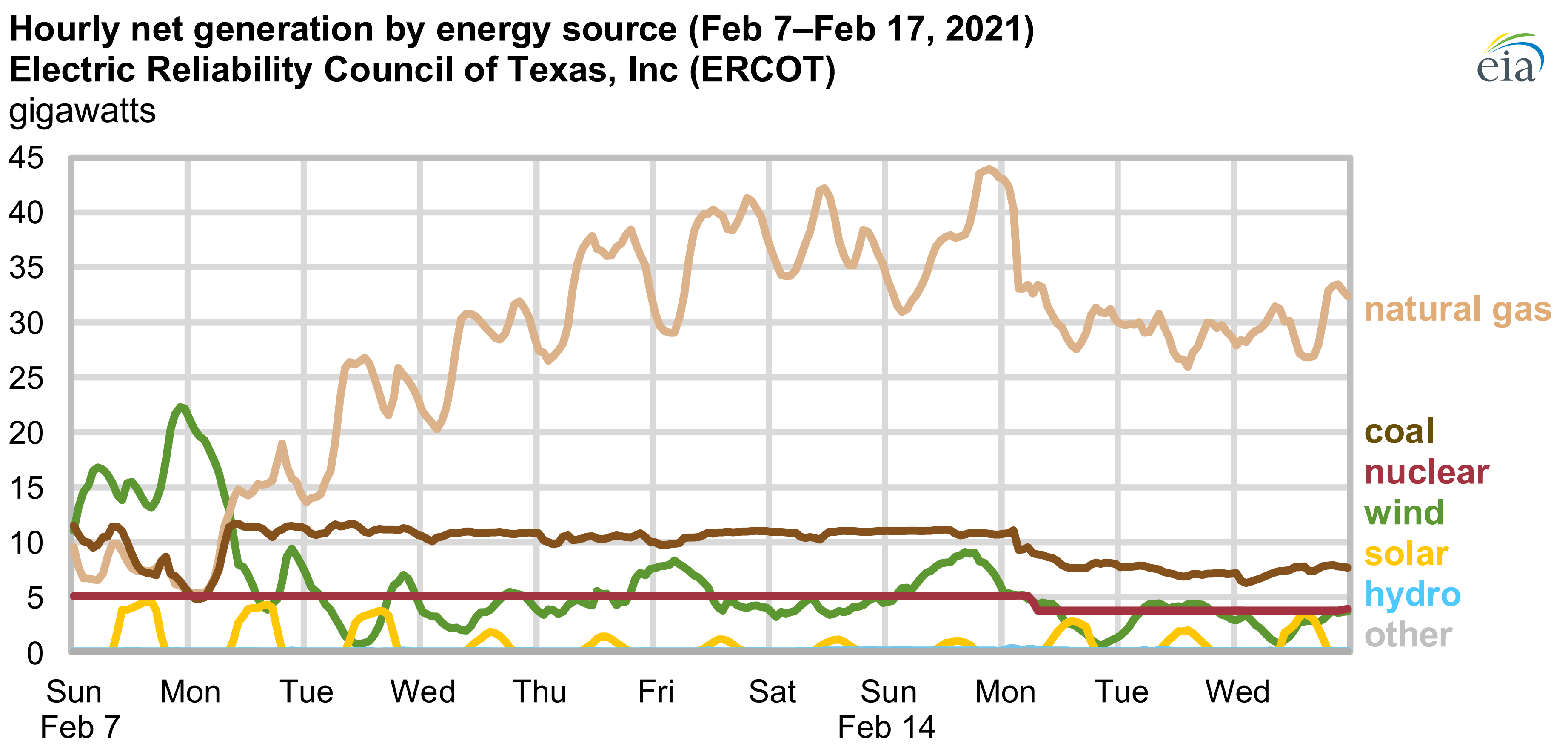
Revisiting Texas…



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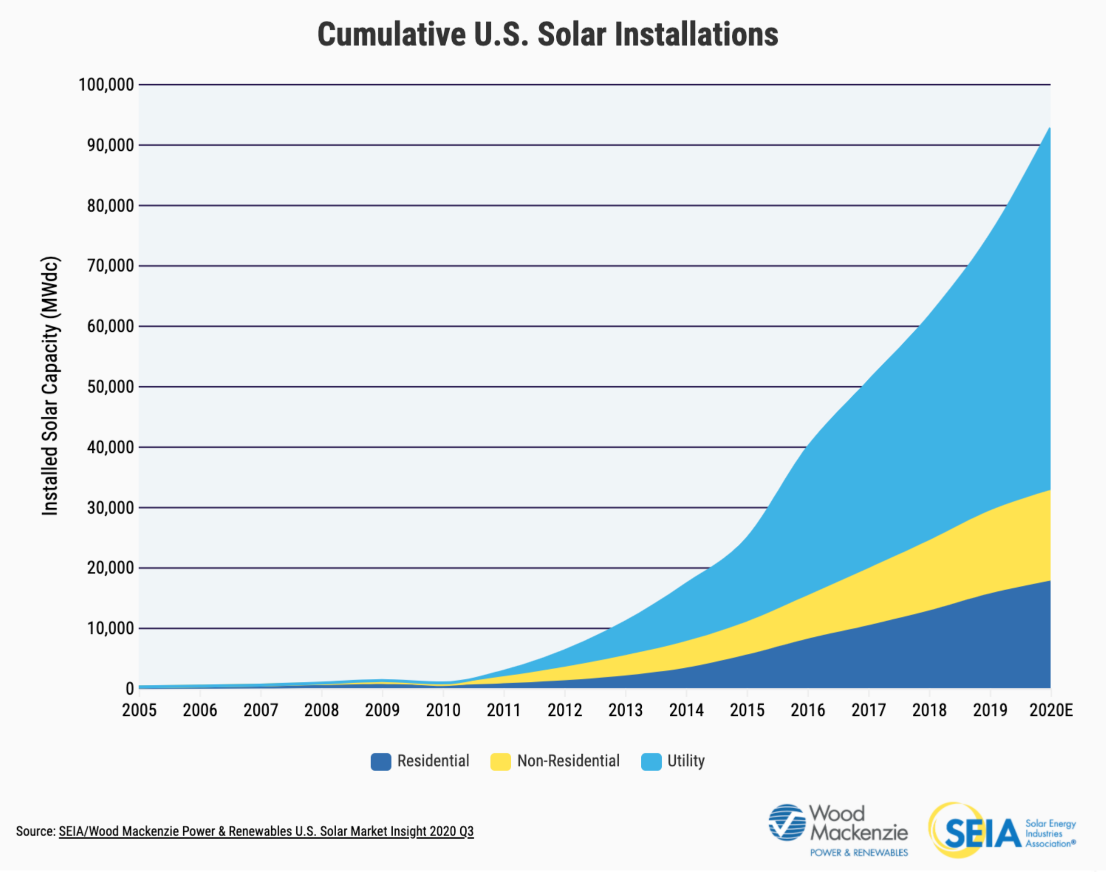
Electricity - Solar

- U.S. has 100 GW_{dc} installed solar capacity as of Q1, 2021
- 2021, 39% of new capacity is projected to be solar
- Comprised 2.3% of electricity generation in 2020



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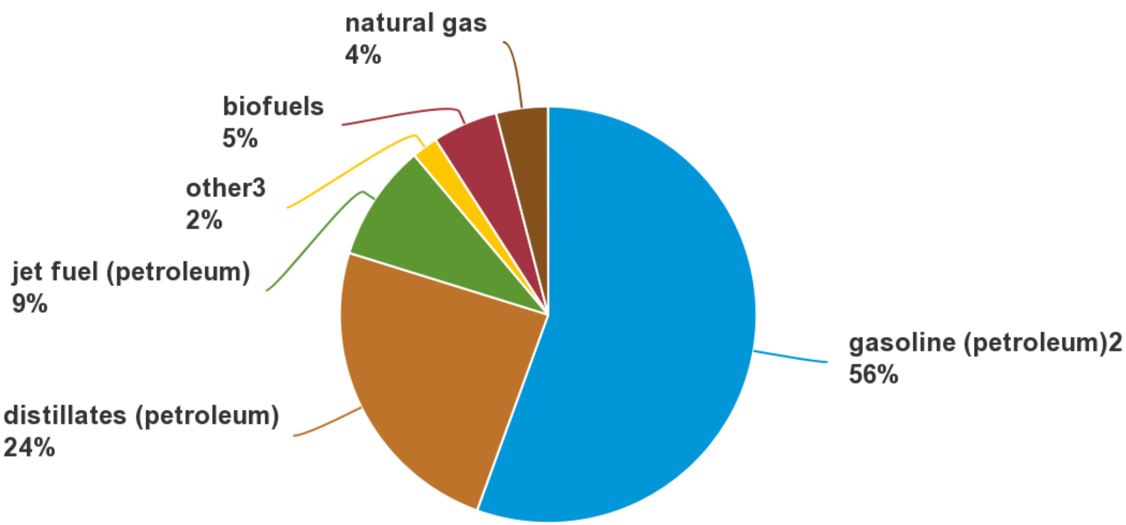
Transportation - Summary

U.S. transportation energy sources/fuels, 2020 1



1. Based on energy content
2. Motor gasoline and aviation gas; excludes ethanol
3. Includes residual fuel oil, lubricants, hydrocarbon gas liquids (mostly propane), and electricity (includes electrical system energy losses).

Source: U.S. Energy Information Administration, *Monthly Energy Review*, Tables 2.5, 3.8c, and 10.2b, April 2021, preliminary data

Note: Sum of individual components may not equal 100% because of independent rounding.

- Electric Vehicles comprised 1.8% of U.S. vehicle registrations in 2020

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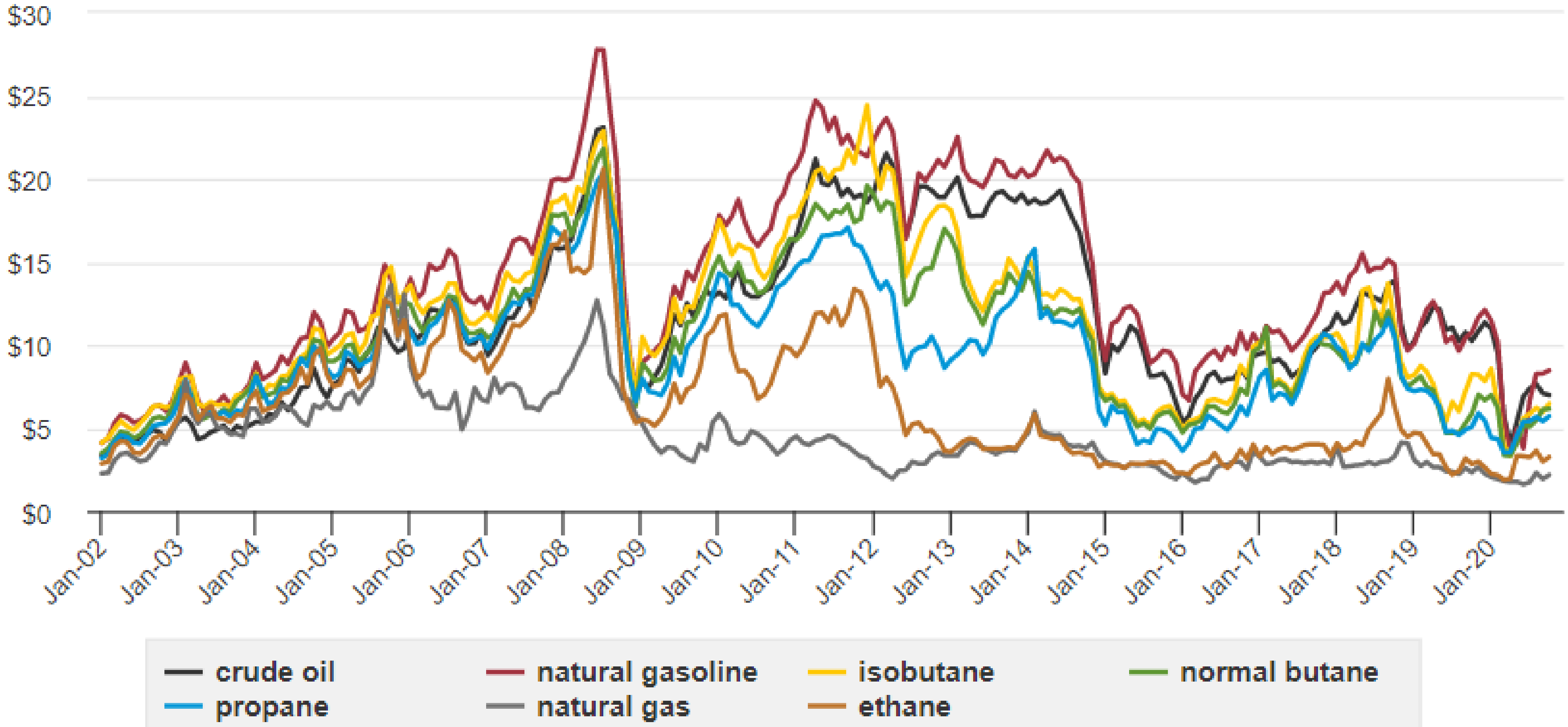
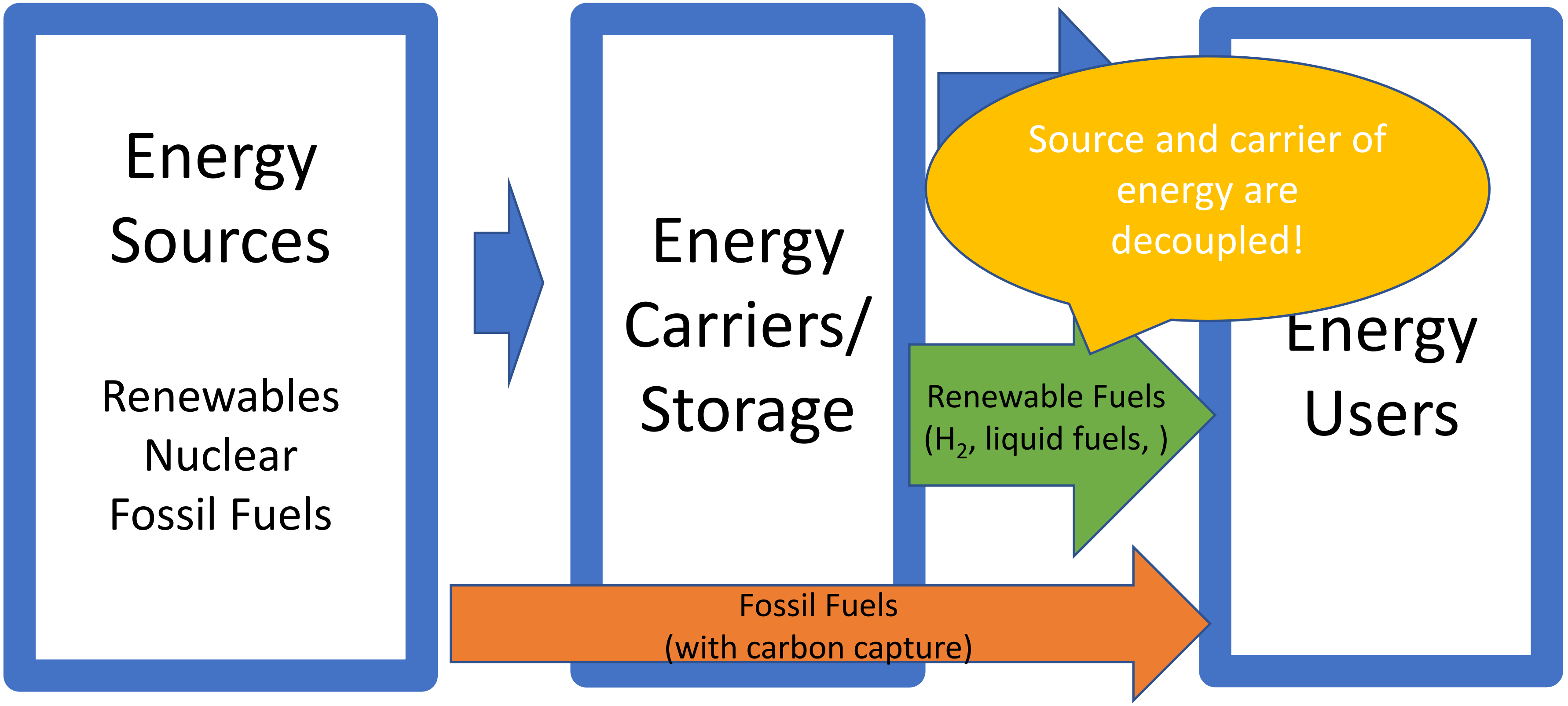
Energy Prices vary significantly by fuel!



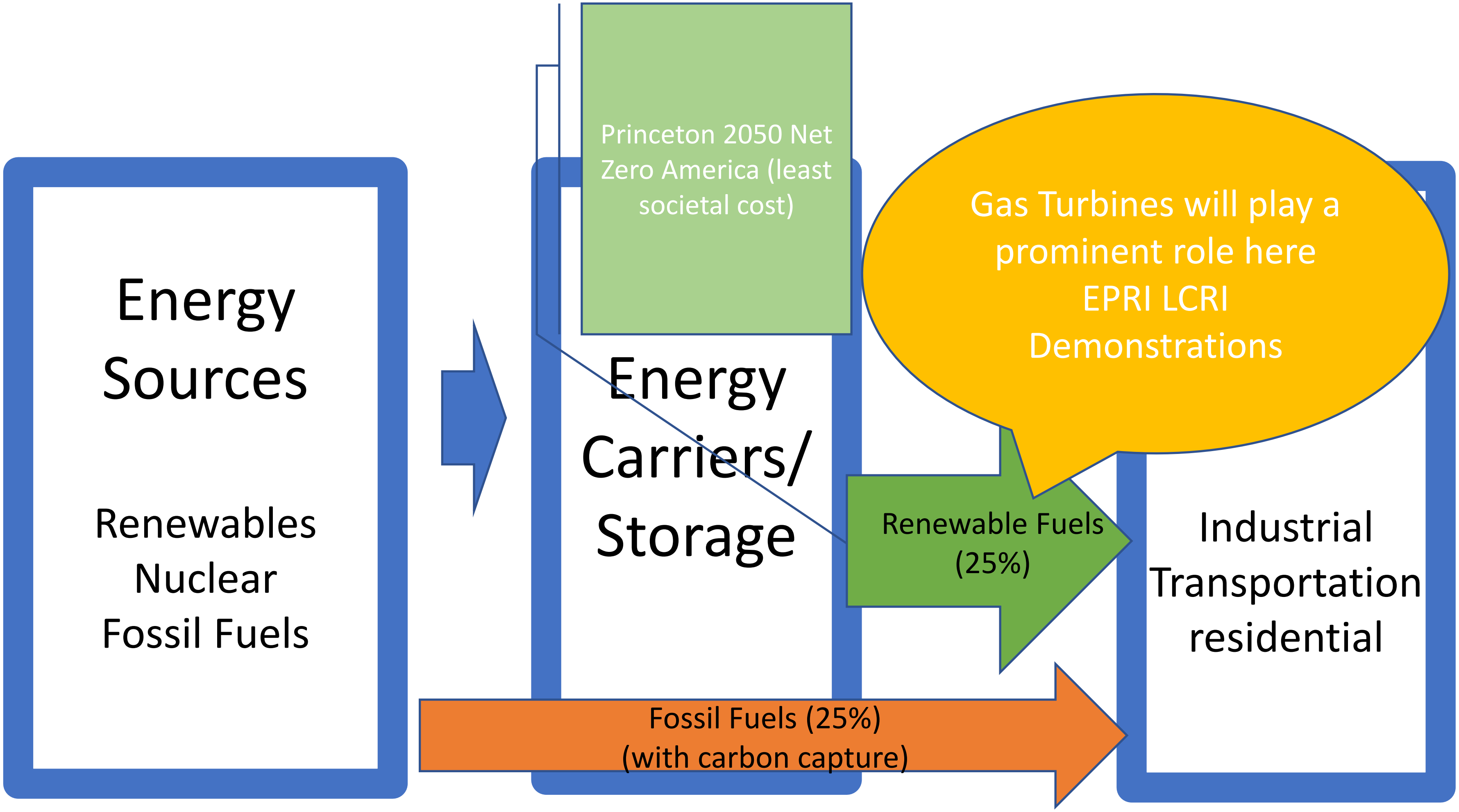
Note: Prices are monthly average of close-of-day spot prices; crude oil is Brent; natural gas is Henry Hub; HGL products are at Mt. Belvieu non-LST (Lone Star Terminal).
Source: U.S. Energy Information Administration from Bloomberg

Source: eia.gov/energyexplained/hydrocarbon-gas-liquids/prices-for-hydrocarbon-gas-liquids.php
Date: February 19, 2021

US Energy System – What will the net-zero CO_2 system look like?



US Energy System – What will the net-zero CO_2 system look like?



Global Interactions and Geopolitics

Global Interactions are Sector Dependent

- US is energy independent in so far as electric power generation
  - Pricing decoupled from electricity prices globally
  - However, exports of LNG could effect gas prices
- Oil: US is net exporter, but also a major importer and fully coupled to global markets
  - Prices set by global markets
- Energy security issue is coupled to transportation, oil imports
- Geopolitical considerations around US LNG exports to allies

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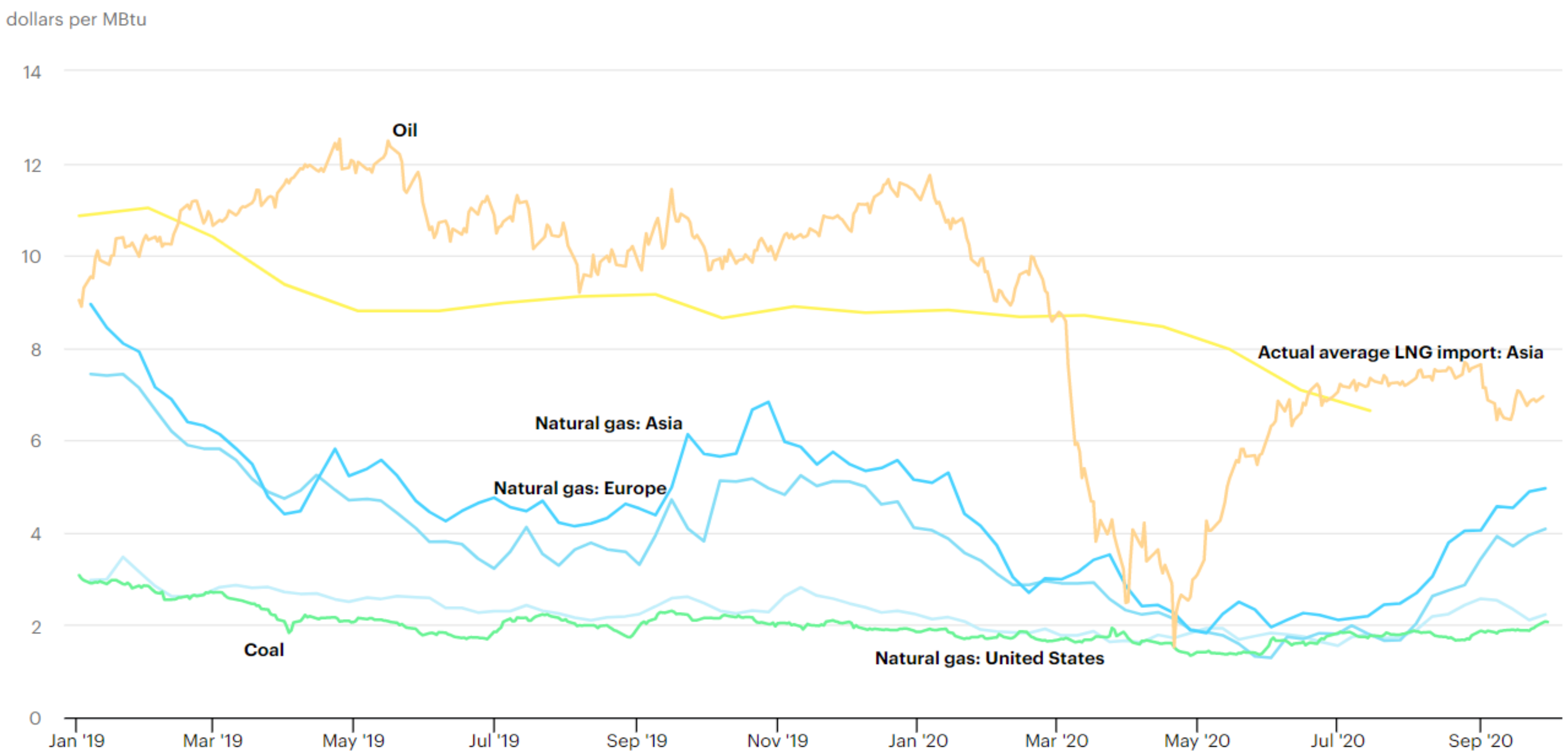
Natural Gas Exports

- Global arbitrage opportunities
- Current U.S. exports are roughly 13% of total production in 2020



https://www.iea.org/data-and-statistics/charts/selected-fossil-fuel-prices-in-2019-2020

Natural Gas and Ethane to Chemicals

- Chemicals Industry in US: $797 Billion in 2019
- Exports - $125B in 2020
  - 9.2% of all exported goods

- Low-cost natural gas and natural gas liquids enable US to be low-cost producer of commodity chemicals, fertilizer, etc., and has attracted over $209B in U.S. chemical industry investment.
  - As of February 2021
    - 229 projects are completed and operating.
    - 40 projects cumulatively valued at $31 billion are under construction,
    - 80 projects valued at $81 billion are in the planning phase.
    - Total completed, under construction, or planned investment is $209 billion across 349 projects.

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Key Domestic Discussion Points

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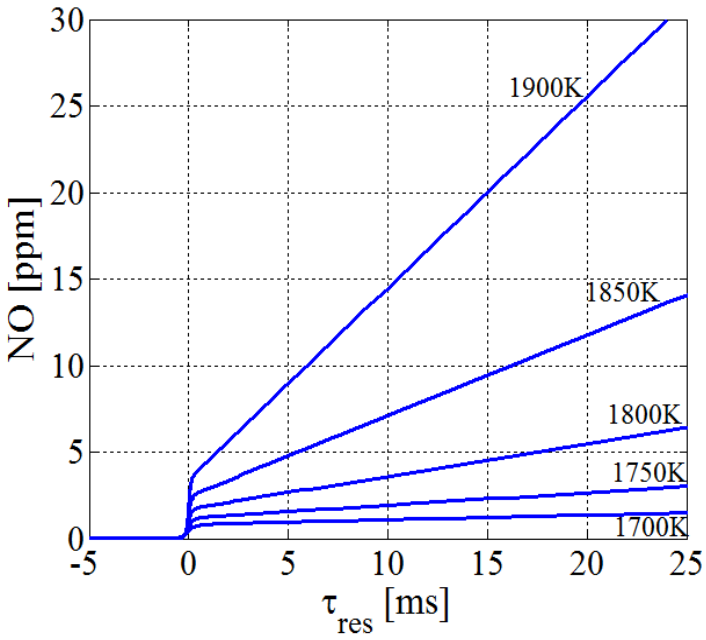
- Category Pollutant and Carbon Emissions
- Energy Imports/Exports, Energy Security, and Global Interactions
- Equity and justice

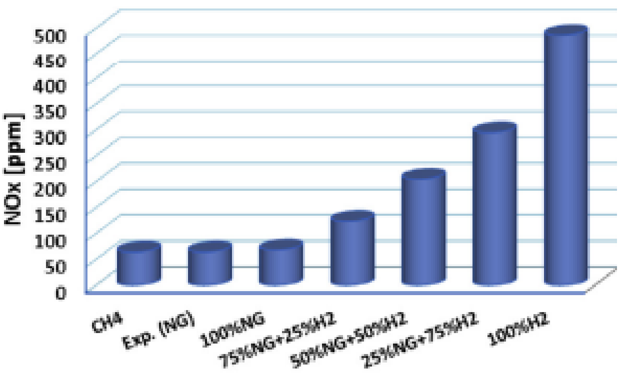
Environmental Justice –Hydrogen Combustion

- NO is a regulated pollutant; leads to smog and respiratory issues
- Heating up air (N_2 +O_2) leads to NO production, even from 100% renewable fuels



Environmental Impacts of H2 Combustion

- *"When hydrogen is burned it emits little or no carbon dioxide — that's the good news. The bad news is that hydrogen combustion produces dangerously high levels of nitrogen oxides – scientific studies indicate that burning hydrogen could produce NO_x levels six times higher than burning methane."* *https://morningconsult.com/opinions/dont-fall-for-the-hydrogen-hype/*
- *"The bad news is that H_2 combustion can produce dangerously high levels of nitrogen oxide (NO_x). Two European studies have found that burning hydrogen-enriched natural gas in an industrial setting can lead to NO_x emissions up to **six times that of methane** (the most common element in natural gas mixes). There are numerous other studies in the scientific literature about the difficulties of controlling NO_x emissions from H_2 combustion in various industrial applications. "* *https://www.renewableenergyworld.com/hydrogen/hydrogen-hype-in-the-air/#gref*



Reference: ***Mehmet Salih Cellek , Ali Pınarbası, "Investigations on performance and emission characteristics of an industrial low swirl burner while burning natural gas, methane, hydrogen-enriched natural gas and hydrogen as fuels"***

- HOWEVER,….
  - Absolute vs. relative effects?
  - Results from "old-fashioned", high NOx devices; need for data in modern lean, premixed configurations

- LCRI program at EPRI (Bobby Noble and Rob Steele)

Environmental Justice – Carbon Capture

GEOENGINEERING 101

CLIMATE JUSTICE ALLIANCE
COMMUNITIES UNITED FOR A JUST TRANSITION

CARBON CAPTURE AND
STOR

An Array of False Solutions

Carbon Capture and Storage

In Carbon Capture and Storage (CCS), carbon dioxide (CO2) is collected from industrial smokestacks, compressed into a liquid and transported by pipeline to a site where it can be pumped underground for storage in saline aquifers, oil or gas reservoirs, or beneath the ocean. This is a dangerous practice. There is no guarantee the CO2 will stay underground. Imagine, for example, an earthquake under a CCS storage site that causes a release of large ammounts of CO2 into the atmosphere.

CCS was developed over 40 years ago for use in enhanced oil recovery (EOR), a practice in which oil companies pump liquid CO2 into old, nearly depleted wells to access deep pools of

the environment and atmosphere when these products are incinerated or decompose. This is (at best) postponing the problem of CO2 emissions and perpetuating the problem of acute environmental injustice from these polluting operations. CCUS creates more emissions than it reduces[2] and contributes to the production of plastics and other polluting materials. Even if some of the emissions are temporarily captured, all the problems with CO2 storage remain.

Direct Air Capture: The New False Hope

Direct Air Capture (DAC) is a largely theoretical technique to remove CO2 (and potentially other greenhouse gases) directly from the atmosphere, using chemical and mechanical means. The current proposed technique would use large fans to move air through a filter, where it passes through a chemical adsorbent to produce a pure CO2 stream that could be stored. To have any significant effect on global CO2 concentrations,

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Thank You

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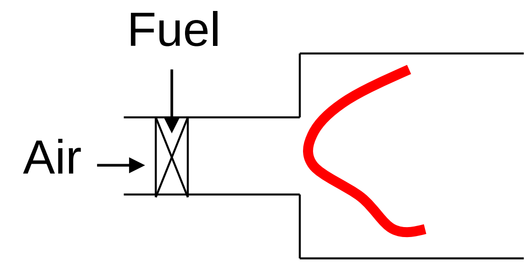
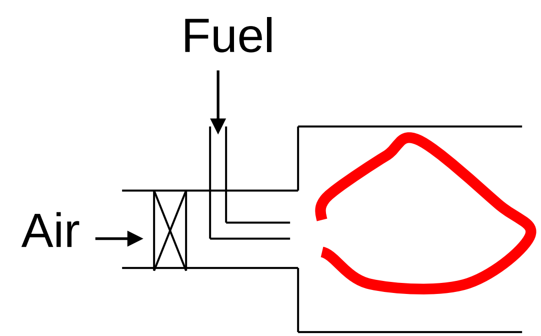
Premixed vs Non-Premixed Flames

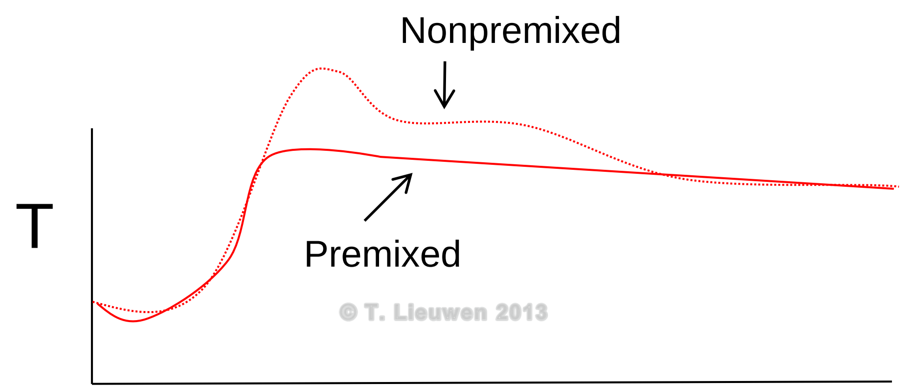
- Premixed flames
  - Fuel and air premixed ahead of flame
  - Mixture stoichiometry at flame can be controlled
  - Method used in low NOx gas turbines (DLN systems)
- Non-premixed flames
  - Fuel and air separately introduced into combustor
  - Mixture burns at f=1
    - i.e., stoichiometry cannot be controlled
    - Hot flame, produces lots of NOx and more sooting
    - More robust, higher turndown, simpler



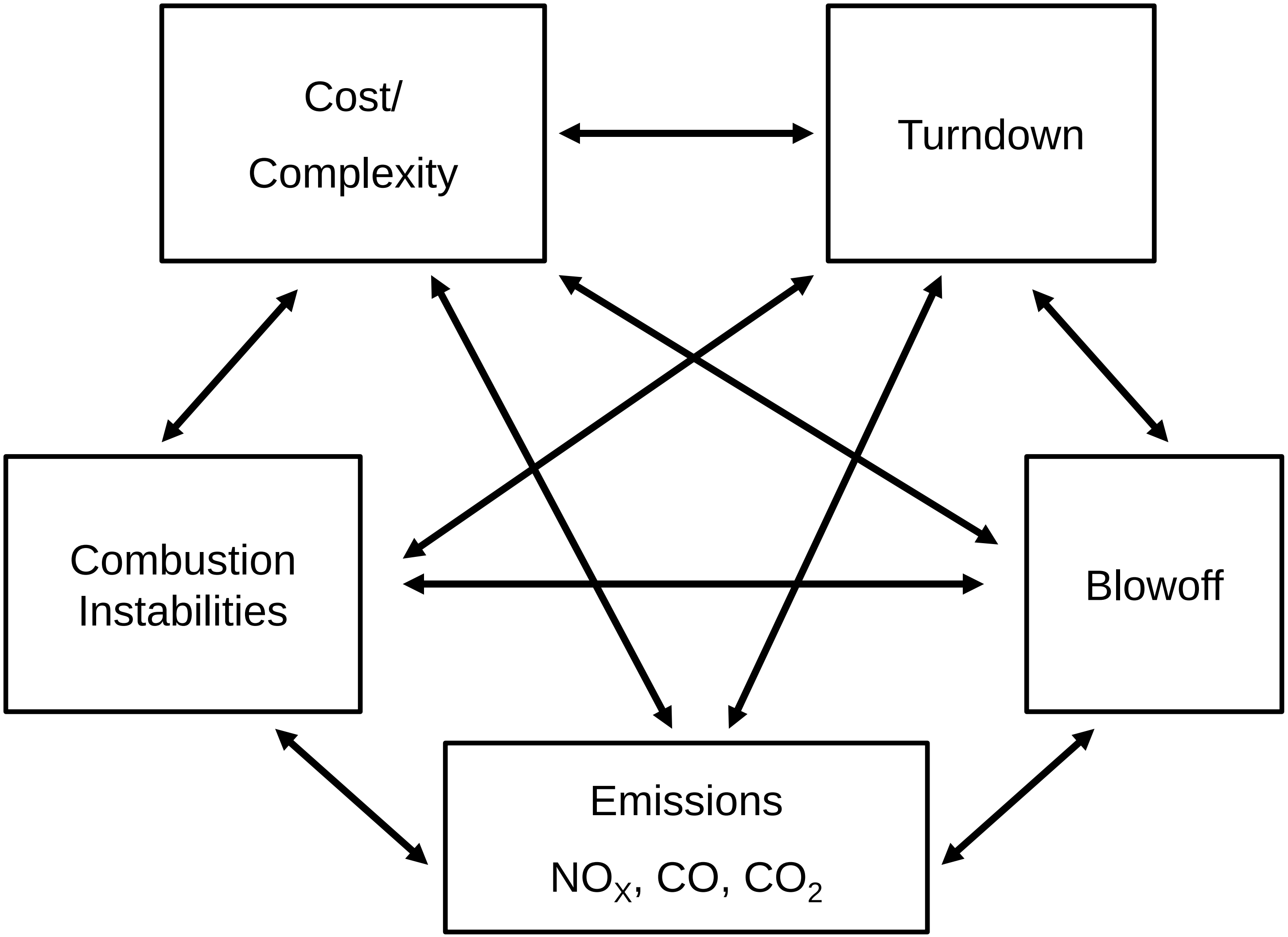


Combustor Configurations
Dry, Low NOx (DLN) Systems

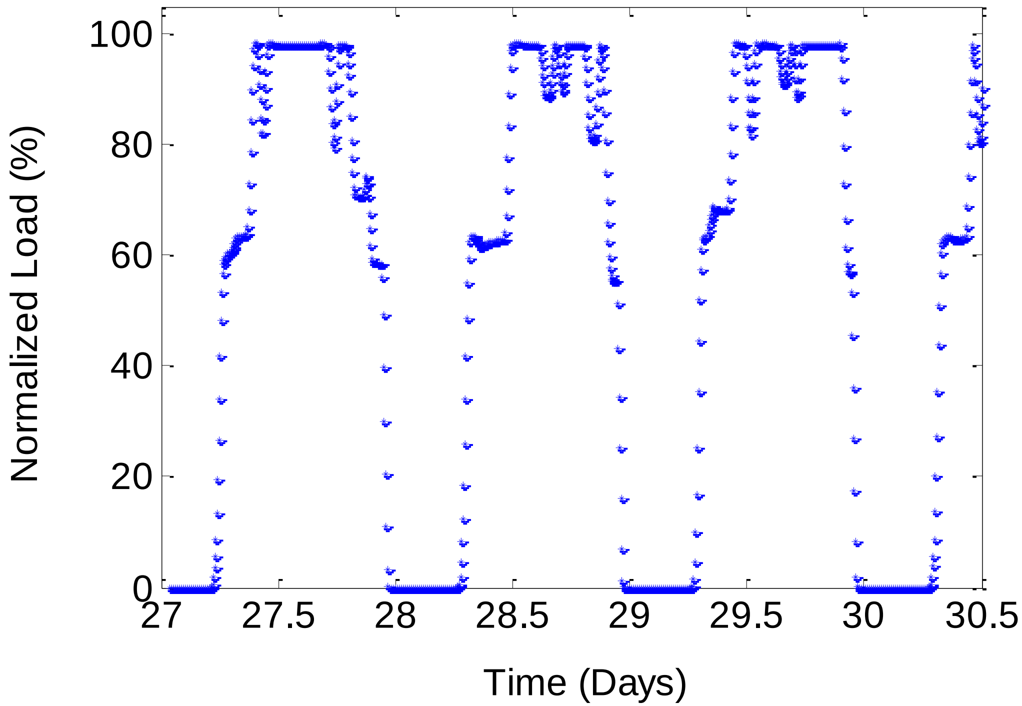
- Premixed operation
  - If liquid fueled, must prevaporize fuel (lean, premixed, prevaporized, LPP)
- Almost all air goes through front end of combustor for fuel lean operation – little available for cooling
- Multiple nozzles required for turndown



Tradeoffs and Challenges

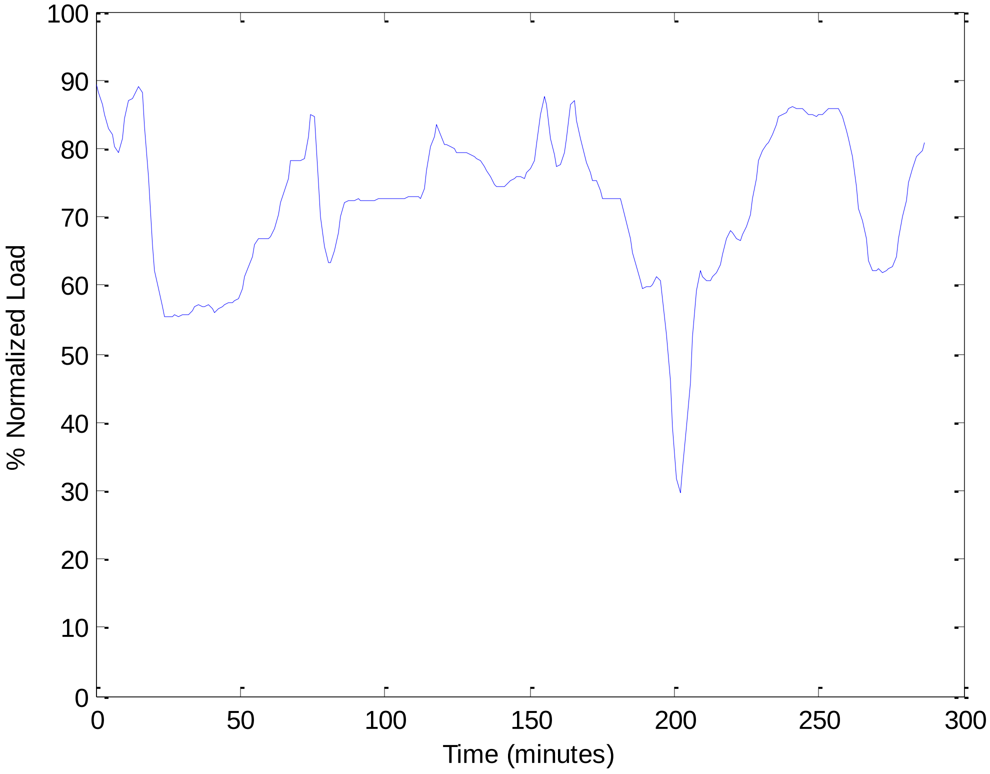


Turndown



- Operational flexibility has been substantially crimped in low NO_X technologies
- Significant number of combined cycle plants being cycled on and off daily

Transient Response Needs



- Locations with high penetration of wind and photovoltaic solar are seeing significant transient response needs
- Avoiding blowoff and flashback are key issues

Blowoff

- Low NO_X designs make flame stabilization more problematic

NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

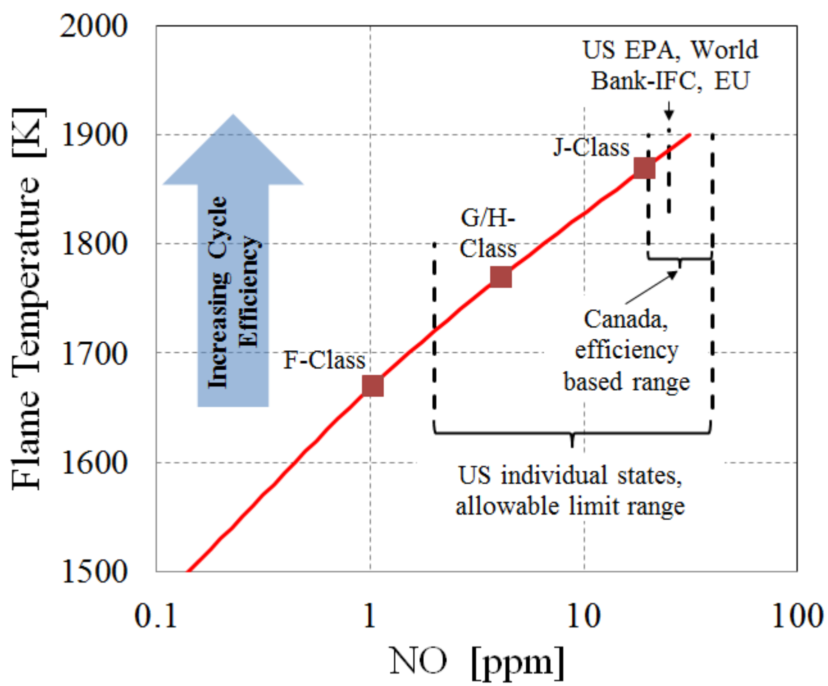
Industry Advisory
June 26, 2008

Background:

On Tuesday February 26th, 2008, the FRCC Bulk Power System experienced a system disturbance initiated by a138 kV transmission system fault that remained on the system for approximately 1.7 seconds. The fault and subsequent delayed clearing led to the loss of approximately 2,300 MW of load concentrated in South Florida along with the loss of approximately 4,300 MW of generation within the Region. Approximately 2,200 MW of under-frequency load shedding subsequently operated and was scattered across the peninsular part of Florida.

Indications are that six combustion turbine (CT) generators within the Region that were operating in a lean-burn mode (used for reducing emissions) tripped offline as result of a phenomenon known as “turbine combustor lean blowout.” As the CT generators accelerated in response to the frequency excursion, the direct-coupled turbine compressors forced more air into their associated combustion chambers at the same time as the governor speed control function reduced fuel input in response to the increase in speed. This resulted in what is known as a CT “blowout,” or loss of flame, causing the units to trip offline.

NOx-Efficiency (CO2) Tradeoffs



- Future turbine efficiency improvements may be NOx rather than turbine inlet temperature limited!