Joint Institute for Strategic Energy Analysis

Coordinated Modeling of Electric Grid and Natural Gas Network Operations

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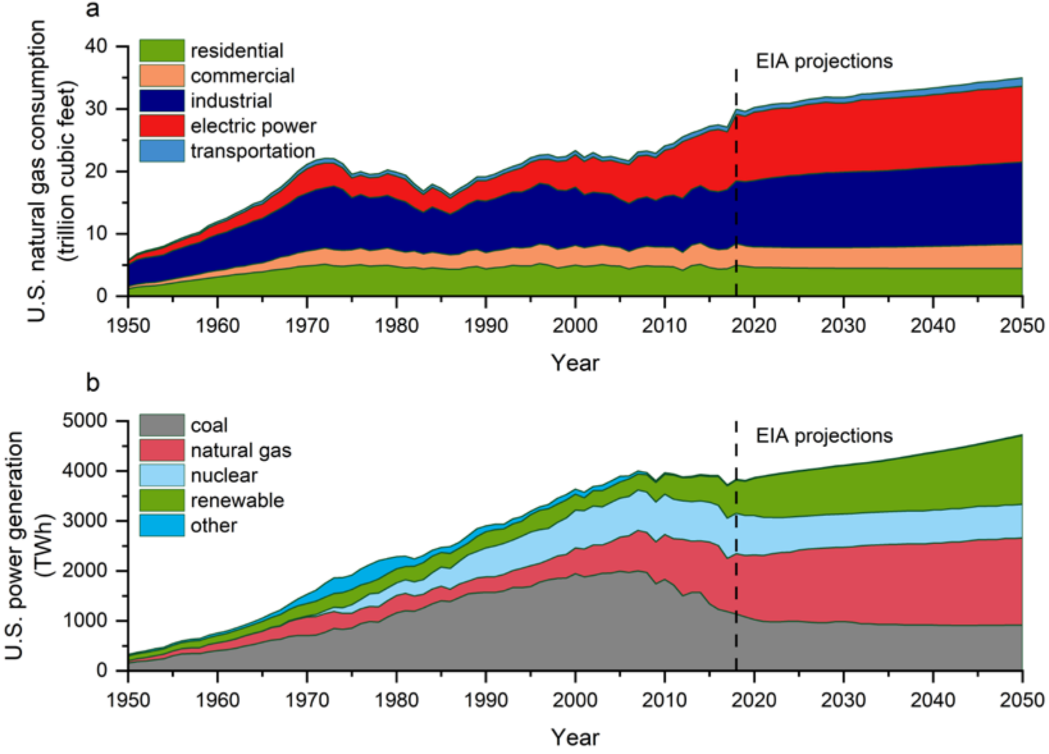
Growing coupling of gas and electricity networks

Historical and projected data for natural gas consumption and power generation in the United States

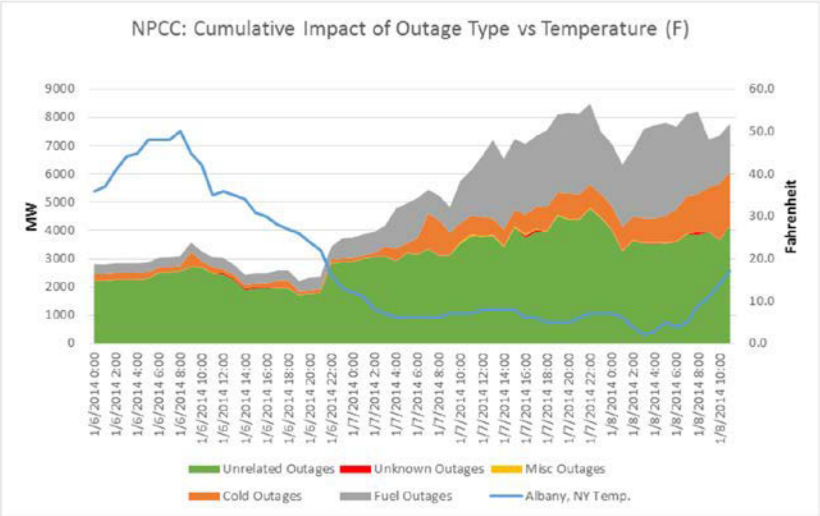


- The power sector accounted for 35.5% of total natural gas demand in 2018 (up from 22.3% in 2000)
- The share of generation from natural gas increased from 14.2% to 31.5% over the same period.
- The share from renewable energy—driven by increases in wind and solar—has increased from 8.8% to 17.4%

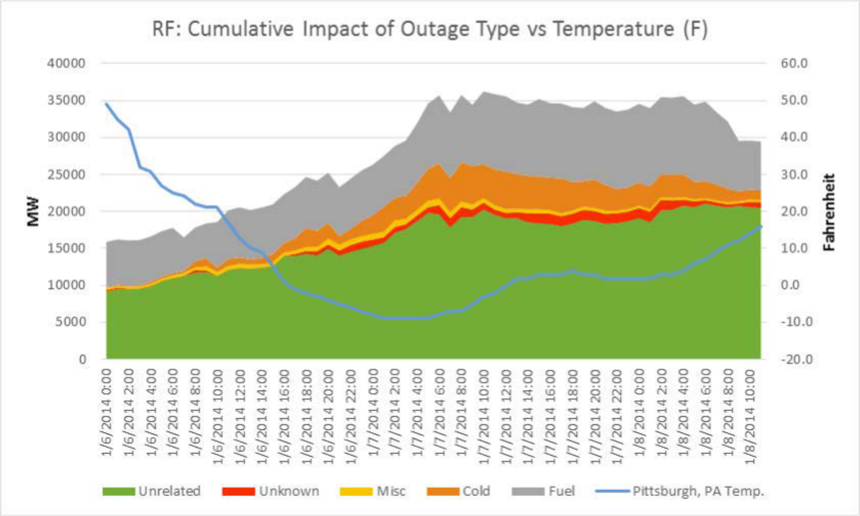
Source: U.S. Energy Information Administration (EIA) Annual Energy Outlook, 2019

2014 East Coast Polar Vortex

Northeast Power Coordinating Council



ReliabilityFirst

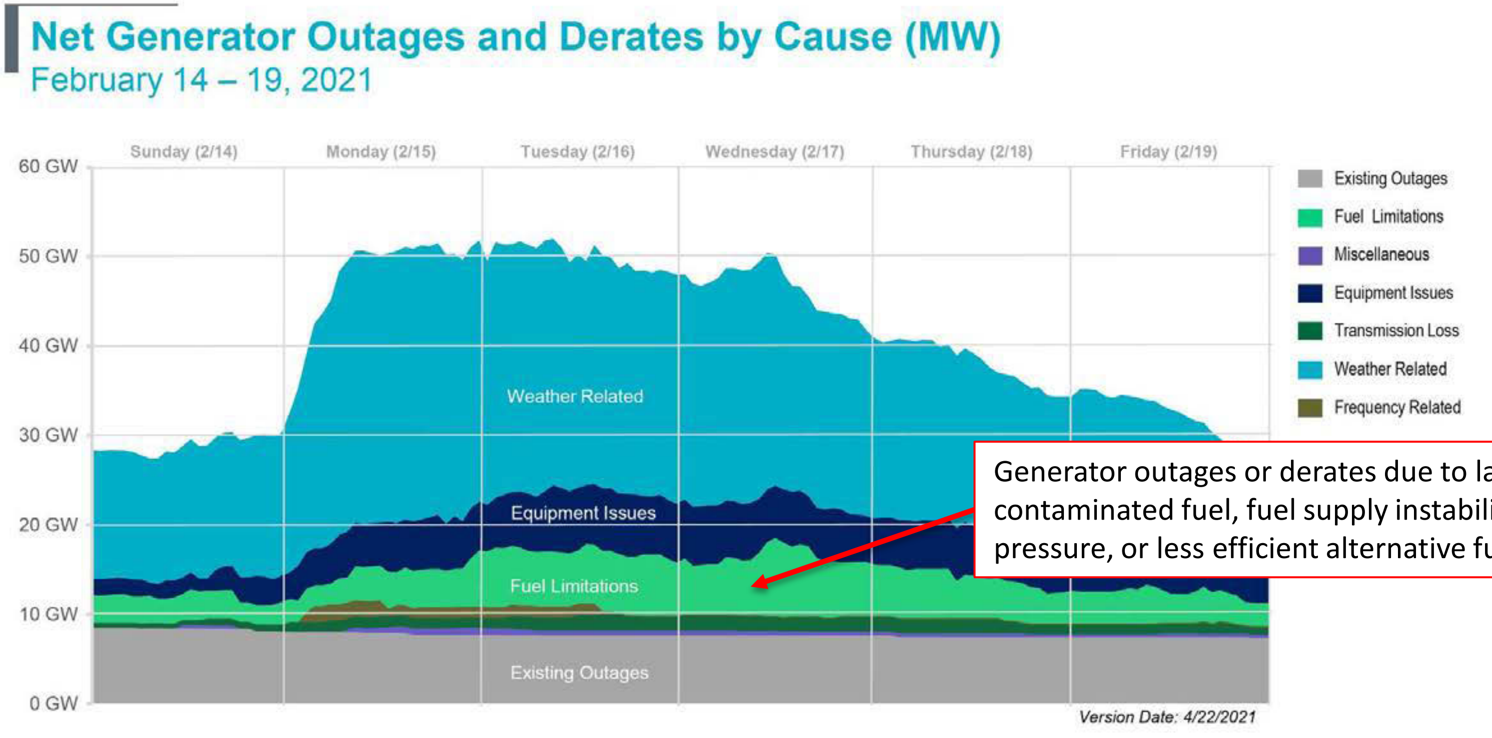


- "…outages related to curtailments and interruptions of natural gas delivery were the significant contributor of the NPCC generator outages."
- In some cases, lack of natural gas prevented starting dual-fuel units with alternate fuels
- 3,296 MW of fuel-related outages

- "it was the number of units that were either unavailable or derated due to the lack of natural gas availability that was the major issue for [Reliability First]"
- Situation exacerbated by the loss of a natural gas compressor station in Delmont, PA on January 7, 2014
- 9,000 MW of fuel-related outages in 25 of the 60 hours of interest

Source: North American Electric Reliability Corporation, "Polar Vortex Review," NERC, Atlanta, 2014.

2021 Texas Winter Storm Uri



Net generator outages at the beginning of each hour on February 14-19, 2021, by cause category.

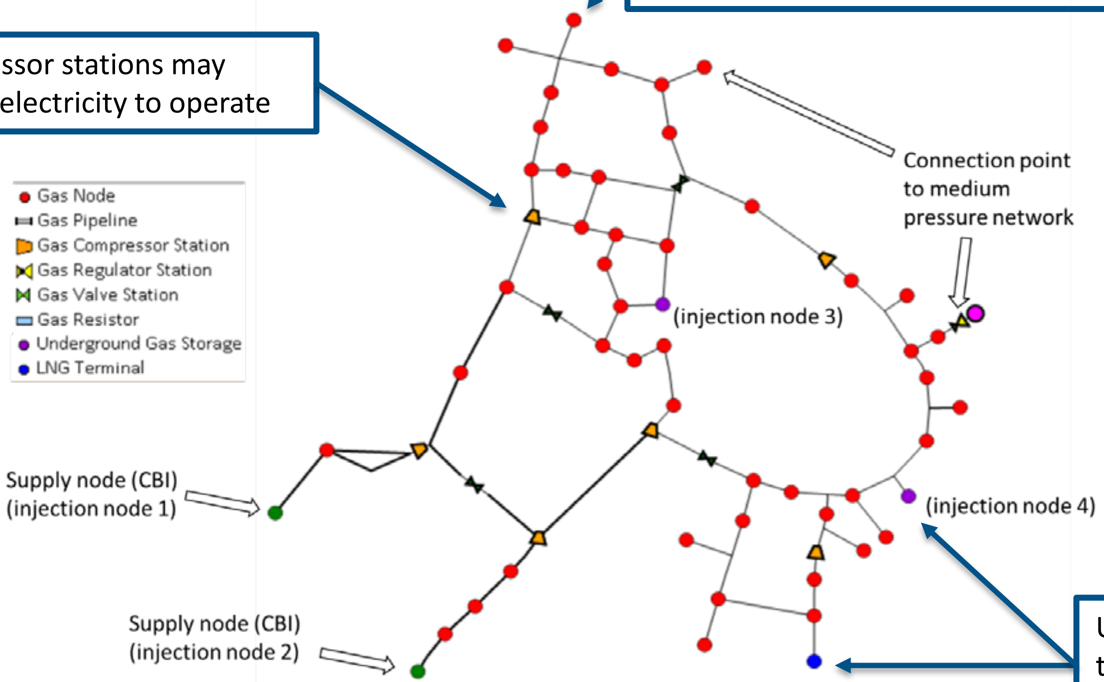
Generator outages or derates due to lack of fuel, contaminated fuel, fuel supply instability, low gas pressure, or less efficient alternative fuel supply.

Source: ERCOT, "February 2021 Extreme Cold Weather Event: Preliminary Report on Causes of Generator Outages and Derates"
http://www.ercot.com/content/wcm/lists/226521/51878_ERCOT_Letter_re_Preliminary_Report_on_Outage_Causes.pdf

Coupling points

Gas fired power plants require natural gas delivered at sufficient pressure

Compressor stations may require electricity to operate

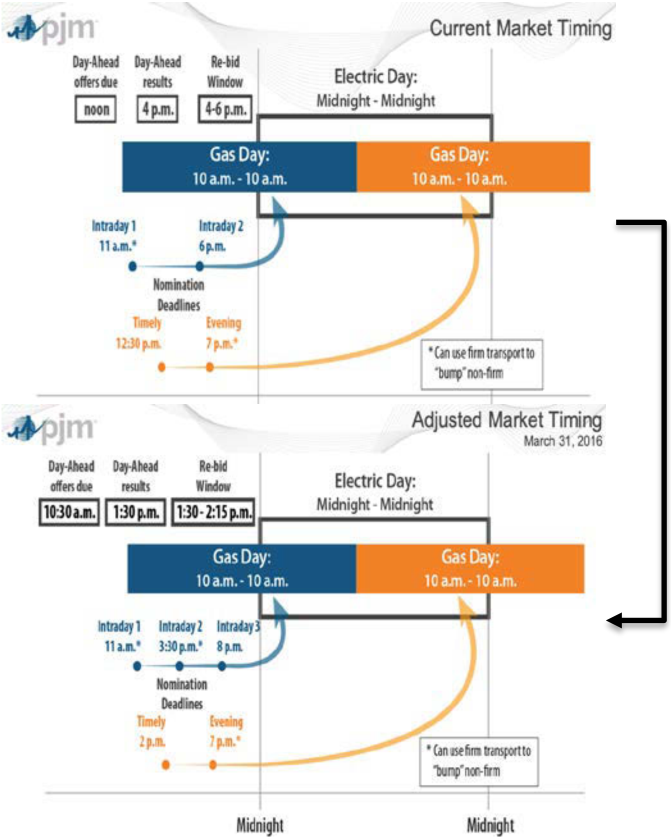


Underground storage or LNG terminals may require electricity to inject gas into the pipeline network

FERC identified the need for better coordination

FERC Order 809 (2015)

- Intended to allow better interactions between gas and electricity market operations
- Gas nomination deadline moved from 12:30pm Eastern time to 2:00pm Eastern time
- Addition of 3rd intraday nomination cycle



Source: "Gas - Electric Coordination at PJM "
http://www.gaselectricpartnership.com/kPJM-Gas%20Electric%20Coordination-.pdf

Different levels of coordination

Decision making level

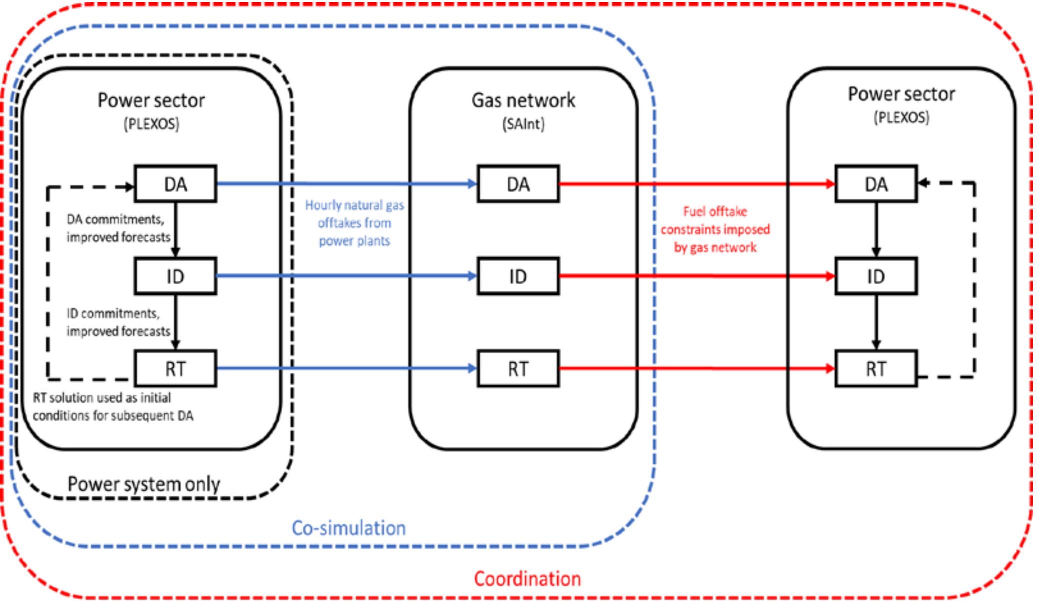
- **Planning**: Optimize the location, capacity, and timing of investment decisions associated with generation or production, transmission, and storage assets in an integrated system.
- **Operations**: Improve reliability and minimize the operational costs associated with natural gas and electricity supply, natural gas supply contracts, and load shedding or unserved natural gas.

Optimization control level

- **Co-optimization (central planning)**: Decisions for the two systems are optimized simultaneously with a single objective function.
- **Co-simulation (market based)**: The two systems are optimized or simulated separately, with coordination occurring via the exchange of information, such as prices, gas demand from generators, gas availability from the gas network, etc.

Coordination framework

Electricity and natural gas systems coordination framework (implemented in Python)

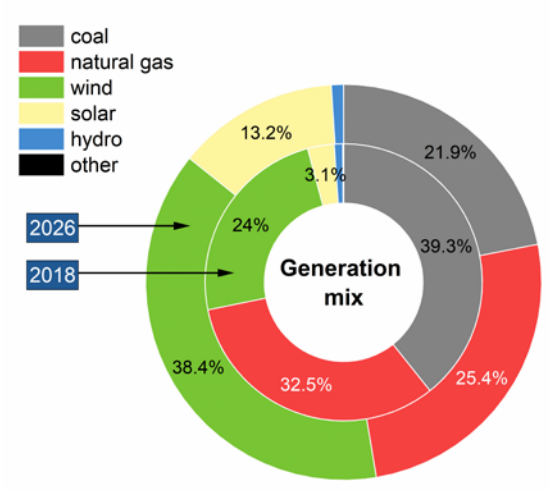


DA: day-ahead market, ID: intra-day market, and RT: real-time market

- **Power system only**: results from the first iteration of the power system model, before any communication with the gas network.
- **Co-simulation**: results after simulating gas offtakes from the power system model in the gas network; reflects curtailed gas but has not yet reoptimized the power system in response to gas constraints.
- **Coordination**: results after re-optimizing the power system with constraints from the gas simulation.

Case study on the Colorado Front Range

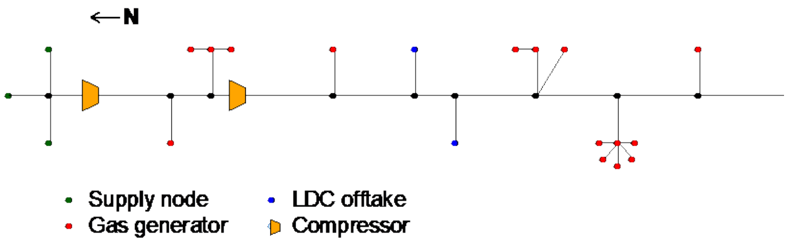
Colorado's annual generation (left) and capacity mix (right)
(Energy Exemplar's PLEXOS was used to optimize power system operations in the DA, ID, and RT markets)



Technology	2018 (GW)	2026 (GW)
Coal	3.88	2.42
Gas	7.58	
Wind	6.02	9.81
Solar	2.25	9.88
Hydropower	0.73	
Other	1.5	

The 2018 fleet is based on current Colorado fleet, benchmarked to actual generation levels; the 2026 fleet is based on plans developed by Western Resource Advocates to meet Xcel targets: https://westernresourceadvocates.org/blog/colorado-energy-plan-explained/

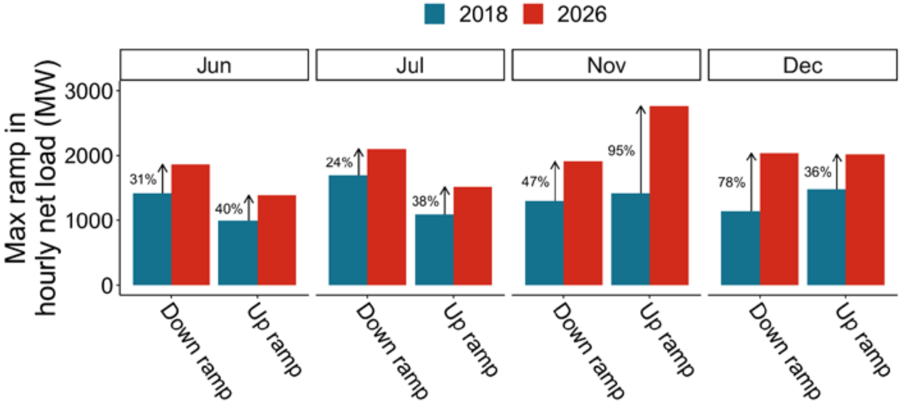
Representation of the gas network. Based on data of the Front Range gas network in Colorado provided by KM.
(encoord's SAInt model used to perform transient hydraulic simulation of the operation of the natural gas system)



The offtake nodes include gas generators representing about 70% of the natural gas generator offtakes in the power system model, as well as information on demand profile for local distribution companies (LDCs).

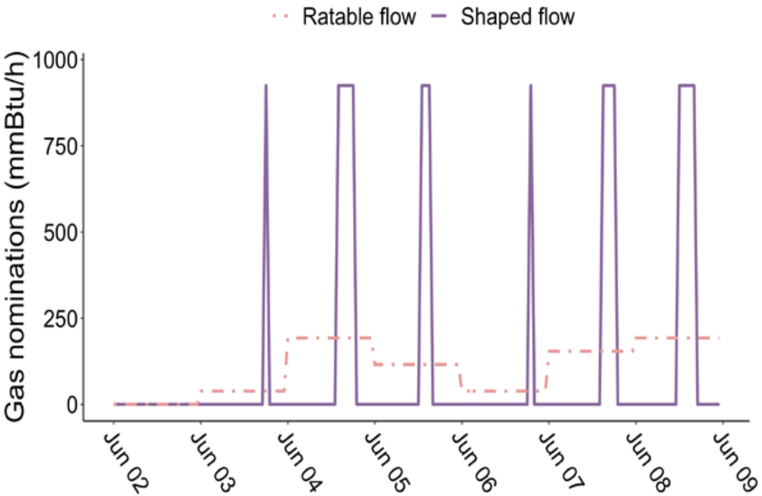
Ramping requirements and gas nominations

Largest up and down ramps in net load (MW) in 2018 and 2026



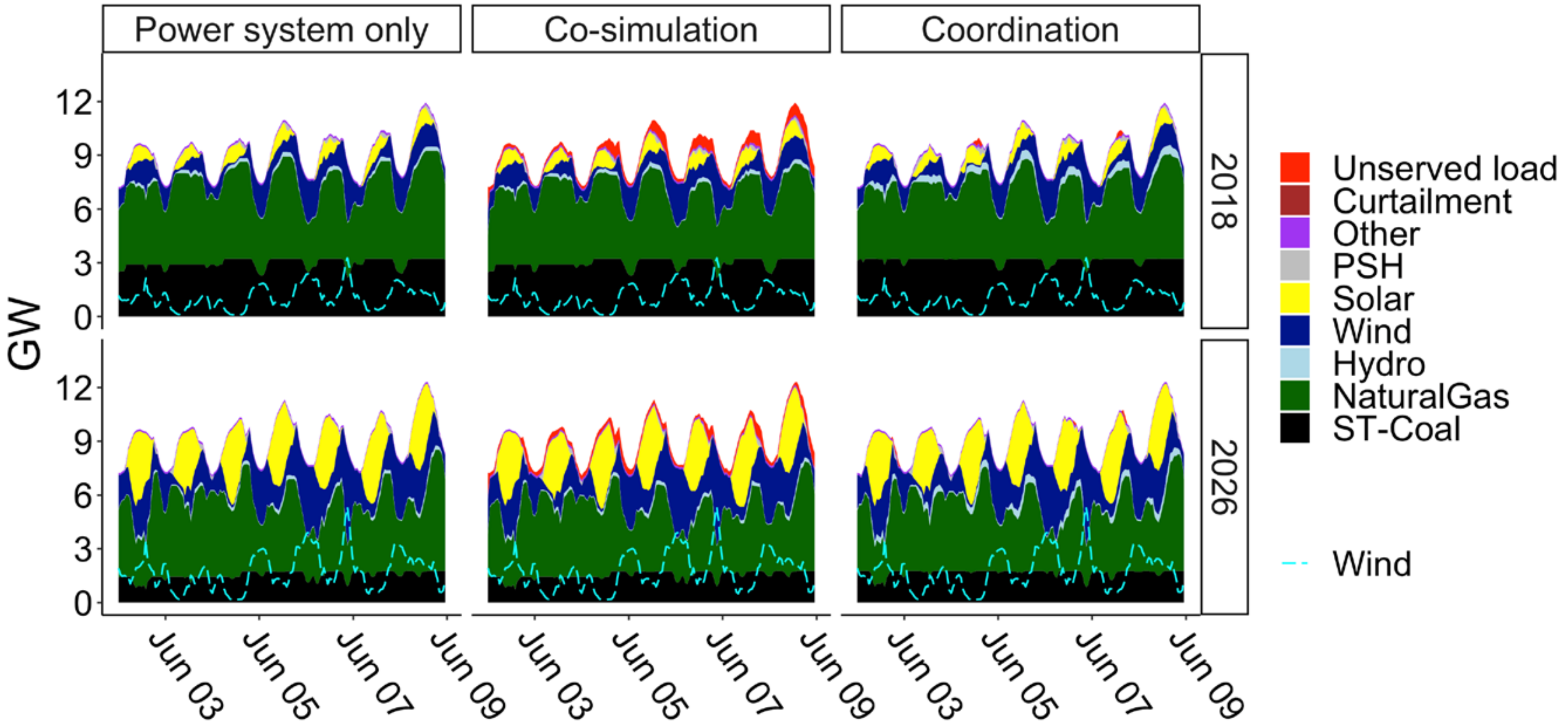
- Highest natural gas demand from the power sector used to select four weeks for analysis, as these weeks are likely to be the times when coordination between the two systems is critical:
  - June 2-8 (spring)
  - July 14-20 (summer)
  - November 17-23 (fall)
  - December 12-18 (winter)

Ratable flow (current practice) and Shaped flow (proposed practice)

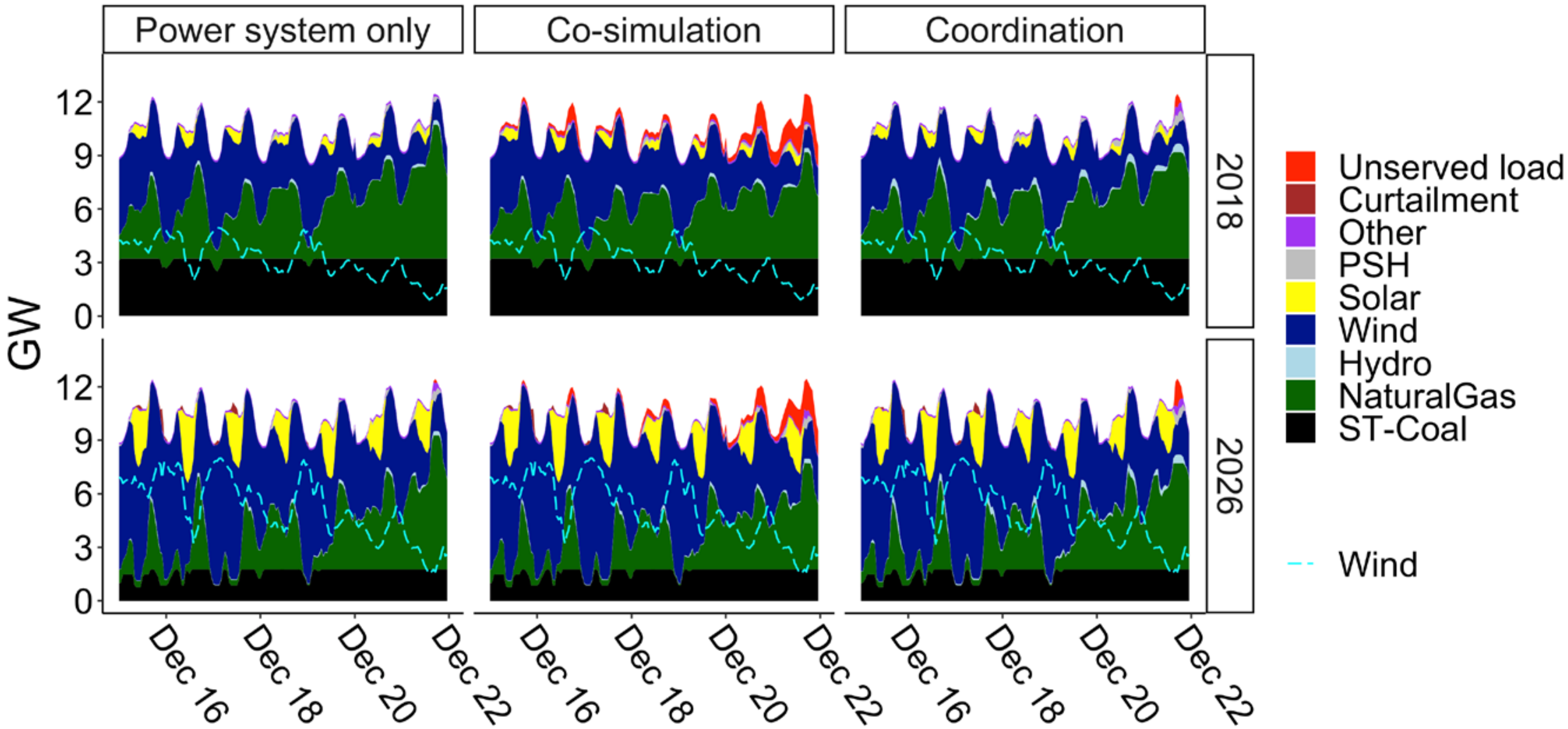


Hourly natural gas nominations from a single combustion turbine during the June week when using ratable gas nominations—in which nominations are the average of hourly gas offtakes over 24 hours—and shaped flow nominations—in which nominations can vary by hour.

Real-time dispatch (June scenario)

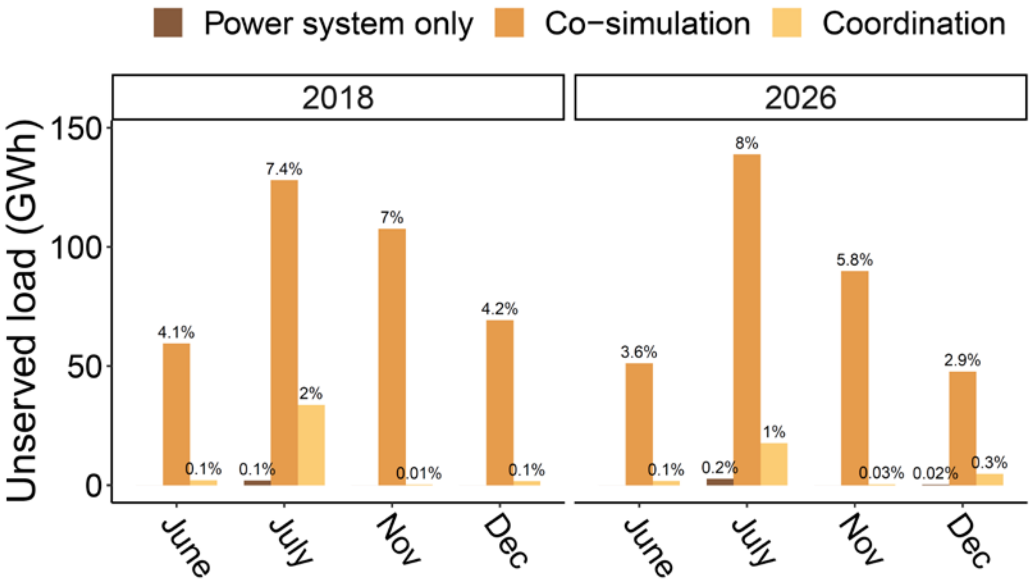


Real-time dispatch (December scenario)



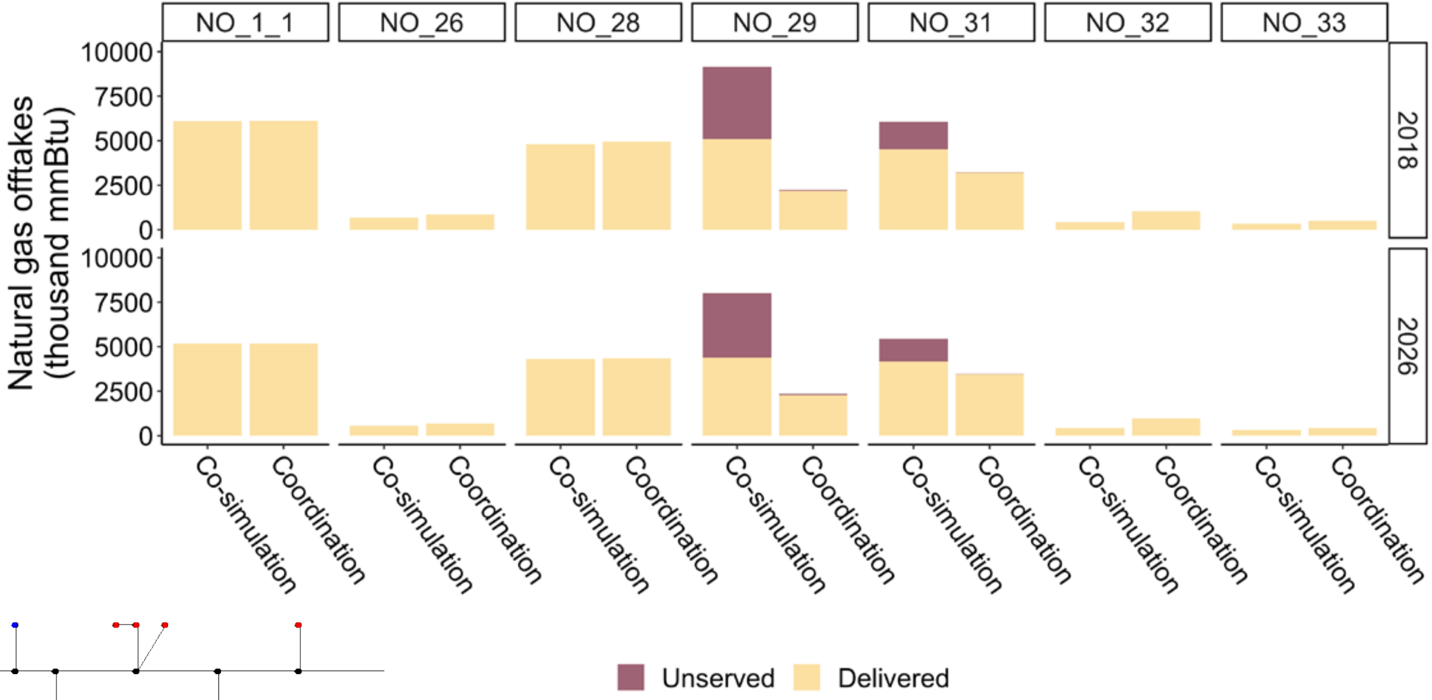
Impacts of coordination on unserved load

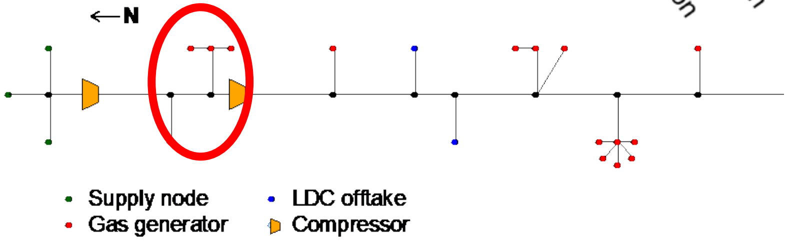
Total unserved load
(Numbers indicate unserved load as a percentage of total load that week).



- No unserved load in the initial power system optimization (power system only); however, when gas curtailments are imposed from constraints in the gas network (co-simulation), large amounts of unserved load occur.
- If the power system is re-optimized based on input from the gas network (coordination), the amount of gas curtailment and unserved load is substantially reduced.

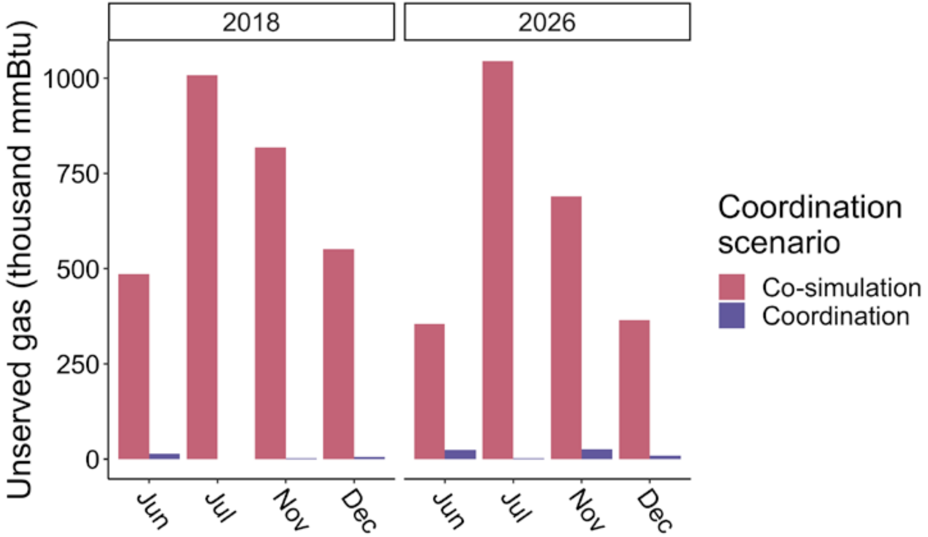
Total real-time gas offtakes by node



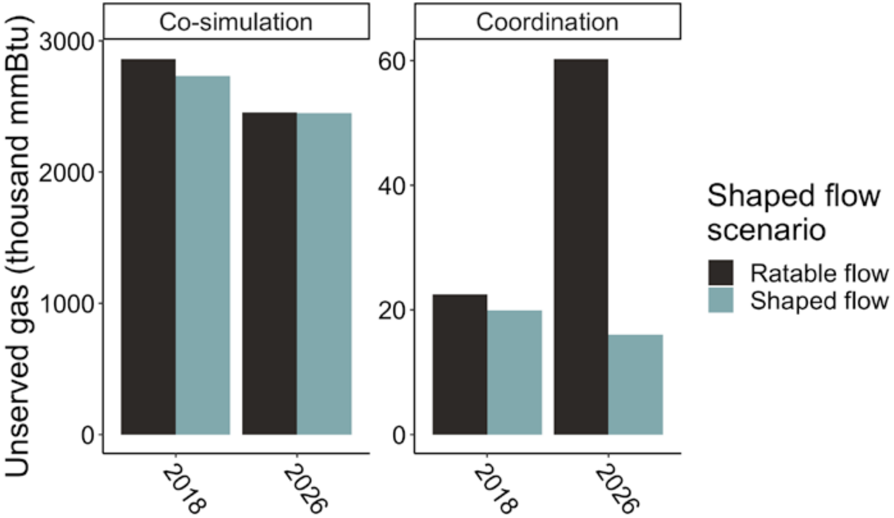


Impacts on unserved gas

Total unserved natural gas by week for the co-simulation and coordination scenarios (based on ratable flows)



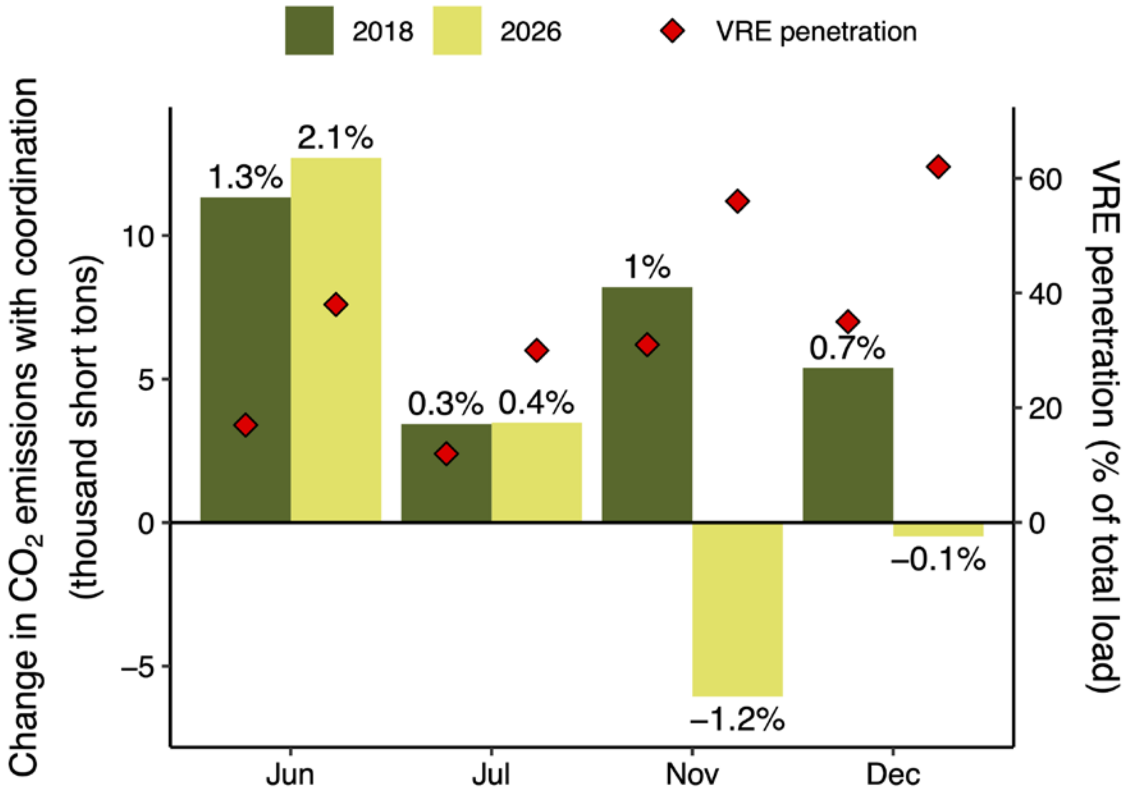
Total unserved natural gas using constant flows at the DA and ID market levels (ratable) and using hourly gas offtakes from generators (shaped flow)



- Redispatch of the power sector based on constraints from the gas model (coordination) serves to reduce unserved gas by upwards of 97% relative to co-simulation.

- Shape flow gas nominations reduce curtailed gas offtakes when compared with ratable gas nominations

Effect on CO2 emissions



Conclusions from the CO case study

- Coordination greatly reduces the amount of curtailed gas generation without substantial cost increases, particularly in high electricity demand time periods.
- The introduction of coordinated intra-day markets (as proposed by FERC Order 809) reduces unserved natural gas by almost 97% relative to uncoordinated operations for the Colorado system.
- The unavailability of gas for power generation can be caused by different factors; in periods of high electricity demand it may be driven by total delivery constraints, whereas in periods with high ramping requirements, it may be a function of constraints at the natural gas compressors.
- Moving from constant (ratable) flow to nominations that can vary by hour (shaped flow) in the day-ahead market can reduce curtailed gas offtakes, particularly for systems with larger penetrations of renewable generation.

Expanded co-simulation via HELICS

The **Hierarchical Engine for Large-scale Infrastructure Co-Simulation** (HELICS) is an open-source cyber-physical-energy co-simulation framework for energy systems

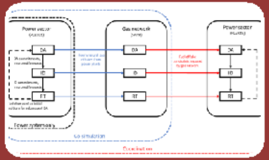
Developed with DOE support through the GMLC

HELICS v2.6 is available on GitHub: https://github.com/GMLC-TDC/HELICS

- Scalable from 2 simulators on laptop to 100k+ on HPC
- Supports Python, C, C++, C#, Java, Julia, MATLAB, FMI, etc.
- Cross-platform: Linux, Windows, OSX

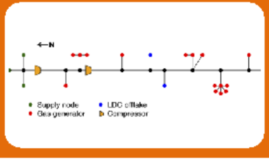
More information, demos, and docs at: https://www.helics.org/

Objectives of the HELICS+ natural gas use case



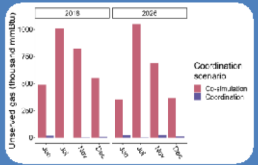
Create a common interface

- Establish framework for gas-grid simulations (e.g. what parameters need to be communicated? When is a simulation converged?)
- Done in collaboration between ANL, NREL, and corresponding industry partners



Develop and validate HELICS bindings

- NREL: SAInt (gas, grid)
  - Validate by comparing HELICS-based co-simulation with SAInt's integrated gas/grid tool
- ANL: NGTransient (gas), MATPOWER MOST (grid)



Open-source use case

- Both NREL and ANL will develop open-source use cases for their respective gas/grid simulation tools (including HELICS bindings and some example data sets)

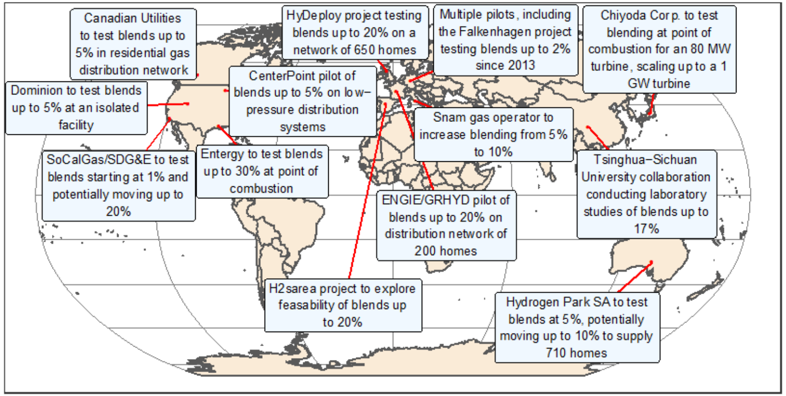
Advanced use cases

- NREL: implications of gas/grid coordination for high variable renewable energy systems
- ANL: co-optimization of gas and grid operations for New England

Modeling hydrogen blending

Multiple projects at the lab related to studying hydrogen blending in existing natural gas pipeline networks

- Technology Commercialization Fund
- DOE HyBlend project



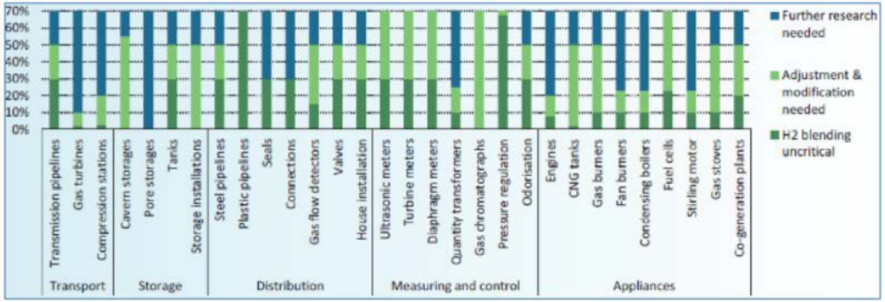
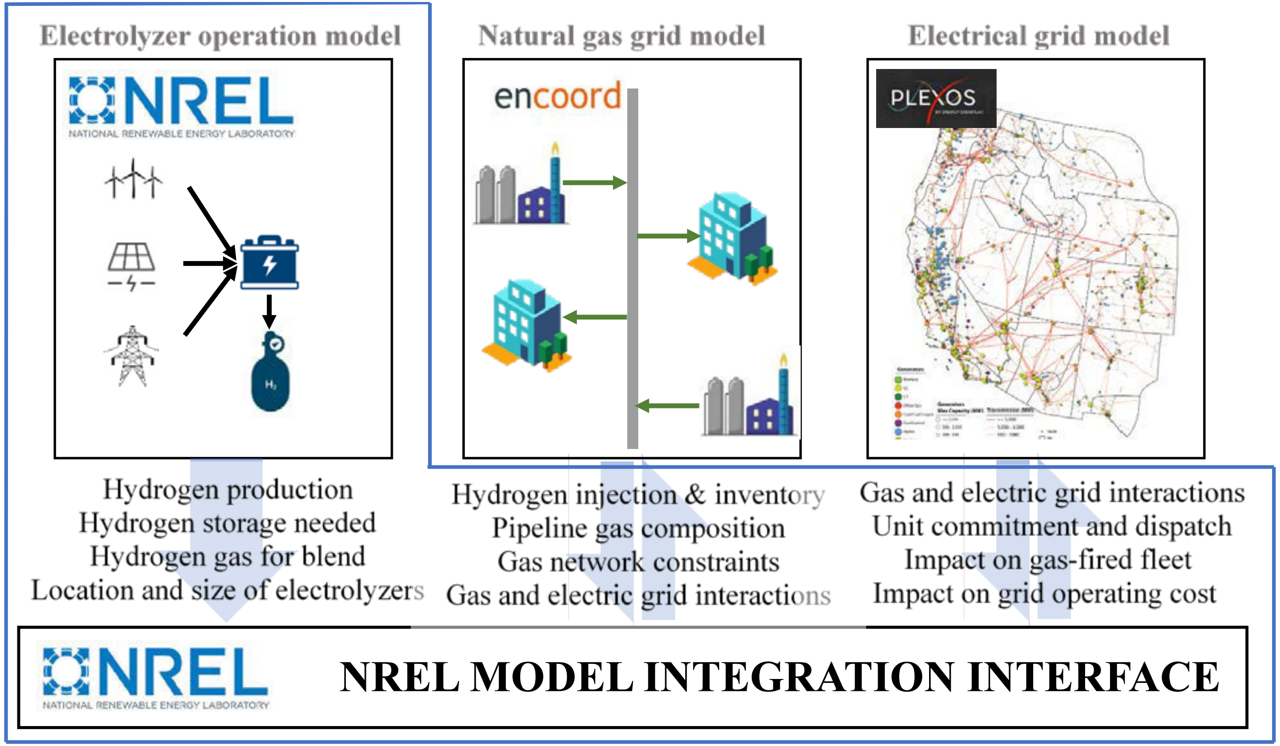


Figure 5 Limitations on the blend share of hydrogen by application – the most important applications to the blend share are gas turbines, compressing stations and CNG tanks. (PG&E R&D and Innovation, 2018)

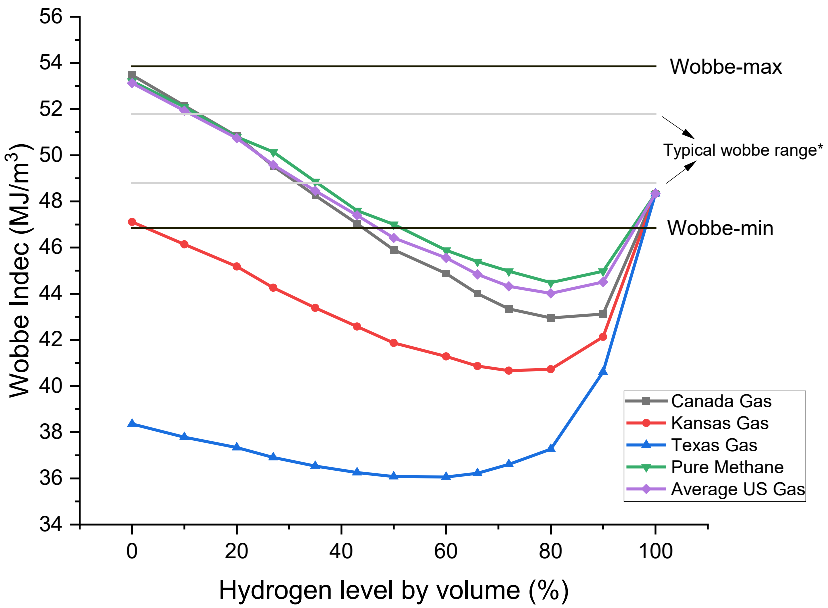
Source: "PG&E Gas R&D and Innovation Whitepaper: Pipeline Hydrogen", 2018

Technoeconomic assessment of blending

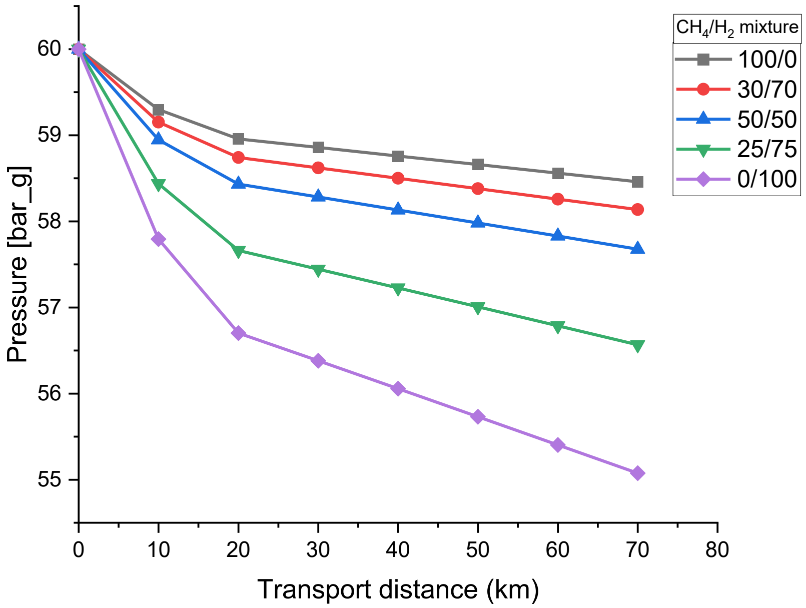


Items in the blue box will be developed under the TCF

Blending impacts on energy content / pressure

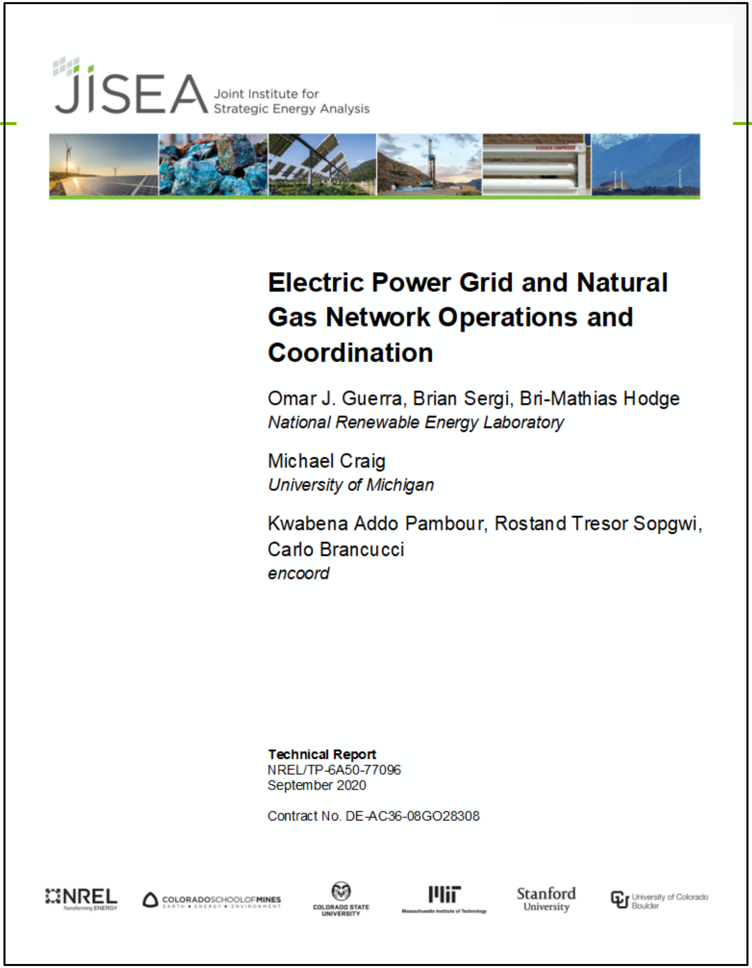


Typical wobbe ranges in US. Wobbe max and Wobbe min values are calculated +/- 4 % based on Wobbe range limits
Sources: Gas Technology Institute, [CRE Interchangeability Shell .PDF]



For more information

Full report of the CO case study and coordination framework available at https://www.nrel.gov/docs/fy20osti/77096.pdf



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Questions?

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