NATURAL GAS *brief*

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Are gas and renewables good for each other, or are they on a collision course? We explored this question using a multi-player, web-based game.

Gas-fired generation in a high-renewables world

By Mark C. Thurber

Low prices for natural gas, thanks mainly to advances in unconventional gas extraction, have made gas-fired power plants the mainstay of electricity supply in the United States and the preferred choice for new dispatchable generation. At the same time, strong government incentives are pushing substantial amounts of new wind and solar onto the grid. California, for example, has adopted renewable energy targets that call for 50% of the state's electricity consumption to be supplied from renewable sources by 2030.

Are gas and renewables good for each other, or are they on a collision course? We explored this question using a multi-player, web-based game we developed at the Program on Energy and Sustainable Development (PESD) at Stanford University. On two separate occasions, we engaged sophisticated participants in games where they played the roles of generating companies ▸

ABOUT THE AUTHOR

Mark C. Thurber is associate director of the Program on Energy and Sustainable Development (PESD) at Stanford University. He uses the web-based game discussed in this brief to teach about energy and environmental markets in a course at Stanford Graduate School of Business as well as in workshops for policymakers and regulators. (Single- and multi-player versions of the game are freely available at energymarketgame.org.)

Dr. Thurber co-edited and wrote multiple chapters of two books on international energy markets: *The Global Coal Market: Supplying the Major Fuel for Emerging Economies* (Cambridge University Press, 2015) and *Oil and Governance: State-owned Enterprises and the World Energy Supply* (Cambridge University Press, 2012). He has written articles and papers about how government policy shapes the value chains for oil and natural gas.

Dr. Thurber also helps oversee PESD's work on business models for distributed solar generation in sub-Saharan Africa. He has previous experience working in high-tech industry, including several years at a manufacturing plant in Mexico. He holds a Ph.D. from Stanford University and a B.S.E. from Princeton University.

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in electricity markets with high renewable energy shares. A first pair of games was conducted at a meeting of Western U.S. policymakers and regulators in San Diego in August 2017, and a second pair of games was run in March 2018 in a course at Stanford Graduate School of Business. The first group of participants was knowledgeable about electricity markets because of their regulatory experience, while the graduate students in the second group had been learning about electricity markets for the previous two months of the academic quarter. This Natural Gas Brief describes insights from the games these groups played.

NATURAL GAS AND RENEWABLES: COMPETING OR COMPLEMENTARY (OR BOTH)?

Operationally, gas and renewables complement each other well. Gas-fired power plants, especially cheap-to-build, open-cycle gas turbines (also known as gas "peakers"), are easy to turn on and off as sun and wind fluctuate. As the shares of solar and wind on the grid grow larger, this property of gas units will be needed more and more.

Economically, the situation is more complicated. At present, gas-fired power plants are most frequently the units that set electricity prices in U.S. electricity markets. For this reason, low gas prices have meant low wholesale electricity prices. Low wholesale electricity prices mean wind and solar costs have to be that much lower for these renewables to be economically competitive.

As the shares of wind and solar increase, an even larger effect on prices may come from wind and solar themselves. Because wind and solar have essentially zero marginal cost, more wind and solar means more periods of very low wholesale electricity prices. When there is enough renewable energy to meet all electricity demand in a given period, wholesale electricity prices will go to zero—or possibly even negative. This reflects the fact that adding more solar units, say, adds no value when solar already meets all of daytime demand (nor does it help boost generation at night or on cloudy days, when solar isn't available). In the case of California, overgeneration conditions during the day might mean paying neighboring states to take California's excess solar energy.

The effect of growing intermittent renewable capacity on wholesale electricity prices could also challenge the economic model of gas-fired units. Especially for a large, highly-efficient natural gas unit that has higher fixed costs, like a combined-cycle gas turbine (CCGT), this increasing frequency of periods where price is below the unit's cost of operation (its marginal cost) may mean it no longer operates enough to be financially viable. (This economic issue will be even more severe for coal or nuclear power plants, which have substantially higher fixed costs than CCGTs.) If the regulator wants such units to remain available to back up renewables, it may have to find an additional way to compensate them.

No one knows for sure what will happen to the mix of thermal units in a very-high-renewables world, as no major electricity grids have yet gotten anywhere close to even 50% generation by intermittent renewables. (Denmark gets over 40% of its power from intermittent renewables, mainly wind, but it benefits from the ample hydro resources in the Nordic countries, which can help balance renewable resources.) PESD's Energy Market Game can help explore how gas-fired generators might fare in the short-term electricity market when the share of intermittent renewables reaches very high levels. By allowing entry and exit of generators, the game lets players try out different strategic responses to robust growth in renewable generation.

One insight from our game is that very high renewable shares don't have to be the death knell for the financial viability of gas-fired generation in the short-term market. However, a high-renewables world is likely to imply a significant increase in wholesale electricity price volatility—and a ▶

corresponding shift in the mix of gas-fired generators away from highly-efficient baseload plants and toward less-efficient, higher-emitting gas peakers.

CAN'T WE JUST USE BATTERY STORAGE INSTEAD OF GAS FOR BACKING UP RENEWABLES?

Before we discuss the effect of high wind and solar shares on gas generation economics, we should address the basic question of whether we still need natural gas to back up renewables in the first place. Some environmental groups argue that batteries can manage renewable intermittency instead, charging up whenever renewable generation is high and discharging when wind and sun are less available.

A full comparison of the current economics of storage versus gas-fired units for backing up renewables is beyond the scope of this brief, but two points are worth noting. First, the business models for storage and generation are very different, so a direct cost comparison is misleading. Generators make money when the average electricity price they receive for generating exceeds their average cost. Storage units make money when the average price difference between when they discharge and when they charge exceeds their average cost. As such, storage units depend on price volatility to be financially viable. Jurisdictions like California that try to limit electricity price volatility, for example through the use of offer caps, may struggle to bring enough storage units into the market to adequately manage renewable intermittency, even with storage receiving non-market payments through storage mandates.

Second, battery storage is an extremely costly way to manage the often significant seasonal variation in renewable output. In California, for example, wind output at its summer peak is roughly three times the value at its winter low. Solar output is also substantially lower in winter. Dealing with this timescale of renewable variation will likely require fundamentally different technology solutions such as the generation of synthetic natural gas or hydrogen to use as a long-term energy storage medium. Long-term energy storage is much further from being economic than short-term storage.

In short, while electricity storage is absolutely going to play an important role in a high-renewables world, declarations that gas-fired power is no longer needed for backing up renewables are almost certainly premature.

EXPLORING HIGH-RENEWABLE SCENARIOS WITH THE ENERGY MARKET GAME

To explore the specific question of how the gas generation mix might change in a high-renewables world, we created a special version of the Energy Market Game in which specified quantities of intermittent wind and solar generation are introduced into the market. Specifically, the expected renewable energy fraction (split evenly between wind and solar) was increased from 0% to 20% to 40% to 60% over the course of four stylized "days." Each day consisted of four hours with different expected electricity demand and wind and solar resources in each hour. Actual wind and solar varied randomly around the forecast value, just as in the real world.

Each of four generating company ("genco") teams started off with simple portfolios of three gas-fired power plants: one baseload unit, one intermediate unit, and one peaker unit. The baseload unit had high fixed costs and low variable costs, the peaker unit had low fixed costs and high variable costs, and the intermediate unit had both fixed and variable costs in the middle of the range. Before each of ▶

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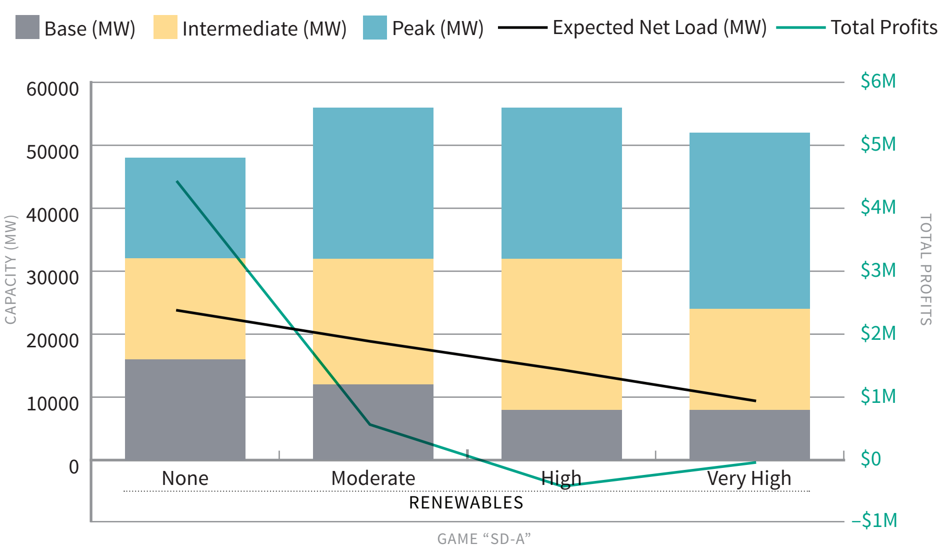
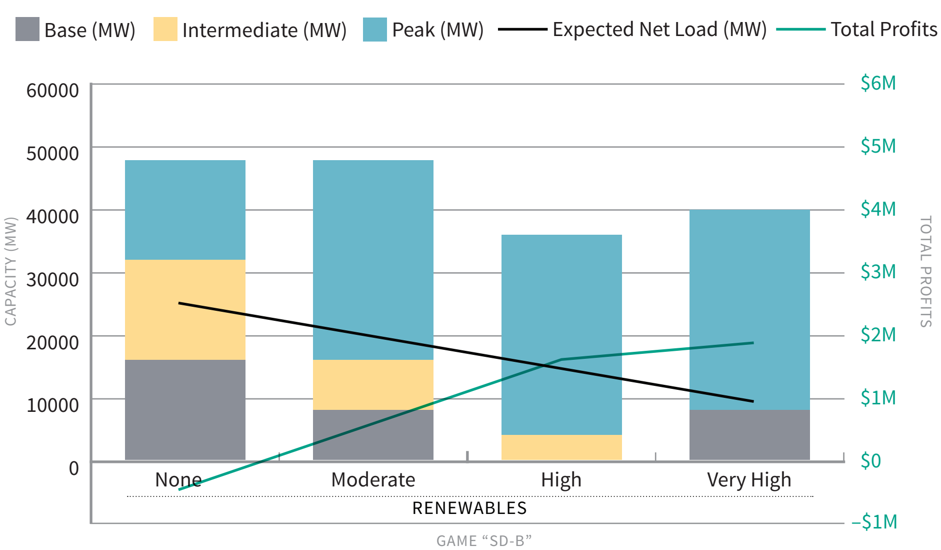
the first three days, each genco could decide to retire any plants it held or acquire any number of new baseload, intermediate, and/or peaker plants, with these retirements or acquisitions coming into effect after a one-day delay. Purchasing a plant required paying the amortized per-period fixed cost of constructing the plant. Each time the plant was operated there was also a variable cost of producing electricity.

Figure 1

Evolution of gas-fired generation capacity (blue = peak, yellow = intermediate, gray = base) as renewables are increased (left axis) and the sum of profits for all generation units in the market (right axis) in games "SD-A" (top chart) and "SD-B" (bottom chart). The black line is expected net load (electricity demand minus renewable output) to be served by gas-fired generation in each day if wind and solar resources are as forecast. (Note: Total profits are unexpectedly low in first day of Game "SD-B" due to questionable bidding strategy by one genco that lowered electricity prices.)





INCREASING RENEWABLES AND THE FINANCIAL VIABILITY OF GAS-FIRED CAPACITY

The top chart in Figure 1 (game "SD-A") illustrates the dynamic that generating companies are concerned about. As renewables increased, the total profits of all of the natural gas units in the system plummeted. (Each renewable unit has an expected daily output of 800 MWh, and in these game runs the renewables were split equally between wind and solar.) The reason was that the zero-marginal-cost renewables displaced higher-marginal-cost gas-fired generators that would have been needed in their absence. This meant a lower-marginal-cost gas-fired unit ended up setting the electricity price at a lower level, so those units that did run were paid less. In the very high renewables day, in which renewables were forecast to generate approximately 60% of the day's electricity, the total amount of wind plus solar generation actually exceeded demand in the 10am hour, and the electricity price went negative. (In these games, we modeled the availability of unlimited "negawatts" that could be paid $25/MWh to reduce any excess demand.)

If the above scenario were the norm, the portfolios of natural gas units would not be able to cover their fixed costs, and they would go out of business in the absence of other means of financial support. However, the bottom chart in ▶

Figure 1 shows that this does not have to be the case. The genco teams in game "SD-B," which had the exact same wind and solar realizations as game "SD-A," collectively reduced gas-fired capacity by almost 20%. They also shifted their generation mix away from baseload plants and toward peakers. In other words, the gas-fired units that remained by the time the highest renewable period rolled around were fewer in number and, on average, had higher marginal cost. As a result, electricity prices stayed higher, and the power plants that remained had positive profits (i.e., they were able to more than cover fixed costs) even in the high renewables days. (Note that the negative profits in Day 1 of this game were an anomaly; one of the gencos unwisely bid below marginal cost, losing a lot of money and pushing down electricity prices for everyone.)

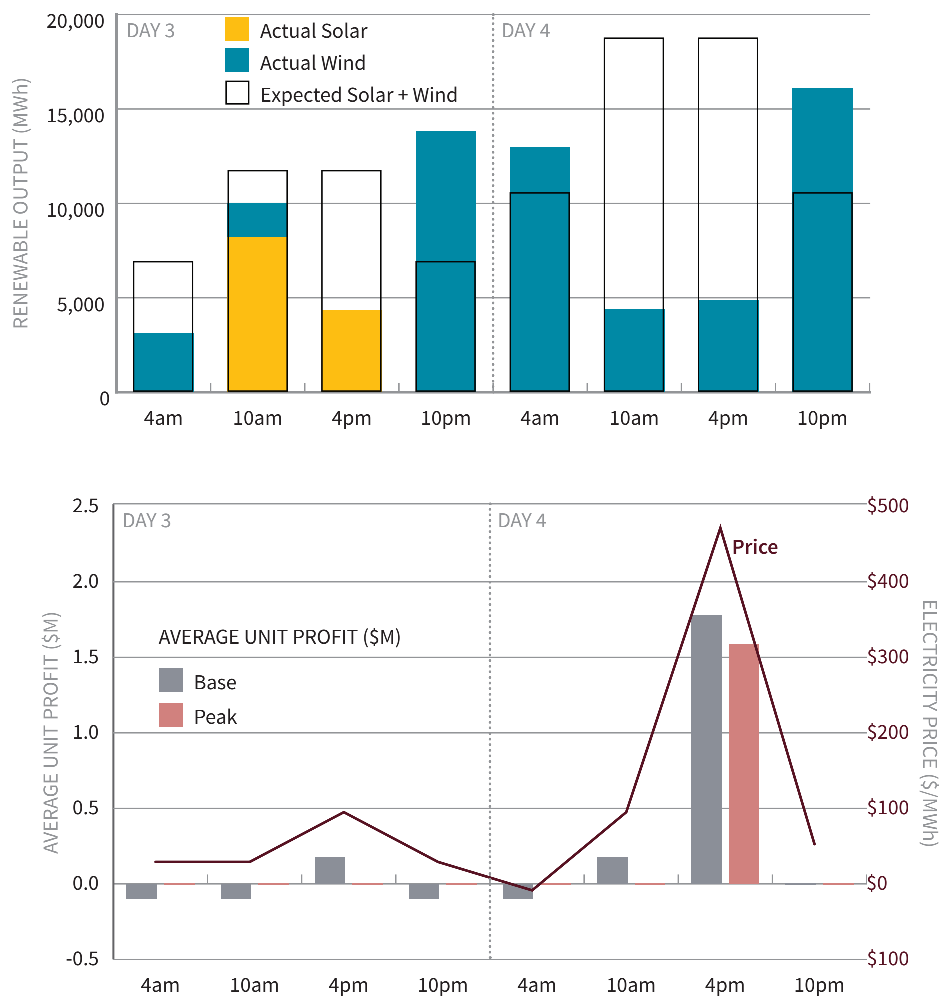
ADVANTAGES OF GAS PEAKERS IN A HIGH-RENEWABLES WORLD

The two games we played at the Stanford Graduate School of Business even more clearly illustrated the advantage to generating companies of shrinking overall thermal capacity and shifting the generation mix toward lower-fixed-cost gas peakers in a high-renewables world. Normally in California, we expect wind and solar to complement each other somewhat during the day, and the expected values of wind and solar in the game reflect this. As shown in the top chart in Figure 2, this pattern held to some degree in Day 3 of game "GSB-B," with solar compensating to an extent for low daytime wind. Day 4, however, turned out to be cloudy, with no solar at all. Wind was robust, but without the expected solar, the need for electricity from the gas-fired units soared during the day, especially in the peak 4pm period.

The final day's capacity mix in this game was 5 peakers, 1 intermediate plant, and 2 baseload units (vs 4 peakers, 4 intermediate plants, and 4 baseload units at the start). The peaker plants bid high in anticipation of possible low renewable supply, and the strategy paid off, pushing the electricity price up to $490/MWh, just below the $500/MWh offer cap. As shown in the bottom chart in Figure 2, which compares peaker and baseload profits in each ▶

Figure 2

Top: Solar (yellow) and wind (blue) output vs. expected output for Days 3 and 4 of "GSB-B" game. Bottom: Average unit profits (left axis) for base units (gray) and peak units (light red) and electricity prices (deep red, shown on right axis) for Days 3 and 4 of "GSB-B" game.

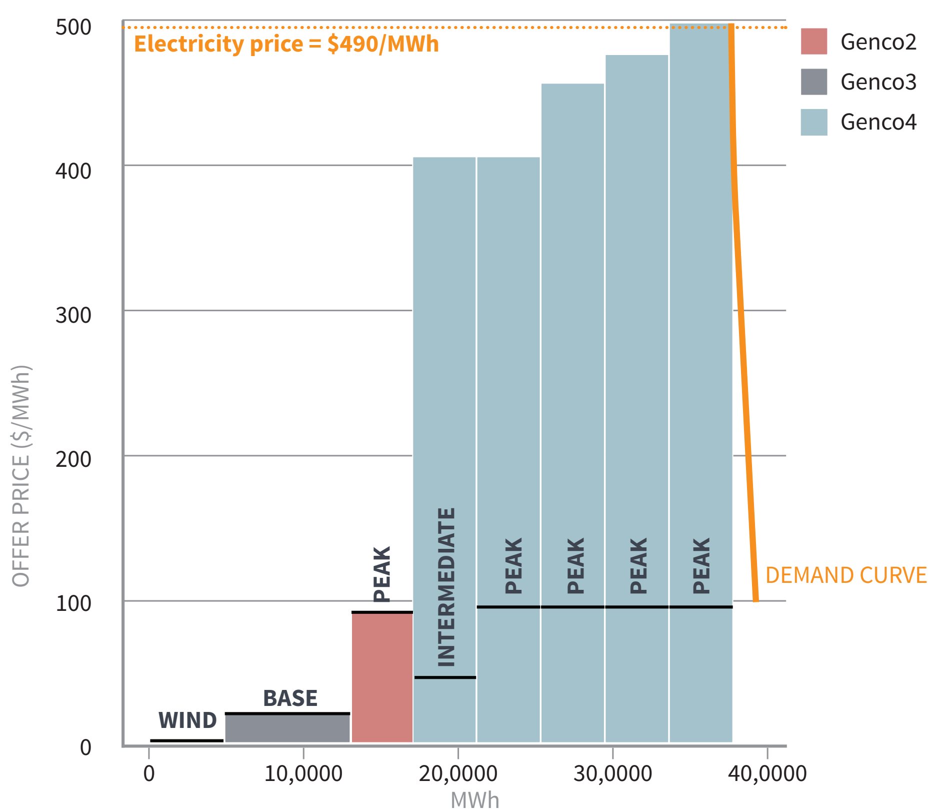


hour of the two days, this led to strong profits for all gas-fired plants. In that high-priced hour, the base unit made more money than the peak unit because of its lower marginal cost (from higher efficiency). If prices hadn't been so high at 4pm on Day 4, however, the baseload unit would not have been financially viable overall. The baseload unit made money (gray bars above the zero line) running in three of the eight hours of the two days and lost substantial money (gray bars below the zero line) in the four hours when it didn't run due to its high fixed costs. (In the 10pm hour of Day 4, the baseload unit ran and broke even, with revenues exactly covering variable plus fixed costs.) The peak unit, on the other hand, with its very low fixed costs (barely visible on the chart), can wait and be available for the low-renewable periods without incurring substantial cost penalties from not running. The earnings of the peakers from the 4pm hour on Day 4 made back their low fixed costs many times over.

Very high renewable shares mean many periods of very low wholesale prices, but they also mean a non-negligible number of periods with low renewable output and very high prices, especially if overall dispatchable capacity has contracted. Peakers are better suited economically to operate in this environment than high-fixed-cost baseload plants. Much of the time, the capacity of peakers will go unused, but when their capacity is needed, it likely indicates there are a limited number of other units that can supply the required power. This allows the peakers to bid high prices into the wholesale power market and still be accepted. (And if they are not accepted, there is limited downside due to their low fixed costs.)

Figure 3 shows this dynamic in action. The "Genco4" team shifted its portfolio heavily toward peakers in preparation for high renewable shares. The team bid high in case of low renewable supply, and when the expected solar output did not materialize at 4pm of Day 4, their high bids were accepted, pushing the electricity price to $490/MWh. This was the only hour these peak units ran in the last two days, but the revenues they made from the high electricity price were enough to cover the fixed costs of these units for many, many hours of not running. "Genco4" made over $8 million in this one low-solar hour, more ▸

Figure 3
Offer curve for 4pm hour of Day 4 of "GSB-B" game.



MARKET PRICE $490.00
SOLAR 0% of expected
WIND 138% of expected
note: black line shows marginal cost

than $4 million more than the next closest team. This example illustrates how the short-term market can provide incentives for low-fixed-cost power plants to stay around in a high-renewables world, as long as wholesale electricity prices are allowed to fluctuate to reflect real-time supply and demand conditions.

THE FUTURE OF GAS GENERATION IN A HIGH-RENEWABLES WORLD

Over the long term, the overall share of natural gas generation seems likely to decline as the share of renewable energy increases, but natural gas is likely to retain an important role for some time to come. Moreover, as illustrated by the games described in this brief, gas-fired generation has the potential to be economically viable. Assuming regulators do not artificially constrain price volatility or force capacity to remain on-line, a high-renewables world will be a world with many low-price periods—but also some high-price ones when renewable resources are not available. Gas peakers are well-suited operationally to filling in during these periods, and their low fixed costs mean that they can build a financially viable business model around such periodic high prices.

There is one notable downside to peakers. Because these units are less efficient, greenhouse gas emissions per unit of electricity output are higher than for baseload units. Therefore, a shift toward peakers would imply an increase in the average emissions rate of the gas-fired generation fleet.

As the game demonstrates, generation companies will face the challenge of rebalancing—and possibly shrinking—their thermal power portfolios over time to adapt to a high-renewables world. Companies with existing gas portfolios with relatively low fixed costs are at a significant advantage. All these adjustments will have to take place in real-world markets where environmental policies sometimes work at cross purposes to each other and where stakeholder processes may create hurdles for new fossil fuel facilities of any kind. On the other hand, it is possible that policymaking will become more pragmatic when it becomes evident how difficult and costly it could be to integrate shares of intermittent renewables of 50% and above. ▲

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THE NATURAL GAS INITIATIVE AT STANFORD

Major advances in natural gas production and growth of natural gas resources and infrastructure globally have fundamentally changed the energy outlook in the United States and much of the world. These changes have impacted U.S. and global energy markets, and influenced decisions about energy systems and the use of natural gas, coal, and other fuels. This natural gas revolution has led to beneficial outcomes, like falling U.S. carbon dioxide emissions as a result of coal to gas fuel switching in electrical generation, opportunities for lower-cost energy, rejuvenated manufacturing, and environmental benefits worldwide, but has also raised concerns about global energy, the world economy, and the environment.

The Natural Gas Initiative (NGI) at Stanford brings together the university's scientists, engineers, and social scientists to advance research, discussion, and understanding of natural gas. The initiative spans from the development of natural gas resources to the ultimate uses of natural gas, and includes focus on the environmental, climate, and social impacts of natural gas use and development, as well as work on energy markets, commercial structures, and policies that influence choices about natural gas.

The objective of the Stanford Natural Gas Initiative is to ensure that natural gas is developed and used in ways that are economically, environmentally, and socially optimal. In the context of Stanford's innovative and entrepreneurial culture, the initiative supports, improves, and extends the university's ongoing efforts related to energy and the environment.

Join NGI

The Stanford Natural Gas Initiative develops relationships with other organizations to ensure that the work of the university's researchers is focused on important problems and has immediate impact. Organizations that are interested in supporting the initiative and cooperating with Stanford University in this area are invited to join the corporate affiliates program of the Natural Gas Initiative or contact us to discuss other ways to become involved. More information about NGI is available at ngi.stanford.edu or by contacting the managing director of the initiative, Bradley Ritts, at ritts@stanford.edu.