Shale-gas Wells as Virtual Storage for Supporting Intermittent Renewables

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Abstract

Mature shale-gas wells possess a property that enables cyclic production and shut-in without incurring revenue losses. Based on this property, we suggest that fields with mature shale-gas wells may act as virtual gas storage for supplying fast-ramping gas power plants which balance intermittent renewable generation. By enabling gas supply to power plants to circumvent intermediate third-party storage, we argue that the proposed integration facilitates demand-driven gas production, and discuss how the scheme may support utilization of renewables and reduce supply-related greenhouse-gas emissions in electricity generation.

Keywords:
Shale gas; Renewables; Gas infrastructure; Energy Efficiency; Climate-change mitigation;

Generation of electricity and heat is the single largest emission source with a 25% share of all global greenhouse-gas (GHG) emissions [1]. Reducing these emissions is imperative to mitigate climate change and will require a shift away from combustion of fossil fuels. Central to the transition from carbon-intensive to renewable electricity generation is the role of natural gas [2, 3], an issue particularly reinforced by the abundance of gas originating from shale-gas exploitation. Even though the economic viability [4] and environmental sustainability of shale gas is disputed [5, 6], an unequivocal result of the U.S. shale-gas revolution is vast fields of mature shale-gas wells combined with massive pipeline infrastructures.

There is a growing conception that in the short to medium term, technology, markets and policies should develop and adapt in a way that promotes the use of gas-fired generation to complement, but not displace renewables [7, 8, 9, 10]. Yet, beyond the price-driven coal-to-gas substitution for baseload electricity generation, there is limited exploration of the extent to which shale-gas production and supply can be tightly integrated with electricity production. We argue that existing fields with mature shale-gas wells have an unexplored potential for integration with renewable energy sources, which reduce the need for gas storage and thereby reduce overall GHG emissions linked to natural gas-fired electricity generation.

1 Current gas-storage practice

Scalable energy storage or fast-ramping electricity generation are necessary for viable intermittent solar and wind electricity production. For future reliable low-carbon electricity generation, ramping sources should eventually become renewable, or the need for them should be eliminated through grid technologies. However, on a short to medium term, natural gas is likely to be the preferred option for ramping generation to support renewables [3, 8], except in regions that are blessed with access to hydro power.

Natural gas cannot be stored in large quantities on-site by power plants and thus requires on-demand pipeline supply. The majority of this gas supply, particularly for peaking power plants, is provided by third-party marketers or local distribution companies (LDCs) which employ underground storage to hedge variations in gas demand and supply [11, 12]. While this practice provides a flexible gas-supply service for end-users, it has some inherent energy inefficiencies. Both gas injection into storage facilities and withdrawal comes at an energy and economic cost due to the required use of compressors to pressurize injected gas, and for pipeline transportation to and from storage facilities. An estimated 25% of methane emissions in the U.S. gas transportation and storage sector is related to gas pressurization, processing, and unintended venting from underground storage facilities [13]. An extreme example of the latter is the Aliso Canyon rupture in California with massive methane emissions [14]. Further, fuel for natural-gas transport and storage accounts for more than 24% of the overall CO_2 emissions from producer to the delivery-gate of end-user [15]. Consequently, minimizing the extent and need for storage and long-distance transportation lowers natural-gas related GHG emissions significantly.

While marketers with underground storage adapts inventory levels and supply to varying gas demands, natural-gas producers adhere to the philosophy that curtailing production implies loss of revenues, and therefore persistently produce wells at their maximum capacities. As a consequence of the shale revolution, the U.S. gas market has been flooded with cheap gas. If this continues and spreads globally, natural gas may prolong the fossil era by limiting growth in low-carbon energy generation rather than enabling a smooth transition to a low-carbon energy regime [16, 17]. One approach to mitigate this problem is to enable gas producers to curtail and adjust production to the dynamic nature of renewable generation without loss of revenues.

2 Proxies for gas storage

Shale-gas extraction has two properties that should be pursued to improve the integration with gas-fired electricity generation and support intermittent renewables. First, mature shale-gas wells have the unique ability to quickly recover from loss of production due to a well shut-in [18]. The characteristic underground system of low-permeable shale matrix-blocks interconnected by high-conductivity fracture networks from the hydraulic fracturing stimulation ensures fast formation pressure build-up during well shut-ins. This pressure build-up causes a subsequent peak in production, which recovers the loss of production during shut-in. In other words, a closed shale-gas well will quickly recover the production loss after reopening its production valve. This property is in stark contrast to conventional gas fields where production losses are recovered in some distant future, thereby incurring large revenue losses due to depreciation.

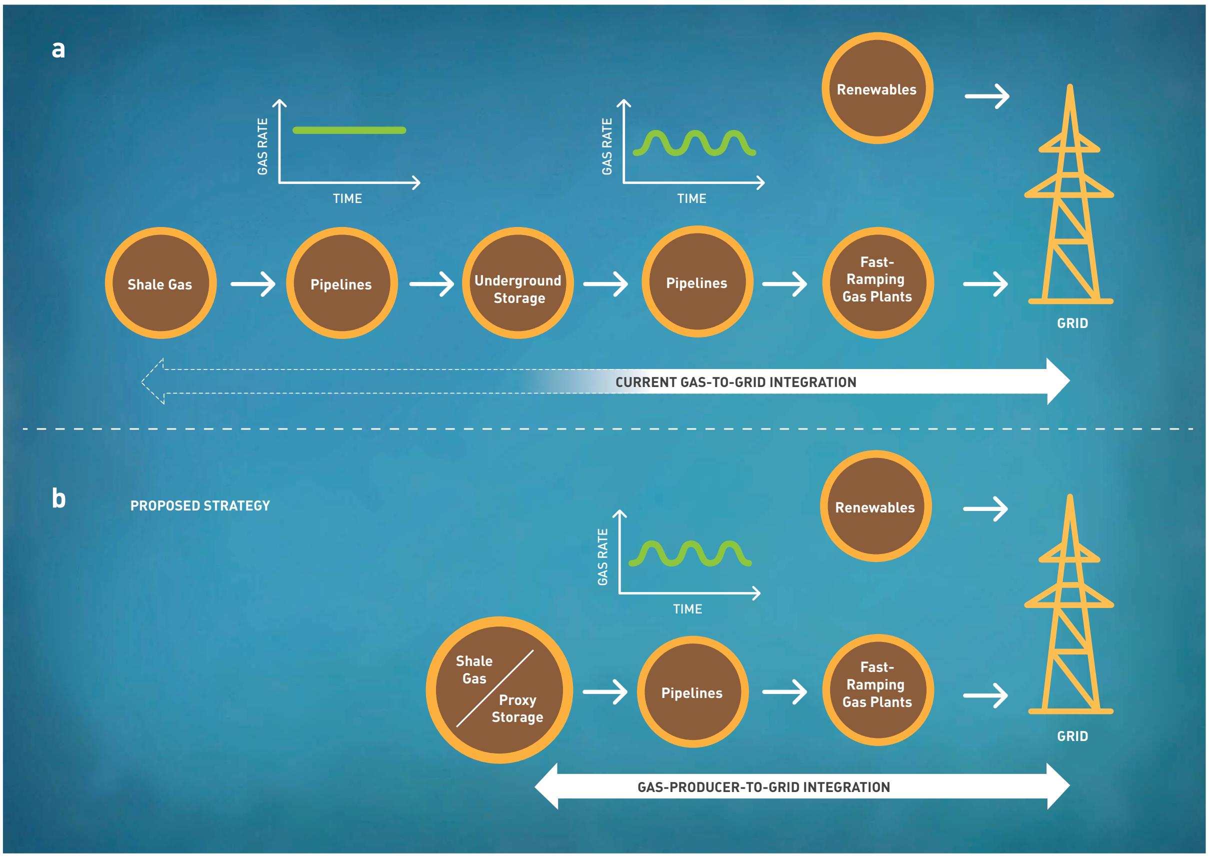

Figure 1: (**a**) Varying natural-gas demand from fast-ramping power plants is currently supported by underground gas-storage facilities. This leaves shale-gas producers as static gas suppliers who flood the market with inexpensive gas, a practice which may delay penetration and full utilization of renewables. (**b**) Mature shale-gas wells can, however, be used as proxies (or substitutes) for underground storage, as they can be closed and re-opened without loss of operator profit. Consequently, shale-gas supply may circumvent third-party storage and supply fast-ramping gas power plants directly. This strategy reduces gas-supply related GHG emissions by avoiding intermediate storage, enables operators to leave gas underground until needed, and thereby facilitates utilization of renewables.

In addition, the distributed, land-based nature of shale-gas exploitation leaves many fields in immediate proximity to natural-gas power plants and gas-intensive industries. In a regional context, shale gas can hence facilitate short-distance gas transportation from producer to end-user, thereby reducing gas transportation needs, and as a consequence lowering compressor fuel-combustion and leakage-related GHG emissions.

By systematically optimizing shut-ins of mature shale-gas wells, always ensuring that a sufficient number of wells are closed so as to meet varying demand from fast-ramping gas power plants, the wells can be re-opened at the desired times to provide quick ramping supply. This property, together with the proximity property, enables utilization of mature shale-gas wells with sufficient connecting pipeline capacity as a proxy for conventional, local gas storage, as illustrated in Figure 1. While mature shale-gas wells are able to provide shut-ins on multiple time scales [18, 19], the proposed proxy or virtual-storage scheme is best suited for providing ramp-up supply on an hourly or daily basis. The ability to provide gas during fast load changes will naturally also depend on the distance to the power plant, as well as how early operators are notified of load changes.

3 A future energy scenario

Shutting in wells with the purpose of leaving gas underground until needed requires a complete mindset shift for operators. It relies not only on confidence that production is not lost, but also that the new production paradigm pays off. The latter is indeed possible, since the proposed strategy removes the cost associated with third-party storage. Thus, increased shale-gas operator flexibility enables both higher supply-side pricing as well as lower gas purchasing costs for power-system operators. This again may result in lower end-user electricity prices, as the gas fuel cost has a large effect on the price of electricity generated from gas turbines [20].

A possible mechanism to value operator flexibility and commitment to supply fast-ramping power plants is an ancillary gas service-market, similar to the services provided by ramping generators in electricity generation [21]. Such a service and valuation mechanism would commit shale-gas operators to deliver specific volumes of gas on a short notice. The pricing would depend on the required response time and volumes to be delivered, as well as a transportation cost to a shipper. Markets for ramping products are currently being explored for electricity generation [22], however, they are still in their infancy and they remain to be developed for ramping of gas production. In the absence of sufficient market incentives and valuation, energy policies may be adapted to reward operators that commit to intermittent, per-demand production that is 'locked' to gas power-plant supply.

A successful transition from current practice to the proposed gas-electricity integration scheme requires addressing and overcoming both market, policy and infrastructure challenges. As shale-gas fields are developed with high-capacity pipeline infrastructure to handle the initial well rates, the necessary connecting pipeline infrastructure to the gas transportation network is largely in place. Still, the regional pipeline capacity is currently scarce and constrained near certain demand centers in the U.S. [23], an issue that poses challenges for the proposed scheme. Policymakers should seek to ease commissioning of pipeline expansion in order to alleviate these current capacity constraints.

Contracts for transportation services should change to facilitate the increasing volatility and flexibility in gas demand and supply our proposal requires. While the demand for firm transportation services is increasing [24], this service needs to be priced at a level closer to interruptible services in order to warrant a supply service to power plants that is both affordable and secure. Consequently, policymakers may need to modify the regulatory contract framework to support pipeline capacity allocation for direct supply from producer to power plants. Authorities and regulators should also encourage an alignment of the current mismatch in scheduling of gas and electricity markets, in order to reduce costs and improve the integration of these interdependent markets [24, 21]. We further note that an increasing use of onsite Liquid Natural Gas (LNG) storage would decrease the need for our proposed approach. Yet, however, the use of this gas-supply alternative is limited [23]. Moreover, even though the proposed scheme does not reduce cumulative shale-well production, higher penetration of renewables may eventually reduce gas-based electricity generation and hence the revenue streams for shale-gas operators.

4 Conclusions and implications

Peak and countercyclic generation of renewables may require relatively large volumes of gas within short time-frames, and therefore high-deliverability storage, which presently means salt caverns and aquifers. While this 'peak-storage' is crucial for reliable gas-fired electricity generation, its capacity is currently insufficient near several key demand centers [23]. The proposed virtual-storage strategy will increase overall gas-storage capacity and thereby improve generation reliability. Thus, it may promote penetration of renewables in areas where there are gas-fired power plants and shale gas but a lack of gas-storage capacity.

An efficient and sustainable integration of shale-gas supply with renewables requires a large, yet viable shift in the industry practice, as well as improved transparency to overcome the industry's environmental issues, particularly the problems related to methane leakages during gas production [25, 26]. Shale-gas supply that circumvents intermediate storage increases energy efficiency between source and power plant, and reduces storage-related GHG emissions. Decreasing the use of underground gas storage also reduces the risk of major gas leaks as experienced during the Aliso Canyon blowout [27]. Moreover, by requiring shale-gas producers to adapt their production dynamically to ramping of gas-fired power plants, the variations in renewable generation and market electricity demands will directly affect gas production. A potential consequence of this is increased utilization of renewables, at the expense of gas-fired electricity generation. We therefore encourage policy makers to ensure that the right incentives are in place to enable shale gas to support rather than to compete with renewable generation.

References

[1] Edenhofer, O. et. al, "Technical summary," in *IPCC Climate Change 2014: Mitigation of Climate Change* (Edenhofer, O. et. al, ed.), Cambridge University Press, 2014.

[2] IEA, "Are We Entering a Golden Age of Gas?: World Energy Outlook Special Report ," tech. rep., International Energy Agency, 2011.

[3] E. Moniz, H. Jacoby, and A. Meggs, "The Future of Natural Gas," tech. rep., MIT Energy Initiative, 2011.

[4] J. D. Hughes, "Energy: A reality check on the shale revolution.," *Nature*, vol. 494, pp. 307–8, Feb. 2013.

[5] R. W. Howart, A. Ingraffea, and T. Engelder, "Should fracking stop?," *Nature*, vol. 477, pp. 271–275, 2011.

[6] D. Hou, J. Luo, and A. Al-Tabbaa, "Shale gas can be a double-edged sword for climate change," *Nature Climate Change*, vol. 2, no. 6, pp. 385–387, 2012.

[7] S. J. Davis and C. Shearer, "A crack in the natural-gas bridge," *Nature*, vol. 514, pp. 436–437, 2014.

[8] J. Channel, T. Lam, and P. S. Shahriar, "Shale & Renewables: A Symbiotic Relationship," tech. rep., Citi Research, 2012.

[9] A. Q. Gilbert and B. K. Sovacool, "Better modelling for the energy mix," *Nature*, vol. 515, no. 7526, p. 198, 2014.

[10] S. Jenner and A. J. Lamadrid, "Shale gas vs. coal: Policy implications from environmental impact comparisons of shale gas, conventional gas, and coal on air, water, and land in the United States," *Energy Policy*, vol. 53, pp. 442–453, 2013.

[11] FERC, "Energy Primer - A Handbook of Energy Market Basics," tech. rep., The U.S. Federal Energy Regulatory Commission, 2012.

[12] "Quadrennial Energy Review: Energy Transmission, Storage, and Distribution Infrastructure, Appendix B: Natural Gas," tech. rep., U.S. Department of Energy, 2015.

[13] D. J. Zimmerle, L. L. Williams, T. L. Vaughn, C. Quinn, R. Subramanian, G. P. Duggan, B. Willson, J. D. Opsomer, A. J. Marchese, D. M. Martinez, and A. L. Robinson, "Methane emissions from the natural gas transmission and storage system in the United States," *Environmental Science & Technology*, vol. 49, no. 15, pp. 9374–9383, 2015.

[14] S. Conley, G. Franco, I. Faloona, D. R. Blake, J. Peischl, and T. B. Ryerson, "Methane emissions from the 2015 Aliso Canyon blowout in Los Angeles, CA," *Science*, vol. 351, no. 6279, pp. 1317–1322, 2016.

[15] J. Bradbury, Z. Clement, and A. Down, "Greenhouse Gas Emissions and Fuel Use within the Natural Gas Supply Chain – Sankey Diagram Methodology," tech. rep., Quadrennial Energy Review Analysis: Department of Energy, Office of Energy Policy and Systems Analysis, 2015.

[16] H. McJeon, J. Edmonds, N. Bauer, L. Clarke, B. Fisher, B. P. Flannery, V. Krey, G. Marangoni, R. Mi, K. Riahi, H. Rogner, and M. Tavoni, "Limited impact on decadal-scale climate change from increased use of natural gas," *Nature*, vol. 514, pp. 482–485, 2014.

[17] S. P. A. Brown, S. Gabrial, and R. Egging, "Abundant Shale Gas Resources: Some Implications for Energy Policy," in *Resources for the Future*, pp. 1–46, 2010.

[18] B. R. Knudsen, C. H. Whitson, and B. Foss, "Shale-gas scheduling for natural-gas supply in electric power production," *Energy*, vol. 78, pp. 165–182, 2014.

[19] B. R. Knudsen and B. Foss, "Designing shale-well proxy models for field development and production optimization problems," *Journal of Natural Gas Science and Engineering*, vol. 27, no. 2, pp. 504–514, 2015.

[20] E. Hittinger and R. Lueken, "Is inexpensive natural gas hindering the grid energy storage industry?," *Energy Policy*, vol. 87, pp. 140–152, 2015.

[21] A. Lee, O. Zinaman, and J. Logan, "Opportunities for Synergy Between Natural Gas and Renewable Energy in the Electric Power and Transportation Sectors," tech. rep., National Renewable Energy Laboratory, 2012.

[22] B. Wang and B. F. Hobbs, "A flexible ramping product : Can it help real-time dispatch markets approach the stochastic dispatch ideal?," *Electric Power Systems Research*, vol. 109, pp. 128–140, 2014.

[23] M. Webster and R. Schmalensee, "Growing Concerns, Possible Solutions: The Interdependency of Natural Gas and Electricity Systems," tech. rep., MIT Energy Initiative, Boston MA, USA, 2014.

[24] ISO New England, "CIGRE 2008 Case Study: Electric & Natural Gas Market Interdependencies Within New England," tech. rep., ISO New England Inc., 2008.

[25] D. R. Caulton, P. B. Shepson, R. L. Santoro, J. P. Sparks, R. W. Howarth, A. R. Ingraffea, M. O. L. Cambaliza, C. Sweeney, A. Karion, K. J. Davis, B. H. Stirm, S. A. Montzka, and B. R. Miller, "Toward a better understanding and quantification of methane emissions from shale gas development," *Proceedings of the National Academy of Sciences*, vol. 111, no. 7, pp. 6237–6242, 2014.

[26] D. Zavala-Araiza, D. R. Lyon, R. A. Alvarez, K. J. Davis, R. Harriss, S. C. Herndon, A. Karion, E. A. Kort, B. K. Lamb, X. Lan, A. J. Marchese, S. W. Pacala, A. L. Robinson, P. B. Shepson, C. Sweeney, R. Talbot, A. Townsend-Small, T. I. Yacovitch, D. J. Zimmerle, and S. P. Hamburg, "Reconciling divergent estimates of oil and gas methane emissions," *Proceedings of the National Academy of Sciences*, vol. 112, no. 51, pp. 15597–15602, 2015.

[27] B. R. Knudsen, "Reducing the risk of another Aliso Canyon," *Science*, vol. 353, no. 6302, p. 878, 2016.