JISEA Joint Institute for Strategic Energy Analysis

Opportunities for Clean Energy in Natural Gas Well Operations

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Motivation & Research Question

Global trends: increases in

- Global warming due to increases in atmospheric greenhouse gases (GHGs) [1]
- Demand for energy and petroleum products [1]
- Social and economic pressures to make energy systems cleaner and more sustainable

Oil & gas (O&G) industry-driven questions:

- How can we reduce our operational **costs**?
- How can we improve our operations to reduce operational **emissions**?

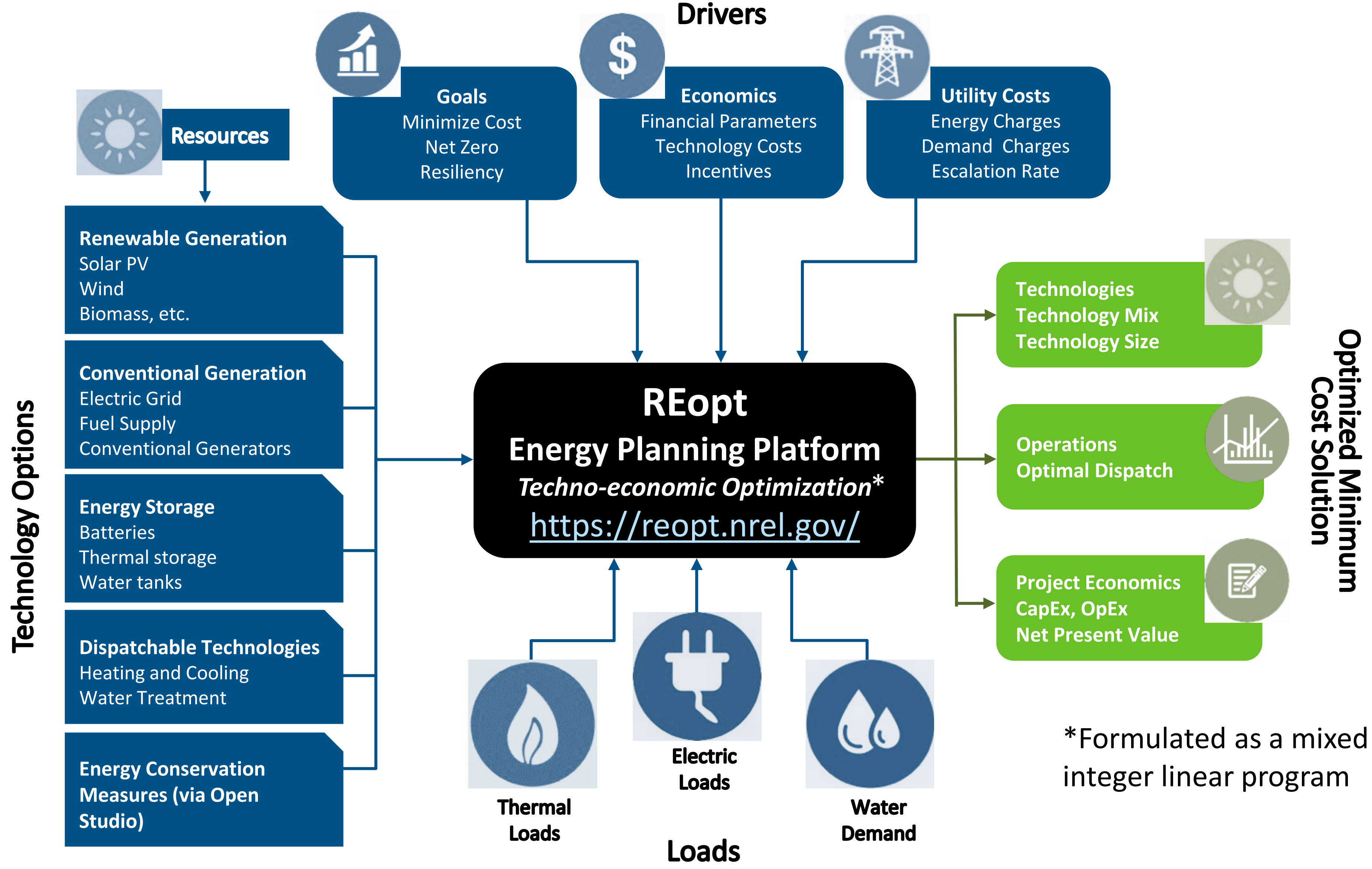
  Currently, O&G industry operations contribute ~9% of global GHGs.[2]

- How can we make our operations more **resilient** to utility grid outages?

Research Question:
How can distributed clean energy generation and storage technologies support energy cost savings, clean energy, and resilience goals at a hypothetical natural gas well site in the Marcellus Shale?

[1] IPCC, "Global Warming of 1.5° C. An IPCC Special Report on the impacts of global warming of 1.5° C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty," Ed: V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield, 2018.
[2] P. Gargett, S. Hall, and J. Kar, "Toward a net-zero future: Decarbonizing upstream oil and gas operations," McKinsey, 2019.

REopt Model Overview



*Formulated as a mixed integer linear program

Case Study Well Site Overview

The case study considers a hypothetical region of 23 electrically-interconnected natural gas wells in the Marcellus Shale of Pennsylvania. Two cases were considered: grid-connected and off-grid wells.

Electric load profile was estimated for three phases of well development and operation [1]

- Analysis focuses on the production phase due to its prolonged duration
- Modeled electric load is assumed flat throughout the year, though in reality electric requirements likely vary over time

Phase	Power [kW]	Duration of Phase	Total Energy Consumption [GWh]
Pad preparation & drilling	436,167	21 days	220
Fracturing	28,957	6 days	4.2
Production	**5,737**	**30-50 years**	**1,505**

Energy costs and emission rates:

	Energy costs	Emission rates
Grid-connected wells	$0.05/kWh plus a monthly demand charge of $4.237/kW [2.3]	756.93 lbCO_2e/MWh [4]
Off-grid wells	$4.832/MMBTU [5]	117 lbCO_2e/MMBTU [6]

[1] D. Moeller and D. Murphy, "Net Energy Analysis of Gas Production from the Marcellus Shale," *BioPhysical Economics and Resource Quality*, vol. 1, no. 5, 2016.
[2] West Penn Power Company, "Supplement No. 60, Electric Pa P.U.C. No. 40 - Electric Service Tariff," Reading, PA, USA, July 1, 2019. Accessed: 2020. [Online]. Available: https://www.firstenergycorp.com/content/dam/customer/Customer%20Choice/Files/PA/tariffs/WPP-Tariff-40-Supp-60.pdf
[3] Pennsylvania Public Utility Commission, "PA Power Switch," Accessed: 2019. [Online]. Available: https://www.papowerswitch.com/
[4] EPA, "Emissions & Generation Resource Integrated Database (eGRID) 2018 v.2," 2020.
[5] EIA, "Annual Energy Outlook 2020," 2020.
[6] EPA, "Greenhouse Gas (GHG) Emissions," Accessed: 2020. [Online]. Available: https://www.epa.gov/ghgemissions

Scenarios Evaluated

The following scenarios were evaluated for both the grid-connected and off-grid case studies:

1. **Cost-optimal sizing**
2. **Emissions reductions targets:** 20%, 40%, 60%, 80%, 100% of emissions from electricity used to power operations (considered Scope 2 emissions for grid-connected wells and Scope 1 emissions for off-grid wells)
   – With net emissions accounting (grid-connected case only)
   – Without net emissions accounting
3. **Resiliency:** surviving major (2-day) and minor (2-hour) grid outages (grid-connected case only)

Results: Cost-Optimal Sizing

For both grid-connected and off-grid wells, the model recommended

- 7.4 MW-DC of solar PV
- No wind or battery storage

to minimize the cost of electricity required to operate the wells.

7.4 MW-DC PV system could provide $0.1M (for grid-connected wells) and $0.5M (for off-grid wells) in net present value (NPV).

Although this is a small percentage of cost savings, the PV system can also support the site's clean energy goals.

	Grid-Connected Wells		Off-Grid Wells	
	Base case	Cost optimal	Base case	Cost optimal
PV capacity [MW-DC]	-	7.4	-	7.4
Wind capacity [MW-AC]	-	-	-	-
Battery energy capacity [MWh]	-	-	-	-
Battery inverter capacity [MW]	-	-	-	-
Natural gas generator capacity [MW]	-	-	5.7	5.7
Total lifecycle costs [$M]	52.5	52.4	66.6	66.1
Net present value [$M]	**-**	**0.1**	**-**	**0.5**

Results: Emissions Reductions – Grid-Connected

The recommended system and cost of grid-connected emissions reductions is significantly impacted by the emissions accounting methodology.

***With* net emissions accounting:**

- Large PV systems that export excess generation to the grid provide the most cost effective route to achieving emissions reductions targets.

***Without* net emissions accounting:**

- Beyond 20% emissions reductions, battery storage and wind turbines are required because this accounting methodology requires the renewable generation to be consumed directly onsite.
- As annual emissions reductions approach 100%, the marginal cost per tCO_2e becomes increasingly expensive due to the high capital costs of battery storage and wind turbines.

	Base case	Cost optimal	Annual % Emissions Reduction - With Net Emissions Accounting					Annual % Emissions Reduction - Without Net Emissions Accounting				
			20%	40%	60%	80%	100%	20%	40%	60%	80%	100%
PV capacity [MW-DC]	-	7.4	10.0	19.9	29.9	39.9	49.9	10.5	13.7	21.8	35.7	63.4
Wind capacity [MW-AC]	-	-	-	-	-	-	-	-	6.0	9.1	10.3	30.5
Battery energy capacity [MWh]	-	-	-	-	-	-	-	-	-	25.5	69.3	282.3
Battery inverter capacity [MW]	-	-	-	-	-	-	-	-	-	3.8	8.5	7.3
Total lifecycle costs [$M]	52.5	52.4	52.7	57.9	65.0	72.7	80.8	52.9	65.4	82.9	107.2	254.4
Net present value [$M]	-	0.1	(0.2)	(5.5)	(12.5)	(20.2)	(28.4)	(0.4)	(12.9)	(30.4)	(54.7)	(201.9)
Annualized cost of emissions reductions [$/$tCO_2e$]	**-**	**(2.1)**	**4.1**	**50.8**	**77.6**	**94.0**	**105.8**	**7.2**	**120.2**	**189.3**	**255.3**	**753.3**

Results: Emissions Reductions – Off-Grid

Similar trends are observed for off-grid emissions reductions as for the grid-connected emissions reductions *without* net emissions accounting.

- Beyond 20% emissions reductions, battery storage and wind turbines are required because this accounting methodology requires the renewable generation to be consumed directly onsite.
- As annual emissions reductions approach 100%, the marginal cost per tCO_2e becomes increasingly expensive due to the high capital costs of battery storage and wind turbines.

Because the modeled natural gas generator produces more carbon emissions per kWh of electricity than the grid:

- **Slightly larger renewables and battery storage capacities are required for the off-grid site than the grid-connected site without net emissions accounting to achieve the same percent decrease in emissions.**
- **However, for the same reason, the cost of emissions reductions per tCO_2e is less expensive for the off-grid site than the grid-connected site.**

	Base case	Cost optimal	Annual % Emissions Reduction				
			20%	40%	60%	80%	100%
PV capacity [MW-DC]	-	7.4	11.1	16.0	22.8	36.4	60.3
Wind capacity [MW-AC]	-	-	-	4.5	8.4	10.1	31.0
Battery energy capacity [MWh]	-	-	-	8.8	29.5	70.1	285.5
Battery inverter capacity [MW]	-	-	-	1.5	4.3	8.6	7.7
Natural gas generator capacity [MW]	5.7	5.7	5.7	5.3	4.7	3.8	-
Total lifecycle costs [$M]	66.6	66.5	68.5	81.0	97.7	120.4	254.4
Net present value [$M]	-	0.1	(1.9)	(14.4)	(31.1)	(53.8)	(187.8)
Annualized cost of emissions reductions [$/$tCO_2e$]	**-**	**-**	**27.1**	**102.5**	**147.0**	**190.8**	**533.3**

Results: Resilience

Solar PV and battery storage could provide resilience against shorter-duration (e.g. 2-hour) outages more cost effectively than purchasing a backup diesel generator for the site. The capital costs for the 11.6 MW-DC PV and 5.7 MW, 14.7 MWh (~3-hr) battery storage are offset by reducing grid purchases during normal operations.

	Major Event (1 day) [1]		Non-Major Event (2 hours) [1]	
	Backup diesel case	RE case	Backup diesel case	RE case
PV capacity [MW-DC]	-	18.2	-	11.6
Wind capacity [MW-AC]	-	-	-	-
Battery energy capacity [MWh]	-	173.8	-	14.7
Battery inverter capacity [MW]	-	5.7	-	5.7
Backup diesel generator capacity [MW]	5.7	-	5.7	-
Total lifecycle costs [$M]	70.4	114.2	70.0	60.9
Net present value [$M]	**(17.9)**	**(61.7)**	**(17.6)**	**(8.5)**

However, for longer-duration (e.g. day-long) outages, the backup diesel provides more cost-effective resilience because the large battery storage capacity required to sustain the load overnight becomes quite costly.

Wind is not being recommended, likely due to a combination of relative capital costs, low wind resource in general, and variability of wind resource leading to low resource during the modeled grid outage.

[1] EIA, "Annual Electric Power Industry Report, Form EIA-861 detailed data files – Final 2018 data," 2019.

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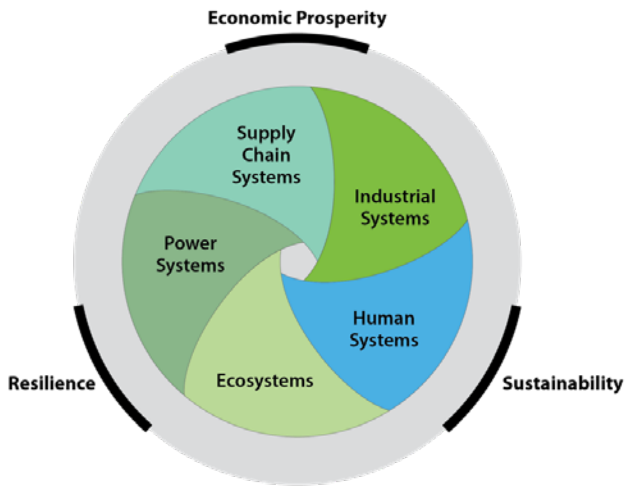
Next Steps

Refinery case study: similar analysis to this natural gas well case study analysis, performed for case study refineries and also incorporating

- Thermal energy technologies: combined heat & power (CHP), landfill gas, biomass, municipal solid waste-to-energy, solar steam for process heat, and an electrolyzer for hydrogen
- Locational sensitivity study

Oil & gas industry consortium: similar analysis as this presentation, using operational data from actual sites, provided by industry partners, instead of publicly available data



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Thank you! Questions?

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