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October 14, 2019

Via Email to: planning@co.coos.or.us

Coos County Planning Department
c/o Planning Director Jill Rolfe
Coos Coimty Courthouse
250 N. Baxter
Coquille, Oregon 97423

Re: Coos County File No. HBCU-19-003/FP-19-003
Concurrent Land Use Applications by Jordan Cove Energy Project L.P.
Multiple Uses Purported to Be Related to LNG Terminal Facility

To Whom It May Concern:

These comments are presented in opposition to the above referenced application. These are only a few reasons the application should be denied. There area few procedural preliminary matters, however.

Process Issues

A. The decision-maker should vacate the planning director's decision deeming the application complete.

The staff report notices several deficiencies which are and should have been deemed fatal to the completeness review. Among other things the applicant failed to provide the geologic assessment required to address Article 5.11. See Staff Report pages 70 and 102. It failed to supply an impact assessment necessary to comply with Policy #5a. See Staff Report pages 35-37.

Moreover, as others have or will point out, the applicant has failed to provide the traffic analysis, an elevation profile and plot plan, documentation from The Tribe related to cultural resources, and often even specific details about the proposed uses, including the meter station, the IWWP, parking and other features regarding the workMan camp.

While the applicant is now in a hurry to get its permits as its representatives stated at the recent hearing, their failure to present the necessary information to obtain a decision before the matter is referred to the hearings office, or at the hearing or even after the hearing prejudices opponents' abilities to review and respond to the evidence and should not be countenanced by the county. The applicant boldly and disrespectfully intends to prejudice opponents and knows that the procedural safeguards in place - like the completeness review - are practically unenforceable on

Exhibit: 6
Date: 10/14/19

review because those prejudiced have to prove a negative - demonstrate what they otherwise might have been able to argue. It is within the authority of the county to enforce fair proceeding rules and it should do so by vacating the department's decision on completeness.

Moreover, proceeding to allow the applicant to submit information specifically and unequivocally required by the LDO after the hearing violates statute, comprehensive plan provisions, state rules and the constitutions related to citizen participation, due process and free speech. The county should not proceed in such a manner.

B. The cumulative effects of the Whole Project must be considered

While the applicant attempts to parse out various aspects of its entire project for separate review, OSCC is correct, "the County should consider the cumulative impacts of the proposed uses together, rather than as separate and unrelated approvals." The hearings officer must find a way to do this and should put the burden on the applicant. And, the list provided by OSCC for such consideration should include the county's decade old permits approving the pipeline throughout the Coastal Management Zone. The hearings officer is well aware of those file numbers.

C. Modifications Must be Denied And Otherwise Approval May Not be Based upon The Prior Proposal's Approval.

The county must apply CCZLDO 5.0.500. To the extent the modifications rely on any aspect of the prior pending application the county shall deem that reliance insufficient as the prior application is defacto revoked. The county's LDO expressly disallows applicants to collect approvals for various and alternative aspects of a project. The code implicitly recognizes the need to view a development and its impacts holistically.

D The power production aspect of the project has not been addressed.

The applicant has been attempting to avoid county and state regulations related to the power it will produce to run the facility, treat the gas and liquify the gas. The applicant continues to do so by its failure to identify such use in this Omnibus 2 application. No permit shall issue until the applicant demonstrates compliance with EFSC and county criteria applicable to its intent to site and use its three steam turbine generators with a nominal capacity greater than 25 MW. See the EFSC litigation comments attached for a summary of what was proposed. The impacts of the production of this power including the steam it will emit must be considered cumulatively to the impacts of the proposed uses presented in this application. In fact, the current application should be denied because it is impossible to do so without knowing what it is the applicant intends to do regarding power production. Said another way, the application is incomplete and should be denied.

Merits Issues.

1. Temporary Uses.

Temporary uses are not allowed unless listed in the applicable CBEMP zone. The applicant's argument that such uses are allowed in every zone in chapter 3 is not objectively reasonable. While the term "special temporary uses" may not appear in the zones, types of temporary uses are listed in some of the zones. And, the applicable LDO specifically states that special temporary uses may be permitted temporarily "as set forth in the Zoning Districts." So, unless the temporary uses are set forth in the zoning districts, they are not allowed without satisfying the further criteria stated in LDO 3.1.400. That has not been satisfied for any of the "temporary uses" the applicant proposes.

Moreover, the county has interpreted its code to require an amendment to every Estuary Zone LDO in order to make its overlay zone criteria applicable. As understood this cumbersome process is a reason the county has failed to impose its hazards overlay criteria. It appears then that the county determination here that a use need not be listed in each zone for it to be authorized is also inconsistent with its prior interpretation of the structure of its code.

2. Gas processing -

Contrary to the applicant's argument, this use will preclude or inhibit water dependent uses of the shoreline. The noise it will create, which is not addressed will, like other uses proposed disturb such uses and the wildlife associated with water-dependent uses. The noise will make the use incompatible with existing and surrounding uses. See articles describing the effects of chronic noise pollution on wildlife.

The application has also not demonstrated compliance with the applicable CBEMP policies. For the reasons stated below, the use is not a water-dependent use. It is not essential to the terminal and the terminal is not a water dependent use. Neither is gas processing water related. Therefore the application does not comply with the policies, including 14, 16, 17 and 18.

The applicant can site a gas processing plant anywhere and pipe the LNG to its terminal which it could even site off shore. All it takes is additional money and a site that is suitable. There is no reason, that the processing needs to be located where the applicant proposes. In fact, it was previously proposed in an industrial zone. While processing may be essential to the project, where it is done has no relationship to water. Do not work backward from the county's typical bias - that this project is essential and therefore whatever makes it less expensive for the applicant is essential. You must determine what is required by the Goal 17 and the state's coastal management act - what is required to protect Coos County's rural shorelands, a valuable resource that has and does merit special considerations.

3. Concrete Batch Plat.

These facilities are highly impacting and emit all manner of pollution. The application fails to demonstrate how that use will not disrupt or cause discord with existing surrounding uses. LDO 4.3.220.6.f.i. The applicant admits that the primary adjacent use is recreational use Just because an adjacent owner supports the project does not mean that the users of the property will not be impacted and in this case, we are talking noise, air and water pollution. See attached guidelines which describe the types of pollution that must be addressed. In addition, the applicant must address how noise from the plant will not effect wildlife as a surrounding use or those human uses related to wildlife that may be impacted.

Neither is this use compatible with the Airport overlay. Its emissions pose a hazard to the use of the airport. And the applicant may not get away with calling the batch plant a mineral processing use and then expect the county to adopt this argument as it relates to the airport zone impact criteria (LDO 4.11.445.4): **"This Application does not include request for authorization of a new or expanded industrial, mining or similar use that as part of its regular operations will cause emissions of smoke, dust or steam that could obscure visibility in airport approach surfaces."** pg 108-019. That is simply not true.

4. The Proposed Uses Are Not Water-dependent and it is not Incidental to Water-dependent Uses.

The application states that many of the applicable criteria are either applicable because of or directly require a determination that the uses are or are incidental to water-dependent uses. While the county has apparently already determined that an export terminal is a water dependent use, the board of commissioners is not bound by any such prior interpretation and should correct itself, given this opportunity. An export terminal is not a water-dependent use and therefore, it and all supportive uses must go through a secondary analysis to be approved.

Under the relevant CBEMP Policy 16 and statewide land use goal 16 water-dependent uses are defined. Neither proposed uses nor the terminal are water-dependent uses. Neither has the applicant demonstrated that the proposed uses are needed for a public use and would satisfy a public need that outweighs harm to navigation, fishing, and recreation.

The LNG terminal - the purported primary use to which the proposed uses support is proposed to exclusively export LNG from Canada to Asia. In contrast and by definition, the uses dependent upon "water borne transportation," however, are limited to uses for transportation (navigation) or import shipments. The transportation of goods category is limited to "water access: ... (ii.) which require the receipt of shipment of goods by water." Neither the state goal, nor the CBEMP policy define water-dependent uses as those requiring water access which require the transport shipments of goods away from port. Thus, export of goods is not included in water-dependent uses.

While a third category of the "water-borne" definition allows terminals, that category, by its terms is limited to terminals or other supports for a transportation use (navigation) or an importation of goods use because only terminals and supports for "water-borne" transportation are permitted: "iii) [Uses] [w]hich are necessary to support water-borne transportation (e.g. moorage fueling, servicing of watercraft, ships, boats, etc. terminal and transfer facilities)." Since the prior two subparagraphs define what "water-borne transportation" is, the third category of uses supporting that use, only allows uses supporting that water-borne transportation which is either a transportation use or an importation of goods use. The express language must be given its "plain, natural and ordinary meaning." *PGE v. Bureau of Labor and Industries*, 317 Or 606, 611 (1993); *Ramirez v. Hawaii T & S Enterprises, Inc.* 179 Or App. 416, 425 (2002). What has been omitted may not be inserted. Or Rev Stat § 174.010.

In defining limits to outright permitted uses in those zones, the secondary criteria - requiring a demonstration of public benefit - apply to export terminals. This is sound policy because importation presumes a need for the goods in Oregon or, at least, a need for them domestically. Exporting has no inferred presumed public benefit. Otherwise, any distributor of goods who wishes to ship them abroad, could claim the right to develop a terminal without further determination of whether that private use is consistent with the resource capabilities and purposes of the management unit; a Canadian company could ship Canadian gas to Asia and reap all the profits and benefits. Moreover, the policy behind this criteria and those similar is designed to avoid unused/stranded assets - a prohibition on superfluous port facilities, docks and piers. The economic reports submitted herewith demonstrate that there is no market for the Canadian product through Oregon and that there is a significant risk that the development will be abandoned. That the applicant continues to dump money into it has no evidentiary value because they fully intend to obtain a 14% guaranteed return on their investment through federal law.

Conclusion

For these and other reasons raised by other opponents, the county should vacate the planning department's completeness determination and otherwise deny the application.

Yours truly,

/s/ Tonia Moro
Tonia Moro

Encl.

Robert F. McCullough, Jr.
Principal

Natural Gas Supplies for the Proposed Jordan Cove LNG Terminal

Robert McCullough
McCullough Research
July 3, 2019

Both documentary evidence and economic theory indicate that natural gas exported from the proposed LNG terminal at Coos Bay will be sourced from British Columbia and Alberta.

Jordan Cove has been an active project since 2006. For its first five years, the project then owned by Fort Chicago and Energy Projects Development was an LNG import facility. As LNG prices rose, Jordan Cove refiled with FERC as an LNG Export facility. Ownership of the project has evolved over time as Fort Chicago changed into Veresen. In 2017, Veresen was acquired by Pembina.

On February 20, 2014, Dan Althoff, the CEO of Veresen, Jordan Cove's corporate parent, was quoted in an article describing the basic structure of supplies to Jordan Cove:

> It provides a bit of diversity to exports. It's the first [U.S.] West Coast facility to be reviewed. It exports Canadian gas, which is pretty positively received in Washington. Some of the petrochemicals industry's concerns and complaints about the Gulf Coast facilities aren't shared on this project, because Jordan Cove pulls gas off existing Canadian infrastructure, from existing fields and pipelines.[1]

Following up Jordan Cove's prospects, Althoff later stated that:

> There are some synergies [between the field and the LNG terminal], because the buyers we're talking to need to find gas and we know where a

[1] How Oregon LNG facilities could be key to exporting Canadian gas to Asia, Yadullah Hussain, Financial Post, February 20, 2014.

> lot of it is," Mr. Althoff said. "We'll connect the dots and we'll support our buyers and we'll support our partners."[2]

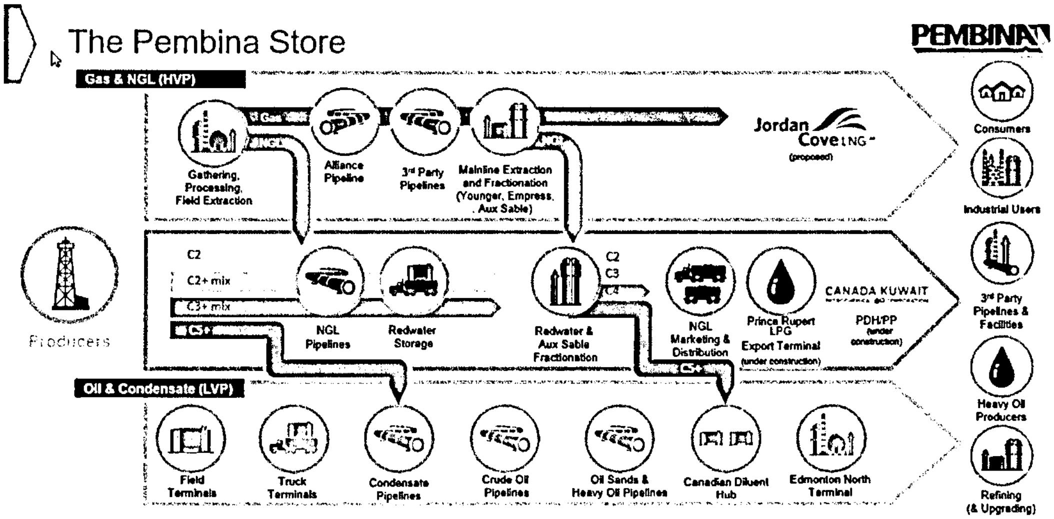
In 2017, Veresen was acquired by Pembina, also based in Alberta. Mick Dilger, Pembina's CEO made clear where Jordan Cove's gas would be coming from:

> Dilger believes Jordan Cove has a higher chance of success under Pembina than it had under Veresen because it has the money to finance it, the expertise to build both the plant and a 400-kilometre pipeline through tough terrain, and the relationships with Western Canadian producers and Asian customers to make it viable.
>
> Some day, Pembina would like to build an LNG facility on the B.C. coast, too, Dilger said, but Jordan Cove has key advantages: it is cheaper to build a pipeline to receive Western Canadian gas from existing networks than build over the Canadian Rockies; its location near larger population centres means there is labour available to build it; and shorter travel time to Asian markets versus the U.S. Gulf Coast means lower transportation costs for its LNG.[3]

Jordan Cove is planned for Coos Bay, Oregon. In order to procure natural gas, a pipeline is planned to connect to supplies at Malin, Oregon. Malin, Oregon connects to Kingsgate, Alberta and Opal, Wyoming. Overall, Coos Bay is over 909 miles from sources of supply in the east and 841 miles from Alberta.[4]

Pembina's financial presentations also indicate that Canada is the primary source of supply since Pembina does not own gathering, processing, or field extraction assets elsewhere:

[2] With Montney assets buy, Veresen eyes building first West Coast LNG facility in Oregon, Geoffrey Morgan, Financial Post, December 23, 2014.
[3] Pembina Pipeline's new purpose: Get Canada's oil and gas to the rest of the world, Claudia Cataneo, Financial Post, February 20, 2018.
[4] The Pacific Connector Gas Pipeline is 229 miles from the Malin hub. The northern terminus of the GTN pipeline is 612 miles away at Kingsgate, Alberta. The eastern terminus of the Ruby pipeline is 680 miles away.



[5]

In the diagram above, taken from a presentation this month to investors, Pembina directly aligns its Jordan Cove investments with their Canadian infrastructure. It is worth noting that the Ruby pipeline, connecting Colorado with the Malin natural gas trading hub, is not mentioned.

I. Background

On September 4, 2007, Jordan Cove LNG was proposed as an import terminal – primarily oriented to meeting domestic U.S. needs from imported natural gas.[6] The Coos Bay location and proposed interconnection to existing natural gas pipelines at Malin, Oregon was as appropriate then as it is inappropriate today. As a general rule, positioning an import terminal near potential loads is a good idea. Positioning an export terminal far from natural gas supplies is a significant disadvantage.

[5] Pembina Pipeline Corporation Corporate Update, June 2019, page 7.
[6] Pacific Connector Gas Pipeline, LP (Docket Nos. CP07-441-000, CP07-442-000, and CP07-443-000) and Jordan Cove Energy Project, L.P. (Docket No. CP07-444-000); Notice of Application for Certificate of Public Convenience and Necessity and Section 3 Authorization, September 19, 2007.

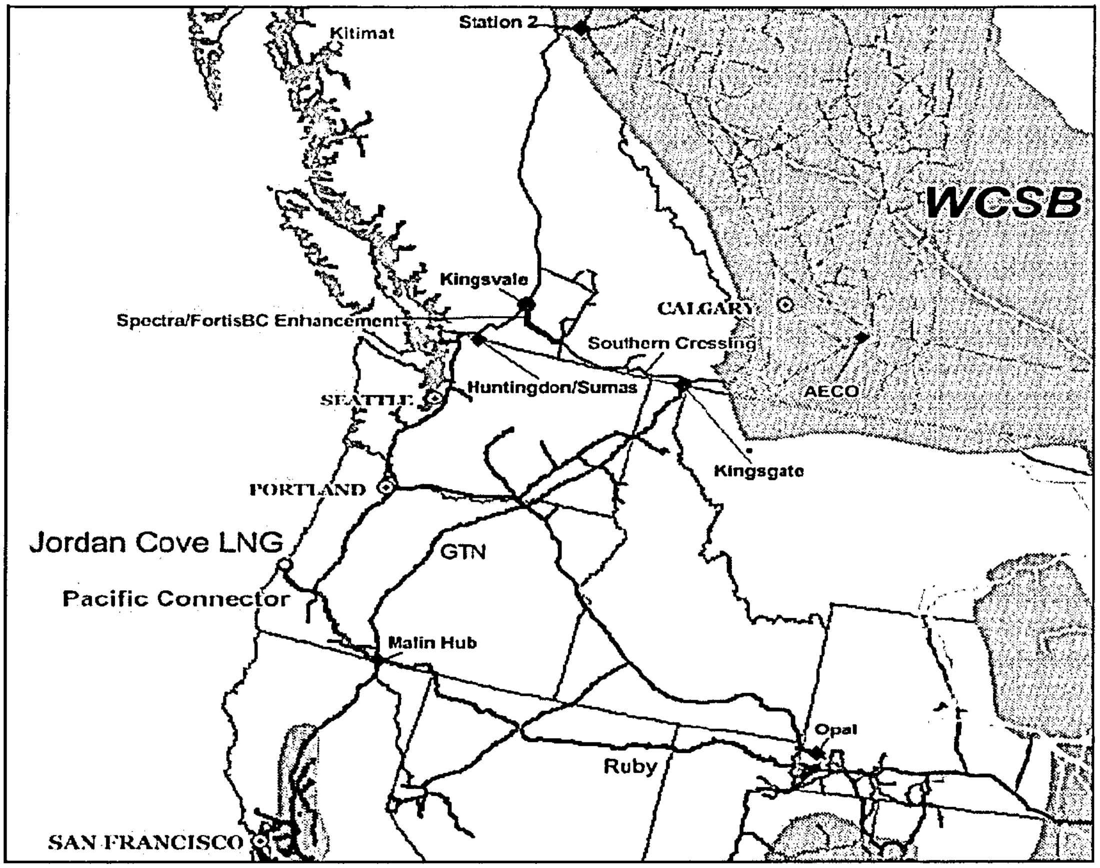


Figure 1: Existing Western North America Pipelines – with Jordan Cove and Pacific Connector[7]

Historically, California natural gas prices are significantly higher than those in Alberta and the Pacific Northwest.[8]

[7] IN THE MATTER OF the National Energy Board Act, RSC 1985, c N-7, as amended; AND IN THE MATTER OF an application by Jordan Cove LNG L.P. for a licence pursuant to section 117 of the National Energy Board Act authorizing the export of gas, September 9, 2013, Appendix A, page 2.
[8] See, for example, Power Market Price Study and Documentation BP-18-FS-BPA-04, July 2017, page 33.

When Pacific natural gas prices were lower than those in the United States, importing LNG at Coos Bay and selling the natural gas into the lucrative California market made economic sense.

This situation did not endure for long. Over the last decade two factors changed the market dramatically:

1. On March 11, 2011, a tidal wave destroyed the nuclear plant at Fukushima Daiichi. Japanese authorities subsequently closed Japan's nuclear fleet and prices spiked dramatically.
2. Technological innovations in the U.S. and Canada revolutionized oil and natural gas production leading to an increasing surplus in North American markets.

Landed LNG prices in Japan, Korea, and China are published daily in the Platts LNG Daily. They are referred to as the JKM index. The major North American trading hub

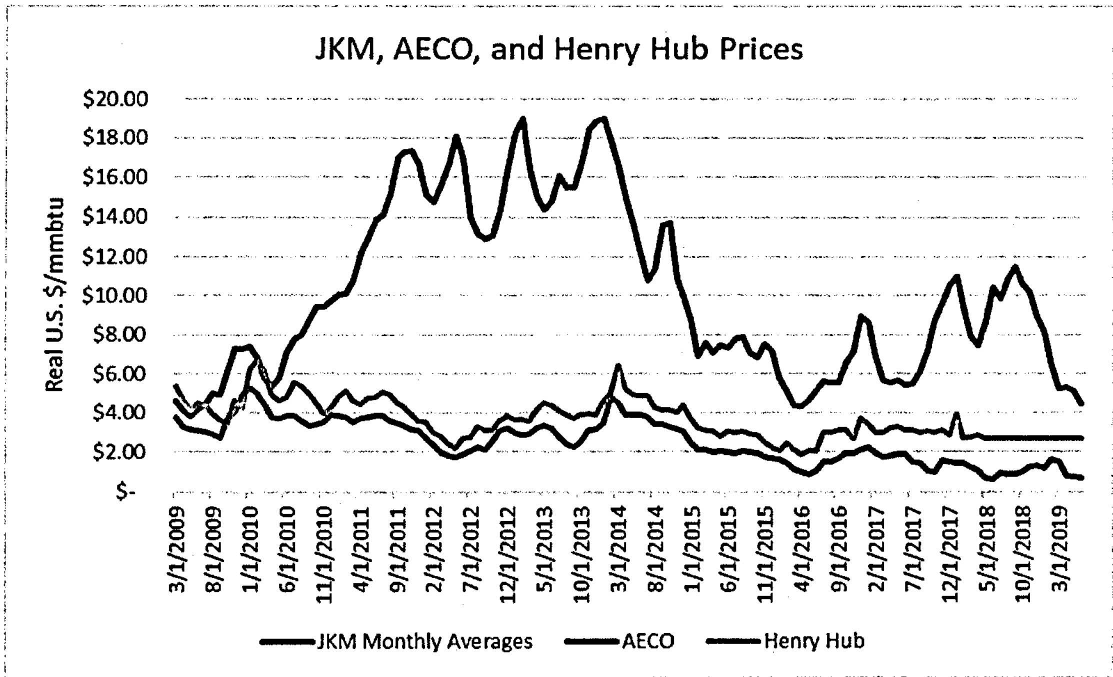
Table 1: Cash Prices at Henry Hub and Basis Differentials (nominal $/MMBtu)

	FY 2018	FY 2019
Henry	3.12	3.00
AECO	-0.89	-0.82
Kingsgate	-0.42	-0.45
Malin	-0.24	-0.24
Opal	-0.31	-0.31
PG&E	0.23	0.23
SoCal City	0.02	0.03
Ehrenberg	-0.15	-0.14
Topock	-0.15	-0.14
San Juan	-0.34	-0.32
Stanfield	-0.32	-0.32
Sumas	-0.41	-0.41

AECO prices are lower than those at Henry Hub in Louisiana – averaging a discount from Henry Hub of $.82/MMBtu.

for natural gas is Henry Hub in Louisiana. Wholesale natural gas prices in Alberta are referred to by the acronym "AECO".

Landed prices in Asia rapidly diverged from those in Alberta and the United States. The following chart shows the dramatic rise in Asian natural gas prices after the Fukushima accident (blue line) and the steady fall in North American natural gas prices in Alberta (red line) and Louisiana (green line):



The prospect of competing with Asian markets for scarce Pacific Rim LNG spelled the end of Jordan Cove's prospects as an LNG importer.

The massive differential between JKM and AECO prices spawned over twenty LNG export terminal proposals – primarily in British Columbia. Two proposals were based in Oregon – one in Astoria and one in Coos Bay.

Japan has gradually restarted its nuclear fleet and other suppliers have stepped in to supply the Pacific Rim. Not surprisingly, JKM prices are falling dramatically with prices today less than half their levels one year ago. At least five of the proposed LNG projects in

British Columbia have cancelled their plans to build LNG export terminals in the province.[9]

At today's JKM price, none of the West Coast LNG export terminals are attractive investments. Only one project, LNG Canada, has received a "Final Investment Decision" and started construction. The economics of Jordan Cove are highly problematic given its high costs and the declining Asian Prices.

On July 2, 2019, the JKM index was $4.625/MMBtu.[10] The breakeven price (the price at which the project would earn zero profits and merely recover its costs) for Jordan Cove is $4.27/MMBtu.[11] The natural gas price at the Malin hub is $1.99/MMBtu.[12] When the cost of transportation to Japan is added in, the cost of Jordan Cove LNG is $7.13/MMBtu. If today's prices would prevail into the future, Jordan Cove would lose $2.50 for every MMBtu shipped.

Scarcity of natural gas pipeline capacity from Alberta has increased the basis differential between Henry Hub and AECO.[13] To the degree that the source and transportation of an LNG export are packaged by Jordan Cove, there is an incentive to access the relatively inexpensive natural gas in Western Canada rather than natural gas from the U.S.

II. Market Hubs and the Structure of Transactions

Natural gas and electricity transactions are commonly organized by hubs – locations where buyers and sellers can make spot and forward purchases. Malin, Oregon is a market hub for both electricity and natural gas. Its development as a hub was largely based on resource and consumption differentials between the Pacific Northwest and California.

The Pacific Northwest is winter peaking, since heating loads tend to occur in cold months. California is a summer peaking region. This difference makes Malin a good location for trading between different buyers and sellers.

[9] Sightline Institute. January 2018. https://www.sightline.org/research_item/maps-british-columbia-lng-proposals/
[10] Platts LNG Daily, July 2, 2019, page 1.
[11] "The Questionable Economics of Jordan Cove LNG Terminal," McCullough Research, June 5, 2019, page 4. http://www.mresearch.com/wp-content/uploads/20190605-Jordan-Cove.pdf
[12] "Easing Heat, Stout Supplies Pressure July NatGas Bidweek Prices; Futures Remain Near Lows," NGI All News Access, July 1, 2019. https://www.naturalgasintel.com/articles/118844-easing-heat-stout-supplies-pressure-july-natgas-bidweek-prices-futures-remain-near-lows
[13] 'Basis differential' is defined as the expected price difference between two hubs.

Unlike larger national gas hubs, Malin has no forward markets traded at the major commodity exchanges. When a forward exchange is absent, long-term transactions must be made with an individual counterparty. This is generally more expensive and less likely to close since the number of counterparties may be quite limited. In language of traders, long-term transactions at the Malin natural gas hub will be over the counter.[14] Price discovery in the absence of forward markets can also be challenging in the same way that buying or selling a vintage car in a small town might be both challenging and poses the risk of paying the wrong price. Generally, such transactions tend to be more successful if you drive to a larger city with more car dealers.

In this case, it means that longer-term transactions will tend to occur at the source of the natural gas where markets are more liquid and there are more counterparties. In this case, the most liquid market for longer-term transactions is AECO in Alberta. Not only are prices generally lower in Alberta than in the Western U.S., Alberta's market is growing very rapidly with recent natural gas discoveries along the Alberta/British Columbia border.

One of the attributes of a market hub is that short term transactions take place at the going price. Regardless of the source the short-term price is the same. Malin's prices tend to reflect the higher prices found in California. As noted above, the decision to connect at Malin was a good choice when the Jordan Cove project was intended to import natural gas for sale to California. The current export proposal is at a disadvantage compared to British Columbia export terminals with a shorter path to low-priced Alberta natural gas.

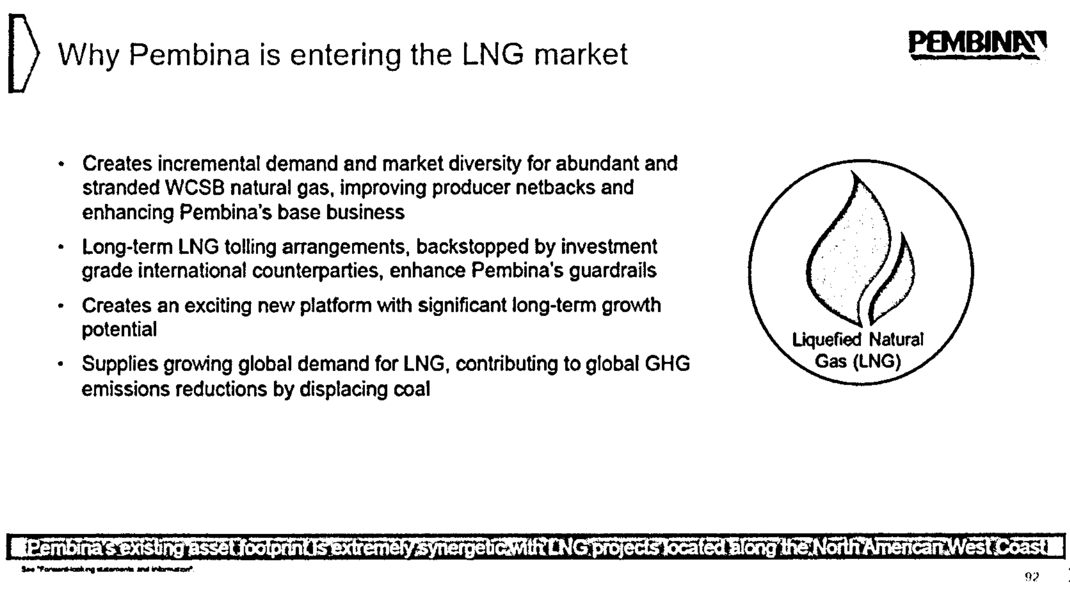
Jordan Cove has frequently referred to its "tolling model," although their presentations often lack precision.[15] In tolling arrangements, the purchaser buys the gas, arranges delivery to the LNG facility, and is responsible for the shipping of the LNG; in theory, Jordan Cove would not be responsible for anything except converting the gas to LNG at their facility. In contrast, the most successful U.S. exporter, Cheniere, offers complete transactions in LNG at their dock. Purchasers do not need to handle natural gas purchasing or transportation issues in the United States.

From Jordan Cove's investor briefings and regulatory filings, it seems very likely that they will be arranging supplies and transportation in fashion similar to Cheniere.

For example, a recent presentation by Jordan Cove states:

[14] 'Over the counter' is a standard term in commodity trading that means that transactions are negotiated directly between counterparties. As a general rule, over the counter transactions are less liquid than those occurring at exchanges like the Chicago Mercantile Exchange or ICE.

[15] See, for example, the discussion of a tolling model for exporters of LNG produced in the USA: LNG Export USA 2014, Guy Dayvault, Veresen, April 30, 2014.



[16,17]

Absent long-term transactions based on Albertan sources, Jordan Cove would not have needed to procure an export license from the Canadian National Energy Board or either an import or export license from the U.S. Office of Fossil Energy. (See section IV, below.) The issue was addressed in Jordan Cove's application for an export license at the NEB. Jordan Cove asked the NEB to exempt them from the standard export reporting requirements. The Board rejected their request:

> The Board has decided to deny Jordan Cove LNG's request for exemption from the Reporting Regulations. The Applicant referred to the competitive disadvantage Jordan Cove LNG would be placed in if other LNG export licence holders were exempted from the reporting requirements with which Jordan Cove LNG is required to comply.
>
> The Board notes that under the Reporting Regulations, Jordan Cove LNG would be reporting exports by pipeline to the U.S., and not LNG exports from the proposed liquefaction facility in Oregon. Reporting on pipeline exports to the U.S. is a well-established practice in which the Reporting Regulations apply to all exporters in a similar manner. The Board reminds Jordan Cove LNG, in any instance where it is acting as an agent, that it is

[16] Pembina Pipeline Company Investor Day. May 14, 2019, page 92.
[17] WCSB stands for the Western Canadian Sedimentary Basin. The WCSB covers eastern British Columbia and almost all of Alberta and Saskatchewan.

> responsible, as the licence holder, for reporting the information prescribed by the Reporting Regulations.[18]

It is clear that Jordan Cove was pursuing a more extensive role than the minimal tolling process described above – it is either exporting Canadian gas it has purchased or, at a minimum, is acting as agent for the purchase of Canadian gas. Moreover, if Jordan Cove was simply helping customers, there would have been little reason to ask for a blanket release from the universal reporting requirements that other exporters must follow.

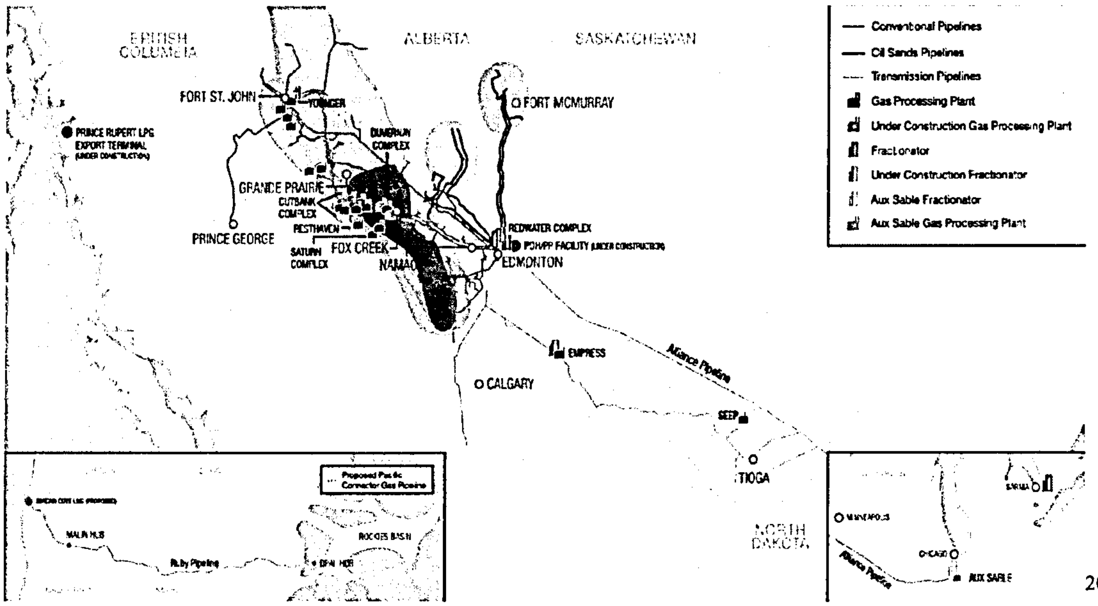
III. Vertical Integration

The Asian markets for North American LNG look highly competitive and volatile. With the first six months of 2019 prices averaging only $5.90/MMBtu, few projects are likely to be considered viable on their own merits. As noted above, a number of Canadian projects, even with export permits already approved, have suspended operations.

Challenging commodity markets often rely on vertical integration to remain profitable. In the same way that independent gasoline stations augment their sales with convenience stores, Jordan Cove has highlighted their integrated Canadian assets as one of the strengths of this project.[19]

A recent investor presentation contained the following graphic of Pembina assets in Western Canada:

[18] LETTER DECISION: "Jordan Cove LNG L.P. (Jordan Cove LNG) 9 September 2013 Application for a Licence to Export Natural Gas pursuant to Section 117 of the National Energy Board Act (NEB Act) National Energy Board (Board) Reasons for Decision," National Energy Board, February 20, 2014, page 9.
[19] Pembina Pipeline Corporation Corporate Update, June 2019, page 7.



[20]

Sources in Colorado are approximately as distant from the Malin hub as the Canadian U.S. border, but Pembina has only one asset in the area. That asset is a minority interest in the Ruby pipeline:

> "Kinder Morgan owns the common interest in and operates Ruby, a 680-mile, 42-inch diameter pipeline system with a capacity 1.5 billion cubic feet per day that extends from Wyoming to Oregon providing natural gas supplies from the major Rocky Mountain basins to consumers in California, Nevada and the Pacific Northwest.
>
> Pembina Pipeline Corporation owns the remaining interest in Ruby in the form of a convertible preferred interest. If Pembina converted its preferred interest into common interest, Kinder Morgan and Pembina would each own a 50 percent common interest in Ruby."[21]

Logically, if Pembina plans to make additional profits through vertical integration, their choice will be to source from Alberta where the majority of their assets are situated.

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[20] Pembina Pipeline Company Investor Day. May 14, 2019, page 15.

[21] https://www.kindermorgan.com/business/gas_pipelines/west/Ruby/ For comparison, TransCanada's GTN pipeline that connects Alberta gas resources to Malin has an operational capacity of up to 2.3 Bcf/day. http://www.tcplus.com/GTN/

IV. Jordan Cove's Import and Export License Applications

Jordan Cove withdrew its FERC application for an LNG import terminal in 2012. Soon afterwards, Jordan Cove applied for a natural gas export license at Canada's National Energy Board, a natural gas import license at the Department of Energy's Office of Fossil Energy, and an LNG export license at the Office of Fossil Energy.

Each of Jordan Cove's license applications – one in Canada and two in the United States – specifically reference the export of Canadian natural gas through the United States via the proposed export terminal at Coos Bay.

Jordan Cove's export permit application at the NEB states:

> 3. The proposed location of Jordan Cove has benefits for Canada, Western Canada's natural gas producers, and Alberta's petrochemical industry. By utilizing existing natural gas transmission systems in Alberta and British Columbia, natural gas supplies for Jordan Cove can be entirely sourced from the Western Canadian Sedimentary Basin ("WCSB"), keeping pipelines and related facilities used and useful, resulting in lower tolls. The petrochemical facilities located at Joffre and Fort Saskatchewan, Alberta, rely on ethane feedstock produced by the extraction plants located on the west-leg of Alberta's natural gas transmission system. Maximizing gas flows through the west-leg delivery system contributes to providing ethane feedstock to Alberta's petrochemical industry. Overall, Jordan Cove will allow for efficient expansion of Canada's natural gas market opportunities.
>
> 4. Use of the existing natural gas pipeline networks of both TransCanada PipeLines and Spectra will help to reduce or eliminate both timing and cost risks associated with new, large-scale, pipeline infrastructure development. With respect to the TransCanada pipeline network, natural gas will be transported on the NOVA Gas Transmission Ltd. system and Foothills Pipe Lines (South B.C.) Ltd. system to the Canada/U.S. border for export at Kingsgate. With respect to gas transportation by Spectra, gas supplies will be gathered and transported on Spectra's BC system through to Kingsvale where, under a proposed common rate structure with FortisBC, supplies will be transported to the Canada/U.S. border for export at Kingsgate. Gas volumes could also flow on the Spectra system to the Canada/U.S. border for export at Sumas, with subsequent swap, exchange or transportation to Jordan Cove.

> 5. For gas exported at Kingsgate, gas supplies will be transported on the Gas Transmission Northwest system ("GTN") to the Malin Hub, located near Malin, Oregon. From the Malin Hub, gas supplies will be transported by the proposed Pacific Connector Gas Pipeline ("Pacific Connector") to Jordan Cove. All existing pipeline routes, as well as the location of Jordan Cove and the Pacific Connector are shown on Figure 1.[22]

Not surprisingly, Jordan Cove's contemporaneous permit application at the DOE's Office of Fossil Energy makes the same statement:

> Import Points: Gas is proposed to be imported at two points on the Canada/United States border. Primarily, gas will cross the border near Kingsgate, British Columbia/Eastport, Idaho (Kingsgate/Eastport) having been transported in Canada on the existing natural gas pipeline networks of both TransCanada PipeLines (using the NOVA Gas Transmission Ltd. And Foothills Pipe Lines (South B.C.) Ltd. Systems) and Spectra (using its BC system to Kingsvale and from there the Spectra/FortisBC Enhancement). This imported gas will then be transported on the existing Gas Transmission Northwest system (GTN) to the Malin Hub, where there will be an interconnection with PCGP, the only new pipeline facility to be constructed in connection with the Project. Alternatively, gas may flow on the Spectra system to the Canada/U.S. border for export near Huntingdon, British Columbia/Sumas, Washington (Huntingdon/Sumas), where it will be transported on Williams' Northwest Pipeline for physical flow, swaps or exchanges to PCGP.[23]

Finally, Jordan Cove's application for an LNG export license reiterates the same basic statement that the exports will be sourced from Canada:

> It is important to note that, especially in its initial years, Jordan Cove exports will draw significantly on Canadian as opposed to U.S. natural gas supplies.[...] The Navigant Study notes that the British Columbia Ministry of Energy and Mines and the National Energy Board of Canada have recently estimated the marketable gas in place in the Horn River Basin alone to be between 61 and 96 Tcf, with total gas in place estimated at 372 Tcf. The other major shale basin in British Columbia, the Montney, has been estimated to contain 65 Tcf of recoverable resources.[...] Other recent esti-

[22] Application by Jordan Cove LNG L.P. for a licence pursuant to section 117 of the National Energy Board Act authorizing the export of gas Appendix A, Veresen, pages 1 and 2.

[23] APPLICATION FOR LONG-TERM AUTHORIZATION TO IMPORT NATURAL GAS FROM CANADA, Jordan Cove LNG L.P., October 21, 2013, pages 7 and 8.

> mates of these resources are even higher[...] and, depending upon which estimate, point to a resource base with a reserve life of 350 to 1,000 years based upon current total demand in British Columbia of one Bcf of gas per day.[24]

V. Conclusion

From the inception of Jordan Cove's reversal from an import terminal to an export terminal, management at Veresen and Pembina have tied the project to Alberta natural gas supplies. This is also reflected in the export and import license applications in the United States and Canada.

In terms of economics, this makes good sense. Prices in Alberta are significantly less than those at the Opal hub in Wyoming.[25] This also utilizes Pembina's other natural gas assets which are primarily situated in Alberta. A profit maximizing entrepreneur would seek the benefits from vertical integration as well as the lowest supply costs.

[24] Application of Jordan Cove Energy Project, L.P. for Long-Term Authorization to Export Liquefied Natural Gas to Non-Free Trade Agreement Nations, FE Docket No. 12-32-LNG, March 23, 2012, pages 11 and 12.
[25] See footnote 8, above, for example.

Foreign or Domestic?

The source of the natural gas that will be processed at the proposed Jordan Cove LNG facility

Prepared for Niskanen Center

July 2, 2019

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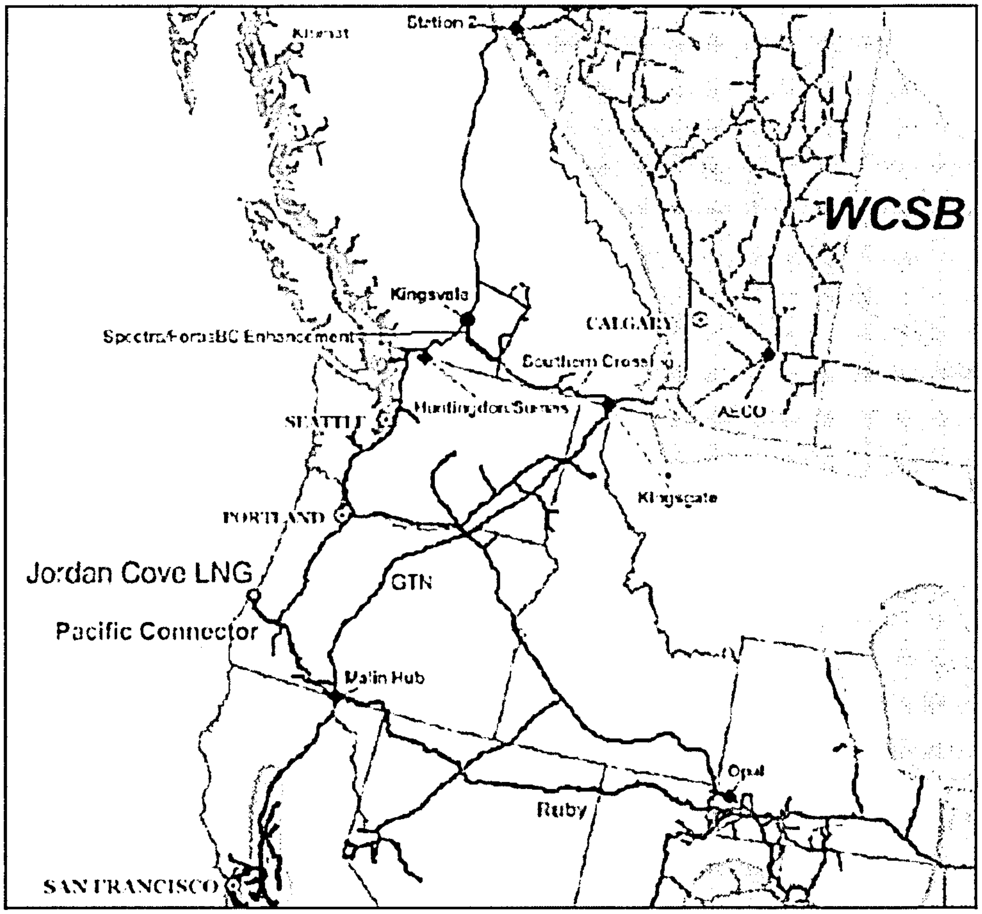
Introduction

Synapse Energy Economics, Inc. was engaged by the Niskanen Center to compare the economics of the potential sources of natural gas that would fuel the proposed Jordan Cove project, which consists of two primary components. The first is a liquefied natural gas (LNG) terminal located in the Port of Coos Bay in Coos County, Oregon, with a liquification design capacity of approximately 1 billion cubic feet per day. The second is the 36-inch diameter "Pacific Connector" gas pipeline, intended to transport natural gas from the Malin Hub to the new LNG terminal.[1] The proposed Jordan Cove project infrastructure is shown in Figure 1, along with other existing natural gas pipeline infrastructure and trading hubs in the Northwest.

Figure 1. Jordan Cove project and existing natural gas infrastructure



Source: Navigant Consulting. September 2013. Supply and Demand Market Assessment and Surplus Evaluation Report. Prepared for Jordan Cove LNG L.P.

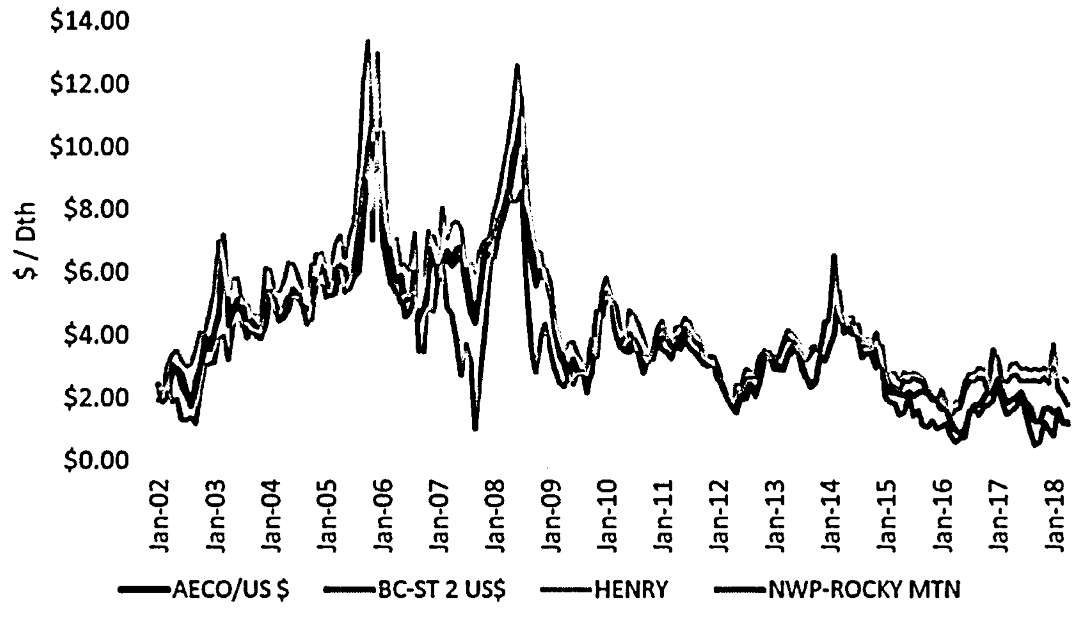
[1] Jordan Cove Project. Accessed June 24, 2019 and available at: https://www.jordancovelng.com/projectcmgh.

Natural gas from Canada would travel from the Kingsgate Hub via the Gas Transmission Northwest (GTN) pipeline while natural gas from the Rocky Mountain region would travel from the Opal Hub via the Ruby pipeline. It is highly likely that the Jordan Cove project would source most, if not all, of its natural gas designated for export from Canadian sources rather than from the Rocky Mountain region. Canadian gas supplies will continue to grow, and prices will be cheaper than natural gas sourced from the Rockies. In addition, documents supporting the applications for permission from the Canadian and U.S. governments to obtain natural gas supplies from Canada show that Jordan Cove developers intend to purchase primarily Canadian gas to supply the proposed project.

Prices for Canadian natural gas are lower than for gas from the Rocky Mountain region

Natural gas customers in the Pacific Northwest have access to gas supplies from both Canada and the Rocky Mountain region and thus can source gas from the least costly area (subject to constraints on long-haul pipelines). As shown in Figure 2, natural gas from the Rocky Mountains (NWP-ROCKY MTN) was less expensive than Canadian gas (AECO and BC-ST 2, which are shown in Figure 1) in many historical years, particularly between 2006 and 2010. That trend reversed in 2015, however, and for the past several years Canadian gas has been much less expensive for consumers in the Pacific Northwest.

Figure 2. Historical natural gas prices at select trading hubs

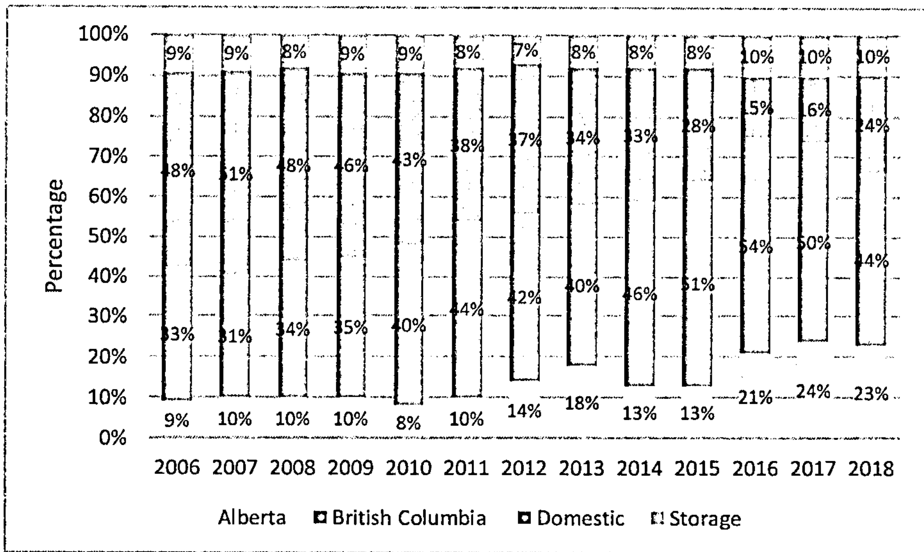


Source: Avista Corporation. 2018. Natural Gas Integrated Resource Plan. Page 96.[2]

[2] AECO refers to the AECO-C-Nova Inventory Transfer market center located in Alberta. BC-ST 2 is the Station 2 Hub located at the center of the Enbridge Westcoast Pipeline system connecting to northern British Columbia. Henry refers to Henry Hub. NWP-Rocky Mountain is the pricing point on the southern end of the NWP system in the Rocky Mountain region.

During the period in which natural gas from the Rockies was cheaper than gas from Canada, consumption of gas from that region in the Pacific Northwest peaked at 51 percent of the total in 2007. Over the last several years, however, natural gas production in British Columbia has grown. Increased supply has led to the declining prices for Canadian gas seen in Figure 2 and the increase in natural gas use from Canada seen in Figure 3. More than two-thirds of the natural gas consumed in the Pacific Northwest region came from Canada in 2018. Figure 3 shows the portions of natural gas consumed in the Pacific Northwest that came from the Rocky Mountain region and from Canada between 2006 and 2018.

Figure 3. Percentage of natural gas supply to the Pacific Northwest from Canada and the Rocky Mountain region

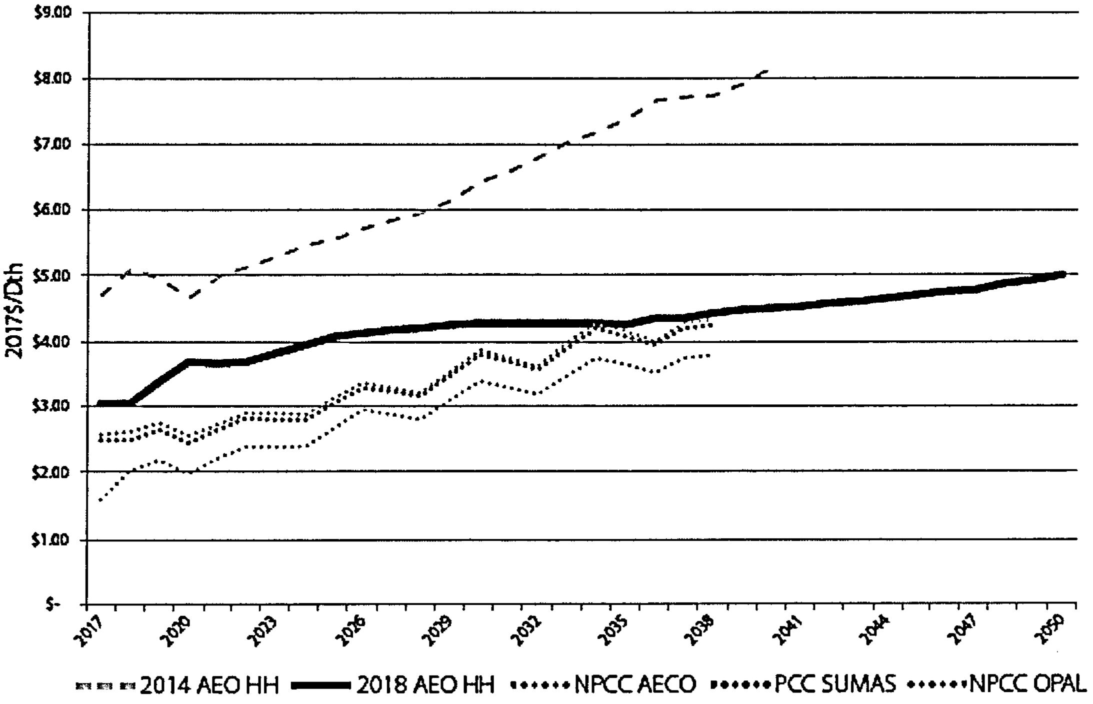


Sources: Northwest Gas Association. 2016. Pacific Northwest Gas Market Outlook. Page 6.
Northwest Gas Association. 2018. Pacific Northwest Gas Market Outlook. Page 6.

We can expect these price and supply trends to continue, as production from the Rocky Mountain region is expected to remain flat over the next decade while production from the Western Canadian Sedimentary Basin (WCSB) is expected to grow by approximately 2 billion cubic feet per day in the same time period.[3] Figure 4 shows prices at the AECO Hub in Canada trending below the Rocky Mountain Opal Hub by approximately $0.50/Dth through 2038.

[3] Northwest Gas Association. 2018. *Pacific Northwest Gas Market Outlook.* Pages 5-6.

Figure 4. Forecasted natural gas prices at select hubs



Source: Northwest Gas Association. 2018. Pacific Northwest Gas Market Outlook. Page 8.[4]

Natural gas flowing to the proposed Jordan Cove project must also include a transportation cost to ship the gas from either the Kingsgate Hub in Canada along the GTN pipeline or from the Opal Hub in the Rockies along the Ruby pipeline. Table 1 and Table 2 show the transportation charges associated with the GTN and Ruby pipelines, respectively, calculated from the rate schedules shown in the tariffs filed by the pipeline companies with the Federal Energy Regulatory Commission (FERC). Table 3 compares the price of natural gas at the Kingsgate Hub and transportation along the GTN pipeline (gas obtained from Canada) with the price of natural gas at the Opal Hub and transportation along the Ruby pipeline (gas obtained from the Rocky Mountain region).

[4] The sources of the "2014 AEO HH" and "2018 AEO HH" are the US Energy Information Administration (US EIA) 2014/2018 Annual Energy Outlook (AEO) for Henry Hub. The NPCC forecasts are from the Northwest Power and Conservation Council (NPCC) 7th Power Plan Midterm Assessment from 2017 for the AECO, Sumas, and Opal natural gas trading hubs.

Table 1. Tariff – Kingsgate to Malin along the GTN Pipeline

	Rate	Unit
Daily Mileage Rate	$0.000391	Dth-Mile
Daily Non-Mileage Rate	$0.030954	Dth
Delivery Charge	$0.000016	Dth-Mile
Fuel Charge (June 2019)	$0.015	Dth
Mileage	612.6	Miles
Total per dth per day	$0.30	

Source: Gas Transmission Northwest LLC. FERC Gas Tariff. Statement of Rates version 18.0.0. Effective January 1, 2019.

Table 2. Tariff – Opal to Malin along the Ruby Pipeline

	Rates per Dth
Monthly Reservation Rate	$34.5826
Commodity Rate	$0.0100
Electric Power Cost	$0.0450
Total per dth per day	$1.19

Source: Ruby Pipeline, LLC. FERC Gas Tariff. Service Rates Version 31.0.0, Effective March 31, 2019.

The cost to transport gas along the GTN pipeline from Canada is approximately one-quarter of the cost to transport gas along the Ruby pipeline. Table 3 compares the price of natural gas at the Kingsgate Hub and transportation along the GTN pipeline (gas obtained from Canada) with the price of natural gas at the Opal Hub and transportation along the Ruby pipeline (gas obtained from the Rocky Mountain region).

Table 3. Hub prices plus transportation costs

	2021 Hub Price $/dth	Transport Price $/dth/day
Kingsgate	$1.92	$0.30
Opal	$2.01	$1.19

Source: Hub prices are from: Bonneville Power Administration. 2019. BP-20 Rate Proceeding. Initial Proposal: Power Market Price Study and Documentation. BP-20-E-BPA-04.

When the natural gas hub price and transportation price are taken together, it becomes clear that it is much cheaper for Jordan Cove LNG to obtain natural gas from Canadian suppliers for export overseas.

Jordan Cove has stated its intent to source most, if not all, of its natural gas from Canada

The Jordan Cove LNG project applied for a license to source Canadian natural gas from the WCSB into the United States for export at the proposed LNG terminal. Developers also stated in the licensing application that the project may be supplied with natural gas from the Rocky Mountain region of the United States but noted in responses to an information request from the National Energy Board (NEB) of Canada that "the mention of the U.S. Rocky Mountain region...simply relates to a potential option for obtaining gas resources for the LNG facility. Like other Canadian LNG export applications, Jordan Cove LNG seeks to preserve the flexibility to source all of its project requirements from Canada..."[5]

In February 2014, the NEB granted Jordan Cove LNG the requested license to export Canadian natural gas. The license has a duration of 25 years and allows for annual export volumes of 1.55 billion cubic feet per day for pipeline fuel and fuel use at the terminal.[6] The U.S. Department of Energy gave its approval for the corresponding import of natural gas from Canada to the Jordan Cove LNG facility in March 2014.[7]

In the NEB's assessment of the Jordan Cove license application, it had to determine whether the natural gas proposed for export at Jordan Cove exceeded the expected surplus after considering projected Canadian demand for natural gas. Jordan Cove submitted a study by Navigant Consulting that concluded that natural gas supplies in the United States and Canada are abundant and can support both domestic market requirements and LNG export demands. In its analysis, Navigant noted that Jordan Cove applied for Canadian export authority to cover the entirety of potential LNG shipments from the project and "anticipates sourcing much, if not all, of its exports from Canadian natural gas supplies."[8]

This report has demonstrated that both Jordan Cove's stated intentions and the economics of western Canadian and domestic Rocky Mountain natural gas supplies support the conclusion that Jordan Cove intends to supply its proposed LNG export facility with Canadian gas.

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[5] Jordan Cove LNG L.P. (Jordan Cove LNG). Jordan Cove LNG Response to NEB Information Request No. 1. Application for a License to Export Natural Gas pursuant to Section 117 of the National Energy Board Act. Filed 9 September 2013 (Application). File OF-EI-Gas-GL-J705-20132-01 01 1.1.

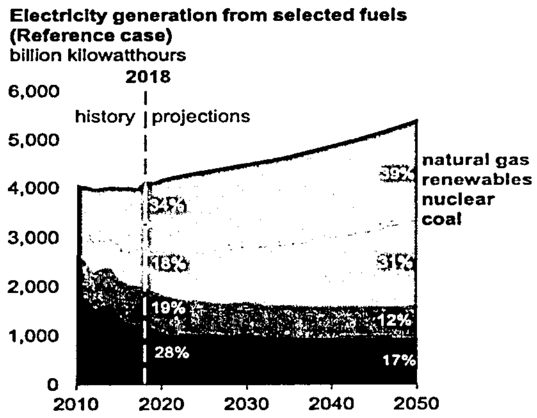
[6] National Energy Board, Canada. February 20, 2014. *Letter Decision.* File OF-EI-Gas_GL-J705-2013-01 01.

[7] U.S. Department of Energy, Office of Fossil Energy. March 18, 2014. *DOE/FE Order No. 3412 Granting Long-Term Multi-Contract Authorization to Import Natural Gas from Canada to the Proposed Jordan Cove LNG Terminal in the Port of Coos Bay, Oregon.* FE Docket No. 13-141-NG.

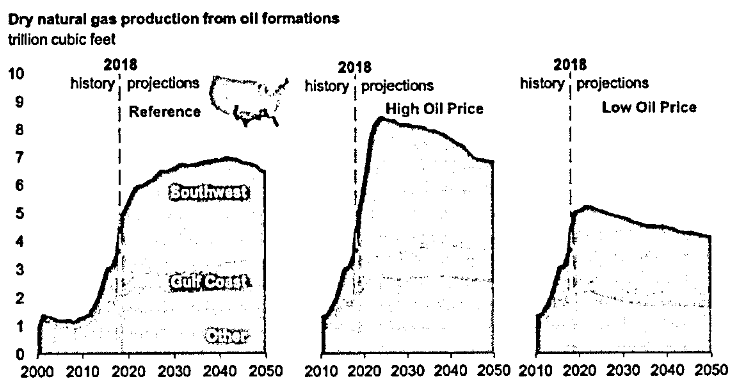
[8] Navigant Consulting. September 2013. *Supply and Demand Market Assessment and Surplus Evaluation Report.* Prepared for Jordan Cove LNG L.P.

Natural Gas Price Outlook:

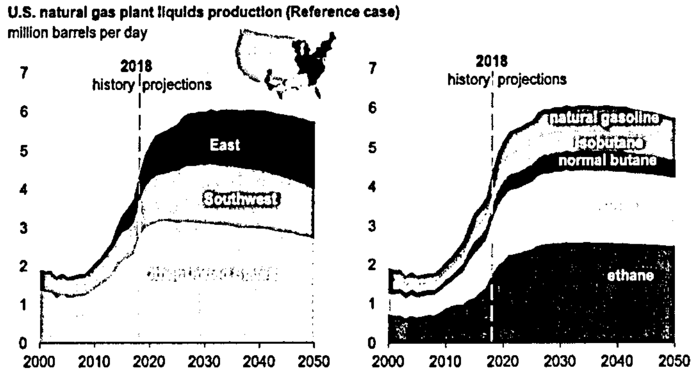
U.S. Energy Outlook 2019 (https://www.eia.gov/outlooks/aeo/pdf/aeo2019.pdf)



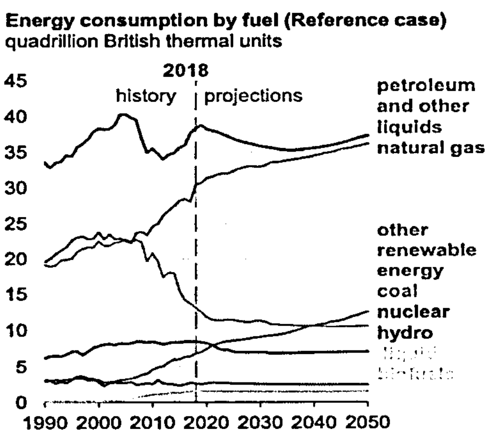
- Slow growth in US energy consumption and increased production of natural gas indicate that the US will become a net energy exporter by 2020. (12)
    - U.S. has been a net natural gas exporter since 2017. (14)
- Natural gas (and NGPLs) currently experiencing the greatest production growth in the US among fossil fuels. (12)
    - Natural gas projected to rise from 34% of 2018 electricity generation to 39% by 2050.
- Natural gas prices are projected to remain comparatively low during the projection period (2018-2050), likely leading to increased natural gas exports and a larger utilization of natural gas in the power sector. (12)
    - Low natural gas prices have helped lower wholesale electricity prices. (22)
    - Natural gas prices are sensitive to factors affecting supply- i.e. domestic resource and technology assumptions. (34)
    - "By 2050 consumption of natural gas increases even as production expands into more expensive-to-produce areas, putting upward pressure on production costs." (34)

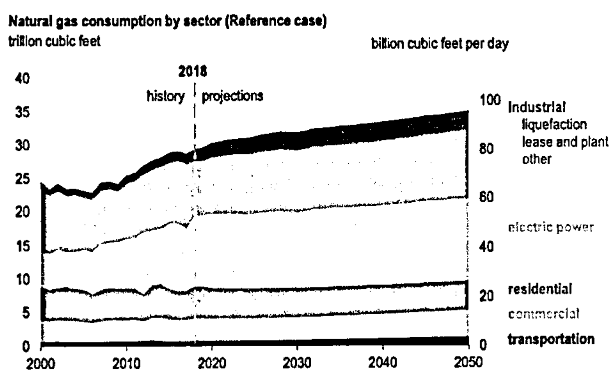


- Further downward pressure on natural gas prices are currently occurring as Southwest region becomes the driver of US natural gas production from tight oil formations. (18)
    - Growth in production in the Southwest region projected to level off after 2030. (78)
- Dry natural gas production from oil formations is anticipated to remain at around 17% through 2050. (18)
- Drilling in oil formations is primarily dependent on crude oil prices, so a drop in crude oil prices increases the production of natural gas putting a downward pressure on the cost of natural gas. (18)



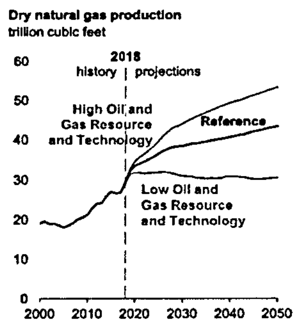
- Natural gas consumption is projected to rise as the price of natural gas is anticipated to remain low. Industrial sector projected to become the largest consumer of natural gas in the early 2020s. Power sector is also anticipated to increase natural gas utilization (28).
    - Increased natural gas consumption in the power sector is supported by the expiration of renewable tax credits in the mid-2020s and a decline in coal and nuclear energy generation. (82)
    - Natural gas in residential and commercial sector projected to remain about the same. (82)
        - Natural gas consumption by commercial buildings is projected to rise by 0.5% per year from 2018 to 2050 while natural gas in the residential sector is anticipated to fall 0.3% per year as natural gas is used less for residential space heating. (134)

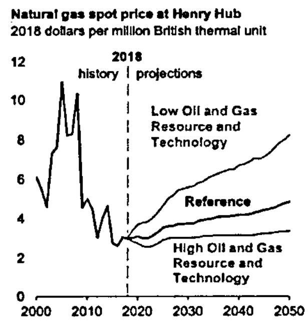




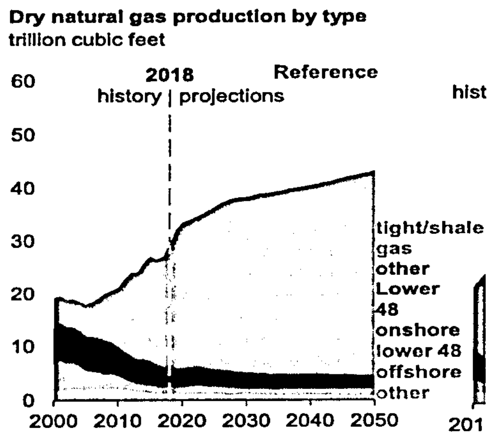
- Natural gas production expected to grow 7% per year from 2018 to 2020. (72)
    - Growth projected to slow to less than 1% per year after 2020 because of decreased domestic demand for natural gas and decreased export demand for US natural gas. (72)

- After 2020, production of natural gas is projected to grow at a higher rate than consumption leading to greater exports of natural gas. (72)
- Natural gas prices expected to remain below $4 million/Btu through 2035, and below $5 million/Btu through 2050 because of increase in lower-cost resources. (74)
  - To satisfy demand, production must be expanded into less prolific and more expensive-to-produce areas, putting upward pressure on production costs. (74)
  - Growing demand is responsible for the rising spot prices of natural gas. (74)

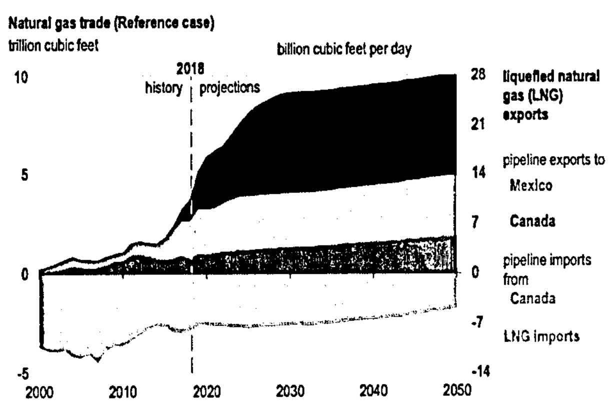




- Technology advancements and high volume of resources allows for decreasing production cost of natural gas from tight oil and shale gas resources. (76)
  - Onshore production of natural gas from sources other than tight oil and shale gas expected to decline through 2050. (76)
  - Offshore natural gas production expected to remain about the same. (76)

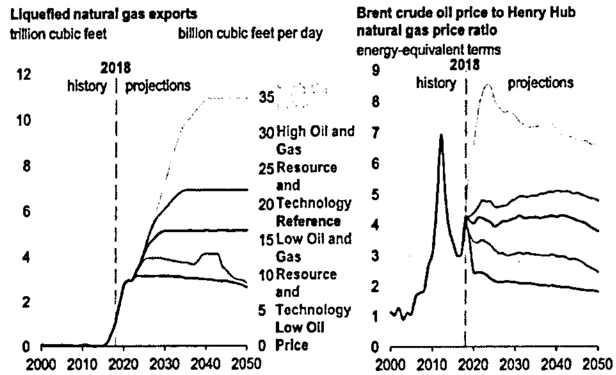


- Gulf Coast anticipated to become the fastest growing domestic demand market. (80)
- Exports to Mexico and LNG exports are expected to increase until 2025 (pipeline infrastructure to Mexico already in place); increased exports to Eastern Canada because of proximity and pipeline infrastructure (84)
  - Exports to Mexico begin to decline as Mexican domestic natural gas begin displacing US imports by 2030; LNG exports continue rising through 2030. (84)
  - LNG exports expected to expand as export facilities complete construction through 2022 and because of growing Asian demand. LNG exports expected to become less competitive and

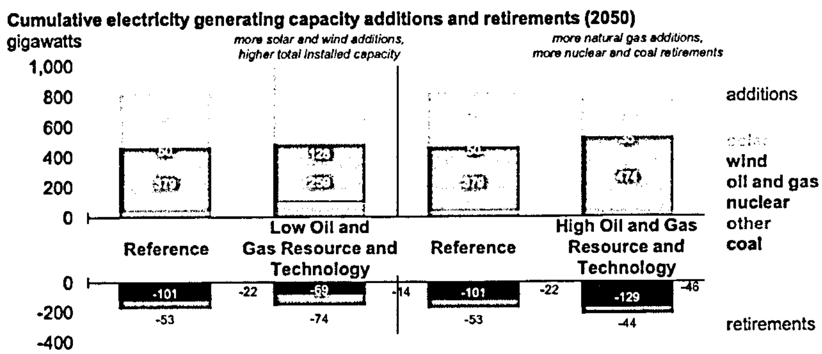


experience slower growth through 2050. (84)

- LNG exports are sensitive to both oil and natural gas prices. (85)
  - Crude oil, to some extent, functions as a natural gas substitute. (86).
  - Demand for LNG increases partially as a result of a consumer shift away from petroleum (86).
  - "As more natural gas is traded via short-term contracts or traded on the spot market, the link between LNG and oil prices weakens over time." (86)

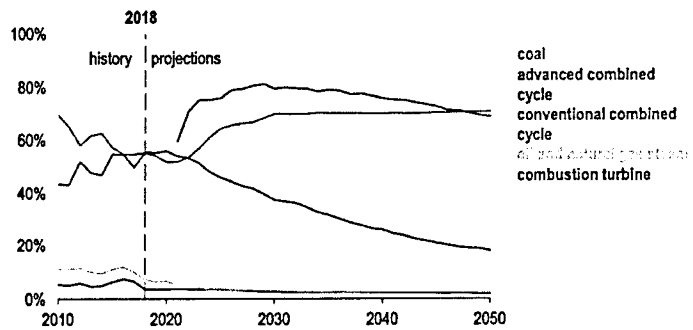


- Low natural gas prices have decreased the competitiveness of coal power generation. (92)
  - Natural gas projected to steadily grow and remain the dominant source of energy in the power sector through 2050. (92)
- New high-efficiency natural gas-fired combined cycle and renewables are projected to be added steadily through 2050 to meet growing electricity demand. (94)

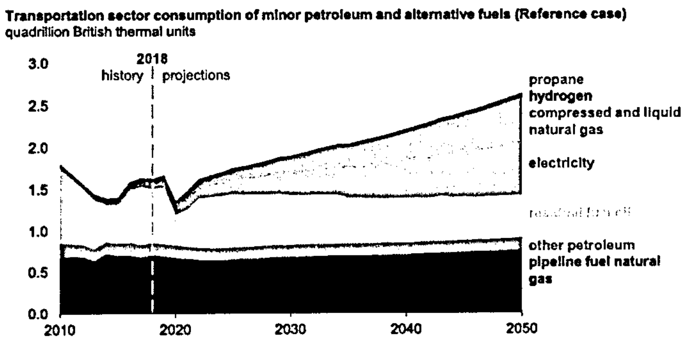


- Electricity generation costs are expected to fall by around 15% from 2018 to 2050. (98)
  - Average electricity prices projected to fall 4.2% from 2018 to 2022 as a result of customer rebates (Tax Cuts and Jobs Act of 2017) and lower construction/ operating costs of new plants. (98)
  - Transmission, distribution costs expected to rise between 18-24% as a result of updating infrastructure and bringing renewables into the grid.
- Lower natural gas prices are expected to accelerate the retirement of nuclear power generation. (105)

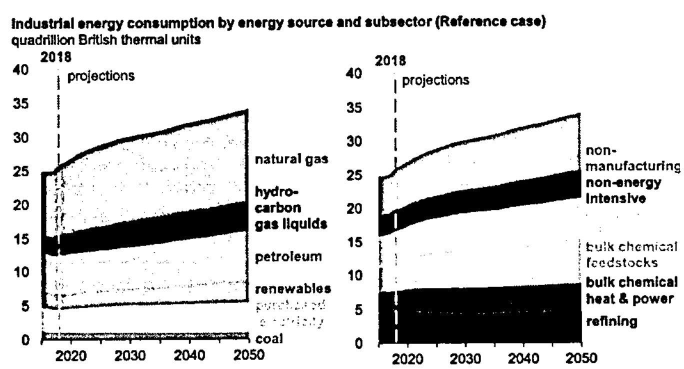
  - Lower cost natural gas options are more competitive with nuclear plants, especially nuclear plants with high operating costs and in regions with deregulated wholesale power. (106)
- "Coal-fired generating capacity decreases by 86 gigawatts (GW) (or 36%) between 2018 and 2035 as a result of competitively priced natural gas and increasing renewables generation before leveling off near 155 GW (in the Reference case) by 2050." (108)
- Lower operating costs and efficiency favor utilization of new CC natural gas-fired units with high capacity factors around 76% over coal, but as natural gas prices begin to increase relative to coal prices later, both energy sources are expected to converge to around 70% utilization by 2050. (112)



- Natural gas consumption increases during the entire projection period because of growing use of heavy-duty vehicles and freight rail. (130)

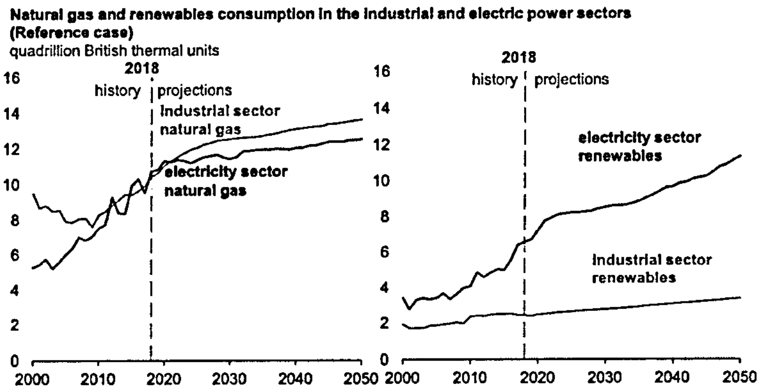


- Natural gas prices in the commercial and residential sector are projected to rise about 0.9% per year through 2050, decreasing consumption in the residential sector. (146)
  - Even with rising natural gas prices, commercial natural gas consumption is expected to rise by 0.5% per year until 2050. (146)
  - "Commercial natural gas-driven generating capacity in 2050 grows to nearly five times its 2018 level." (146)
- Natural gas & petroleum account for most delivered industrial energy consumption. (152)
  - Energy intensity is projected to decline by about 0.9% per year from 2018 to 2050 as a result of

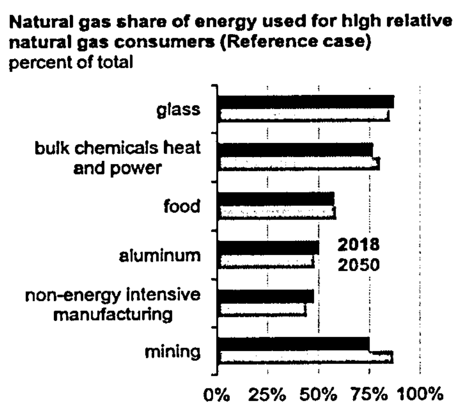


more efficient capital equipment and a shift toward more non-energy intensive industries.

- After the mid-2020s the industrial sector is projected to use more natural gas than the power sector. (156)
    - The chemical industry within the industry sector utilizes natural gas as chemical feedstock. (82)
    - Increased natural gas use in the industrial sector is largely a result of increased energy use for heat and power, lease and fuel for plants, and energy use for liquefaction. (156)
        - Energy use to liquefy natural gas for export increases by 5% per year. (152)



- Four major energy-intensive industries, the entire non-energy intensive industry, and the mining industry are projected to use natural gas for more than 40% of their energy needs in 2050. (158)
    - These industries consumed 7.2 quadrillion Btu of natural gas in 2018 and are projected to use 10.0 quadrillion Btu by 2050. (158)



BP 2019 Energy Outlook - U.S. Specific Insights

(https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2019-country-insight-us.pdf)

- -1% decline in US energy consumption from 2017 to 2040.
    - In 2040, U.S. comprises 12% of global energy consumption.
- +29% growth in U.S. energy production from 2017 to 2040.

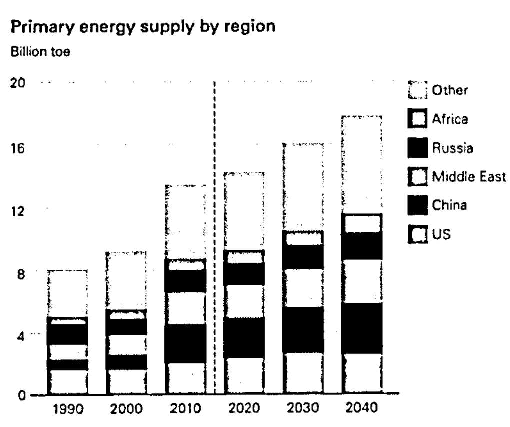
  - In 2040, U.S. comprises 14% of global energy production.
  - Natural gas production expected to rise by 54% by 2040.
  - U.S. is projected to remain the largest producer of liquid fuels and natural gas.
    - Natural gas outputs are expected to rise from 400 Bcm to over 1130 Bcm; LNG exports to rise to over 175 Bcm
- Natural gas demand is projected to pass demand for oil in the early-2030s.
- Natural gas is expected to become the leading source of fuel, making up 37% of energy consumption by 2040 compared with 28% today.
- By 2040 natural gas and renewables are projected to be nearly equal sources of power generation.

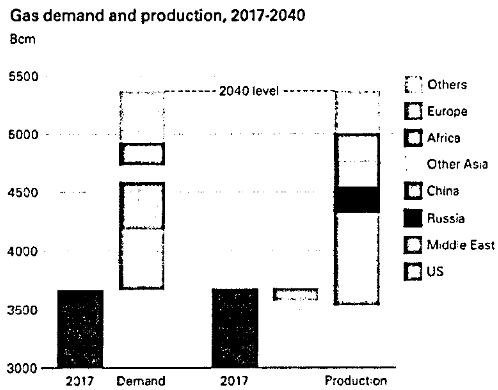
	Level		Shares		Change (abs.)		Change (%)		Change (annual)*	
	2017	2040	2017	2040	1995-2017	2017-2040	1995-2017	2017-2040	1995-2017	2017-2040
Primary energy consumption (units in Mtoe unless otherwise noted)										
Total	2235	2223			164	-12	8%	-1%	0.3%	0.0%
Oil¹ (Mb/d)	19	15	39%	31%	1	-3	6%	-18%	0.3%	-0.9%
Gas (Bcm)	739	957	28%	37%	141	218	24%	29%	1%	1.1%
Coal	332	138	15%	6%	-149	-194	-31%	-58%	-1.7%	-3.8%
Nuclear	192	104	9%	5%	31	-88	20%	-46%	0.8%	-2.6%
Hydro	67	69	3%	3%	-3	2	-5%	2%	-0.2%	0.1%
Renewables (including biofuels)	132	394	6%	18%	114	263	635%	199%	9.5%	4.9%
Transport*	670	568	30%	26%	113	-102	20%	-15%	0.8%	-0.7%
Industry*	594	598	27%	27%	-84	4	-12%	1%	-0.6%	0.0%
Non-combusted*	116	149	5%	7%	9	32	9%	28%	0.4%	1.1%
Buildings*	855	908	38%	41%	126	53	17%	6%	0.7%	0.3%
Power	912	1028	41%	46%	82	115	10%	13%	0.4%	0.5%
Production										
Oil¹ (Mb/d)	14	19			5	5	54%	35%	2%	1.3%
Gas (Bcm)	735	1132			231	397	46%	54%	1.7%	1.9%
Coal	371	233			-156	-138	-30%	-37%	-1.6%	-2.0%

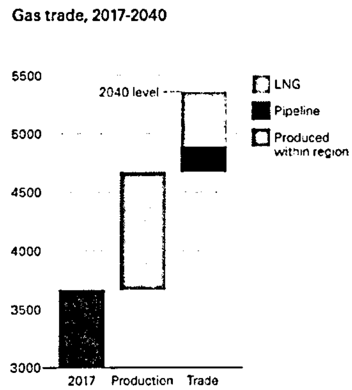
BP 2019 Energy Outlook Report

(https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2019.pdf):

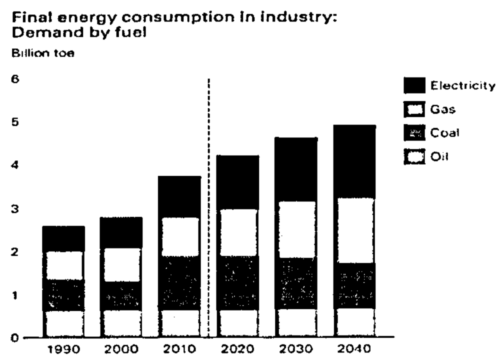
- The US is projected to be the largest contributor to energy growth until the mid-2020s. After the mid-2020s US growth is expected to slow as tight oil production hits peak and begins to decline. (69)
- The growth of US tight oil and shale projected to increase US energy exports. (71)
- Widespread growth in gas demand, US demand depicted in the graph below. (95)







- Natural gas is projected to grow much more than oil or coal (1.7% p.a.), surpassing coal as the second largest source of energy globally and converging on oil by 2040.
- Overall energy consumption slows as energy efficiency increases. (29)
- International industrial energy demand is dominated by the changing energy needs in China. (31)
    - China's industrial energy demand is anticipated to peak in the mid-2020s before shifting toward less energy-intensive industries; growth of industrial production occurring in India, Other Asia, and Africa. (31)
    - Net growth in industrial energy demand anticipated to be met with natural gas and electricity. (31)

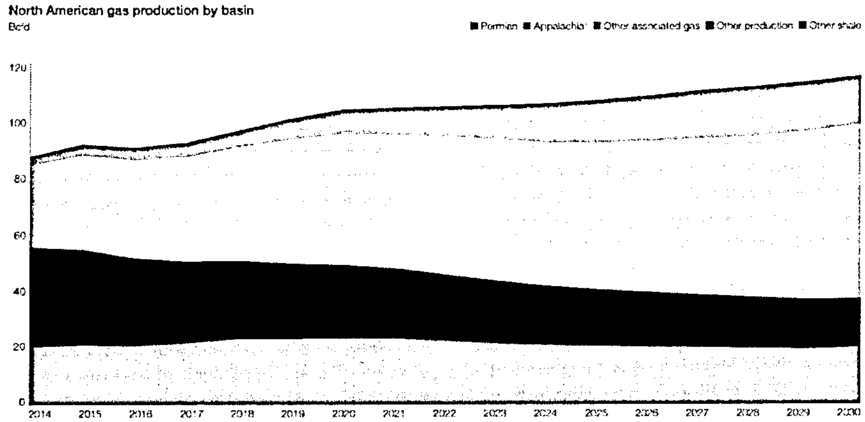


- The transportation sector continues to be dominated by oil despite increasing competitiveness of alternative fuels like natural gas. (45)
    - In transportation sector oil will decrease from a share of 94% to 85% by 2040. (45)
    - Natural gas, electricity, and biofuels account for about half of new energy used in the transportation sector. Natural gas will cover about 5% of transportation demand in 2040. (45)

McKinsey North American Gas Outlook (2018)

(https://www.mckinsey.com/solutions/energy-insights/north-american-gas-outlook-to-2030/~/media/E9DD367260D74CDD8EC8E9287E2628CB.ashx)

- North America has enough gas resources to meet demand for around 25 years below \$2.8/mmbtu. (7)
- By 2030 the Permian and Appalachia areas are projected to produce around 55% of the North American market. (8)



- "Despite global oversupply, utilization of US LNG export capacity expected to remain high (80-90%) through 2024 when new capacity comes online." (10)
    - Demand for U.S. LNG increases as liquefaction facilities are utilized at a rate of about 90% until 2020 and more capacity is added. (10)
    - Utilization to remain at about 80% from 2021 to 2024 as new capacity is added primarily from the Middle East and Mozambique. (10)
- Natural gas prices projected to remain constant in short- and medium-term, but anticipated to lower in the long-term. (11)

	Key factors	Near-term (2018-19)	Medium-term (2019-21)	Long-term (post-2021)
Demand	Power: coal, nuclear, renewable – gas switching	▼ Coal/gas switching shifting between $2-3/ mmbtu will keep prices low ▲ Early retirements and cancellation of under construction nuclear plants will increase gas demand	▲ As coal capacity is removed from the power mix, demand response from the power sector due to rising gas prices is limited ▼ Continued decline of renewable costs leads to additional renewable generation	▼ Gas demand decreases due to renewables displacing gas in the power sector, especially as power storage becomes increasingly economics
	Export (LNG, Mexico)	▲ LNG exports will have limited pricingimpact with addition demand of ~2 bcfd ◧ Exports to Mexico will have limited pricing impact with an addition demand of ~1 bcfd	▲ LNG exports can increase by ~2 bcfd due to underutilized end-user and portfolio contracts ▲ Pipe capacity addition, CCGT and industrial investment in Mexico will further boost Mexican consumption of US gas by ~2 bcfd	▲ LNG capacity expected to tighten post 2024, increasing LNG plant utilization ▼ Falling solar costs and a rebound in indigenous production slow Mexican demand growth for US gas imports
Supply	Appalachian supply	▲ With increased Appalachian supplies bottlenecked, marginal production will come from higher break-even basins to support LNG exports	▼ As more pipeline infrastructure comes online post-2019, inexpensive Appalachian supplies will continue to grow and limit price fly up potential	▼ Potential for further efficiency gains in drilling and completion decreases break-evens
	Associated gas supply	▼ With efficiency gains and a stable oil price outlook, drilling in oil basins is rebounding, with the Permian taking the lead	▼ At $65/bbl, 'zero cost' associated gas production could increase by ~4.5 bcfd by 2021, most of which is expected from the Permian	▼ Associated gas production continue to increase, making up ~30% of US gas production by 2030
	Others– (e.g., oil field service cost, drilling efficiency)	▲ OFS cost are expected to recover	▲ OFS costs could keep rising if a recovery of commodity price drives a boom in drilling ▼ Drilling efficiency increases and new completion technology will lower well and service costs	OFS costs could keep rising if a recovery of commodity price drives a boom in drilling ▼ Drilling efficiency increases and new completion technology will lower well and service costs

(https://www.mckinsey.com/solutions/energy-insights/north-american-gas-outlook-to-2030)

- North American gas demand is expected to grow by about 2% per year toward 116 billion ft^3/day in 2030.
    - LNG to make up 55% of that growth
- Among other drivers of demand include Mexico, the industrial and petrochemical industries, and changes in energy generation in the power sector.

- Gas demand in the power sector projected to rise 2% per year through 2020, largely replacing coal. After 2020, gas is anticipated to only grow at around 0.3% per year as renewables become more competitive.
- Appalachia is expected to make up about 30% of total US gas production by 2030.
- New pipeline infrastructure will stabilize supply and prices.
- "Supply and demand drivers will enable gas prices to remain stable in the short- to mid-term" (until about 2021).
    - As renewables become more cost-efficient, they are likely to take some of the demand from gas after 2021. McKinsey projects that prices will move below $3 per million Btu.

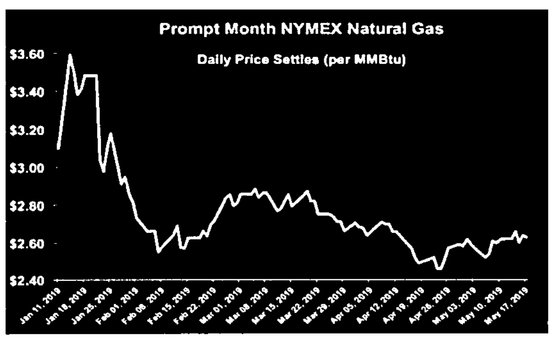
Bloomberg 2019 U.S. New Energy Outlook

(https://about.bnef.com/new-energy-outlook/)

- "We expect global gas prices to converge towards U.S. netback parity and the cost of bringing new LNG liquification capacity online outside of the U.S."
- The U.S. (as well as India and other countries) are projected to see growing gas demand.
- "Gas-fired power grows just 0.6% per year to 2050, supplying system back-up and flexibility rather than bulk electricity in most markets."

Forbes- U.S. Natural Gas Prices Remain Low and Stable

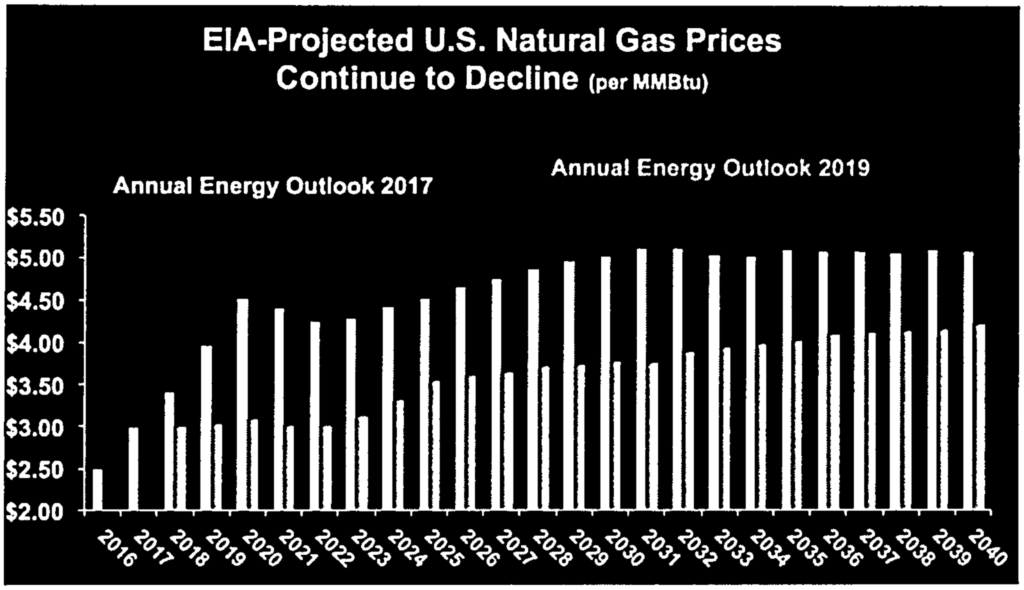
(https://www.forbes.com/sites/judeclemente/2019/05/19/u-s-natural-gas-prices-remain-low-and-stable/#3779bb9e5c0c)



U.S. natural gas prices have been low and stable since the end of January. DATA SOURCE: CME GROUP INC

- April 2019 natural prices broke below $2.50 for the first time since June 2016.
- Since April prices have varied less at just around 10%.
- 2019 production has been at 86 Bcf/d compared to 79 Bcf/d in 2018.
    - This 7 Bcf/d has kept prices low while demand has only risen by 5 Bcf/d.
- Natural gas storage deficit is being addressed, further helping to stabilize natural gas markets.
- Three new LNG export facilities are being added with the potential of adding 4 Bcf/d in demand by 2020.
- "Over the past two years, for instance, EIA's forecast for U.S. gas prices in 2030 has plummeted 25%."

  - Falling prices make natural gas even more competitive compared to other electricity- generating sources in the power sector.
- Natural gas prices in 2030 are projected to remain below $4 per MMBtu in 2030.



Forecasts for future U.S. natural gas prices seemingly get lower every year. DATA SOURCE: EIA; JTC

A Leader of America's Fracking Boom Has Second Thoughts- WSJ
(https://www.wsj.com/articles/a-leader-of-americas-fracking-boom-has-second-thoughts-11561388670?mod=hp_lead_pos5)

- "Over the past 10 years, 40 of the largest independent oil and gas producers collectively spent roughly $200 billion more than they took in from operations."
- Under pressure to generate positive cash flows, executives have been slashing overhead and dialing back drilling plans.

U.S. Natural Gas Prices Have Collapsed- Forbes
(https://www.forbes.com/sites/judeclemente/2019/06/23/u-s-natural-gas-prices-have-collapsed/#3d5edb93286e)

- "There are no contracts on the forwards curve above $3.00 until January 2024."
- Given that prices were as high as $4.92 in mid-November, nobody projected such a rapid decline in natural gas prices.
- "And such low prices obviously discourage bringing new output online, but I still expect us to surpass 90 Bcf/d in the coming months."
    - Generating more output despite already low prices and oversupply.

Supply Glut Drives Natural Gas Prices to Lowest Since 2016- Yahoo Finance
(https://finance.yahoo.com/news/supply-glut-drives-natural-gas-140802595.html)

- Quantifying the oversupply:
    - "Stockpiles held in underground storage in the lower 48 states rose by 115 billion cubic feet (Bcf) for the week ended June 14."
    - Total natural gas stocks at 2.203 trillion cubic feet (Tcf) - 209 Bcf (10.5%) above 2018 levels.
- Consumption has stayed relatively flat while supply has increased.

Natural Gas Price Forecast- Natural gas markets collapsed again- FX Empire
(https://www.fxempire.com/forecasts/article/natural-gas-price-forecast-natural-gas-markets-collapsed-again-581779)

- Natural gas prices have continued to decline as "we continue to see a lot of exhaustion in demand and of course concerns about the global economy if the Federal Reserve is looking to cut interest rates."
- " the economies around the world slow down, it's very likely that natural gas demand will continue to fail to catch up to the oversupply of this commodity. There is nothing good-looking about this chart."

The global boom in natural gas demand is about to slow, the IEA says- CNBC
(https://www.cnbc.com/2019/06/07/the-global-boom-in-natural-gas-demand-is-about-to-slow-iea-says.html)

- Global demand for natural gas was 4.6% in 2018, but moving forward is only expected to increase by about 1.6% per year.
    - A large amount of this demand is expected to be generated by China (40% of demand through the next 5 years)
- Although global demand is increasing, a sizeable portion of this demand is overseas so increases in pipelines are not a better way to distribute natural gas. Rising demand abroad will largely be met with LNG exports overseas.

Natural Gas Moves to Lower Lows
(https://seekingalpha.com/article/4271547-natural-gas-moves-lower-lows)

- Natural gas is at its lowest price since 2016.
- Rising inventories of natural gas are primarily responsible for what has pushed natural gas prices so low.

Seeking Growth: What will drive US natural gas demand?- Deloitte
(https://www2.deloitte.com/us/en/pages/energy-and-resources/articles/us-natural-gas-consumption-demand.html)

- "Future demand growth poses other challenges. With expected low-to-moderate economic growth, slowing population growth, and increases in energy efficiency, domestic energy consumption may expand more slowly over the next ten years than the last—and potentially may even decline."
- "Export growth could be limited as global natural gas markets are in a state of flux with a glut of capacity that could potentially last until the early 2020s."
- Projections for the future of natural gas:
    - The market it likely to grow more slowly than it has in the past
    - Prices are anticipated to remain low

Pipeline Bubble

NORTH AMERICA IS BETTING OVER $1 TRILLION ON A RISKY FOSSIL INFRASTRUCTURE BOOM

Ted Nace, Lydia Plante, and James Browning

ABOUT GLOBAL ENERGY MONITOR

Global Energy Monitor (formerly CoalSwarm) is a network of researchers developing collaborative informational resources on fossil fuels and energy alternatives. Current projects include the Global Coal Plant Tracker, the Global Fossil Infrastructure Tracker, the CoalWire newsletter, and the CoalSwarm and FrackSwarm wiki portals.

ABOUT THE GLOBAL FOSSIL INFRASTRUCTURE TRACKER

The Global Fossil Infrastructure Tracker is an online database that identifies, maps, describes, and categorizes oil and gas pipelines and oil, gas, and coal terminals. Developed by Global Energy Monitor, the tracker uses footnoted wiki pages to document each project. For further details, see "Methodology" at http://ggon.org/fossil-tracker/.

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FURTHER RESOURCES

For additional data on proposed and existing pipelines, see Summary Data at http://ggon.org/fossil-tracker/, which provides over 30 tables providing results from the Global Fossil Infrastructure Tracker (GFIT), broken down by nation and region. To obtain primary data from the GFIT, contact Ted Nace (ted@tednace.com).

Global Energy Monitor

Pipeline Bubble

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INTRODUCTION: FOOLED ME ONCE

From 2011 to 2016, following a period of heady optimism and over-expansion based on expectations of surging Asian demand, coal mining company values plummeted and bankruptcies decimated the sector (see Sidebar: "The Coal Mining Equities Crash"). Today, investors in the booming expansion of oil and gas infrastructure appear headed for a similar shock, as boom-fueled optimism runs into climate realities and fiscal limits:

- Rapid expansion: A newly completed survey of oil and gas pipeline projects by the Global Fossil Infrastructure Tracker reveals a tripling in the pace of oil and gas pipeline building since 1996, with over half (51.5%) of projects located in North America and gas projects dominating the mix by a 4:1 ratio over oil projects. North America's oil and gas pipeline expansion plans total $232.5 billion (pre-construction and construction) out of total North American oil and gas infrastructure expansion plans of over $1 trillion.

- Reliance on Asian growth: Domestic demand growth cannot support the current North American oil and gas infrastructure boom. Like the over-investment that occurred in the coal sector, the current expansion in oil and gas infrastructure is predicated on a "super cycle" of increased demand from overseas buyers, especially in Asia.

- Sectoral stigmatization on climate grounds: Like the coal sector in the 2011–2016 period, the oil and gas sector faces rapidly growing censure from civil society, including divestment actions by over 1,043 institutions representing over $8.7 trillion in capital. New findings by the Intergovernmental Panel on Climate Change have called for a 65% reduction in oil use and a 43% reduction in gas use by 2050, relative to 2020. Such reductions are incompatible with rapid infrastructure expansion.

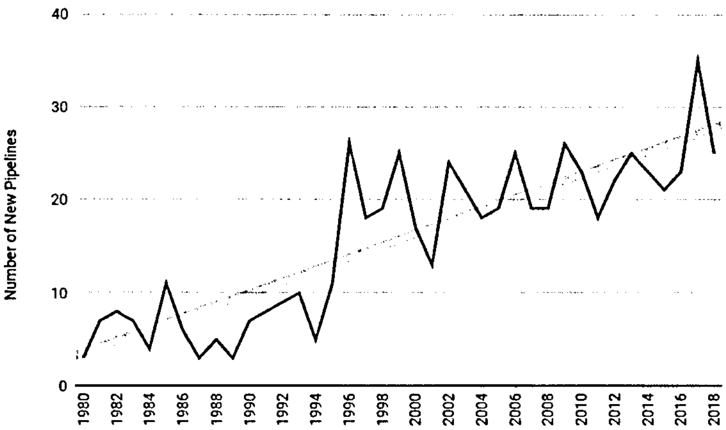
THE NEW PIPELINE BOOM

After adding an average of seven new pipelines a year from 1980 to 1995, the global system added an average of 25 new pipelines a year from 2009 to 2018. Currently 302 new pipelines are under development, including 78 in construction and 166 in pre-construction planning. If built, these projects will increase the number of global pipelines by 29%, including a 35% increase in the number of gas pipelines and a 19% increase in the number of oil pipelines.

GAS DOMINATES THE MIX

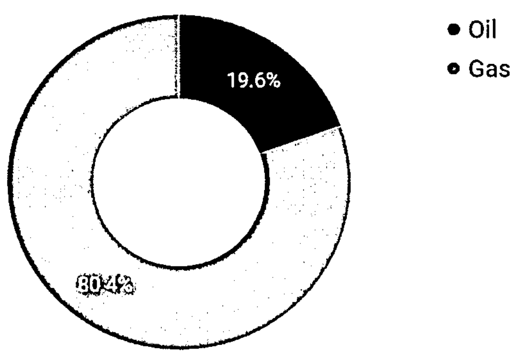
Since 1980, global production of natural gas has grown at three times the rate of oil—148% for gas, 48% for oil (Ritchie 2019). The ongoing production shift toward gas is reflected in the respective length of pipelines under development, which also favor gas over oil by 4:1 ratio, as shown in Figure 2.

Figure 1. New pipelines per year, 1980–2018



Source: Global Fossil Infrastructure Tracker, January 2019.

Figure 2. Shares of Oil and Gas in Global Pipeline Development (by Length)



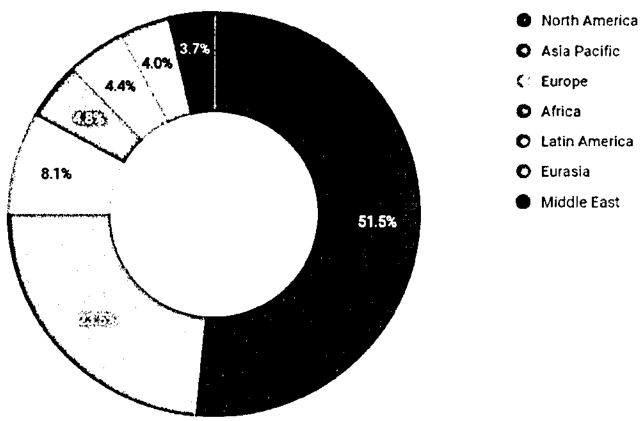
Includes projects in construction and pre-construction stages. Source: Global Fossil Infrastructure Tracker, January 2019.

ACTIVITY BY REGION: NORTH AMERICA'S BUILDING SPREE

By all measures, North America leads the world in development of new pipelines, followed by the Asia Pacific region. As shown in Figure 3 and Table 1, North America accounts for over half of pipeline projects under development (if measured by number of projects) or for over a third (if measured by pipeline lengths). This includes 64% of oil pipelines in development worldwide (36 out of 56) and 48% of gas pipelines in development worldwide (104 out of 216).

North America's pipeline projects are concentrated in three areas. The most active area is the Permian Basin of west Texas and southeast New Mexico, where numerous pipelines aimed at feeding Gulf Coast refineries and export terminals are currently under development. At least 12 pipelines originating in Texas fields are under construction, with an additional 26 in pre-construction development. If built, these Texas-originating pipelines will add over 16,000 km (10,000 miles) to the North American

Figure 3. Regional Shares in Global Pipeline Development (by Number of Projects)



Based on number of projects (construction and pre-construction categories). Source: Global Fossil Infrastructure Tracker, January 2019.

Table 1. Regional Distribution of Pipeline Development (Km)

	Oil		Gas			
Region	**Proposed**	**Construction**	**Proposed**	**Construction**	**Total**	**Share**
Africa	6,602	2,336	8,910	497	18,344	10%
Asia Pacific	952	69	34,775	7,460	43,255	24%
Eurasia	1,384	0	9,510	5,372	16,266	9%
Europe	0	0	13,345	2,520	15,865	9%
Latin America	475	0	6,907	6,145	13,527	7%
Middle East	4,415	0	7,795	1,900	14,110	8%
North America	17,592	2,144	31,356	11,058	62,149	34%
Total	**31,419**	**4,549**	**112,597**	**34,952**	**183,517**	

Source: Global Fossil Infrastructure Tracker, January 2019 pipeline system and will increase the capacity of the system by at least 12 million barrels of oil equivalent per day. By length, Texas-originating pipelines account for 34% of North America's proposed and under-construction new pipelines; by capacity, they account for 40%.

The second major origination area for new pipelines is the Marcellus and Utica shale formations in Pennsylvania, Ohio, and West Virginia, with pipelines feeding refineries and terminals located on the Atlantic coast and Great Lakes. In addition, some pipelines will transport liquid natural gas byproducts within the region to new ethane cracker facilities located along the Ohio River (Bruggers 2009).

The third major origination area is the Canadian tar sands of Alberta, with pipelines transporting oil southwest toward the Pacific coast and southeast toward the Gulf Coast.

Table 2. Pipeline Development by Originating State or Province, Ranked by Length

Originating State or Province	Number	Length (km)
Texas	38	16,747
Alaska	3	4,715
Alberta	10	4,415
British Columbia	8	3,955
Illinois	2	2,334
Oklahoma	8	2,148
Pennsylvania	14	1,974
Ohio	6	1,711
West Virginia	4	1,678
New Mexico	4	1,379
Utah	1	1,046
Louisiana	7	797
Chihuahua	1	625
South Carolina	1	579
Veracruz	2	496
Oaxaca	1	440
Hidalgo	1	420
Oregon	2	394
Wyoming	3	388
San Luis Potosi	1	374
Maryland	1	306
Durango	1	290
New York	1	286
Colorado	4	238
Michigan	2	219
Yucatan	1	159
California	1	155
Washington	1	129
Virginia	1	91
North Carolina	2	79
North Dakota	2	54
New Jersey	1	48
Sonora	2	45
New Hampshire	1	44
North America	**138**	**48,756**

Includes projects in construction and in pre-construction development. Length in km. Source: Global Fossil Infrastructure Tracker, January 2019.

WHAT'S DRIVING THE NORTH AMERICA BOOM?

North America's own domestic appetite for natural gas and oil is not the primary reason for the boom in pipeline activity. According to the U.S. Energy Information Agency, overall U.S. demand for petroleum liquids will decline from 2020 to 2035 by about three quads (quadrillion British thermal units) (U.S. EIA 2019), or about 8% of current consumption. Similarly, for natural gas, domestic demand growth, which the U.S. EIA estimates will be about two quads from 2020 to 2035, or about 10%, is not sufficient to support the large boom taking place in new infrastructure (U.S. EIA 2019).

With domestic demand insufficient to drive the oil/gas infrastructure boom, sponsors of pipeline projects are looking instead to overseas markets, especially the Asia Pacific region, where natural gas is expected increasingly to replace coal in power generation and industrial processes. In this version of the future, encapsulated in the International Energy Agency's "Current Policies" scenario, natural gas demand grows 1.6% percent per year worldwide from 2017 to 2040, with the Asia Pacific region growing at 3.1% per year in the same period as natural gas increasingly replaces coal (IEA 2018). By 2040, gas demand relative to 2017 rises by 55% and oil demand by 26% under the Current Policies scenario.

THE COAL MINING EQUITIES CRASH

On April 13, 2016, the largest U.S. coal company, Peabody Energy, declared bankruptcy. By that point four other major companies had already filed for Chapter 11 protection: Arch Coal, ANR, Patriot Coal, and Walter Energy. One analyst called it "the day coal died in the United States."

What's striking is how fast the coal industry went from boom to bust. In 2010, forecasts about the future of global coal demand closely resembled today's optimistic forecasts about growing global demand for natural gas. Those optimistic expectations were reinforced by a strong upward trend in coal prices, with benchmark coal prices increasing from $100 per tonne in January 2010 to $140 per tonne in January 2011. In early 2011, coal mining company stocks hit an all-time high, as analysts predicted a "super cycle" of growth based on China's domestic consumption. In its *World Energy Outlook 2010*, the IEA projected that the coal mining industry would see continued growth, including a 38% increase in Chinese production from 2008 to 2015, supporting coal-supply infrastructure investment of $720 billion in the period 2010–2035.

Figure 4. Peabody Energy stock chart, 2011–2016

Based on the confluence of indicators pointing safely toward an ongoing boom, coal mining companies took on increased debt as they undertook aggressive ramp-ups in new acquisitions of mines and investments in new mines.

In retrospect, the warning signs were clear, and the parallels with today's gas boom are particularly striking:

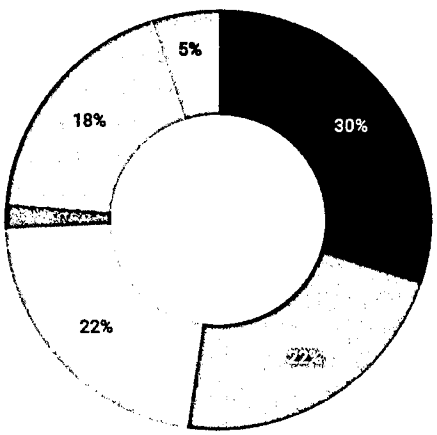
- Mining companies were convinced that coal, long touted as the cheapest fuel, would maintain that advantage into the future. Similarly, today's boom in North American pipelines is based on a belief that the fracking boom has given North American producers a long-term advantage in global markets. But just as the fracking revolution enabled natural gas to push coal out of North American power markets, today plunging solar and wind cost structures threaten to similarly drive the displacement of natural gas.
- Mining companies, along with their political allies in Washington, D.C., and other capitals, failed to factor growing global concern over carbon pollution and other environmental impacts into their growth calculations. As of February 2019, over 24 governments had committed to phasing out coal and over 100 banks and other financial lenders had instituted restrictions on coal financing.

PIPELINES AS PART OF A $1 TRILLION EXPANSION

Banks, equity investors, and bondholders are in the process of placing over $600 billion in bets on an expanded pipeline system with an expected lifespan of 40 years or more. Table 3 estimates the capital costs by region in pipelines that are currently in pre-construction or construction.

As shown in Table 3, $232.5 billion, or 37% of the total, is for pipelines in North America. This estimate falls at the low end of the oil and gas industry's own projections for pipeline capital expenditures for the U.S. in the period 2017–2035, which range from $234 billion to $362 billion and account for 22% of projected capital spending during that period for U.S. oil and gas industry infrastructure, as shown in Figure 5, according to the base case scenario developed for the American Petroleum Institute by ICF (Petak 2017). Applying API's ratio to the $232.5 billion North American and $632.5 billion global estimates shown in Table 3 suggests overall infrastructure expansion plans of $1.05 trillion for North America and $2.9 trillion globally.

Figure 5. Shares of U.S. Oil and Gas Infrastructure Capital Expenditures 2017–2035



Source: Petak, K. et al. "U.S. Oil and Gas Infrastructure Investment Through 2035." American Petroleum Institute, 2017. Base case scenario. http://bit.ly/2SEW72M

Table 3. Estimated Investments in Pipelines Under Development (Billion $)

Region	Gas (billions)	Oil (billions)	Total (billions)
Africa	41.8	31.4	73.2
Asia Pacific	137.4	4.5	141.9
Eurasia	69.9	6.6	76.5
Latin America	35.1	2.3	37.3
Middle East	50.2	21.0	71.1
North America	148.9	83.6	232.5
Total	**483.3**	**149.2**	**632.5**

Includes projects in pre-construction and construction stages. Based on $4.75 million/km ($7.65 million/mile) for proposed onshore US gas pipeline projects in 2015–16, as reported by "Natural gas pipeline profits, construction both up," *Oil & Gas Journal*, November 2018. Based on estimated and reported pipeline lengths, Global Fossil nfrastructure Tracker, January 2019.

INVESTOR RISK FACTOR #1: IS FOSSIL FUEL INFRASTRUCTURE LOSING ITS SOCIAL LICENSE?

The message that today's energy system must transition away from fossil fuels took on new urgency with the release of an October 2018 report by the Intergovernmental Panel on Climate Change (IPCC), "Global Warming of 1.5°C." According to that report, developed by 91 scientists from 40 countries, gas and oil production must begin to drop within the coming decade, not expand further. As shown in Table 4, which is based on pathways that would allow a one-in-two to two-in-three chance of limiting global warming to 1.5°C above pre-industrial levels, gas and oil usage must decline 15% and 21% respectively by 2030 relative to 2020. By 2050, reductions must be steeper: 43% for gas, 65% for oil. Failure to make such changes will result in cascading levels of damage to the global ecosystem and human society, including sea level rise and coastal inundation, heat waves, drought, accelerated species extinction, and widespread crop failures. In North America, the current pipeline boom can only pay off if these warnings are brushed aside and greenhouse gas levels are permitted to rise to ever more damaging levels.

Changing the trajectory of oil and gas use means changing levels of upstream extraction, and it also means avoiding further lock-in of new midstream infrastructure. In that regard, it is important to remember that new infrastructure not only follows the development of new extraction areas, but also facilitates further extraction. For that reason investments in pipelines, terminals, and other midstream components of the energy system are increasingly being challenged on ethical grounds.

Many of those challenging the moral and financial wisdom of fossil fuel investing were once among the industry's most important allies: banks and sovereign wealth funds. Challenges to the social license for fossil fuel infrastructure include divestment actions by over 1,043 institutions representing more than $8.7 trillion in capital (Fossil Free: Divestment 2019), a growing bipartisan support for alternative energy over fossil fuels (Gallup 2016), the proliferation of citizen protests and direct action campaigns targeting individual pipelines or terminals, and a growing array of institutional policies aimed at restricting investment in fossil fuels. Restrictive measures toward oil and gas extraction have been adopted by the World Bank as well as the governments of New Zealand, France, Costa Rica, Belize, New York, and Maryland (Trout 2019). Most recent was been the action of Norway's massive pension fund to divest from independent oil and gas producers and to begin investing in unlisted renewable energy infrastructure (Reed 2019).

The growing trend toward institutional restrictions on support for oil and gas parallels a similar trend by over 100 financial institutions to restrict support for coal. As one analyst noted, "Global capital is fleeing the thermal coal sector. This is no passing fad." (Buckley 2019).

Table 4. Median primary energy supply (Exajoules) for below IPCC 1.5°C pathways with low overshoot.

	2020	2030	2050
Gas	132.95	112.51	76.03
Oil	197.26	156.16	69.94

Source: IPCC, "Global Warming of 1.5°C," Table 2.6, October 2018

INVESTOR RISK FACTOR #2: OVEREXPANSION

A second risk factor for investors in oil and gas pipelines arises from what John Maynard Keynes termed "animal spirits" —the sense of optimism that has arisen from the extraordinary success of the fracking boom. Riding on the enthusiasm and production boosts of the U.S. fracking boom, the last decade of rapid growth for North America's oil and gas producers has created a sense of permanent global dominance. But there are many indicators that the current disproportionate growth in production occurring in North America will fade far sooner than the 40-year expected life of today's infrastructure investments. Overseas, surging growth is projected in numerous new and expanding extraction areas, including the following:

- Middle East. According to the IEA, Middle Eastern supplies of natural gas are expected to rise sharply in the coming decades, as major new fields come into production in Qatar (North Dome field), Iran (South Pars field), and Saudi Arabia. Overall, Middle Eastern production is projected to increase by 65% in 2040 relative to 2017 under the IEA's New Policies scenario (WEO 2018).

- Central and South America. New offshore fields in Brazil (Pre-salt field) and new onshore fields in Argentina (Vaca Muerta) are projected to drive the region's production upward by 60% in 2040 relative to 2017 under the IEA's New Policies scenario (WEO 2018).

- Asia Pacific. According to the IEA, by 2040 China's own production is projected to increase by 142%, with a 40% increase already recorded in 2018 in the Sichuan Basin (Aizu 2018, Jacobs 2019). The IEA projects India's gas production to grow by by 166% by 2040, with the country's oil ministry recently projecting that production would double in the coming four years (Abdi 2018). Finally, the IEA projects Australia's production of natural gas to increase by 98% by 2040 (WEO 2018).

- Africa. Africa's natural gas production is projected to increase by 131%, based on gas discoveries in 14 sub-Saharan countries and a U.S. government program to provide $175 billion in investment funds for the sector (Husseini 2018, WEO 2018).

Overall, global production of natural gas outside North America is projected to increase 46% between 2017 and 2040, while North American natural gas production is projected to increase by 36% in the same period. The discrepancy is even greater in the period from 2025 to 2040, when global production outside North America is projected to grow by 31%, compared to 12% in North America (WEO 2018).

Accelerating renewables also place an overbuilt North American pipeline network at risk of underutilization. Over the past decade, projections by the International Energy Agency about the pace of renewables have consistently proved to be overly conservative. According to Auke Hoekstra, who has documented the IEA's pro-fossil bias, the same tendency applies to battery storage and electric vehicles.

OWNERSHIP AND EXPOSURE

Globally, pipeline construction is primarily in the hands of state-owned enterprises, as shown in Table 5. This domination of transportation infrastructure matches the state domination of other parts of the oil and gas industry, including both reserves and production (Carpenter 2018). By definition, such enterprises are either partly or wholly shielded from private financial markets.

In North America, the ownership pattern is reversed, with most pipeline projects owned by private entities, as shown in Table 6 (on the next page.) One major exception is Alaska, where the quasi-public Alaska Gasoline Development Corporation appears to be weighing whether the $44 billion Alaska LNG pipeline project is too risky. Meanwhile the government of Canada has been widely criticized for acquiring the financially questionable C$5 billion Trans Mountain Pipeline after Kinder Morgan backed out of the project.

Table 5. The Top 20 Global Builders of Oil and Gas Pipelines (by km)

Owner	Proposed	Construction	Total	Ownership	Country
Gazprom	4,625	5,173	9,797	Private	Russia
Ministry of Petroleum of Iran	4,481	1,900	6,381	State-owned	Iran
TransCanada	4,530	1,311	5,841	Private	Canada
Gas Authority of India Limited	3,066	1,373	4,439	State-owned	India
Kinder Morgan	1,304	2,962	4,266	Private	U.S.
Alaska Gasline Development Corporation	3,888	0	3,888	State-owned	U.S.
Plains GP Holdings	2,627	628	3,255	Private	U.S.
Petrobras	0	3,100	3,100	Semi-private	Brazil
Bangladesh Petroleum Corporation	3,010	0	3,010	State-owned	Bangladesh
Iranian Ministry of Petroleum	2,800	0	2,800	State-owned	Iran
Pasargad Energy Development Company	2,800	0	2,800	Private	Iran
Gujarat State Petronet	709	2,042	2,751	State-owned	India
Iraq Ministry of Oil	2,460	0	2,460	State-owned	Iraq
Oil and Natural Gas Corporation	2,333	0	2,333	Private	India
Total S.A.	871	1,444	2,315	Private	France
Government of Kenya	1,799	446	2,245	State-owned	Kenya
Türkmengaz	300	1,814	2,114	State-owned	Turkmenistan
Pertamina	1,611	443	2,054	Private	Indonesia
Sonatrach	1,724	0	1,724	State-owned	Algeria
Indian Oil Corporation Limited	513	1,205	1,718	State-owned	India

Source: Global Fossil Infrastructure Tracker, January 2019

Table 6. The Top 20 North American Builders of Oil and Gas Pipelines (by km)

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TransCanada	4,530	1,311	5,841	Private	Canada
Kinder Morgan	1,304	2,962	4,266	Private	U.S.
Alaska Gasline Development Corporation	3,888	0	3,888	State-owned	U.S.
Plains GP Holdings	2,627	628	3,255	Private	U.S.
Eagle Spirit Energy Holdings	1,601	0	1,601	Private	Canada
Tellurian Inc.	1,482	0	1,482	Private	U.S.
Williams Companies	1,437	17	1,454	Private	U.S.
Energy Transfer TP	0	1,341	1,341	Private	U.S.
Tallgrass Energy	1,304	0	1,304	Private	U.S.
Targa Resources	998	191	1,189	Private	U.S.
Sempra Energy	677	400	1,077	Private	U.S.
Magnum Development	1,046	0	1,046	Private	U.S.
Phillips 66	1,030	0	1,030	Private	U.S.
Canada Development Investment Corporation	980	0	980	State-owned	Canada
Dominion Energy	622	241	863	Private	U.S.
Fairbanks Pipeline Company	827	0	827	Private	U.S.
Fermaca	161	664	825	Private	Mexico
Comisión Federal de Electricidad	0	780	780	State-owned	Mexico
ExxonMobil	698	77	775	Private	U.S.
Magellan Midstream Partners	604	121	724	Private	U.S.

Source: Global Fossil Infrastructure Tracker, January 2019

THE PERFECT STORM

The short-term outlook for fossil fuel investors in North America may seem rosy, with large plays such as the Permian and Marcellus undergoing development, gas replacing coal in many markets, and the Trump administration advocating for more offshore drilling. A storm is coming, however, and the current surge in pipeline construction may prove to be fleeting as the legal system, public opinion, and financial markets increasingly challenge the fossil fuel industry.

Legal Obstacles: In 2016 the Obama Administration established a rule that applications to the Federal Energy Regulatory Commission (FERC) must include an assessment of a pipeline's or other project's impact on climate change. Given that FERC rejected just two out of 400 pipelines applications it received between 1999 and 2017, this new rule could have seismic implications (Horn 2017). With a majority of its five commissioners now serving as Trump appointees, FERC has taken a "see no evil" approach to findings submitted under this rule; for example, when a study found that the proposed Sabal Trail pipeline from Alabama to Florida would increase Florida's rate of greenhouse gas emissions by between 3.6% and 9.9%, FERC approved the project on the grounds that such an increase was not significant. However this rule may be interpreted in the future, the principle that projects must justify their existence in terms of their emissions is taking root in the legal community. In March 2019 a U.S. District Judge blocked the leasing of 500 square miles for drilling in Wyoming on the grounds that the U.S. Bureau of Land Management had not considered the impact of emissions from oil and gas leases nationwide. "This is the Holy Grail ruling we've been after, especially with oil and gas," said Jeremy Nichols of WildEarth Guardians, which sued to block the leases. "It calls into question the legality of oil and gas leasing that's happening everywhere." (Brown and Mead 2019)

Shifting Public Opinion: American public opinion is also turning against the fossil fuel industry. A January 2019 poll by Yale University and George Mason University found that 69% of Americans are "worried" about climate change and 29% are "very worried." This represents an 8% rise among those who are "very worried" since these pollsters' previous survey in April 2018. The shift in public opinion comes as more Americans are personally affected by climate change, from historically-devastating fires in California to catastrophic floods in places such as Houston, Texas and the Carolinas.

Shifting Economics: The world for which many North American pipelines are being built may no longer exist by the time they are completed. Because of their typical lifespans of 40 years or more, pipeline projects and their sponsors tend to be highly leveraged, with long payback periods. For example, as of late 2018 one analyst reported that Enbridge expected to end 2018 with a leverage ratio of 5.0 times debt to EBITDA (earnings before interest, taxes, depreciation, and amortization)—"a bit higher than its comfort zone"—not including a "massive slate" of $16.7 billion in additional pipeline projects (DiLallo 2018).

High Leverage and Unrealistic Expectations: The combination of high leverage and expectations for growth based on ever-increasing Asian demand set the stage for investor disappointment and losses. Such a possibility is not just hypothetical: it is exactly the combination of elements that created the coal mining meltdown of 2008 to 2014, as discussed in the sidebar, "The Coal Mining Equities Crash." While the crash of the coal mining industry cost investors tens of billions, a similar stumble in the oil and gas industry has much larger implications because of the larger size of the sector. At their peak in 2011, the combined equity value of the coal mining sector amounted to about $80 billion; by mid-2015 that value had dropped about $12 billion, a $68 billion loss (Coats 2015). In contrast, the amount of capital expenditure on pipelines alone is expected to be well over $200 billion over the coming decades, out of a total midstream oil and gas infrastructure investment of $1 trillion for the U.S. alone. The combination of large financial sums at stake, excess enthusiasm based on uncertain overseas markets, and growing social stigmatization are all factors that should cause both individual and institutional investors to turn away from further bets on pipelines and other midstream infrastructure investments.

METHODOLOGY

The Global Fossil Infrastructure Tracker uses a two-level system for organizing information. Summary data is maintained in Google sheets, with each spreadsheet row linked to a page on the SourceWatch wiki. Each wiki page functions as a footnoted fact sheet, containing project parameters, background, and mapping coordinates. Each worksheet row tracks an individual pipeline project. Under standard wiki convention, each piece of information is linked to a published reference, such as a news article, company report, or regulatory permit. In order to ensure data integrity in the open-access wiki environment, Global Energy Monitor researchers review all edits of project wiki pages by unknown editors. For each project, one of the following status categories is assigned and reviewed on a rolling basis:

- **Proposed:** Projects that have appeared in corporate or government plans in either pre-permit or permitted stages.
- **Construction:** Site preparation and other development and construction activities are underway.
- **Shelved:** In the absence of an announcement that the sponsor is putting its plans on hold, a project

is considered "shelved" if there are no reports of activity over a period of two years.

- **Cancelled:** In some cases a sponsor announces that it has cancelled a project. More often a project fails to advance and then quietly disappears from company documents. A project that was previously in an active category is moved to "Cancelled" if it disappears from company documents, even if no announcement is made. In the absence of a cancellation announcement, a project is considered "cancelled" if there are no reports of activity over a period of four years.
- **Operating:** The pipeline has been formally commissioned or has entered commercial operation.
- **Mothballed:** Previously operating projects that are not operating but maintained for potential restart.
- **Retired:** Permanently closed projects.

To allow easy public access to the results, Global Energy Monitor worked with GreenInfo Network to develop a map-based and table-based interface using the Leaflet Open-Source JavaScript library. The public view of the Global Fossil Infrastructure Tracker can be accessed at OilWire.org.

REFERENCES

Aizu, C. "Stepping on the gas: China's home-built fracking boom." Reuters, June 21, 2018. https://reut.rs/2SHedRG

Brown, M. and Gruver, M. "Judge Blocks Oil and Gas Drilling on Wyoming Land, Citing Climate Change." Time, March 20, 2019. http://bit.ly/2Z63Qvt

Bruggers, J. "Plastics: The New Coal in Appalachia?" Inside Climate News, February 25, 2019. http://bit.ly/2SFpmT8

Buckley, T. "Over 100 Global Financial Institutions Are Existing Coal, With More to Come." Institute for Energy Economics and Financial Analysis. February 27, 2019. http://bit.ly/2Tactk9

Carpenter, J. "The World's Biggest State-Owned Oil Companies." Investopedia, November 9, 2018. http://bit.ly/2XxFzNS

Coats, C. "US coal industry market value plummets by nearly half in under a year." SNL, June 10, 2015. http://bit.ly/2SBys3n

DiLallo, M. "Pipeline Stocks 101: An Investor's Guide." Motley Fool, September 23, 2018, http://bit.ly/2InenOx

Horn, S. "FERC, Which Rejected 2 Gas Pipelines Out of 400 Since 1999, to Review Approval Policy." EcoWatch, Dec. 26, 2017. http://bit.ly/2Z2VWCP

Husseini, T. "African countries to benefit from $175bn US gas investment." Offshore Technology. July 25, 2018. http://bit.ly/2SBv4oZ

International Energy Agency (IEA). World Energy Outlook 2018. http://bit.ly/2SA10KA

Jacobs, T. "China Flexes Shale Muscles as CNPC Ups Gas Output 40%." Journal of Petroleum Technology, January 10, 2019. http://bit.ly/2SDFnsI

Petak, K. et al. "U.S. Oil and Gas Infrastructure Investment Through 2035." American Petroleum Institute, 2017. http://bit.ly/2SEW72M

Ritchie, H. and Roser, M. "Global fossil fuel consumption over the long-term." Accessed March 2019. http://bit.ly/2SzPSgI

RBP. Statistical Review of World Energy. 2018. https://on.bp.com/2SD6NPF

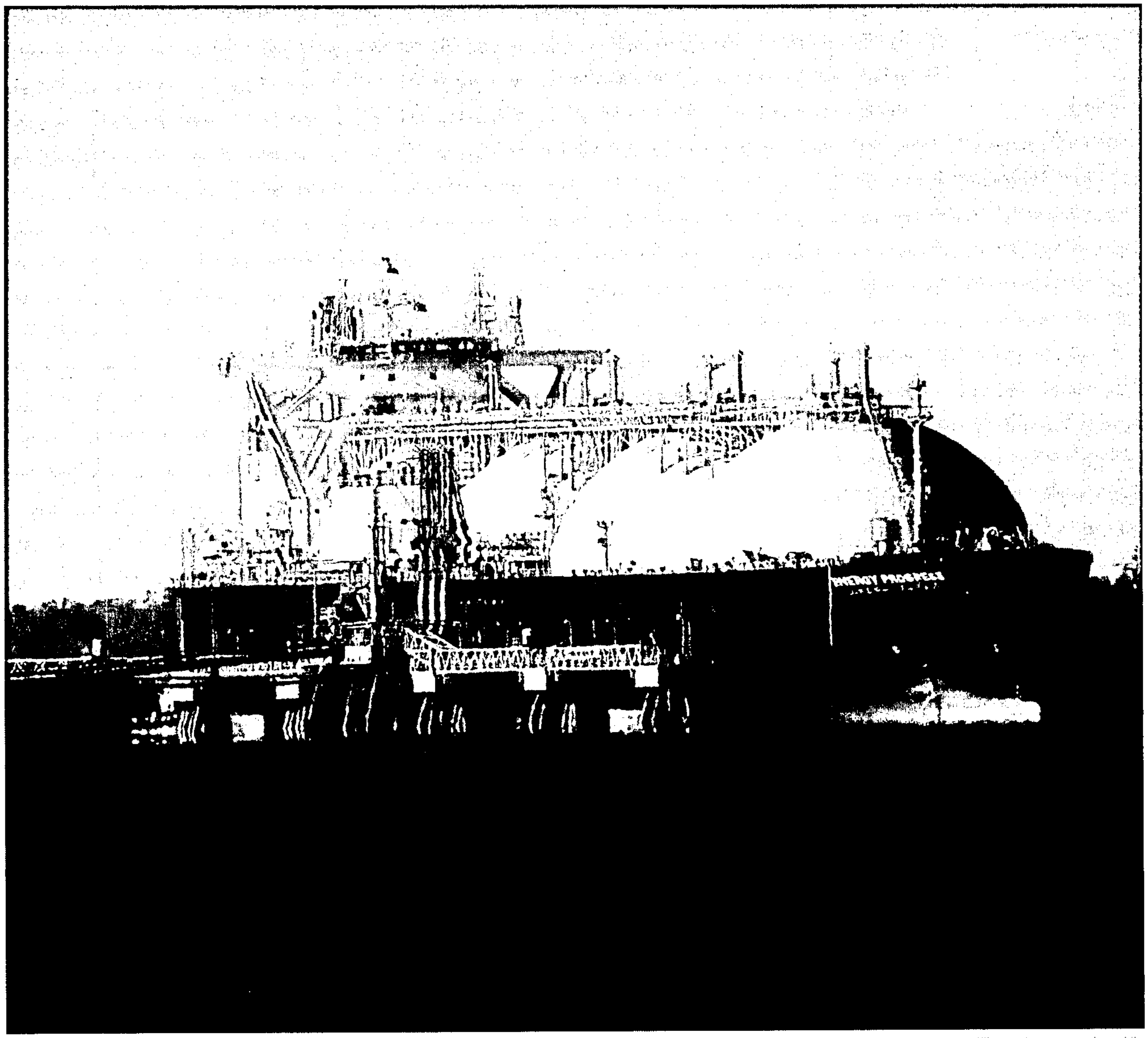
Smil, Vaclav. Energy Transitions: Global and National Perspectives. 2018. http://bit.ly/2SFM5yu

U.S. Energy Information Administration (US EIA). Annual Energy Outlook 2019. 2019. http://bit.ly/2SSSPsR

The New Gas Boom

TRACKING GLOBAL LNG INFRASTRUCTURE

Ted Nace, Lydia Plante, and James Browning



ABOUT THE COVER

LNG tanker Energy Progress taking on cargo at Darwin LNG Terminal, Northern Territory, Australia, in March 2016.

Global Energy Monitor

ABOUT GLOBAL ENERGY MONITOR

Global Energy Monitor (formerly CoalSwarm) is a network of researchers developing collaborative informational resources on fossil fuels and alternatives. Current projects include the Global Coal Plant Tracker, the Global Fossil Infrastructure Tracker, the CoalWire newsletter, and the CoalSwarm and FrackSwarm wiki portals.

ABOUT THE GLOBAL FOSSIL INFRASTRUCTURE TRACKER

The Global Fossil Infrastructure Tracker is an online database that identifies, maps, describes, and categorizes oil and gas pipelines and oil, gas, and coal terminals. Developed by Global Energy Monitor, the tracker uses footnoted wiki pages to document each plant. For further details, see "Methodology" at http://ggon.org/fossil-tracker/

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FURTHER RESOURCES

For additional data on proposed and existing pipelines, Summary Data at http://ggon.org/fossil-tracker/ provides over 50 tables compiled from the Global Fossil Infrastructure Tracker (GFIT), broken down by nation and region. To obtain primary data from the GFIT, contact Ted Nace (ted@tednace.com).

The New Gas Boom

TRACKING GLOBAL LNG INFRASTRUCTURE

Ted Nace, Lydia Plante, and James Browning

EXECUTIVE SUMMARY

Through a massive increase in portside infrastructure, floating offshore terminals, and oceangoing LNG vessels, the natural gas industry is seeking to restructure itself from a collection of regional markets into a wider and more integrated global system. If successful, this transformation would lock in much higher levels of natural gas production through mid-century—a seeming win for the industry—except that the falling cost of renewable alternatives will make many of these projects unprofitable in the long term and put much of the $1.3 trillion being invested in this global gas expansion at risk. Such an expansion is also incompatible with the IPCC's warning that, in order to limit warming to 1.5°C above pre-industrial levels, gas use must decline 15% by 2030 and 43% by 2050, relative to 2020.

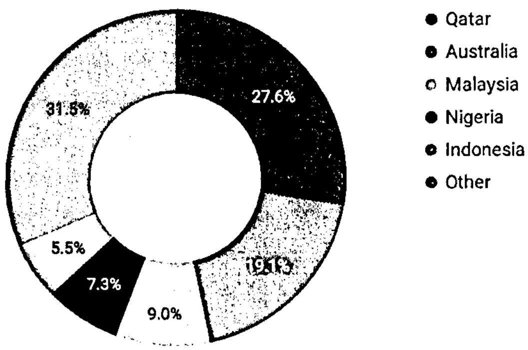
This report provides the results of a worldwide survey of LNG terminals completed by the Global Fossil Infrastructure Tracker. The report includes the following highlights:

- Methane, the chief component in natural gas, is responsible for 25% of global warming to date.
- Measured by global warming impacts, the scale of the LNG expansion under development is as large or greater than the expansion of coal-fired power plants, posing a direct challenge to Paris climate goals.
- Due to falling costs of renewable alternatives, the expansion of LNG infrastructure faces questions of long-term financial viability and stranded asset risk. However, since only 8% of terminal capacity under development has entered construction, there is still time to avoid overbuilding.
- At least 202 LNG terminal projects are in development worldwide, including 116 export terminals and 86 import terminals.
- LNG export terminals are under development in 20 countries, of which Canada and the U.S. account for 74% of proposed new capacity. If built, LNG terminals in pre-construction and construction would increase current global export capacity threefold.
- LNG import terminals are in development in 42 countries, of which 22 have no current import capacity. Capacity expansion is focused on the Asia Pacific Region.
- Overall, LNG terminals in development represent capital outlays of $1.3 trillion, of which 70% is for North American export terminals and 6% is for Asia Pacific import terminals. In terms of capital outlays for import and export terminals combined, the top ten countries are United States ($507 billion), Canada ($410 billion), Russia ($86 billion), Australia ($38 billion), Tanzania ($25 billion), China ($24 billion), Indonesia ($24 billion), Mozambique ($23 billion), Iran ($21 billion), and Papua New Guinea ($17 billion).

THE GROWING ROLE OF LNG IN NATURAL GAS MARKETS

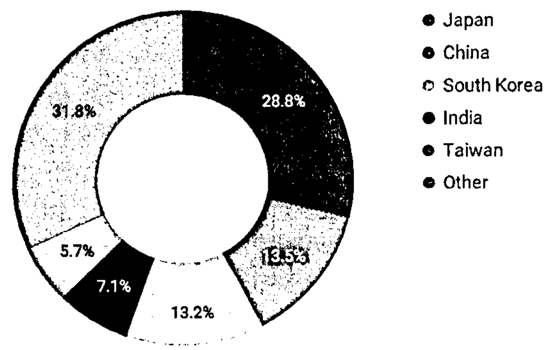
Historically, most natural gas was transported by pipeline within regions, with a small fraction (5.5% in 2000) transported by ship as liquified natural gas (LNG), mainly from a handful of producing countries (led by Qatar and Australia) to a handful of importing countries (led by Japan, China, and South Korea). In the case of both imports and exports, just five exporting and five importing countries accounted for two-thirds of the global LNG trade in 2017, as shown in Figures 1 and 2. Since 2000, the share of LNG in the global system has doubled to 11%, with 432 billion cubic meters of LNG in 2018 out of total global natural gas production of 3,940 bcm (IEA 2019).

Figure 1. Shares of LNG Exports for Top Five Countries, 2017



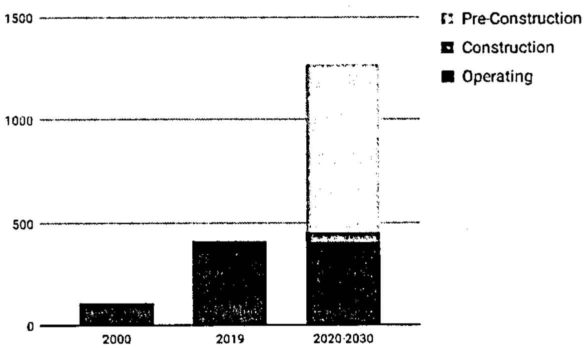
Source: International Gas Union, 2018

Figure 2. Shares of LNG Imports for Top Five Countries, 2017



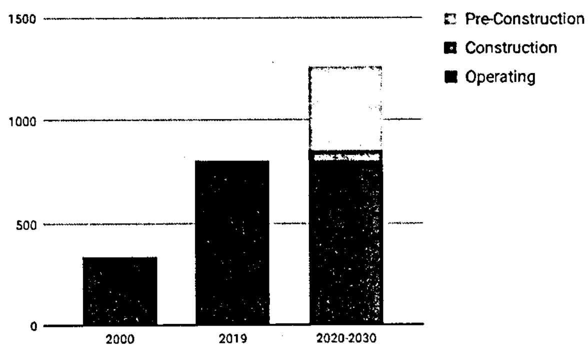
Source: International Gas Union, 2018

Figure 3. LNG Export Capacity in 2000, 2019, and in Development



Source: Global Fossil Infrastructure Tracker, April 2019

Figure 4. LNG Import Capacity in 2000, 2019, and in Development



Source: Global Fossil Infrastructure Tracker, April 2019

TOWARD A NORTH AMERICA–CENTERED, GLOBALLY INTEGRATED NATURAL GAS SYSTEM

As shown in Figure 3, projects currently under construction or in pre-construction would more than triple global export capacity. If fully implemented, current proposals will raise the share of LNG in overall gas production to 20% by 2030, assuming sector growth in line with the IEA New Policies Scenario (IEA 2018).

Besides growing in market share, LNG is also growing in geographic scope to include more producing and recipient countries. Together, the two developments are shifting the global gas system to a more globally integrated system connected by shipborne LNG cargoes.

Although some new LNG export capacity is under development in 20 countries, as shown in Table 2, the vast majority is concentrated in North America, including 352.7 million tonnes per annum (MTPA) under development in the U.S. and 281.6 MTPA under development in Canada, or 74% of all export capacity in development globally.

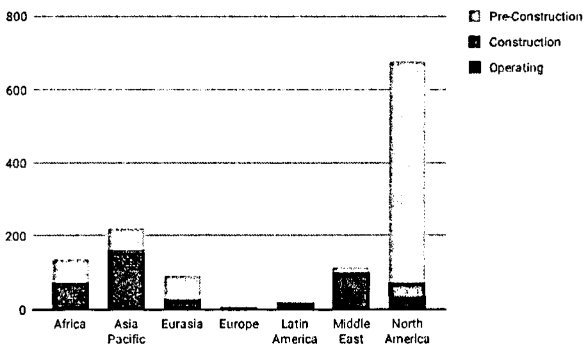
As shown in Figure 4 and Table 1, expansion of LNG import capacity is more widely distributed, including 65.6 million tonnes per annum of new capacity in 22 countries that currently have no import capacity. Overall, projects under development would increase the number of countries with LNG import capacity from 40 to 62.

Table 1. LNG Importing Countries, 2000, 2019, and 2030 (projects in development shown in red)

Year	Countries
2000	Belgium, France, Greece, Italy, Japan, South Korea, Spain, Taiwan, Turkey, USA
2019	Argentina, Bangladesh, Belgium, Brazil, Canada, Chile, China, Colombia, Dominican Republic, Finland, France, Greece, India, Indonesia, Israel, Italy, Jamaica, Japan, Jordan, Kuwait, Lithuania, Malaysia, Malta, Mexico, Netherlands, Pakistan, Panama, Poland, Portugal, Russia, Singapore, South Korea, Spain, Sweden, Taiwan, Thailand, Turkey, United Arab Emirates, United Kingdom, USA
2030	Argentina, **Australia**, **Bahrain**, Bangladesh, Belgium, Brazil, Canada, Chile, China, Colombia, **Croatia**, **Cyprus**, Dominican Republic, Finland, **Egypt**, **Estonia**, France, **Germany**, **Ghana**, Greece, **Haiti**, India, Indonesia, **Ireland**, Israel, Italy, Jamaica, Japan, Jordan, **Kenya**, Kuwait, Lithuania, Malaysia, Malta, Mexico, **Morocco**, **Myanmar**, **Namibia**, Netherlands, **Nigeria**, Pakistan, Panama, **Philippines**, Poland, Portugal, **Romania**, Russia, Singapore, **South Africa**, South Korea, Spain, **Sri Lanka**, Sweden, Taiwan, Thailand, Turkey, United Arab Emirates, **Ukraine**, United Kingdom, USA, **Uruguay**, **Vietnam**

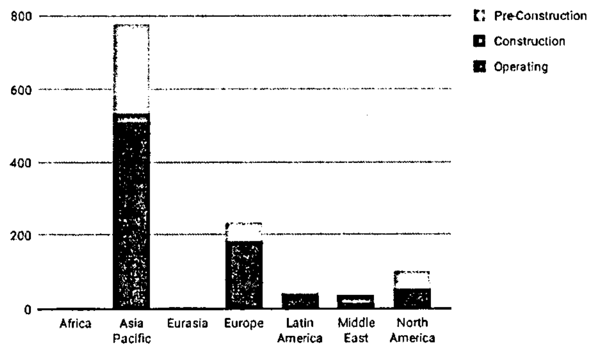
Source: Global Fossil Infrastructure Tracker, April 2019

Figure 5. LNG Export Capacity by Region and Developmental Status, 2019 (million tonnes per annum)



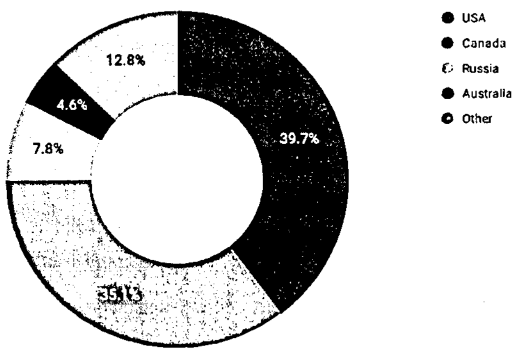
Source: Global Fossil Infrastructure Tracker, April 2019

Figure 6. LNG Import Capacity by Region and Developmental Status, 2019 (million tonnes per annum)



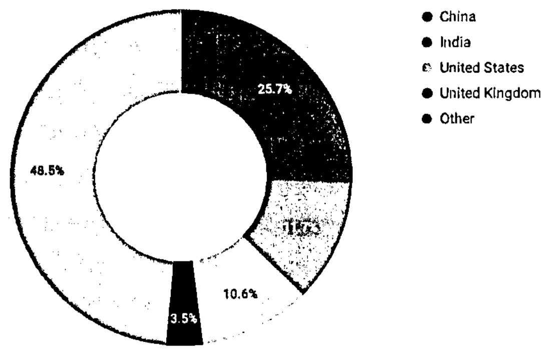
Source: Global Fossil Infrastructure Tracker, April 2019

Figure 7. LNG Export Capacity in Development (Pre-Construction and Construction), 2019, Top Four Countries



Source: Global Fossil Infrastructure Tracker, April 2019

Figure 8. LNG Import Capacity in Development (Pre-Construction and Construction), 2019, Top Four Countries



Source: Global Fossil Infrastructure Tracker, April 2019

Table 2. LNG Export (Liquefaction) and Import (Regasification) Capacity by Country and Developmental Status (million tonnes per annum), 2019

	Export Terminals			Import Terminals		
Country	Operating	Construction	Pre-Construction	Operating	Construction	Pre-Construction
Algeria	25.3	0.0	4.0	0.0	0.0	0.0
Angola	5.2	0.0	0.0	0.0	0.0	0.0
Argentina	0.0	0.0	0.0	7.8	0.0	0.0
Australia	83.2	0.0	36.7	0.0	0.0	5.2
Bahrain	0.0	0.0	0.0	0.0	6.1	0.0
Bangladesh	0.0	0.0	0.0	5.0	3.5	7.5
Belgium	0.0	0.0	0.0	9.0	0.0	0.0
Brazil	0.0	0.0	0.0	8.9	3.6	0.0
Brunei	7.2	0.0	0.0	0.0	0.0	0.0
Cameroon	2.4	0.0	0.0	0.0	0.0	0.0
Canada	0.0	0.0	281.6	21.2	0.0	11.0
Chile	0.0	0.0	0.0	5.3	3.3	1.4
China	0.0	0.0	0.0	73.2	8.6	78.5
Colombia	0.0	0.0	0.0	3.0	0.0	0.0
Croatia	0.0	0.0	0.0	0.0	0.0	1.5
Cyprus	0.0	0.0	5.0	0.0	0.0	1.3
Dominican Republic	0.0	0.0	0.0	1.9	0.0	0.0
Egypt	12.2	0.0	0.0	0.0	0.0	0.0
Equatorial Guinea	3.7	0.0	8.8	0.0	0.0	0.0
Estonia	0.0	0.0	0.0	0.0	0.0	4.5
Finland	0.0	0.0	0.0	1.6	0.1	0.0
France	0.0	0.0	0.0	27.8	0.0	0.0
Germany	0.0	0.0	0.0	0.0	0.0	11.0
Ghana	0.0	0.0	0.0	0.0	3.4	0.0
Greece	0.0	0.0	0.0	7.7	0.0	0.0
India	0.0	0.0	0.0	49.0	10.0	29.5
Indonesia	26.5	4.3	11.0	8.9	0.0	7.8
Iran	0.0	0.0	13.3	0.0	0.0	0.0
Ireland	0.0	0.0	0.0	0.0	0.0	2.0
Israel	0.0	0.0	0.0	3.7	0.0	0.0
Italy	0.0	0.0	0.0	11.7	0.0	3.5
Jamaica	0.0	0.0	0.0	4.8	0.0	2.5
Japan	0.0	0.0	0.0	219.7	0.0	11.7
Jordan	0.0	0.0	0.0	5.5	0.0	0.0
Kenya	0.0	0.0	0.0	0.0	0.0	0.3
Kuwait	0.0	0.0	0.0	9.6	11.3	0.0
Lithuania	0.0	0.0	0.0	2.2	0.0	0.0
Malaysia	30.5	1.5	0.0	7.3	0.0	0.0

Table 2 (continued)

	Export Terminals			Import Terminals		
Country	**Operating**	**Construction**	**Pre-Construction**	**Operating**	**Construction**	**Pre-Construction**
Malta	0.0	0.0	0.0	0.4	0.0	0.0
Mexico	0.0	0.0	7.0	16.1	0.0	0.0
Mozambique	0.0	3.4	12.0	0.0	0.0	0.0
Myanmar	0.0	0.0	0.0	0.0	0.0	4.0
Netherlands	0.0	0.0	0.0	9.0	0.0	0.0
Nigeria	21.9	0.0	10.0	0.0	0.0	0.0
Norway	4.5	0.0	0.0	0.0	0.0	0.0
Oman	10.8	0.0	0.0	0.0	0.0	0.0
Pakistan	0.0	0.0	0.0	14.5	0.0	4.5
Panama	0.0	0.0	0.0	1.5	0.0	0.0
Papua New Guinea	6.9	0.0	14.0	0.0	0.0	0.0
Peru	4.5	0.0	0.0	0.0	0.0	0.0
Philippines	0.0	0.0	0.0	0.0	1.5	0.0
Poland	0.0	0.0	0.0	3.7	0.0	1.8
Portugal	0.0	0.0	0.0	6.0	0.0	0.0
Qatar	77.0	0.0	0.0	0.0	0.0	0.0
Romania	0.0	0.0	0.0	0.0	0.0	6.0
Russia	28.0	2.0	62.6	2.7	0.0	0.0
Senegal	0.0	0.0	2.5	0.0	0.0	0.0
Singapore	0.0	0.0	0.0	11.0	0.0	5.3
South Africa	0.0	0.0	0.0	0.0	0.0	1.6
South Korea	0.0	0.0	0.0	101.8	0.0	3.6
Spain	0.0	0.0	0.0	46.0	0.0	2.0
Sri Lanka	0.0	0.0	0.0	0.0	0.0	2.7
Sweden	0.0	0.0	0.0	0.4	0.0	0.0
Taiwan	0.0	0.0	0.0	12.0	0.0	7.8
Tanzania	0.0	0.0	20.0	0.0	0.0	0.0
Thailand	0.0	0.0	0.0	10.0	0.0	9.0
Trinidad and Tobago	15.5	0.0	0.0	0.0	0.0	0.0
Turkey	0.0	0.0	0.0	19.4	0.0	0.0
Ukraine	0.0	0.0	0.0	0.0	0.0	7.3
United Arab Emirates	5.8	0.0	0.0	4.0	0.0	0.0
United Kingdom	0.0	0.0	0.0	35.0	0.0	12.0
Uruguay	0.0	0.0	0.0	0.0	0.0	0.1
USA	37.3	34.3	318.4	17.6	0.0	36.0
Vietnam	0.0	0.0	0.0	0.0	0.0	4.6
Yemen	7.2	0.0	0.0	0.0	0.0	0.0
Total	**415.5**	**45.5**	**806.9**	**805.9**	**51.4**	**287.5**

Source: Global Fossil Infrastructure Tracker, April 2019.

EXPORT INFRASTRUCTURE IS THE FOCUS OF THE EXPANSION

Global LNG export capacity is smaller than global LNG import capacity, and utilization rates are higher than for LNG import terminals. This means that LNG export capacity is the limiting factor in the growth of global LNG usage, particularly from North American fracked gas production. In 2018, average utilization rates were 79% for export terminals and 40% for import terminals. Since existing export capacity is rarely idle, significant growth in LNG exports will not be possible without building new LNG export terminal capacity.

As shown in Table 3, import terminal capacity under development is heavily concentrated in the Asia Pacific region, led by China with 87.1 million tonnes per annum (MTPA) and India with 39.5 MTPA, as shown in Table 2. The leading importer, Japan, has comparatively modest expansion plans, with only 11.7 MTPA in development.

CAPITAL COSTS: $1.3 TRILLION

The capital expenditures required for LNG terminals in development amount to $1.3 trillion globally and are overwhelmingly concentrated in North America, where $914.5 billion in export terminals are development, representing 70% of the global total. As shown in Table 3, export terminals dominate proposed expenditures, for two reasons. First, a larger amount of export capacity is currently under development globally. Second, on a tonne-for-tonne basis, the liquefaction process at export terminals is more expensive than the regasification process at import terminals, due to the massive cooling and pressurization processes required for liquefaction. The International Gas Union estimates capital costs for export terminals at $1,501 per tonne of annual capacity for greenfield projects and $458 per tonne for brownfield projects; IGU estimates capital costs for import terminals projects at $274 per tonne (IGU 2018).

Table 3. Capital Investments for LNG Export (Liquefaction) and Import (Regasification) Terminals Under Development (Billion US$)

Region	Export	Import	Total
Africa	85.0	1.4	86.5
Asia Pacific	75.5	73.2	148.7
Eurasia	85.6	0.0	85.6
Europe	7.5	14.2	21.7
Latin America	0.0	3.0	3.0
Middle East	21.0	4.8	25.8
North America	914.5	12.9	927.4
Total	**1,189.2**	**109.4**	**1,298.6**

Sources: Capacity estimates from Global Fossil Infrastructure Tracker, April 2019; Capital costs from IGU 2018.

STRANDED ASSET RISK

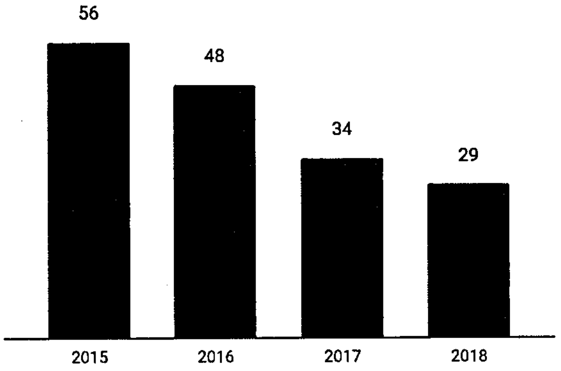
Despite its price tag ($1.3 trillion) and its role in the climate crisis, the expansion of LNG infrastructure has received relatively little scrutiny in terms of stranded asset risk. But attention to stranded asset issues is rising due to increased cost pressure on natural gas by renewable alternatives. In its 12th annual levelized cost of energy study, Lazard Bank reported that unsubsidized solar PV is now cheaper or comparable in cost to natural gas peaking power in all economies studied, including the U.S., Australia, Brazil, India, South Africa, Japan, and Northern Europe. Similarly, wind power is now cheaper or comparable in cost to combined cycle gas turbines across the same set of countries (Lazard 2018). A 2018 study by Rocky Mountain Institute concluded that U.S. power system portfolios built around renewables and distributed energy resources will offer the same grid reliability at lower cost as gas generators by 2026 at gas prices of $5 per million Btu, or by 2040 at $3 per million Btu. Such a shift would place hundreds of billions of dollars of relatively new gas plants in jeopardy of becoming stranded assets (Dyson 2018). To the extent that new LNG terminals are relying on power sector demand, that infrastructure is also at risk of underutilization.

As an example of how competitive renewables are fundamentally changing the power industry, falling orders for natural gas turbines have dramatically impacted the market value of power equipment manufacturer General Electric, which has declined in value from over $350 billion in 2007 to under $90 billion in 2019, including a $23 billion write-down on its investment in the power and grid division of Alstom. According to one analysis, "While financial leverage drove the collapse of GE's value over 2016–2018, the trigger was the halving of global thermal power sector demand." (Buckley 2019a) Figure 10 shows the decline in worldwide orders for gas turbines that drove the fall in GE's market value.

The financial shocks now being experienced in the natural gas sector are reminiscent of similar patterns in the coal sector, where euphoric forecasts of growth based on East Asian demand a decade ago led to overexpansion and financial collapse. In 2010, Peabody Energy Chairman Gregory Boyce predicted that rising demand in China and China's neighboring economies would create "a long-term super-cycle for coal." (Schmidt 2010.) Yet in a relatively short time span, 2011 to 2016, falling coal prices and competitive alternatives forced Peabody Energy along with most other major American coal companies to file for Chapter 11 protection (Nace 2019).

The sort of instability that has afflicted the coal sector similarly threatens the long-term financial viability of fracked gas. As with coal, capital investments in the gas sector must be made under conditions of inherent uncertainty about key factors such as the rate of decline in the cost of renewables and the level of climate regulation a decade in the future. For natural gas, the fact that fracking remains a relatively new practice whose long-term economics are still not well understood adds yet another dimension of risk. After a cross-section of 29 fracking-focused companies found more than $2.5 billion in negative free cash flows in the first quarter of 2019, raising the aggregate negative cash flow from fracking to $184 billion since 2010, analysts at Sightline Institute and the Institute for Energy Economics and Financial Analysis concluded that negative cash flows appeared to be chronic and "should be of grave concern to investors." The analysts wrote, "Until fracking companies can demonstrate that they

Figure 9. Gas Turbine Industry Orders (gigawatts)



Source: GE 2018 Annual Report. Includes turbines 30 megawatts and larger.

can produce cash as well as hydrocarbons, cautious investors would be wise to view the fracking sector as a speculative enterprise with a weak outlook and an unproven business model." (Williams-Derry, 2019.)

Compounding questions of financial risk are widening concerns about the impact of natural gas on global warming. As detailed in the sidebar "Hero to Villain," the perception of gas, especially when produced by fracking and shipped as LNG, has shifted in recent years due to several new findings:

- Estimates of the level of fugitive emissions have risen.
- Estimates of the potency of methane as a global warming gas have also risen.
- Fracked gas, with approximately 50% higher fugitive emissions than conventional natural gas, now dominates the production mix in North America.
- Due to the additional energy demands and opportunities for fugitive emissions involved in liquefaction, shipborne transport, and regasification, LNG is seen as particularly damaging to climate stability.
- In its most recent reports, the IPCC has called for near-term reduction in natural gas production of 15% by 2030 and 43% by 2050, relative to 2020 (see Table 5). Such reductions are not compatible with expansion of the current natural gas system, including the building of new LNG capacity.

METHANE AS A GLOBAL WARMING GAS: 7 KEY NUMBERS

As described in the sidebar, "Hero to Villain: Changing View of Natural Gas," the perception of the benefit or harm of natural gas in a climate-constrained energy system has shifted over the past decade from positive to negative, as climate scientists measure with increasing accuracy the level of leakage throughout the natural gas supply and delivery system and the potency of methane as a global warming gas. While carbon dioxide plays a larger role than methane in global warming, a number of recent findings indicate that the role of methane is larger than previously thought. Seven key numbers illustrate the shift in understanding.

Table 4. Seven Key Methane Numbers

700	In the pre-industrial era, the level of gas was about 700 parts per billion (NASA 2016).
1,850	In 2018, climate scientists reported that atmospheric methane had risen from 1,775 parts per billion in 2006 to 1,850 ppb in 2017 and was growing at an accelerating rate. The rapid growth, which had not been expected, "is sufficient to challenge the Paris Agreement." (Nisbet 2017)
25%	The percentage of global warming to date caused by methane (Myhre 2014).
2.3%	In 2018, a major peer-reviewed study estimated that the leakage rate for the U.S. gas system was 2.3%. The estimate was 60% higher than the figure previously used by the U.S. government in major assessments of natural gas (Alvarez 2018).
86	Compared to carbon dioxide (CO_2), methane (CH_4) is a relatively short-lived but highly potent global warming gas, which remains in the atmosphere for only a decade but during that time has more than 100 times as much effect on global warming as carbon dioxide. Considered over a 20-year horizon, methane's global warming impact is 86 times that of carbon dioxide, according to the most recent IPCC assessment (Myhre 2014).
34	Considered over a 100-year horizon, methane's global warming impact is 34 times that of carbon dioxide, according to the most recent IPCC assessment (Myhre 2014).
25%	In 2016 the authors of the IPCC's 2014 assessment concluded that methane's impact on global warming is about 25% higher than previously estimated, further raising concerns (Etminan 2016).

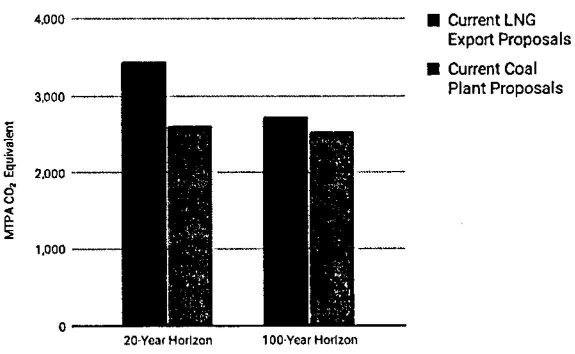
WORSE THAN THE COAL BOOM: MEASURING THE CARBON FOOTPRINT OF THE LNG BOOM

To assess the global warming footprint of the LNG terminal boom, we can compare it to another boom: the expansion of global coal-fired generating capacity. Both expansions involve the construction of massive new facilities with life expectancies of four decades or more.

Currently, over 579 gigawatts (GW) of coal power capacity is under construction or in pre-construction (Shearer 2019). In order to compare that to the 856 million tonnes per year of LNG export capacity under construction or in pre-construction, we need to examine both expansions on the basis of lifecycle emissions for both CO_2 and methane, including all stages from mining or drilling through final consumption. That analysis is detailed in Appendix B. It uses a common basis for comparison known as "CO_2 equivalency" or CO_2e. Since methane (CH_4) in natural gas lasts for only about a decade, but during time has over 100 times the global warming potency of CO_2, determining CO_2e requires that the analysis specify the time horizon over which the global warming averages are being averaged. Analyses of methane typically use two alternative comparisons, one over a 20-year period, the other over a 100-year period. The 20-year horizon is relevant for understanding how greatly methane emissions will affect the climate in the short term; the 100-year horizon is relevant for understanding the long-term effect on climate.

The results of the lifecycle comparison, including fugitive methane emissions, show that current proposals for new LNG terminal capacity, if fully developed, would lock in global warming impacts that are roughly equivalent, when considered on a 100-year horizon, to those of current proposals for new coal-fired power plants. These proposals amount to 574 GW of new coal-fired generating capacity, or 1,214 generating units (Global Coal Plant Tracker, January 2019). When considered on a 20-year horizon, the global warming impact of current proposals for new LNG terminals exceed current proposals for new coal-fired plants by 25%.

Figure 10. Comparing the Life Cycle Global Warming Footprint of Proposed Expansion of LNG-Transported Natural Gas (856.4 MTPA) to the Life Cycle Global Warming Footprint of Proposed Coal Plants, (574 GW). Both Life Cycle estimates in Million Tonnes Per Annum CO_2 Equivalent.



Based on Global Coal Plant Tracker (January 2019) and Global Fossil Infrastructure Tracker (April 2019). For details, see Appendix A.

HERO TO VILLAIN: CHANGING VIEWS OF NATURAL GAS

"With the move to natural gas, it's as if we proudly announced we kicked our Oxycotin habit by taking up heroin instead." —Bill McKibben

Because power plant combustion of natural gas produces about 40% less carbon dioxide than combustion of coal, proponents of natural gas have characterized it as a "bridge" from coal to renewables (Oil Change International 2017, Sightline 2019). However, a full life cycle comparison of both natural gas and coal requires also including the effect of leakages in natural gas production and transportation, since methane (CH_4), the main component of natural gas, is a far more powerful global warming gas than carbon dioxide.

Early life cycle comparisons favor gas. A milestone in addressing the full life cycle impacts of natural gas was the U.S. Department of Energy's 2014 report "Life Cycle Greenhouse Gas Perspectives on Exporting Liquefied Natural Gas from the United States." That report showed lower life cycle greenhouse gas impacts from exporting LNG to overseas power plants than from burning domestic coal (U.S. Department of Energy, 2014).

Updated leakage estimates alter the assessment. The 2014 DOE report was based on the assumption that methane leakage was 1.3% for conventional onshore gas and 1.4% for fracked gas. In 2018, a comprehensive reassessment of methane emissions in the U.S. oil and gas supply chain, based on facility-scale measurements and validated with aircraft observations in areas accounting for about 30% of U.S. gas production, concluded that the overall leakage rate for natural gas was 2.3% of gross U.S. gas production, a figure 60% higher than the U.S. Environmental Protection Agency inventory estimate (Alvarez 2018). At the higher leakage rate, the advantage to using coal disappears. Multiple studies estimate the overall leakage rates even higher than the 2.3% Alvarez estimate, due to the fact that the Alvarez study did not include "downstream" leaks in the distribution of gas. Such leaks account for an additional 2.7 ± 0.6%, according to a study of Boston (McKain 2015).

Fracked gas versus conventional gas. Side-by-side comparisons of conventionally produced gas and gas produced by fracking indicate that fracked gas, also known as "unconventional" gas, is associated with approximately 50% great leakages than conventional gas (Brandt 2014). From 2000 to 2015, the share of fracked gas in U.S. production went from less than 5% to 67%, and continues to rise (US EIA 2016). With the greater share of fracked gas in the overall mix, the relative level of fugitive emissions has correspondingly risen.

Adding shortwave effects shows even more harm from methane. More recently, the authors of the IPCC findings issued a significant revision in their estimate of the relative ratios that incorporated new findings based on the inclusion of shortwave climate forcing. The new findings raise estimates of methane's climate impact relative to carbon dioxide by about 25% (Etminan 2016).

20-Year or 100-Year? Methane has a residence time in the atmosphere of only a decade, but while present its greenhouse warming effect is more than 100 times that of carbon dioxide, on a mass-to-mass basis (Howarth 2015). Averaged over a 20-year time period, the ratio between methane and carbon dioxide, including climate-carbon feedbacks, is 86:1; over a 100-year time period the ratio including climate-carbon feedbacks is 34:1, according to the Intergovernmental Panel on Climate Change (IPCC 2014).

Additional considerations. Increasingly, climate advocates have pointed out that the debate over whether coal or gas is worse from a climate perspective misses a larger point, namely, that according to the most findings of the IPCC, the entire global system must decarbonize by 2050 (Stockman 2019). Replacing old coal infrastructure with new gas infrastructure will lock in a fossil-based system, effectively resetting the clock on system transformation by another 40 or more years. Such a result is incompatible with the mandate that fossil emissions be phased out by mid-century.

IPCC 1.5° findings. The October 2018 report of the IPCC, "Global Warming of 1.5°C," brought new urgency to the need for fossil fuel reductions. As shown in Table 5, which is based on pathways that would allow a 1-in-2 to 2-in-3 chance of limiting global warming to 1.5°C above pre-industrial levels, gas must decline 15% by 2030 and 43% by 2050, relative to 2020.

Table 5. Median primary energy supply (Exajoules) for below IPCC 1.5°C pathways with low overshoot.

	2020	2030	2050
Gas	132.95	112.51	76.03

Source: IPCC, "Global Warming of 1.5°C," Table 2.6, October 2018

CONCLUSION: A MORATORIUM IS NEEDED ON NEW LNG CONSTRUCTION

As shown in Table 2, plans for LNG export terminals includes 45.5 MTPA in projects under construction and 806.9 MTPA in pre-construction projects; for LNG import terminals, plans include 51.4 MTPA in projects under construction and 349.3 MTPA in pre-construction projects. As shown in Table 6, which reflects only projects with known dates and does not account for schedule slippage, a large amount of capacity has announced dates prior to 2026 and may be close to entering construction. Given the climate mandate that natural gas be scaled back over the next decade, not to mention the risk to investors of stranded assets and financial losses from overbuilding, a sensible approach to the question of LNG terminal expansion would be a moratorium on further construction.

Table 6. LNG Terminal Projects in Pre-Construction, including Export and Import, by Announced Start Year (million tonnes per annum)

Start Year	MTPA
2019	99
2020	71
2021	69
2022	162
2023	63
2024	58
2025	112
2026	37
2027	21
2028	0
2029	0
2030	20
Total	**712**

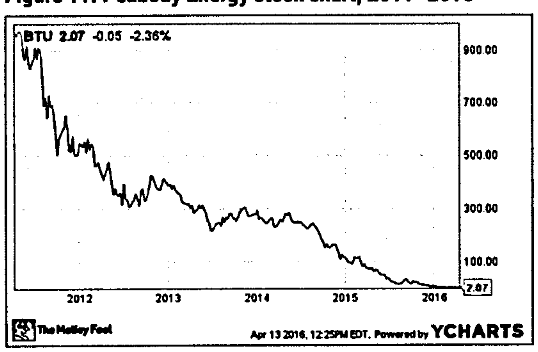
Source: Global Fossil Infrastructure Tracker, April 2019

APPENDIX A. THE COAL MINING EQUITIES CRASH

On April 13, 2016, the largest U.S. coal company, Peabody Energy, declared bankruptcy. By that point four other major companies had already filed for Chapter 11 protection: Arch Coal, ANR, Patriot Coal, and Walter Energy. One analyst called it "the day coal died in the United States."

What's striking is how fast the coal industry went from boom to bust. In 2010, forecasts about the future of global coal demand closely resembled today's optimistic forecasts about growing global demand for natural gas. Those optimistic expectations were reinforced by a strong upward trend in coal prices, with benchmark coal prices increasing from $100 per tonne in January 2010 to $140 per tonne in January 2011. In early 2011, coal mining company stocks hit an all-time high, as promoters predicted a "super cycle" of growth based on China's domestic consumption. In its *World Energy Outlook 2010*, the IEA projected that the coal mining industry would see continued growth,

Figure 11. Peabody Energy stock chart, 2011–2016



including a 38% increase in Chinese production from 2008 to 2015, supporting coal-supply infrastructure investment of $720 billion in the period 2010–2035.

Based on the confluence of indicators pointing safely toward an ongoing boom, coal mining companies took on increased debt as they undertook aggressive ramp-ups in new acquisitions of mines and investments in new mines.

In retrospect, the warning signs were clear, and the parallels with today's gas boom particularly striking:

- Mining companies were convinced that coal, long touted as the cheapest fuel, would maintain that advantage into the future. Similarly, today's boom in North American LNG terminals is based on a belief that the fracking boom has given North American producers a long-term advantage in global markets. But just as the fracking revolution enabled natural gas to push coal out of North American power markets, today plunging solar and wind cost structures threaten to similarly drive the displacement of natural gas.
- Mining companies, along with their political allies in Washington, D.C., and other capitals, failed to factor growing global concern over carbon pollution and other environmental impacts into their growth calculations. Yet as of early 2019, over 24 governments had committed to phasing out coal and over 100 banks and other financial lenders had instituted restrictions on coal financing.

APPENDIX B. METHODOLOGY

The Global Fossil Infrastructure Tracker uses a two-level system for organizing information. Summary data is maintained in Google sheets, with each spreadsheet row linked to a page on the SourceWatch wiki. Each wiki page functions as a footnoted fact sheet, containing project parameters, background, and mapping coordinates. Each worksheet row tracks an individual LNG plant unit. Under standard wiki convention, each piece of information is linked to a published reference, such as a news article, company report, or regulatory permit. In order to ensure data integrity in the open-access wiki environment, Global Energy Monitor researchers review all edits of project wiki pages by unknown editors. For each project, one of the following status categories is assigned and reviewed on a rolling basis:

- **Proposed:** Projects that have appeared in corporate or government plans in either pre-permit or permitted stages.
- **Construction:** Site preparation and other development and construction activities are underway.
- **Shelved:** In the absence of an announcement that the sponsor is putting its plans on hold, a project is considered "shelved" if there are reports of activity over a period of two years.
- **Cancelled:** In some cases a sponsor announces that it has cancelled a project. More often a project fails to advance and then quietly disappears from company documents. A project that was previously in an active category is moved to "Cancelled" if it disappears from company documents, even if no announcement is made. In the absence of a cancellation announcement, a project is considered "cancelled" if there are no reports of activity over a period of four years.
- **Operating:** The plant has been formally commissioned or has entered commercial operation.
- **Mothballed:** Previously operating projects that are not operating but maintained for potential restart.
- **Retired:** Permanently closed projects.

To allow easy public access to the results, Global Energy Monitor worked with GreenInfo Network to develop a map-based and table-based interface using the Leaflet Open-Source JavaScript library. The public view of the Global Fossil Infrastructure Tracker can be accessed at http://ggon.org/fossil-tracker/.

APPENDIX C. LIFE CYCLE GREENHOUSE GAS COMPARISON OF GLOBAL COAL PLANT DEVELOPMENT AND GLOBAL LNG TERMINAL DEVELOPMENT

To compare the impacts of the two fossil fuel categories—increased production and consumption associated with LNG terminals and increased coal production and consumption associated with new coal-fired power plants—we consider the full life cycle impacts from wellhead or coal mine through combustion. The results are shown in Table 7.

For coal, greenhouse gas impacts are mainly in the form of the carbon dioxide produced by coal-fired power plants. Additional global warming impacts result from the venting and leaking of methane from coal mines, and from releases of carbon dioxide by trains and ships.

The comparison between coal and gas requires converting any impacts from fugitive methane emissions into the atmosphere into a CO_2 equivalent. For natural gas, fugitive emissions occur throughout the production cycle, including well site, processing, transmission, storage, liquefaction, and distribution. Some methane "boils off" during ocean transit but is recaptured and burned by ship engines; methane is also combusted to fuel the liquefaction process and by end-use applications such as industrial heating or power generation.

Coal mining produces significant amounts of methane due to outgassing of coal seams. Such emissions are dramatically higher in underground mines. This analysis assumes that approximately equal shares of coal are produced globally by underground and surface mining. The analysis does not include combustion emissions resulting from the powering of natural gas wellhead or coal mining operations.

Table 7. Comparison between the greenhouse gas emissions enabled by pre-construction and in-construction coal plants (573 gigawatts) and the pre-construction and in-construction LNG export terminals (772 million tonnes per annum), based on 2018 utilization rates. Emissions in million tonnes CO_2 equivalent per annum.

Source of Emissions	Natural gas (20-year Horizon)	Coal (20-year Horizon)
Supply Chain Fugitive Methane	1,339	335
LNG Liquefaction	237	
LNG Transport	130	
LNG Regasification	8	
Coal Transport (ship)		11
Coal Transport (rail)		40
Combustion	1,733	2,361
Total	**3,446**	**2,747**

Source of Emissions	Natural gas (100-year Horizon)	Coal (100-year Horizon)
Supply Chain Fugitive Methane	529	133
LNG Liquefaction	221	
LNG Transport	130	
LNG Regasification	8	
Coal Transport (ship)		10
Coal Transport (rail)		40
Combustion	1,733	2,361
Total	**2,621**	**2,544**

Coal emissions are based on coal plants in pre-construction or construction as estimated by the Global Coal Plant Tracker, January 2019, in "Coal Plants by Country: Annual CO_2 (Million Tonnes) at http://bit.ly/31yblfC. For natural gas, emissions are based on LNG export terminals in pre-construction or construction as reported in Table 6 of this report, assuming the 2018 average global utilization rate of 79.04%. Supply chain methane leakage is assumed to be 2.3% (Alvarez 2018). Liquefaction, transport, regasification emissions are based on estimates by Pace Global (Pace 2015). In addition to the carbon dioxide emissions from coal, the estimate includes methane leakage from coal mines based on the assumption that half of thermal coal comes from surface mines, with an average of 8 cubic feet of methane released per short ton of coal, and half comes from underground mines, with an average of 360 cubic feet per short ton of coal (US DOE 2014). Coal shipping emissions are based on 2015 global CO_2 emissions for bulk shipping estimated by the International Council on Clean Transportation (Olmer 2017) of which 18.75% is thermal coal (Open Seas 2019). Coal rail emissions are based on 51.5 million tonnes per year CO_2 from total rail transport in the U.S. (Association of American Railroads 2008), of which 13% was coal (AARC 2016), scaled globally based on U.S. share of global thermal coal production (WEO 2018).

For additional methodology notes, see: Comparison of GHG Emissions for Proposed Terminals and Coal Plants, SourceWatch. http://bit.ly/2KKz5Y8

APPENDIX D: CAPITAL EXPENDITURES BY COUNTRY

The table below (Table 8) provides estimates by country for LNG projects (both export and import) in pre-construction and construction stages. Costs are based on International Gas Union estimates of $1,501 per tonne of annual capacity for greenfield export (i.e. liquefaction) projects, $458 per tonne for brownfield export projects, and $274 per tonne for greenfield and brownfield import (i.e. regasification) projects (IGU 2018).

Table 8. Capital Investments for LNG Terminals Under Development by Top 20 Countries (Billion US$)

Country	Pre-Construction	Construction	Total
USA	469.4	37.4	506.8
Canada	410.1	0.0	410.1
Russia	82.6	3.0	85.6
Australia	37.5	0.0	37.5
Tanzania	24.8	0.0	24.8
China	21.5	2.4	23.9
Indonesia	17.1	6.5	23.5
Mozambique	18.0	5.1	23.1
Iran	21.0	0.0	21.0
Papua New Guinea	17.3	0.0	17.3
Nigeria	15.0	0.0	15.0
India	8.1	2.7	10.8
Mexico	10.5	0.0	10.5
Cyprus	7.9	0.0	7.9
Equatorial Guinea	6.3	0.0	6.3
Algeria	6.0	0.0	6.0
Senegal	3.8	0.0	3.8
United Kingdom	3.3	0.0	3.3
Japan	3.2	0.0	3.2
Kuwait	0.0	3.1	3.1
Other	48.6	9.6	58.1
Total	**1,231.9**	**69.8**	**1,301.6**

Sources: Capacity estimates from Global Fossil Infrastructure Tracker, April 2019; Capital costs from IGU 2018.

REFERENCES

Alvarez, R., et al. "Assessment of methane emissions from the U.S. oil and gas supply chain." *Science* Vol. 361 No. 6398, July 13, 2018. http://bit.ly/2VvGGvi

Association of American Railroads. "Freight Railroads & Greenhouse Gas Emissions." June 2008. http://bit.ly/2IH2Tn7

Association of American Railroads. "Railroads and Coal." 2018. http://bit.ly/2KCQ52z

Bradbury, J. Testimony before the U.S. House of Representatives Energy and Commerce Subcommittee on Energy and Power. World Resources Institute. May 7, 2013. http://bit.ly/30wdZlQ

Brandt, A., et al. "Methane Leaks from North American Natural Gas Systems." Science, Vol. 343, Issue 6172. February 14, 2014. http://bit.ly/2KvgpLR

Buckley, T., Hipple, K., Sanzillo, T. "General Electric Misread the Energy Transition: A Cautionary Tale." June 6, 2019. http://bit.ly/2KJbJ54

Buckley, T., "Over 100 Global Financial Institutions Are Exiting Coal, With More to Come." IEEFA. February 27, 2019. http://bit.ly/2Tactk9

Chintamaneni, V., Showalter, J. M. "Fracking Debate Moves into Insurance Realm." SchiffHardin. September 20, 2016. http://bit.ly/2KP3xAj

Driver, A., Braden, R. "Big oil companies facegrowing concern on fracking." Reuters. May 26, 2011. https://reut.rs/2KOrYOe

Dyson, M., Engel, A., Farbes, J. "The Economics of Clean Energy Portfolios." Rocky Mountain Institute. 2018. http://bit.ly/2KMEPQT

Etminan, M., Myhre, G., Highwood, E., Shine, K. "Radiative forcing of carbon dioxide, methane, and nitrous oxide: A significant revision of the methane radiative forcing." Geophysical Research Letters. December 27, 2016. http://bit.ly/2W4X9Xz

Food and Water Watch. "The Fracking Endgame: Locked Into Plastics, Pollution and Climate Chaos." June 2019. http://bit.ly/2KC4SdP

GIIGNL. "Annual Report 2019." http://bit.ly/30x0P7T.

Howarth, R. "Methane emissions and climatic warming risk from hydraulic fracturing and shale gas development: implications for policy." Energy and Emission Control Technologies 2015:3, 45-54. http://bit.ly/2Wbhzyp

Howarth, R., Santoro, R., Ingraffea, A. "Methane and the greenhouse-gas footprint of natural gas from shale formations." Climate Change. 2011. http://bit.ly/2KuKWcM

Howarth, R. "A bridge to nowhere: methane emissions and the greenhouse gas footprint of natural gas." Energy Science & Engineering. 2014. http://bit.ly/317zs4x

Intergovernmental Panel on Climate Change. "Global Warming of 1.5° C." October 2018. https://www.ipcc.ch/sr15/

International Energy Agency. "Gas 2018." June 2018. http://bit.ly/2KtdaV6

International Energy Agency. "Gas 2019." June 2019. http://bit.ly/2KDUnGP

International Energy Agency. "Outlook for Natural Gas." 2017. http://bit.ly/2Kw9p17

International Gas Union. "2018 World LNG Report." http://bit.ly/30Gj2ju

International Gas Union. "Wholesale Gas Price Survey, 2019 Edition," May 2019. http://bit.ly/2VE8mOs.

Jaramillo, P. "A Life Cycle Comparison of Coal and Natural Gas for Electricity Generation and the Production of Transportation Fuels." Carnegie Mellon University. December 2007. http://bit.ly/2W9wvwK

Lattanzio, R. "Life-Cycle Greenhouse Gas Assessment of Coal and Natural Gas in the Power Sector." Congressional Research Service. June 26, 2015. http://bit.ly/31b4d8X

Lazard. "Lazard's Levelized Cost of Energy Analysis, Version 12.0." November 8, 2018. http://bit.ly/2KHKU10

McKain, K., et al. "Methane emissions from natural gas infrastructure and use in the urban region of Boston, Massachusetts." Proceedings of the National Academy of Sciences of the United States of America. February 17, 2015. http://bit.ly/2KMj6IQ

Mufson, S. "Exporting U.S. natural gas isn't as 'clean' as you think," Washington Post, June 9, 2014. https://wapo.st/30sHJzI

Muttitt, G., and Stockman, L. "Burning the Gas 'Bridge Fuel' Myth," Oil Change International. November 2017. http://bit.ly/30sLzIj

Myhre, G., et al. (2014), "Anthropogenic and natural radiative forcing" in *AR5 Climate Change 2014: Mitigation of Climate Change*. April 2014. http://bit.ly/2Wbt7kU

NASA. A Global View of Methane. January 1-31, 2016. https://go.nasa.gov/2KFfyIl

Nisbet, E., et al. "Very Strong Atmospheric Methane Growth in the 4 Years 2014–2017: Implications for the Paris Agreement." *Global Biogeochemical Cycles*. February 15, 2019. http://bit.ly/310NViN

Olmer, N., et al. "Greenhouse Gas Emissions from Global Shipping, 2013-2015." ICCT. October 2017. http://bit.ly/2KvlqE0

Pace Global. "LNG and Coal Life Cycle Assessment of Greenhouse Gas Emissions." Center for Liquefied Natural Gas. October 2015. http://bit.ly/2KDE251

Pérez, A. "Global Gas Lock-in. Bridge to Nowhere." Rusa Luxemburg Stiftung. October 2018. http://bit.ly/31l4KF9

Schmidt, D. "Long-term coal super-cycle coming: Boyce." Mining Monthly, June 21, 2010. http://bit.ly/2KHvsSE

Shearer, C., et al. "Boom and Bust 2019: Tracking the Global Coal Plant Pipeline." Global Energy Monitor. April 2019. http://bit.ly/2KKSU1g

Stockman, L. "Burning the Gas 'Bridge Fuel' Myth: Why Gas Is Not Clean, Cheap, or Necessary." Oil Change International. May 2019. http://bit.ly/31kn2Xi

U.S. Department of Energy. "Life Cycle Greenhouse Gas Perspective on Exporting Liquefied Natural Gas from the United States." May 29, 2014. http://bit.ly/2W8keso

U.S. Energy Information Administration. "Global LNG trade posts record growth again in 2018, led by the growth in spot and short-term trade," April 25, 2019. http://bit.ly/2VC8PRv

U.S. Energy Information Administration. "Hydraulically fractured wells provide two-thirds of U.S. natural gas production." May 5, 2016. http://bit.ly/31jB8YT

UNCTAD. "Review of Marine Transport." 2017. http://bit.ly/2Ktj3BB

Whitaker, M., Heath, G., O'Donoughue, P, Vorum, P. "Life Cycle Greenhouse Gas Emissions of Coal-Fired Electricity Generation." Journal of Industrial Ecology. April 4, 2012. http://bit.ly/2W3djRf

Williams-Derry, C., Hipple, Kl, Sanzillo, T. "Red Ink Keeps Flowing for U.S. Fracking Sector." Sightline Institute and Institute for Energy Economics and Financial Analysis. June 2019. http://bit.ly/2KHU261

TRADE STUDY, COOS BAY FLOATING OFFSHORE WIND VS LNG EXPORT
May 15, 2019

INTRODUCTION

"Engineers for a Sustainable Future" ("ESF") is an organization of engineers located in Oregon. We recommend that the application to construct the *230-mile Pacific Connector Natural Gas Pipeline from Malin to Coos Bay and the Jordan Cove Liquid Natural Gas (LNG)* be rejected. (Hereafter we will refer the the project as the Jordan Cove Project.)

Jordan Cove will have negative impacts on Oregon's environment as well as Oregon's efforts to reduce greenhouse gas pollution. There are other major projects worth considering for Coos Bay – one being the development of a project to build and support floating offshore wind (FOW) generation.

OFFSHORE WIND CAPACITY

Total installed electricity generation capacity in the United States is 1000+ GW. The National Renewable Energy laboratory (NREL) estimates that the offshore wind resource on the west coast is 800+ GW and that the area of highest resource is 200 miles south to 100 miles North or the California – Oregon border. In a 2017 article written by Robert Collier from the UC Berkley Labor Center entitled "*High Road for Deep Water: Policy Options for a California Offshore Wind Industry*", it is stated that substantial amounts of wind generation could be developed with installation of (FOW) turbines.

PORT OF COOS BAY

Offshore wind farms must be developed in conjunction with a suitable port to build and support the project. The Port of Coos Bay is well situated to serve as the supply chain hub for the FOW farm. It has sufficient land and a deep draft coastal harbor for import, assembly, manufacturing, operation and maintenance.

COMPARISON TABLE

The Table which follows - "Trade Study, Off-shore Wind vs LNG Export - compares the economic and environmental features of the Jordan Cove Project with a FOW project with base operations at Coos Bay. The table presents a high-level description of the two projects and compares commercial and environmental aspects.

COMPARISON TABLE (CONTINUED)

Information for the Jordan Cove project is based primarily on the project owner's March 2019 "Draft Environmental Impact Statement for the Jordan Cove Energy Project" (DEIS) and a January 2018 Oil Change International report entitled "Jordan Cove LNG and Pacific Connector Pipeline Greenhouse Gas Emissions Briefing".

The information presented for the FOW project is not complete. Construction Cost and State and Property Tax Revenue for the FOW project are not presented. Jobs that can be expected from the FOW wind project are only stated in terms of jobs associates with other FOW projects. (Item 9 in the attached table.) The *"High Road for Deep Water: Policy Options for a California Offshore Wind Industry"* and the *"Vineyard Wind Signs Lease for Staging Operations in New Bedford"* articles give an indication of the economic benefit of locating a FOW wind farm project construction, operation and maintenance at Coos Bay.

Michael Unger
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Trade Study, Coos Bay Floating Offshore Wind vs LNG Export
Engineers for a sustainable Future
May 15, 2019

Item Number	Item	North Spit Floating Offshore Wind (FOW) Project (1)	Pacific Connector Pipeline and Jordan Cove LNG Export Terminal Project (1)
PROJECT DESCRIPTION			
1	Renewable Energy Technology	Floating offshore wind	None
2	Energy Produced	Electricity delivered to CA / OR	LNG carbon intensive fuel, exported
3	Project Development/Management	EDPR Offshore North America LLC ("EDPR Offshore"), Principle Power, Inc. (PPI), and Aker Solutions Inc. ("ASI"), collectively the "Project Partners" has given consideration to development of land-based operations in Coos Bay. There is significant interest on the part of developers to construct floating offshore wind farms in the offshore areas 200 miles south and 100 miles north of the Oregon California boarder. Recently the U.S. Bureau of Ocean Energy Management (BOEM) received expressions of interest from 14 developers in the call for information and nominations for obtaining commercial wind energy leases offshore California. (2)	Pembina Pipeline Corporation (Canada)
4	Project concept	Docks built, offshore turbines assembled in Coos Bay, components delivered by sea, assembled turbines delivered to off-shore sites from harbor.	Methane delivered by Oregon pipeline, compressed in Coos Bay, docks built, off-loaded to vessels and delivered to Pacific Rim
5	Timespan for project development	30 years, possibly more	5 years construction. 40 years operation (estimate)
6	Construction Cost		$7.3 Billion over a 53-month construction period with $2.99 Billion spent in Oregon. Page 4-593 in DEIS (3)
7	Investors of Record		Carbon lenders in decline
8	Land Affected	Dock space and space for storage and assembly on the North Jetty.	LNG terminal facilities - 1,355 Acres, Connector pipeline and associated above ground facilities - 4,946 Acres, Page 2-38 and 2-39 in DEIS (3).

Trade Study, Coos Bay Floating Offshore Wind vs LNG Export
Engineers for a sustainable Future
May 15, 2019

Item Number	Item	North Spit Floating Offshore Wind (FOW) Project (1)	Pacific Connector Pipeline and Jordan Cove LNG Export Terminal Project (1)
ECONOMIC CONSIDERATIONS			
9	Jobs in Oregon	<u>16 GW FOW Project</u> - "13,620 full-time Jobs for construction, installation and manufacturing by 2040 - 2050" and "4,330 full-time, long term jobs in operation and maintenance, plus thousands more service-sector jobs in the broader economy". Service sector jobs not included. (4) The 16 GW FOW project is a National Renewable Energy Laboratory (NREL) high-case estimate. Job estimates must be adjusted for different project sizes and development times. Also, Coos Bay jobs will depend on amount of manufacturing activities actually completed in Coos Bay. <u>0.8 GW FOW Project</u> - Vineyard Wine has committd to develop a 0.8 GW FOW farm. The company estimates that 3,600 jobs will be required to build and support the project. (4) Note: California's summer peak load is 76.414 GW and Oregon's peak summer load is 16.515 GW. (5)	Construction direct impact work force average over a 53-month construction period - 1023 Jobs. First year of operations - 180 Jobs in Coos Bay and 20 Jobs in Portland, Page 4-594 in DEIS (3). Service sector jobs not included.
10	Investment opportunities / risks	California - Renewable portfolio standard 100% by 2045. Renewable energy procurements rising rapidly	Vessels half the size of competitors, no contracts for product, volatile market pricing, sunset industry, will face increasing worldwide carbon caps/price.
11	State and Property Tax Revenue		Annual State Tax - $50 Million, Annual Property Tax - $60 Million. Pembina Jordan Cove web page.
12	Social Cost of Carbon Globally (Based on $40 per metric ton)	Net reduction due to renewable energy build-out.	$1,470 - $2,080 Million per year. Emission estimates based on Oil Change International Briefing (6)
13	Social Cost of Carbon in Oregon (Based on $40 per metric ton)	Net reduction due to renewable energy build-out.	$88 Million per year. Emission estimates based on Oil Change International Briefing (6)
ENVIRONMENTAL CONSIDERATIONS			
14	Global Emissions - Carbon Dioxide Equialent (CO2e)	Net reduction due to renewable energy build-out.	Increase in CO2e emissions 36.8 - 52.0 million metric tons per year. Emission estimate based on Oil Change International Briefing (6)

Trade Study, Coos Bay Floating Offshore Wind vs LNG Export
Engineers for a sustainable Future
May 15, 2019

Item Number	Item	North Spit Floating Offshore Wind (FOW) Project (1)	Pacific Connector Pipeline and Jordan Cove LNG Export Terminal Project (1)
ENVIRONMENTAL CONSIDERATIONS (CONTINUED)			
15	Oregon Emissions - Carbon Dioxide Equialent (CO2e)	Net reduction due to renewable energy build-out.	Increase in CO2e emissions - 2.2 million metric tons per year. Emission estimate based on Oil Change International Briefing (6)
16	Investment in fossil fuel infrastructure	Possible minor investment in fossil fuel equipment such as tugboats.	$7.3 Billion (3).
17	Other Environmental Impacts	Limited to industrial site on North Spit.	Dredging of oyster beds, clearing of forests for pipe-laying, fowling at water-crossings, water temperature in salmon streams rise by 0.5 Deg C.

(1) The FOW and Jordan Cove LNG projects could both be constructed in Coos Bay although the large ships required to transport the LNG to Asia would hinder operation of FOW transport operations in Coos Bay.

(2) US Bureau of Offshore Energy Management (BOEM) Request for Information. https://www.offshorewind.biz/:https://www.offshorewind.biz/2019/04/26/14-answer-california-offshore-wind-call/

(3) "*Draft Environmental Impact Statement for the Jordan Cove Energy Projec* t", Docket Nos. CP17-494-000 and CP17-495-000 March, 2019, https://www.federalregister.gov/documents/2019/04/12/2019-07313/notice-of-availability-of-the-draft-environmental-impact-statement-for-the-proposed-jordan-cove

(4) "*High Road for Deep Water: Policy Options for a California Offshore Wind Industry*". UC Berkley Labor Center, Robert Collier, November 2, 2017 Presents 2016 Analysis by National Renewable Energy laboratory (NREL Speer et all), http://laborcenter.berkeley.edu/high-road-for-deep-water/
See also "*Vineyard Wind Signs Lease for Staging Operations in New Bedford*", WBUR, Oct. 22, 2018. https://www.wbur.org/bostonomix/2018/10/22/vineyard-wind-new-bedford

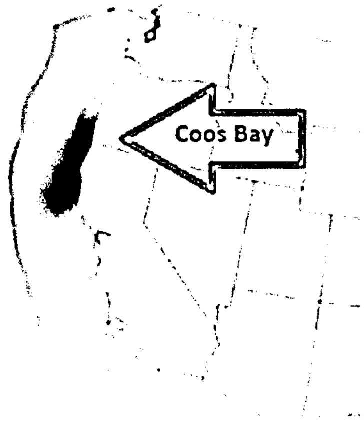
(5) "*State Electricity Profiles*", U. S. Energy Information Administration, January 8, 2019, https://www.eia.gov/electricity/state/

(6) "*Jordan Cove LNG and Pacific Connector Pipeline Greenhouse Gas Emissions Briefing*", Oil Change International, January, 2018 http://priceofoil.org/content/uploads/2018/01/JCEP_GHG_Final-Screen.pdf

OFFSHORE WIND – AN ECONOMIC DEVELOPMENT OPPORTUNITY FOR COOS BAY

SUMMARY

A combination of recent developments has created a massive new economic opportunity for the port of Coos Bay. Utility scale solar and wind generation are now less expensive than new coal or gas plants. Last September California, the world's fifth largest economy, passed legislation (SB 100) requiring that 100% of its electric power be carbon-free by 2045. However, land-use restrictions, real estate costs, increasing scarcity of prime sites and other factors will limit the build-out of California's onshore wind and solar capacity.



These factors create a huge opportunity for offshore wind generation of electricity on the west coast. Typically stronger and more consistent than winds on land, offshore winds can help fill some gaps created at night by solar. The U.S. offshore potential is estimated to be four times the current generating capacity of the entire country. The area with the highest energy potential on the entire west coast is an offshore zone extending from Coos Bay 300 miles south into Northern California.

Coos Bay is the largest deep draft coastal harbor from San Francisco to the Puget Sound. It is well suited to establish itself as the nucleus for the development of this unique and vital natural resource. Much of the economic benefit that results from floating offshore wind farms comes from activities that are all done in port – staging turbines and components, assembly, local fabrication of parts, maintenance, operations base, etc. Completed turbines are towed offshore and anchored. If needed they are towed back to port for major maintenance and upgrades.

If the supply chain, assembly and service operations take root in Coos Bay, it will transform the economic vitality of the region and provide thousands of sustainable family-wage jobs according to a recent NREL/UC Berkeley report. Offshore wind is a new industry compared to land-based wind, but already employs 50,000 in Germany and the UK alone. Developers are currently planning wind farms in California waters near the Oregon border. This provides a short window of opportunity to leverage the superior port facilities at Coos Bay and secure the construction, operations and maintenance business of these projects.

Once a port is selected and the process begins, there is little incentive to duplicate it anywhere nearby due to the ease of transporting (towing) floating turbines. Oregon has a mature ($15 billion) marine construction industry and 2 major international players in offshore wind energy. This can help establish Coos Bay as the hub on the Pacific coast for this promising new industry .

Michael Mitton – 350PDX, Climate Reality Project

COOS BAY OFFSHORE WIND – OUTLINE FOR DISCUSSION & RESEARCH REFERENCES

1. SB100 (California 100% carbon-free by 2045) creates massive demand for clean energy

a) SB 100 was signed into law Sept. 10, 2018 and ramps up RPS to 100% by 2045[1]
b) This landmark climate action sends a clear signal to the market about the future of energy[2]
c) Ranked as a separate country, California's economy would be the world's 5th largest
d) California consumes 8% of US electricity but has 12% of the population
e) California's aggressive goal to electrify transportation will further increase demand[3]
f) Corporate renewable energy procurements rising rapidly further increasing demand[4]
g) Since 2001 California carbon emissions have dropped 12% while its GDP increased 91%[5]

2. Utility scale costs for solar/wind generation are now lower than coal/gas and still declining

a) Fuel is the major cost for coal/gas plants, but is free for wind/solar and always will be[6]
b) Unpredictability of future gas/coal costs increases investment risk for these plants[7]
c) Plants using fossil fuels also face significant and growing risk of GHG emission caps
d) Storage is a key factor for wind/solar but cost are declining, new technologies emerging[8]
e) All-in cost of wind energy (LCOE) now lower than fully depreciated natural gas plants[9]
f) Wind now lowest cost technology type in many U.S. counties including externalities[10]
g) LCOE onshore wind unsubsidized cost as low as $29 per MWh per Lazard 2018[11]
h) Including subsidies onshore wind LCOE estimated as low as $14/MWh per Lazard[12]
i) Offshore developed later than onshore wind so costs are higher but dropping fast[13]
j) Worldwide offshore LCOE have fallen 56% and onshore LCOE 49% since 2010[14]
k) APAC Offshore LCOE expected to fall 44% by 2023 per Wood Mackenzie[15]
l) APAC expects 20X boom in offshore wind bringing it close to Europe's installed capacity[16]
m) Overlapping competencies from oil/gas are benefiting offshore wind development[17]
n) Stronger/steadier offshore wind increases capacity factor, lowers costs (Hywind 65%)[18]
o) Wind will be EU's largest power source by 2027 more than gas, coal, nuclear per IEA[19]
p) Europe now has several decades of experience; this will accelerate cost reductions in U.S.
q) European technology, public policy, financing will inform, help expedite US development
r) 2018 prices for offshore wind power in Europe now half of contract price paid in 2015[20]
s) Aug 2018 offshore wind contract price in U.S. was $79 per MWh (PDX-based Avangrid)[21]
t) Most recent previous U.S contract price was $132 per MWh, more than twice as much[22]
u) Bigger turbines, economies of scale, install/operations improvements further reducing costs[23]
v) Study projects 50% annual compound growth rate for U.S. offshore wind through 2026[24]
w) Floating offshore wind (FOW) fleets have minimal environmental impact to sea-bed
x) FOW has lower installation costs and risks due to onshore assembly, less specialized vessels[25]
y) FOW vessels have less demanding port/harbor requirements than fixed foundation offshore
z) FOW significantly lowers maintenance cost, structures towed back to port for major repairs[26]

3. Land-use issues, other factors favor offshore wind to provide big portion of renewable power

a) Solar and wind generation requires several times more land compared to fossil fuel plants[27]
b) PV solar needs at least 2.8 acres for 1GWh/yr meaning 32 acres required per 1000 homes[28]
c) Onshore solar/wind face public resistance, land-use restrictions, high real-estate costs[29]

d) Growing population increases opportunity costs for land-based solar/wind
e) FOW's seasonal/geographical availability mitigates intermittency from other renewables
f) FOW complements California's vast solar capacity smoothing out the duck curve
g) Offshore wind typically has 2X the capacity factor vs. solar, key competitive advantage
h) Offshore wind has lower carbon footprint than fossil fuel, biomass, hydro and solar[30]
i) FOW spacing can accommodate/protect other ocean resources like fishing
j) 14 companies eyeing California offshore wind as of April 2019, up from 2 in 2018[31]

4. <u>Most valuable section of the offshore wind resource is centered on the California/Oregon border</u>

a) Total installed electricity generation capacity in United States is 1000+ GW
b) NREL estimates offshore wind resource on the west coast alone is 800+ GW
c) Area of highest energy density runs 300 miles south from Coos Bay into California
d) Wind resource in this area averages 10 meters/sec will yield high capacity performance
e) This area is relatively close to shore but deep, requiring floating offshore turbines
f) This area interferes less with shipping and military than other areas to north and south
g) Significant new transmission infrastructure needed to get this renewable power to market
h) Permitting, siting, litigations for transmission build-out could take up to 10 years

5. <u>Port of Coos Bay is well suited to act as the supply chain hub for this promising new industry</u>

a) Uptake of offshore wind depends on suitable port and grid infrastructure
b) Coos Bay is the largest deep draft coastal harbor from San Francisco to Puget Sound
c) New generation offshore turbines arrive by sea (too large for roads/rail)
d) Import, assembly, manufacturing requires enough quayside area, proximity to fleet site
e) Coos Bay served by deepwater with no overhead restriction, enough land available
f) Operations & maintenance (O&M) vessels need proximity to fleet site to optimize costs
g) Coos Bay was first choice of FOW developer (Principle Power) for pilot project in 2015
h) PPI met with stakeholders, local/state/federal agencies, elected officials[32]
i) Unable to secure an adequate PPA, project move 150 miles south to Eureka, CA[33]

6. <u>Clean energy is the industry of the future and provides long-term sustainable family wage jobs</u>

a) NE states 8GW offshore goal projects 36,300 full time jobs by 2030[34]
b) By 2014 Europe's 7.5GW offshore produced 75000 jobs in mfg, maintenance, ops[35]
c) UK offshore green collar jobs set to triple by 2030[36]
d) 4GW U.S. NE offshore lease sales (Dec. 2018 $405 million) highest ever[37]
e) 800MW offshore project creates 3600 jobs for port in Mass. to build/support wind farm[38]
f) Offshore supply chain development will drive most of the economic benefit for Coos Bay
g) Clean energy workers earn higher,more equitable wages compared to all workers nationally[39]
h) Establishing Coos Bay as supply chain and service hub for FOW will create many jobs
i) Full 16 GW offshore build-out in California generates 15,000 full time jobs per NREL[40]
j) 16GW build-out (high case) 4,330 full-time sustainable O&M jobs per UC Berkeley study[41]
k) 16GW build-out 13,620 full-time construction from 2020 to 2050[42]
l) 16GW build-out also adds thousands of service-sector jobs in the broader economy[43]
m) Wind turbine technician job growth rate and pay are twice the next best job (medical)[44]
n) If turbine, component firms manufacture locally, the economic impact is far greater
o) Coos Bay can benefit from jobs/economic activity even if wind farms are in California

7. There is a short window of opportunity to ensure the supply chain takes root in Oregon

a) SB100's time goals are aggressive: 60% carbon-free by 2030, 100% by 2045
b) FOW is a new and complex industry so build-out will take decades
c) These factors force FOW developers to make initial decisions ASAP
d) Port selection is a key early decision and drives where supply chain takes root
e) Leverage Oregon's $15 billion maritime industries to accelerate supply chain development[45]
f) Identifying workforce skills gap and developing strategies to fill it is critical for FOW
g) Clean Energy Jobs bill can provide funding for training in skills needed by FOW
h) Identify/reduce barriers to establishing Coos Bay as the supply chain and service hub

8. Success depends on Oregon's policy makers sending clear signals to wind developers, suppliers

a) Offshore wind is a new segment of clean energy and is capital intensive
b) Proving stable, long-term policy support will enable developers to attract investors
c) SB100 will drive exponential growth for FOW, need to ensure Coos Bay is ready
d) Policy needs to protect ocean resources and maintain adequate access for existing users
e) Policy framework in California has resulted in several offshore projects already[46]
f) Fishing industry and offshore wind co-exist and thrive at world's largest offshore wind farm[47]

9. Additional Topics

a) Explore synergies Highview LAES/Jordan Cove LNG liquefaction to increase efficiency[48]
b) Use surplus wind energy to convert sea water to hydrogen (H2) when demand is low[49]
c) Use H2 to produce power when demand is high, making FOW even more grid friendly[50]
d) H2 also valuable to de-carbonize difficult segments of transportation, heating, etc.[51]
e) Explore synergies with OSU's PacWave offshore hydrokinetic project near Newport[52]

Michael Mitton – 5/5/2019

REFERENCES

[1] https://www.cbsnews.com/news/california-aims-to-go-100-percent-carbon-neutral/
[2] https://www.smithsonianmag.com/smart-news/california-commits-100-percent-clean-energy-2045-180970262/
[3] https://cleantechnica.com/2018/06/03/california-approves-738-million-transportation-electrification-initiative/
[4] https://www.greentechmedia.com/articles/read/corporate-renewable-energy-deals-smash-record-2018
[5] https://qz.com/1372946/california-is-poised-to-be-the-worlds-largest-economy-with-a-zero-emissions-goal/
[6] https://www.e-education.psu.edu/ebf483/node/584
[7] http://www.searchanddiscovery.com/pdfz/documents/2017/80595krane/ndx_krane.pdf.html
[8] https://www.forbes.com/sites/mikescott/2018/11/09/battery-energy-storage-is-a-1-trillion-opportunity-as-costs-continue-to-crash/#4ed549846849
[9] https://canwea.ca/blog/2018/11/26/new-lazard-analysis-shows-that-wind-energy-costs-have-dropped-69-per-cent-since-2009/

[10] http://newenergyupdate.com/wind-energy-update/us-onshore-wind-costs-fall-7-year-full-cost-wind-lower-gas-many-counties
[11] https://www.lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2018/
[12] https://www.lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2018/
[13] https://www.forbes.com/sites/energyinnovation/2018/05/02/is-offshore-wind-about-to-hit-cost-competitiveness-in-new-york-and-new-england/#2238125b6720
[14] https://www.forbes.com/sites/mikescott/2019/04/16/batteries-offshore-wind-lead-clean-energy-cost-cuts-as-renewables-continue-to-undercut-coal-and-gas/#7230d1dc47d7
[15] https://www.greentechmedia.com/articles/read/asia-pacific-pv-demand-holds-steady-offshore-wind-spikes#gs.NABNxcg
[16] https://www.greentechmedia.com/articles/read/asia-pacific-pv-demand-holds-steady-offshore-wind-spikes#gs.NABNxcg
[17] https://www.energy.gov/eere/wind/articles/renewable-future-oil-and-gas-industry
[18] https://www.greentechmedia.com/articles/read/worlds-first-floating-offshore-wind-farm-65-capacity-factor
[19] https://www.neweurope.eu/article/iea-wind-will-become-the-eus-largest-power-source-in-2027/
[20] https://www.pri.org/stories/2018-02-14/europe-s-investment-offshore-wind-paying-us
[21] https://www.offshorewind.biz/2018/08/02/first-large-scale-us-offshore-wind-farm-to-lower-electricity-bills/
[22] https://www.utilitydive.com/news/massachusetts-utilities-file-us-record-offshore-wind-contracts-at-65mwh/529208/
[23] https://e360.yale.edu/features/after-an-uncertain-start-u-s-offshore-wind-is-powering-up
[24] https://www.greentechmedia.com/articles/read/offshore-wind-takes-off-in-america#gs.IJEI3ks
[25] https://www.windpowerengineering.com/projects/offshore-wind/riding-the-waves-of-complexity-in-floating-offshore-wind/
[26] https://www.carbontrust.com/media/670664/floating-offshore-wind-market-technology-review.pdf, page 45
[27] https://www.strata.org/pdf/2017/footprints-full.pdf
[28] https://www.energymanagertoday.com/it-takes-2-8-acres-of-land-to-generate-1gwh-of-solar-energy-per-year-says-nrel-094185/
[29] LA Times, 8/21/2018 All-renewable energy in California? Land-use calculations say it's not going to happen
[30] https://en.wikipedia.org/wiki/Life-cycle_greenhouse-gas_emissions_of_energy_sources
[31] https://news.bloombergenvironment.com/environment-and-energy/avangrid-equinor-among-14-firms-eyeing-calif-offshore-wind
[32] Principle Power Final Report Windfloat Project, page 23
[33] Principle Power Final Report Windfloat Project, page 31
[34] https://www.northeastwindcenter.org/wp-content/uploads/US-job-creation-in-offshore-wind.pdf
[35] https://www.americanprogress.org/issues/green/reports/2018/04/02/448673/offshore-wind-means-blue-collar-jobs-coastal-states/
[36] https://www.gov.uk/government/news/green-collar-jobs-in-offshore-wind-set-to-triple-by-2030
[37] https://www.doi.gov/pressreleases/bidding-bonanza-trump-administration-smashes-record-offshore-wind-auction-405-million
[38] https://www.wbur.org/bostonomix/2018/10/22/vineyard-wind-new-bedford
[39] https://www.brookings.edu/research/advancing-inclusion-through-clean-energy-jobs/
[40] http://laborcenter.berkeley.edu/high-road-for-deep-water/
[41] http://laborcenter.berkeley.edu/high-road-for-deep-water/
[42] http://laborcenter.berkeley.edu/high-road-for-deep-water/
[43] http://laborcenter.berkeley.edu/high-road-for-deep-water/
[44] Bureau of Labor Statistics 2018 Fastest growing occupations: https://www.bls.gov/ooh/fastest-growing.htm
[45] http://oregonbusinessplan.org/wp-content/uploads/2016/12/Maritime-Sector.pdf
[46] http://newenergyupdate.com/wind-energy-update/california-floating-wind-pioneers-build-new-fishing-harbor-frameworks
[47] Fishing and offshore wind in Europe (doc)

[48]https://warwick.ac.uk/fac/sci/eng/research/grouplist/electricalpower/images/newsnevents/hies2017/presentations/hies2017_highview.pdf
[49] https://www.scientificamerican.com/article/europe-stores-electricity-in-gas-pipes/
[50] https://www.elektormagazine.com/news/seasonal-energy-storage-vital-for-growth-of-renewables
[51] https://www.iea.org/newsroom/news/2018/may/commentary-offshore-wind-and-hydrogen-for-industry-in-europe.html
[52] https://www.sciencedirect.com/science/article/pii/S0196890414010292
https://www.researchgate.net/publication/264082615_SYNERGIES_FOR_A_WAVE-WIND_ENERGY_CONCEPT

Document Content(s)

Via email: jordancove.comment@oregon.gov

Sean Mole
Federal Projects Coordinator
Oregon Department of Energy
550 Capitol St. N.E.
Salem, OR 97301

Re: Jordan Cove Energy Project Application for Exemption from a Site Certificate

Greetings,

According to the Public Notice issued by the Oregon Department of Energy (Department) on June 28, 2018, Jordan Cove Energy Project (JCEP) has applied for an exemption from the requirement to obtain a site certification for its electrical generation project designed to provide electrical power to its Liquified Natural Gas (LNG) terminal. The notice stated that comments to be considered in the proposed order the Department will issue in advance of the September 2018 Energy Facility Siting Council meeting are due August 13, 2018. Please accept these comments to be considered in the proposed order.

For the reasons stated below, the application must be denied because the relevant criteria are not met; JCEP made a significant error in the relevant calculation.

These comments are submitted on behalf of:

Rogue Climate
Rogue Riverkeeper
Hair on Fire Oregon
Oregon Shores Conservation Coalition
Citizens for Renewables
Citizens Against LNG
350 Corvalllis
350 Eugene
350PDX
Center for Sustainable Economy
Climate Action Coalition
Climate Justice Task Force, Unitarian Universalist Fellowship of Corvallis
Douglas County Global Warming Coalition
Earthworks
Food & Water Watch
Honor the Earth
Landowners United
Northwest Environmental Defense Center
Oregon Coast Alliance

Oregon Physicians for Social Responsibility
Oregon Wild
Pipeline Awareness Southern Oregon
Sierra Club, Oregon Chapter
Signal Fire
South Umpqua Rural Community Partnership
Southern Oregon Climate Action Now
Stop Fracked Gas/PDX
Sustainable Energy & Economy Network
Umpqua Watersheds Inc.
Western Environmental Law Center
Affected Landowner Bob Barker
Affected Landowners Ron Schaaf and Deb Evans

Relevant Background

In 2014, JCEP filed an application for a site certificate for its South Dunes (SDP) energy facility which was designed to provide energy to a prior version of an LNG terminal. The facility and EFSC jurisdiction was described by staff in the proposed order as follows:

> The proposed energy facility is a natural-gas-fueled combined-cycle generating plant, consisting of two 210-megawatt blocks, with duct-firing capability. The nominal generating capacity of the proposed SDP is 420 MW for the two power blocks combined. Average electrical generating capacity is defined in ORS 469.300(4) as the peak generating capacity of the facility divided by a factor determined by the facility type. Because the proposed facility uses natural gas, under ORS 469.300(4)(c), the factor to be applied to the peak generating capacity is 1.00. Therefore, the average generating capacity for the energy facility is expected to be 420 MW for the two power blocks combined. Each power block would consist of three combustion turbine generators, three heat recovery steam generators and one steam turbine generator. Steam produced by the SDP heat recovery steam generators would be delivered to the Jordan Cove Energy Project's (JCEP) liquefied natural gas (LNG) terminal gas conditioning systems, acting as a cogeneration terminal.

In December 2016, JCEP withdrew the application and sought dismissal of the pending contested case proceeding.

The current application is equivocal about whether the power generating system is an energy facility but generally describes it as:

> The electrical power generating system at the proposed LNG Terminal consists of three steam turbine generators ("STGs"). Each STG will generate electricity and will have a nominal electrical generating capacity of greater than 25 MW. Given the nominal electrical generating capacity of the STGs, the facility could be considered an "energy facility" under the statute. Without waiving any rights including jurisdiction over the

proposed LNG Terminal, JCEP submits this application requesting a determination from EFSC that the proposed facility qualifies for an exemption from the site certificate requirement.

***

The total power requirements for the LNG Terminal are 39.2 MW (holding mode) and 49.5 MW (loading mode). Electrical power will be via two 30 MW STGs and one spare 30 MW STG. The steam is efficiently generated by HRSGs using exhaust from the refrigerant compressor combustion turbine drivers. A black-start auxiliary boiler will be used to generate steam for power when gas turbines are not in operation. In addition, there are two standby diesel generators for the LNG Terminal and two for the SORSC. The facility will not be connected to the local grid, and will not import or export power.

It appears, then, that the main differences are the amount of power being generated and the site where the power will be generated.

Relevant Criteria:

Pursuant to EFSC's enabling statutory scheme an "energy facility" must be permitted by a site certificate unless an exemption applies. In 2014, an energy facility was and it still is:

(11)(a) "Energy facility" means any of the following:
(A) An electric power generating plant with a nominal electric generating capacity of 25 megawatts or more, including but not limited to:
(i) Thermal power;
(ii) Combustion turbine power plant; or
(iii) Solar thermal power plant

ORS 469.300. An exemption is provided in ORS 469.320(2):

(2) A site certificate is not required for:
(c) An energy facility, except coal and nuclear power plants, if the energy facility:
(A) Sequentially produces electrical energy and useful thermal energy from the same fuel source; and
(B) Under average annual operating conditions, has a nominal electric generating capacity:
(i) Of less than 50 megawatts and the fuel chargeable to power heat rate value is not greater than 6,000 Btu per kilowatt hour;
(ii) Of 50 megawatts or more and the fuel chargeable to power heat rate value is not greater than 5,500 Btu per kilowatt hour; or
(iii) Specified by the Energy Facility Siting Council by rule based on the council's determination relating to emissions of the energy facility.

Many years ago, however, the legislature also gave EFSC authority to change the efficiency standard when it enacted subsection 3 which states:

> (3) The Energy Facility Siting Council may review and, if necessary, revise the fuel chargeable to power heat rate value set forth in subsection (2)(c)(B) of this section. In making its determination, the council shall ensure that the fuel chargeable to power heat rate value for facilities set forth in subsection (2)(c)(B) of this section remains significantly lower than the fuel chargeable to power heat rate value for the best available, commercially viable thermal power plant technology at the time of the revision.

As understood, EFSC subsequently adopted the following rules:

> The Council shall, upon request, determine whether a proposed facility or proposed expansion of a facility is exempt from the requirement to obtain a site certificate. A site certificate is not required for:
>
> * * *
>
> (3) A high efficiency cogeneration facility, as defined in OAR 345-001-0010.

OAR 345-015-0350. And:

> (29) "High efficiency cogeneration facility" means an energy facility, except coal and nuclear power plants, that sequentially produces electrical and useful thermal energy from the same fuel source and under average annual operating conditions:
>
> > (a) Has a nominal electric generating capacity of less than 50 megawatts and the fuel chargeable to power heat rate value is not greater than 5550 Btu per kilowatt-hour (higher heating value); or
> >
> > (b) Has a nominal electric generating capacity of 50 megawatts or more and the fuel chargeable to power heat rate value is not greater than 6000 Btu per kilowatt-hour (higher heating value).

OAR 345-001-0010.

JCEP's project has a nominal electric generating capacity of 90 MW and so it attempts to qualify for an exemption by demonstrating that the fuel chargeable to power heat rate value is not greater than 6,000 Btu per kilowatt hour pursuant to OAR 345-010-0010(29)(b).

Argument:

The calculation to determine the fuel chargeable to power heat rate is described in OAR 345-001-0010(25). The "fuel chargeable to power heat rate" is the net heat rate of electric power production during the first twelve months of commercial operation. It is calculated based upon average temperature, barometric pressure and relative humidity at the site during the times of the year when the facility is intended to operate and is determined using a formula: FCP = (FI - FD)/ P, where:

(a) FCP = Fuel chargeable to power heat rate.

(b) FI = Annual fuel input to the facility applicable to the cogeneration process in British thermal units (higher heating value).

(c) FD = Annual fuel displaced in any industrial or commercial process, heating, or cooling application by supplying useful thermal energy from a cogeneration facility instead of from an alternate source, in British thermal units (higher heating value).

(d) P = Annual net electric output of the cogeneration facility in kilowatt-hours

As Patricia Weber, PE, explains in her declaration in support of these comments, the applicant miscalculates the fuel input. Miscalculating the fuel input is the only means by which JCEP demonstrate a rate less than the 6,000 Btu standard. Starting with the correct value for the fuel input will result in a fuel chargeable to power heat rate value much higher than 6,000 Btu. Therefore, JCEP is not subject to an exemption from siting.

Ms. Weber provides a detailed analysis in her declaration; the following excerpts provide a summary:

> In calculating the fuel chargeable to power heat rate (FCP), the applicant has mischaracterized the fuel input (FI) to the cogeneration system as "the fuel gas used for the Duct Burners and the fuel gas used for the Auxiliary Boiler." The useful thermal energy that is produced during the "sequential production of electrical energy and useful thermal energy" - aka cogeneration - is produced by the gas turbines, not the Duct Burners or the Auxiliary Boiler. Therefore, the correct fuel input value is the amount of fuel used for the gas turbines, which is much larger.
>
> * * *
>
> The applicant attempts to justify this decision by claiming that the power derived from the gas turbines is mechanical drive power and thus not applicable to the cogeneration process. However, the applicant elides the fact that the mechanical power delivered by the turbines to the liquefaction compressors is created by the combustion of gas, i.e. by thermal energy. Said another way, there would be no "heat exhaust due to efficiency losses" if the gas fed to the turbine were not combusted in the first place.
>
> ***
>
> Because the technical specifications for the gas turbines are not included in the application (having been redacted) it is not possible for a member of the public to calculate the actual power heat rate value for the cogeneration system. However, by design it is higher than the value that the applicant used to calculate FI,

resulting in a sufficiently higher FCP than the 5,960 Btu/kW-hr value included in the application.

* * *

In conclusion, the applicant failed to demonstrate compliance with the definition of a "high efficiency cogeneration facility."

Conclusion:

For these reasons and the reasons stated in Ms. Weber's declaration, the propose order should deny JCEP's application for an exemption and direct JCEP to submit a site certificate application.

Dated this 11th day of August, 2018.

/s/ Tonia Moro
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On behalf of:

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Rogue Climate, Executive Director

Rogue Riverkeeper
Stacey Detwiler, Conservation Director

Oregon Coast Alliance
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Hair on Fire Oregon
Deb Evans, Co-Founder

Citizens for Renewables/Citizens Against LNG
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Center for Sustainable Economy
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Bonnie McKinlay, Coalition Member, Co-Founder
Rick Rappaport, Coalition Member

Climate Justice Task Force, Unitarian Universalist Fellowship of Corvallis
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Food & Water Watch
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Landowners United
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Oregon Wild
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Pipeline Awareness Southern Oregon
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South Umpqua Rural Community Partnership
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Western Environmental Law Center
Susan Jane Brown, Wildlands Program Director & Staff Attorney

Affected Landowner
Bob Barker

Affected Landowners
Ron Schaaf and Deb Evans

Center for Sustainable Economy
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Daphne Wysham
Nick Caleb

DECLARATION OF PATRICIA WEBER
IN OPPOSITION TO
JORDAN COVE ENERGY PROJECT'S APPLICATION FOR EXEMPTION

I, Patricia J Weber, do declare and state as follows:

1. I make and offer this declaration in my capacity as an expert in the field of Electrical Engineering.

2. My training is in Electrical Engineering and I hold a BSEE from Montana State University. I am a licensed Professional Engineer in the state of Oregon.

3. I have reviewed the application dated 14 June 2018 that was submitted for a high efficiency exemption from the Department of Energy's energy facility siting requirements. Per ORS 469.320(2)(c)(A), 469.320(2)(c)(B)(ii), and OAR 345-015-0350 a site certificate is not required for an energy facility that sequentially produces electrical energy and useful thermal energy from the same fuel source, under average annual operating conditions has a nominal electric generating capacity of 50 megawatts or more, and has a fuel chargeable to power heat rate value that is not greater than 6,000 Btu per kilowatt hour. Per OAR 345-001-0010(25), "Fuel chargeable to power heat rate" means the net heat rate of electric power production during the first twelve months of commercial operation. A fuel chargeable to power heat rate is calculated with all factors adjusted to the average temperature, barometric pressure and relative humidity at the site during the times of the year when the facility is intended to operate using the formula, FCP = (FI - FD)/ P, where:

(a) FCP = Fuel chargeable to power heat rate.

(b) FI = Annual fuel input to the facility applicable to the cogeneration process in British thermal units (higher heating value).

(c) FD = Annual fuel displaced in any industrial or commercial process, heating, or cooling application by supplying useful thermal energy from a cogeneration facility instead of from an alternate source, in British thermal units (higher heating value).

(d) P = Annual net electric output of the cogeneration facility in kilowatt-hours.

The application fails to meet this criterion for the following reasons.

A. In calculating the fuel chargeable to power heat rate (FCP), the applicant has mischaracterized the fuel input (FI) to the cogeneration system as "the fuel gas used for the Duct Burners and the fuel gas used for the Auxiliary Boiler." The useful thermal energy that is produced during the "sequential production of electrical energy and useful thermal energy" – aka cogeneration - is produced by the gas turbines, not the Duct Burners or the Auxiliary Boiler.

Therefore, the correct fuel input value is the amount of fuel used for the gas turbines, which is much larger.

B. Defining the fuel input into the gas turbines as part of the cogeneration system is characteristic practice in the LNG industry.

Figure 1 is excerpted from *"Waste Heat Recovery in LNG Liquefaction Plants"*[1]:

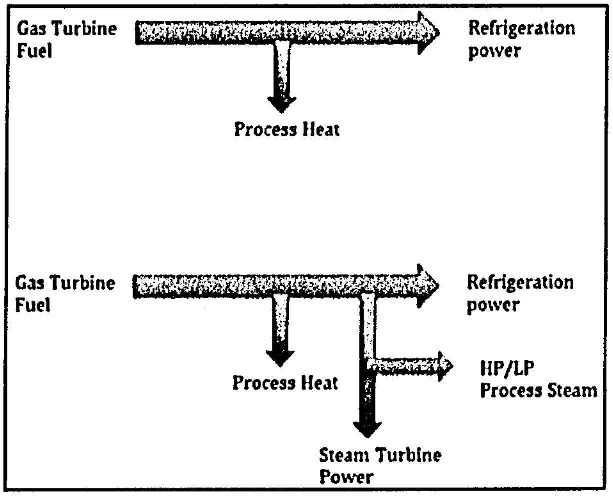

Figure 4. Cogen and Heat Recovery Concepts for LNG plants

Figure 1

This diagram presents two different possible schemes for implementing cogeneration processes at LNG plants; both schemes indicate that the Gas Turbine Fuel is part of the cogeneration process. (N.B. This diagram and citation are included to demonstrate that within the LNG industry, fuel input into the Gas Turbines used in the LNG liquefaction process is considered part of the cogeneration system - despite the applicant's assertion to the contrary.)

The system proposed in the application is described in the second (bottom) scheme. As shown in Figure 2, the values that would be used for the calculation of the Power Heat Rate value in the equation FCP = (FI –FD)/P are:

FI = Gas Turbine Fuel
FD = Process Heat + HP/LP Process Steam + Steam Fed to Power Generation Turbine
P = Steam Turbine Power Generated

[1] *Waste Heat Recovery in LNG Liquefaction Plants*, P. Pillai, C. Meher-Homji, F. Meher-Homji (Bechtel Corporation), presented at 'Proceedings of ASME Turbo Expo 2015: Turbine Technical Conference and Exposition' in Montreal CA, June 2015

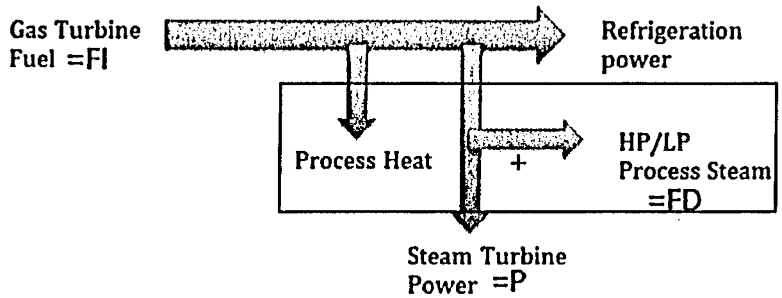

Figure 2

C. The applicant did not use values that reflect the terms described above; this results in an incorrect value for the fuel chargeable to the power heat rate (FCP). The applicant instead chose to use only the values of the gas being fed to the Duct Heaters and the Auxiliary Boilers as the basis for the FI calculation. By doing this, the applicant is attempting to include the value of the useful thermal energy produced by the gas turbines as fuel that is displaced in the cogeneration system, without accounting for the fuel that is burned in the gas turbines to create that thermal energy. (Note: The auxiliary boiler is supplemented by this gas feed; but also takes thermal energy that is recovered after the gas turbines operate the compressors that liquify the feedstock fuel.)

D. The applicant attempts to justify this decision by claiming that the power derived from the gas turbines is mechanical drive power and thus not applicable to the cogeneration process. However, the applicant elides the fact that the mechanical power delivered by the turbines to the liquefaction compressors is created by the combustion of gas, i.e. by thermal energy. Said another way, there would be no "heat exhaust due to efficiency losses"[2] if the gas fed to the turbine were not combusted in the first place. Figure 3 shows the terms as the applicant has mis-applied them to reach their desired result – which is to avoid the process necessary to obtain a site certificate for the LNG terminal power generating facility.

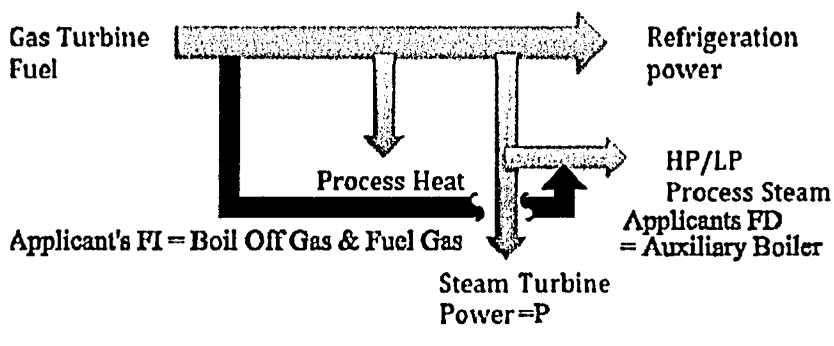

Figure 3

[2] *Jordan Cove Site Certificate Exemption Application*, 14 June 2018, p. 7

E. Because the technical specifications for the gas turbines are not included in the application (having been redacted) it is not possible for a member of the public to calculate the actual power heat rate value for the cogeneration system. However, by design the fuel to the gas turbines is significantly higher than the value that the applicant used for FI, which means the FCP for the facility is also significantly higher than the 1,116 Btu/kW-hr value included in the application.

F. In conclusion, the applicant failed to demonstrate compliance with the definition of a "high efficiency cogeneration facility."

4. I declare under penalty of perjury and the laws of the State of Oregon that the foregoing is true and correct to the best of my knowledge, information, and belief.

Signed this 7 day of August, 2018.

Patricia J Weber

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RESEARCH ARTICLE

Journal of Applied Ecology | BRITISH ECOLOGICAL SOCIETY

Large-scale manipulation of the acoustic environment can alter the abundance of breeding birds: Evidence from a phantom natural gas field

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Handling Editor: Vitor Paiva

Abstract

1. Altered animal distributions are a consequence of human expansion and development. Anthropogenic noise can be an important predictor of abundance declines near human infrastructure, yet more information is needed to understand noise impacts at the spatial and temporal scales necessary to alter populations.
2. Energy development and associated anthropogenic noise are globally pervasive, and expanding. For example, 600,000 new natural gas wells have been drilled across central North America in less than 20 years.
3. We experimentally broadcast energy sector noise (recordings of compressor engines) in Southwest Idaho (USA). We placed arrays of speakers creating a 'phantom natural gas field' in a large-scale experiment and tested the effects of noise alone on breeding songbird abundance. To examine variation in human-caused noise, we broadcast two types of compressor noise, one with a slightly higher sound intensity and greater bandwidth than the other.
4. Our phantom natural gas field encompassed approximately 100 km^2. We broadcast noise over three continuous months, for each of two seasons, and quantified over 20,000 hr of background sound levels.
5. Brewer's sparrows (*Spizella breweri*) were affected by our narrowband playback, declining 30%, 50 m from the speaker arrays. During our broadband playback, all species combined and Brewer's sparrows decreased 20% and 33%, respectively, at the scale of our sites (~0.5 km^2; up to 400 m from speaker arrays).
6. *Synthesis and applications*. Our results show the importance of incorporating the acoustic structure of noise when estimating the cost of noise exposure for populations. We suggest an urgent need for noise mitigation, such as quieting compressor stations, in energy extraction fields and other sources in natural areas broadly.

KEYWORDS
anthropogenic noise, noise exposure, noise pollution, oil and gas development, populations, sagebrush steppe, sensory ecology, songbird abundance

1 | INTRODUCTION

From urban areas (Barber, Crooks, & Fristrup, 2010) to the deepest ocean trench (Dziak et al., 2015), anthropogenic noise is ubiquitous. Extensive literature documents the negative effects of noise on foraging efficiency, survival, distribution and reproductive success of wildlife (see reviews Francis & Barber, 2013; Shannon et al., 2016). Recent studies have experimentally broadcast noise to disentangle the role of the acoustic environment from other covarying factors associated with human disturbance (e.g. direct deaths, edge effects, chemical pollution). For example, playback of intermittent traffic noise and continuous drilling noise reduced male sage grouse (*Centrocercus urophasianus*) lek attendance by 73% and 29% respectively (Blickley, Blackwood, & Patricelli, 2012). An experiment that replicated the soundscape of a highway demonstrated that moderately intense (~55 dBA, 24 hr L_{eq} at 50 m) acoustic environments can alter bird distributions (McClure, Ware, Carlisle, Kaltenecker, & Barber, 2013), change the age structure of a bird community (McClure, Ware, Carlisle, & Barber, 2016) and thwart the ability of birds to gain weight during migratory stopover (Ware, McClure, Carlisle, & Barber, 2015).

Energy extraction is a globally distributed, and rapidly expanding source of noise (Bentley, 2002). For example, 50,000 new wells per year have been drilled throughout central North America since 2000 (Allred et al., 2015). Energy extraction fields cause habitat loss and fragmentation, and bring roads and other permanent infrastructure to the landscape (McDonald, Fargione, Kiesecker, Miller, & Powell, 2009). Consequently, energy extraction fields reduce songbird abundance, alter nesting success and change large mammal space use and behaviour (Northrup & Wittemyer, 2013). To understand the role of energy extraction noise in these multimodal effects, previous studies have taken advantage of variation in sound levels created by different types of energy extraction infrastructure: loud compressor stations (engines that maintain pressure in pipelines) and quieter well pads. Comparing bird communities near these types of infrastructure, Bayne and colleagues (Bayne, Habib, & Boutin, 2008) showed that density and occupancy rates of several songbird species decreased near loud compressor stations in the Canadian boreal forest. Francis and coworkers describe similar patterns in a natural gas field in New Mexico; they report decreased songbird species richness near loud gas compressor stations (Francis, Ortega, & Cruz, 2009), which altered ecosystem services such as pollination and seed dispersal (Francis, Kleist, Ortega, & Cruz, 2012). Further work in the same gas field has documented reduced bat activity (Bunkley, McClure, Kleist, Francis, & Barber, 2015), and altered arthropod distributions (Bunkley, McClure, Kawahara, Francis, & Barber, 2017). In these natural experiments, there were other unmeasured factors such as air pollution (Roy, Adams, & Robinson, 2014), and presence of additional power lines at compressor stations (Braun, Oedekoven, & Aldridge, 2002) that may have influenced the results. Regardless of caveats, these studies strongly indicate that the causal factors behind these ecological impacts are likely noise mediated.

Due to the importance of understanding the scale of noise effects, and the significant and expanding footprint of energy extraction noise globally, we aimed to experimentally test the influence of compressor station noise on large-scale space use during the breeding season, a critical time for wildlife. We created a 'phantom natural gas field' with speaker arrays broadcasting compressor noise on a spatial scale large enough (sites distributed across 100 km^2) and a temporal scale long enough (an entire breeding season) to alter populations. Because sound propagation varies with topography and over time due to changing atmospheric conditions, we were able to create a gradient of noise exposure across sites and time (see Figures 1d and 2). We conducted our experiment in the sagebrush steppe, an ecosystem that has suffered rapid alterations due to human expansion and disturbance (Knick et al., 2003), including widespread energy extraction (Northrup & Wittemyer, 2013).

Based on economic incentives and resource properties, extraction fields contain many types of compressor stations (U.S. Energy Information Administration, 2007) that produce different spectral bandwidths (the range of frequencies contained in a sound source) and associated sound levels (Francis, Paritsis, Ortega, & Cruz, 2011). Given this variation, we replicated two distinctly different noise profiles, one more broadband and higher intensity than the other (Figure 1). We predicted that playback of compressor station noise of broader bandwidth and intensity would have a greater negative impact on bird abundance owing to increased overlap with the hearing ranges of birds and other trophically connected groups (Greenfield, 2014). To test the effects of our playbacks, we evaluated noise as a categorical and continuous variable. To examine noise as a categorical variable, we compared bird abundance at control and noise sites. To test the continuous effects of noise, we used the variation in sound levels at each site as a predictor of bird abundance (Figure 1d). Studying the relationship between sound level and bird abundance can provide managers information on the ecological benefits of quieting anthropogenically altered ecosystems.

2 | MATERIALS AND METHODS

2.1 | Phantom natural gas field

We played compressor station noise in the sagebrush steppe of Southwest Idaho (USA), in an area used for recreation and military training—the Orchard Combat Training Center. We broadcast noise from 1 April to 15 October in 2014 and 2015. We selected experimental sites, and randomly assigned them to noise versus control treatments—seven control and eight noise sites in 2014, where we broadcast our narrowband playback, and six control and six noise sites in 2015 (reusing 10 sites from 2014, and establishing 2 new sites), where we broadcast our broadband playback (details below) (See Figure 2 and Figure S1 in Supporting Information). At control sites, we placed dummy 'speakers' that were similar in shape, size and colour to our broadcast speakers. Sites were at least 1 km apart and 500 m or more from a dirt road.

All sites had similar plant communities, dominated by big sagebrush (*Artemesia tridentata*). To quantify the percentage of sagebrush cover at each site we used photographic methods (Booth, Cox,

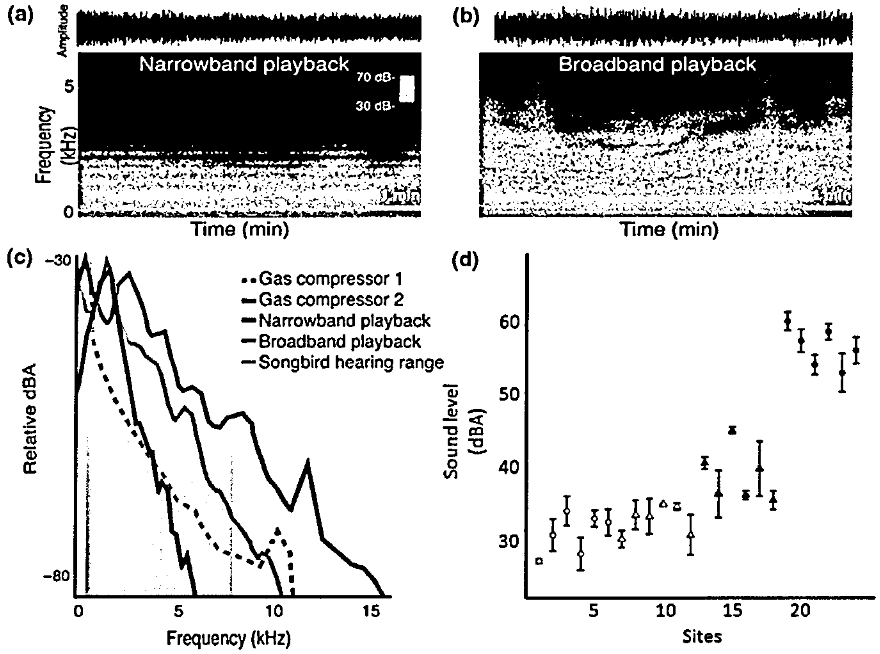

FIGURE 1 Broadcast files and equipment. (a) A 5-min recording of our narrowband playback displayed as a spectrogram (frequency (kHz) × time (min)), and oscillogram showing the amplitude (voltage × time). (b) A 5-min recording of our broadband playback displayed as a spectrogram (frequency × time), and oscillogram showing the amplitude (voltage × time). (c) Visual comparison of real compressors and our playbacks. Power spectra (sound level × frequency) of two gas compressor stations in New Mexico (Compressor 1) and Wyoming (Compressor 2), and recordings of the two files broadcast in our experiment (all files recorded at 40 meters). Compared to the narrowband playback, the broadband playback was ~6 kHz higher in bandwidth as measured 55 dB below peak frequency. The average songbird hearing range (as measured 55 dB above the best hearing threshold for the average bird) is depicted by the shaded grey bar (Dooling, 2011), showing strong overlap between our noise broadcasts and bird spectral sensitivity. When comparing the narrowband and broadband playbacks, note the greater spectral overlap of the broadband treatment with bird hearing at both low and high frequencies. (d) Mean values (±*SE*) of sound levels (dBA) from each site at the 50 and 250 m point count locations. Circles represent 50-m sites and triangles represent 250-m sites. Yellow represents control sites and red represents noise sites. The larger variation of noise sites at 250 m is due to changes in wind direction and our playback noise travelling 250 m from the speakers

& Berryman, 2006). We measured vegetation along five 300-m transects radiating from the centre of each site. With a camera (Fujifilm FinePix XP70 16.4 Megapixel Compact Camera) attached to a 2-m pole (Sokkia 724,290 Economy 2 m Aluminum 2 Section GPS Rover Rod), we photographed 20 points along each transect that were 15 m apart, obtaining a hundred pictures per site. We obtained 1-m^2 photographs that were analysed using the open source software SamplePoint (version 1.58; Booth et al., 2006). We identified the vegetation type of 64 individual points of each photograph to obtain a percent cover for sagebrush.

2.2 | Noise playback and acoustic monitoring

We broadcast two noise stimuli, one per year (Figure 1a–c). For each stimulus type (narrowband and broadband) we used one playback file that in combination with two different speaker systems created the two different noise stimuli. Arrays were mounted on support structures 2 m above the ground. For the narrowband playback in 2014, we placed four horn-loaded speakers (Dayton RPH16; MCM 40W; 400–3,000 Hz ± 5 dBA) in the four cardinal directions, and amplified them using class D amplifiers (Parts Express, 2W, 4-ohm). In 2015, for the broadband playback, we used omni-directional speakers (Octasound SP820A; 35–20,000 Hz ± 10dBA,) and subwoofers (Octasound OS2X12; 25–20,000 Hz ± 10dBA) driven by class T amplifiers (Lepai LP-2020A 20W, 4-ohm). Amplifiers were powered by solar array systems (Solarland SLP 15S-12 panels, Morningstar PS-30M controllers and PowerSonic 12 V batteries). We delivered sound files (WAV) to the amplifiers using Olympus LS-7 players that were powered with 20-amp hour LiFePO4 (Batteryspace) batteries.

We played synthetic compressor noise, created in Audacity version 2.1.2. Because compressor stations tend to be idiosyncratic, we created our audio file from an average of three compressor stations recorded in the San Juan basin, New Mexico and Green River Basin, Wyoming. Compressor stations were recorded with a Sennheiser ME66 microphone (40–20,000Hz; ±2.5dBA) and Roland R-05 recorder (sampling rate 48 kHz) at 40 m. We created a 3-hr playback file that was repeated 24 hr/day. It is important to note that the compressor stations we recorded very likely produced energy below 20 Hz (Francis et al., 2011), outside of the recording or playback capabilities of our equipment.

To measure sound levels at each site through the season, we placed acoustic recording units (ARUs; Roland R-05 audio

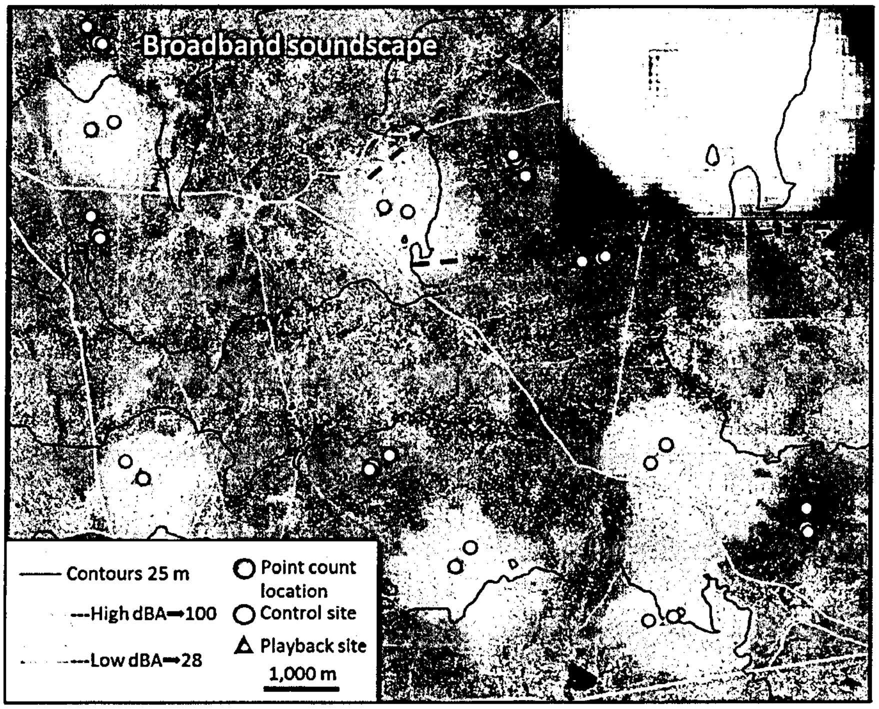

FIGURE 2 The phantom natural gas field. Estimated sound levels (dBA 1 hr LEQ) of noise sites against a background of 28 dBA, the median L50 for control sites from May to June during broadband playback (2015). Sound level was modelled using SPreAD-GIS (Reed, Boggs, & Mann, 2010); see supporting information for details (Appendix S1). This map is a heuristic of the broadband soundscape. Green circles (control) and triangles (noise) represent the centre of the site, speakers or dummy speakers. Yellow circles represent the two point count locations. Pullout in the upper right corner represents sound levels from an example playback site

recorders) that were calibrated following Mennitt & Fristrup, 2012, and mounted inside a protective wind screen at each bird point count location (30 in 2014 and 24 in 2015). We camouflaged ARUs in shrubs and mounted them 50 cm above the ground by lashing support rods to vegetation. Using custom programs (Damon Joyce, NPS, AUDIO2NVSPL and Acoustic Monitoring Toolbox), we obtained hourly sound levels from MP3 recordings (equivalent continuous sound level; LEQ in dBA).

Across our study site, the gradient of background noise ranged from ~22 dBA to 63 dBA (Figure 1d), allowing us to compare not only noise and control sites but also examine a gradient of sound levels due to the variation between sites with the same treatment, and variation within the same site (decibels at 50 m vs. 250 m). For each site, we obtained the median of the hourly LEQ (dBA) per month (Lynch, Joyce, & Fristrup, 2011) as a predictor of bird abundance. In 2014, under the narrowband playback (Figure 1a), sound levels at 50 m from the speaker arrays averaged 56.3 ± 1.7 dBA (mean ± *SE*) at noise sites and 37 ± 0.7 dBA at control sites. At 250 m, noise sites averaged 46 ± 1.5 dBA and control sites 35 ± 1.59 dBA. In 2015, under the broader bandwidth and higher intensity playback (Figure 1b), sound levels at 50 m averaged 58 ± 1 dBA at noise sites and 30.6 ± 1 dBA at control sites. At 250 m, noise sites averaged 39.8 ± 1 dBA and control sites averaged 33 ± 0.9 dBA. It is important to note sound levels of our control sites were higher than many natural environments (Buxton et al., 2017) due to military training and recreational activity in our study area. Furthermore, the sound levels of our control sites were similar to control sites (well pad sites) used in previous 'natural' ecological experiments in real natural gas fields (e.g., Francis et al., 2009). Figures 1 and 2 show the heterogeneity and variability between sites due to atmospheric (wind) conditions and topography in 2015. See supporting information for details about our soundscape map during the narrowband playback in 2014 (Figure S1).

2.3 | Bird abundance

We counted birds at each site seven to ten times from 8 April to 17 June 2014 during the narrowband playback, and seven to eight times from 5 April to 15 June 2015 during the broadband playback. At each site, we placed two point count locations, one at 50 m from the speaker array and the second at 250 m from the array. Point count locations were placed in opposite directions from the speaker array to maximize the independence of count sites. All counts were 6 min in length, and conducted within 4 hr after sunrise by the same two observers, during both seasons. No surveys were conducted under strong wind or heavy rain. Counting methodology followed a modified protocol of the Rocky Mountain Bird Observatory (Hanni et al., 2014). For each detected bird, we recorded species, direction and distance (using laser range finders) of all birds. We identified species by call, song or sight. Because probability of detection can vary between observers (Alldredge, Simons, & Pollock, 2007; 2015 & Barber, 22015; Sauer, Peterjohn, & Link, 1994), we randomized the surveys that each observer completed within site (50 m vs. 250 m) and between sites, making sure both observers visited all sites. Excessive noise can decrease the number of birds detected during point counts (e.g. McClure et al., 2015; Simons, Alldredge, Pollock, & Wettroth, 2007; Pacifici, Simons, & Pollock, 2008). However, Ortega and Francis (2012) found that noise from natural gas compressors did not interfere with detection rates for sound levels under 45 dBA. Furthermore, Koper and colleagues showed that quiet to moderate levels of extraction noise were unlikely to interfere with detection of songbirds (Koper, Leston, Baker, Curry, & Rosa, 2016). Nevertheless, we turned off our speakers during point counts so that noise would not interfere with rates of detection (McClure et al., 2013). Because noise levels were between ~30 and 37 dBA under noise-off conditions at control and noise sites, relative comparison of bird counts between the two site types are likely not biased by imperfect detection.

2.4 | Statistical analysis

We analysed all data using R (R Core Team, 2000 R language definition), version 3.2.1 and package lme4 (Barton, 2016; Bates, Maechler, Bolker, & Walker, 2014). We truncated data to include detections only within 150 m of point count locations. Truncating our detections to 150 m allowed us to include individuals that were 400 m from the noise source at the 250-m point count location (250 m + 150 m), therefore, our results only apply within 400 m of our speaker arrays.

We were interested in the five songbird species that breed in our site and are associated with the sagebrush ecosystem—Brewer's sparrow (*Spizella breweri*), horned lark (*Eremophila alpestris*), western meadowlark (*Sturnella neglecta*), sagebrush sparrow (*Artemisiospiza nevadensis*) and sage thrasher (*Oreoscoptes montanus*) (Baker, Eng, Gashwiler, Schroeder, & Clait, 1976). We modelled abundance of our five species of interest combined, and each species individually, using generalized linear mixed models with a Poisson distribution (Bolker et al., 2009). We only considered parameters as informative if they had 95% confidence intervals excluding zero (Arnold, 2010). To test the effects of different playbacks independently, we analysed each year separately. We also z-transformed independent variables to improve model convergence.

To test whether bird abundance is related to the presence or absence of noise we first created a model with the variables 'treatment' (indicating noise vs. control sites), interaction of treatment and point count location (50 or 250 m from the speakers), combinations of linear and quadratic effects of the day of the census (to include seasonal fluctuations), and percent sagebrush cover (because it is an important predictor of songbird settlement decisions; Chalfoun & Martin, 2007). To test the relationship between bird abundance and sound level, we created another model with a variable 'dBA' (indicating the monthly median sound level (LEQ in dBA) at each point count location), combinations of linear and quadratic effects of day, and percent sagebrush cover. Note that dBA and treatment were never in the same model, thus avoiding multicollinearity. For both models, we included site and point count location as random effects. During the analysis, we kept the whole model and we did not drop any parameter that was not informative. Due to various methods of studying soundscapes, even though our results do not qualitatively change, we include a separate analysis using the median sound level (L50; Table S2).

3 | RESULTS

3.1 | Treatment model

During the narrowband playback, parameters that explained Brewer's sparrow abundance were treatment, interaction of treatment and point count location, day and day^2. Brewer's sparrow showed a negative response to treatment only at the 50-m point count location, decreasing 30% at noise sites (average count 1.13 ± 0.18 at control and 0.76 ± 0.12 at noise sites). Parameters that explained the abundance of the songbird community were day and day^2 (Table 1, Figure 3). During the broadband playback, the parameters that explained Brewer's sparrow abundance were treatment, interaction of treatment and point count location, day and day^2. Brewer's sparrow, showed a negative response to treatment at both 50-m and 250-m count locations, decreasing 51.8% (average count 2.31 ± 0.32 at control and 1.11 ± 0.18 at noise sites), and 13% (average count 2.06 ± 0.25 at control and 1.79 ± 0.25 at noise sites), respectively, in the presence of noise. Parameters that explained the abundance of the songbird community were treatment, day and day^2, decreasing 20% (average count 1.12 ± 0.06 at control and 0.89 ± 0.05 at noise sites) at noise sites (50 m and 250 m counts combined). The parameters that explained the abundance of sagebrush sparrow were day and day^2, only under the broadband playback. The parameter that explained the abundance of sage thrasher with a positive relationship under both playbacks was sagebrush cover (Table 1, Figure 3). All responses to day and day^2 were positive quadratics (Table 1). This response indicates that bird abundance increases with time as migrant species arrived at our study site, and later in the summer, fewer birds are detected as a result of the end of the breeding season. Horned lark and western meadowlark showed no response to any parameters.

3.2 | Sound level model

During the narrowband playback, parameters that explained Brewer's sparrow abundance were dBA, day and day^2. Brewer's sparrow showed a negative response to increased sound levels with a decrease of 15% per 9 dBA. Parameters that explained the abundance of the songbird community were day, and day^2. During the broadband playback, parameters that explained Brewer's sparrow abundance were dBA, day, and day^2. Brewer's sparrow showed a negative response to increased sound levels with a decrease of 17% per 9 dBA. During the broadband playback, parameters that explained the abundance of the songbird community were dBA, day and day^2, with a decrease of 7.5% per 9 dBA. The parameters that explained the abundance of sagebrush sparrow only under the broadband playback were day and day^2. The parameter that explained the abundance of sage thrasher with a positive relationship under both playbacks was percentage of sagebrush cover (Table 1, Figure 3). All responses to day and day^2 were positive quadratics

TABLE 1 Scaled estimate values, standard errors, *p* values and 95% confidence intervals of all parameters with 95% confidence intervals excluding zero

	Parameter	Estimate	Std. Error	*p*	95 C.I.	95 C.I.
Treatment model						
All birds, narrowband	**Day²**	**−1.71**	**0.38**	**0.00**	**−0.96**	**−2.46**
	Day	**1.69**	**0.38**	**0.00**	**2.43**	**0.95**
	Treatment	−0.19	0.17	0.25	−0.53	0.15
	Treatment × Point	0.00	0.21	0.99	−0.47	0.44
	Point	−0.10	0.15	0.51	−0.43	0.23
	Sagebrush cover	0.02	0.06	0.76	−0.12	0.15
All birds, broadband	**Day²**	**−4.13**	**0.58**	**0.00**	**−2.99**	**−5.26**
	Day	4.20	0.58	0.00	5.33	3.06
	Treatment	**−0.29**	**0.10**	**0.00**	**−0.10**	**−0.48**
	Treatment × Point	0.10	0.13	0.44	−0.16	0.37
	Point	0.06	0.09	0.50	−0.11	0.23
	Sagebrush cover	0.06	0.03	0.05	0.00	0.13
Brewer's sparrow, narrowband	**Day²**	**−10.68**	**1.16**	**0.00**	**−8.40**	**−12.97**
	Day	**10.34**	**1.11**	0.00	**12.52**	**8.16**
	Treatment	**−0.51**	**0.25**	0.04	**−0.03**	**−1.01**
	Treatment × Point	**0.50**	**0.25**	0.04	**1.13**	**0.16**
	Point	−0.14	0.17	0.43	−0.49	0.21
	Sagebrush cover	0.05	0.10	0.60	−0.16	0.28
Brewer's sparrow, broadband	**Day²**	**−10.79**	**1.13**	0.00	**−8.57**	**−13.01**
	Day	**10.85**	**1.12**	0.00	**13.05**	**8.65**
	Treatment	**−0.78**	**0.17**	0.00	**−0.44**	**−1.12**
	Treatment × Point	**0.56**	0.23	0.01	**1.01**	**0.11**
	Point	−0.11	0.14	0.44	−0.38	0.16
	Sagebrush cover	0.02	0.05	0.72	−0.09	0.13
Sage thrasher, narrowband	Day²	2.19	2.09	0.29	−2.15	6.14
	Day	−2.57	2.05	0.21	−6.51	1.62
	Treatment	0.53	0.69	0.44	−0.80	2.08
	Treatment × Point	−0.23	0.84	0.78	−2.18	1.42
	Point	0.61	0.65	0.35	−0.66	2.14
	Sagebrush cover	**0.66**	**0.26**	**0.01**	**1.16**	**0.16**
Sage thrasher, broadband	Day²	−2.46	2.39	0.30	−7.25	2.18
	Day	2.78	2.42	0.25	−1.92	7.60
	Treatment	−0.31	0.48	0.52	−1.30	0.82
	Treatment × Point	0.31	0.61	0.62	−0.88	1.53
	Point	0.26	0.38	0.49	−0.48	1.03
	Sagebrush cover	**0.82**	**0.18**	**0.00**	**0.47**	**1.50**
Sagebrush sparrow, broadband	**Day²**	**−4.95**	**1.35**	**0.00**	**−2.30**	**−7.60**
	Day	4.98	1.35	0.00	7.62	2.34
	Treatment	−0.26	0.22	0.24	−0.71	0.18
	Treatment × Point	−0.37	0.31	0.24	−0.99	0.25
	Point	0.20	0.19	0.29	−0.17	0.59
	Sagebrush cover	0.11	0.07	0.13	−0.06	0.27

(Continues)

TABLE 1 (Continued)

	Parameter	Estimate	Std. Error	p	95 C.I.	95 C.I.
Sound level (dBA) model						
All birds, narrowband	**Day²**	**−1.71**	**0.38**	**0.00**	**−1.00**	**−2.51**
	Day	**1.71**	**0.38**	**0.00**	**2.46**	**0.97**
	dBA	−0.02	0.05	0.71	−0.12	0.09
	Sagebrush cover	0.01	0.07	0.85	−0.13	0.15
All birds, broadband	**Day²**	**−4.10**	**0.58**	**0.00**	**−2.97**	**−5.24**
	Day	**4.17**	**0.58**	**0.00**	**5.31**	**3.04**
	dBA	**−0.10**	**0.03**	**0.00**	**−0.02**	**−0.17**
	Sagebrush cover	0.06	0.03	0.08	−0.01	0.13
Brewer's sparrow, narrowband	**Day²**	**−10.78**	**1.17**	**0.00**	**−13.15**	**−8.53**
	Day	**10.43**	**1.12**	**0.00**	**8.27**	**12.68**
	dBA	**−0.16**	**0.07**	**0.03**	**−0.31**	**−0.01**
	Sagebrush cover	0.06	0.10	0.53	−0.15	0.28
Brewer's sparrow, broadband	**Day²**	**−10.77**	**1.13**	**0.00**	**−13.04**	**−8.60**
	Day	**10.83**	**1.12**	**0.00**	**8.67**	**13.06**
	dBA	**−0.24**	**0.07**	**0.00**	**−0.37**	**−0.11**
	Sagebrush cover	0.01	0.06	0.90	−0.13	0.14
Sage thrasher, narrowband	Day²	2.26	2.08	0.28	−2.07	6.21
	Day	−2.65	2.05	0.20	−6.58	1.54
	dBA	0.20	0.20	0.33	−0.20	0.62
	Sagebrush cover	**0.62**	**0.25**	**0.01**	**0.12**	**1.20**
Sage thrasher, broadband	Day²	−2.51	2.40	0.30	−7.30	2.16
	Day	2.83	2.43	0.24	−1.89	7.67
	dBA	−0.24	0.17	0.15	−0.61	0.07
	Sagebrush cover	**0.80**	**0.19**	**0.00**	**0.43**	**1.39**
Sagebrush sparrow, broadband	**Day²**	**−4.87**	**1.35**	**0.00**	**−7.58**	**−2.26**
	Day	**4.91**	**1.35**	**0.00**	**2.30**	**7.54**
	dBA	−0.06	0.11	0.60	−0.26	0.17
	Sagebrush cover	0.11	0.09	0.25	−0.10	0.33

Note: In bold parameters that predict bird abundance. The parameter 'treatment' represents noise versus control sites, 'sagebrush cover' represents the percent of sagebrush cover at each site, 'dBA' represents sound levels, 'day' represents Julian day and 'day²' represents the quadratic effects of day.

(Table 1). Horned lark and western meadowlark showed no response to any parameters.

3.3 | Carryover effects

Because we randomized sites each year, and used some of the same sites across years, we tested for carryover effects on bird abundance from the treatment in the previous year. Admittedly, our low sample sizes provide only a weak test. No difference was observed in songbird abundance in 2015 when comparing control sites that were exposed to noise in 2014 ($N = 2$) to sites that did not receive noise exposure in either year (i.e. sites that were controls both years) ($N = 2$), nor to control sites studied only in 2015 ($N = 2$), indicating carryover effects were unlikely ($\beta = 0.04, \pm 0.08, p = 0.62$; Figure S2). Over two years, we recorded 2,074 detections of five songbird species that nested in our study site (Table S1).

4 | DISCUSSION

Our large-scale, experimental broadcast of compressor station noise revealed a marked effect on breeding songbird abundance. Under playback of broadband noise, the abundance of all birds combined, and one individual species, decreased. In contrast, playback of

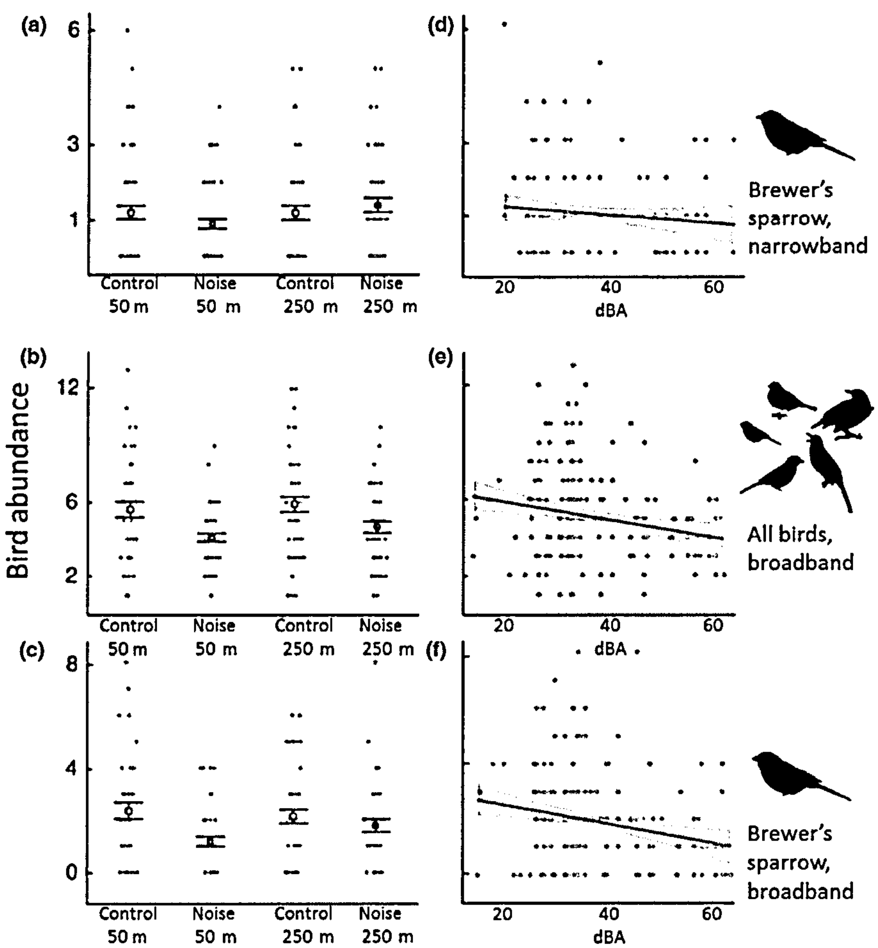

FIGURE 3 Bird abundance results. (a–c) Songbird abundance results from our first treatment model. Small grey dots represent the number of bird detections in a day at each site, red squares represent mean values (±*SE*) at noise sites and yellow squares represent mean values (±*SE*) at control sites. (d–f) Songbird abundance results from our second dBA model. Small grey dots represent bird detections per sound level (dBA), indicating a negative relationship between bird abundance and increased sound levels

narrowband noise altered the abundance of only one species, supporting our prediction that a higher bandwidth and level of noise would result in a stronger negative effect on bird populations. We demonstrate that noise alone can recreate similar patterns of songbird space use found in natural gas extraction fields. Gilbert and Chalfoun (2011) obtained comparable results in a Wyoming natural gas field where an analogous songbird community showed changes in abundance as density of extraction infrastructure increased near bird count locations. Additionally, our work broadly confirms other studies performed in energy extraction fields (e.g. Bayne et al., 2008; Francis et al., 2009) aimed at teasing apart noise from other variables.

Under the narrowband broadcast, Brewer's sparrow abundance decreased 30% compared to controls at the 50 m survey locations only. A similar narrowband playback of roadway traffic noise during songbird migration resulted in an ~30% decrease in abundance, with significant declines in 12 migratory species (McClure et al., 2013). Although there is no overlap in bird species examined between our current study and this previous work, our results highlight the importance of examining wildlife responses to noise during divergent life stages (e.g. migration vs. breeding season). At sites that received our broadband noise playback, the abundance of the entire sagebrush songbird community, and Brewer's sparrow alone, declined 20% and 33% respectively. Note that these percentage decreases in bird abundance, although derived from small reductions in overall average counts, translate to significant declines when considering the amount of area potentially exposed to gas compressor noise across sage steppe habitat (Allred et al., 2015).

To provide managers with an informative metric to parameterize the ecological effects of quieting landscapes, we examined the relationship between songbird abundance and sound level, specifically. This is particularly relevant for existing energy extraction fields where removal of noise sources is unlikely, yet quieting sources is tractable. The overall songbird community declined 7.5% per 9 decibels under the broadband playback, although there was no measurable change under the narrowband playback. We found that Brewer's sparrow decreased 15% per 9 decibels under the narrowband playback and 17% per 9 decibels under the broadband playback. Our noise sites did not recreate some of the highest sound level compressor stations that exist in extraction fields (Bunkley et al., 2015; Mason, McClure, & Barber, 2016). We can, therefore, predict that these intense noise sources will have a more detrimental effect on bird populations. Our findings could have been influenced by a year effect. However, the number of bird encounters each year was similar (Table S1), and our experiment was designed to test the relative, not absolute, differences between noise and control sites between treatments. In addition, based on plumage, 70% of the Brewer's sparrow males in our system that were banded for the purposes of a different study in our area, were first time breeders, aged as second year individuals (birds known to have hatched in the calendar year preceding the banding year) during both years.

Although we do not know the mechanism behind the decrease in songbird abundance we observed, our playbacks could have increased visual vigilance behaviour owing to lost auditory awareness, and thus reduced foraging rates—forcing birds to leave (Ware et al., 2015). Alternatively, foraging behaviour might have been altered by reduced acoustic detectability of prey (Montgomerie & Weatherhead, 1997), indirectly by altering arthropod distributions (Bunkley et al., 2017), or perhaps by altering food webs (Francis et al., 2009). In fact, a recent study indicates that arthropods change space use in a natural gas field in response to noise (Bunkley et al., 2017).

Songbird species that produce lower frequency songs exhibit a stronger avoidance response to anthropogenic noise (Francis, 2015). In our sagebrush songbird community, most species have similar song bandwidth and peak frequency (see Table S3), apart from horned larks that have a slightly broader bandwidth of frequencies in their song. However, sage thrashers, a species with the lowest peak frequency song in our community, showed no response to noise exposure. It seems song characteristics, although showing intriguing trends with bird responses, are not a predictor of the distributional shifts we quantified. Thus, the underlying mechanisms driving the distributional shifts we observed remain unclear.

Altered conspecific interactions, perhaps driven by vocalization-mediated processes, such as interactions between males (Kleist, Guralnick, Cruz, & Francis, 2016) and mates (Halfwerk et al., 2011), might also underpin some results from our study. It is conceivable that altered abundances of species in the bird community might have changed heterospecific interactions, such as alarm calling networks (Grade & Sieving, 2016), with cascading consequences. Furthermore, noise could have altered stress hormones of individuals, either directly or indirectly, thus driving birds to abandon breeding sites (Kleist, Guralnick, Cruz, Lowry, & Francis, 2018). Future research into causes of altered distributions and the potential of some species to habituate to noise exposure is essential to provide better predictive models of traits that increase risk for wildlife exposed to chronic anthropogenic noise.

The data we present here are important for management decisions regarding where future noise-producing infrastructure is placed and the current implementation of mitigation strategies in high-value habitats exposed to noise. Energy extraction companies can design and build compressor engines to be quieter and lower bandwidth (Motruik, 2000) and place compressor stations where they will create the lowest noise footprint (Keyel et al., 2018). Building noise-attenuating walls around existing compressor stations will reduce both the sound level (Francis et al., 2011) and potentially the bandwidth of noise that intrudes onto adjacent wildlife habitat (Hidaka, Beranek, & Okano, 1995). In some areas, walls have already been built around compressor stations, decreasing sound levels by 10 decibels (dBC) at 30 m (Francis et al., 2011). Energy development and its associated chronic noise exposure comes with an ecological cost, and the current efforts by the US government to open drilling in protected areas (The White House, 2017) will degrade the habitat quality of these critical ecological preserves. One clear route to protecting ecosystems is to include noise exposure thresholds in leases of public lands to energy extraction companies. Our study adds to mounting evidence indicating significant ecological effects of anthropogenic noise exposure for breeding birds and supports the assertion that noise mitigation should be implemented in energy extraction fields post haste (Bayne et al., 2008; Blickley et al., 2012; Francis et al., 2009). The soundscape must be considered if we are to holistically protect ecological systems.

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AUTHORS' CONTRIBUTIONS

E.C.M., J.R.B. and C.J.W.M. designed the experiment and methodology; E.C.M. collected the data; E.C.M., J.R.B., and C.J.W.M. analysed the data; E.C.M. and J.R.B. led the writing of the manuscript. All authors contributed critically to manuscript drafts and gave final approval for publication.

DATA AVAILABILITY STATEMENT

Data available via the Dryad Digital Repository https://doi.org/10.5061/dryad.7d069p5 (Cinto Mejia, McClure, & Barber, 2019).

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REFERENCES

Alldredge, M. W., Simons, T. R., & Pollock, K. H. (2007). Factors affecting aural detections of songbirds. *Ecological Applications*, *17*, 948–955. https://doi.org/10.1890/06-0685

Allred, B. W., Smith, W. K., Twidwell, D., Haggerty, J. H., Running, S. W., Naugle, D. E., & Fuhlendorf, S. D. (2015). Ecosystem services lost to oil and gas in North America. *Science*, *348*, 401–402. https://doi.org/10.1126/science.aaa4785

Arnold, T. W. (2010). Uninformative parameters and model selection using Akaike's information criterion. *Journal of Wildlife Management*, *74*, 1175–1178. https://doi.org/10.2193/2009-367

Baker, M. F., Eng, R. L., Gashwiler, J. S., Schroeder, M. H., & Clait, E. (1976). Conservation Committee Report on effects of alteration of sagebrush communities on the associated avifauna. *The Wilson Journal of Ornithology*, *88*, 165–171.

Barber, J. R., Crooks, K. R., & Fristrup, K. M. (2010). The costs of chronic noise exposure for terrestrial organisms. *Trends in Ecology & Evolution*, *25*, 180–189. https://doi.org/10.1016/j.tree.2009.08.002

Barton, K. (2016). MuMIn: Multi-model inference. R package version 1.15.6. Retrieved fromhttp://R-Forge.R-project.org/projects/mumin

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2014). lme4: Linear mixed-effects models using S4 classes. R package version 1.1-7. Retrieved from http://CRAN.R-project.org/package=lme4

Bayne, E. M., Habib, L., & Boutin, S. (2008). Impacts of chronic anthropogenic noise from energy-sector activity on abundance of songbirds in the boreal forest. *Conservation Biology*, *22*, 1186–1193. https://doi.org/10.1111/j.1523-1739.2008.00973.x

Bentley, R. W. (2002). Global oil and gas depletion: An overview. *Energy Policy.*, *30*, 189–205. https://doi.org/10.1016/S0301-4215(01)00144-6

Blickley, J. L., Blackwood, D., & Patricelli, G. L. (2012). Experimental evidence for the effects of chronic anthropogenic noise on abundance of Greater Sage-Grouse at leks. *Conservation Biology*, *26*, 461–471. https://doi.org/10.1111/j.1523-1739.2012.01840.x

Bolker, B. M., Brooks, M. E., Clark, C. J., Geange, S. W., Poulsen, J. R., Stevens, M. H. H., & White, J.-S. (2009). Generalized linear mixed models: A practical guide for ecology and evolution. *Trends in Ecology & Evolution*, *24*, 127–135. https://doi.org/10.1016/j.tree.2008.10.008

Booth, D. T., Cox, S. E., & Berryman, R. D. (2006). Point sampling digital imagery with "Samplepoint" Environ. *Monit. Assess.*, *123*, 97–108. https://doi.org/10.1007/s10661-005-9164-7

Braun, C. E., Oedekoven, O. O., & Aldridge, C. L. (2002). Oil and gas development in western North America: Effects on sagebrush steppe avifauna with particular emphasis on sage-grouse. *Transactions of the North American Wildlife and Natural Resources Conference*, *67*, 337–349.

Bunkley, J. P., McClure, C. J. W., Kawahara, A. Y., Francis, C. D., & Barber, J. R. (2017). Anthropogenic noise changes arthropod abundances. *Ecology and Evolution*, *7*, 2977–2985. https://doi.org/10.1002/ece3.2698

Bunkley, J. P., McClure, C. J. W., Kleist, N. J., Francis, C. D., & Barber, J. R. (2015). Anthropogenic noise alters bat activity levels and echolocation calls. *Global Ecology and Conservation*, *3*, 62–71. https://doi.org/10.1016/j.gecco.2014.11.002

Buxton, R. T., McKenna, M. F., Mennitt, D., Fristrup, K., Crooks, K., Angeloni, L., & Wittemyer, G. (2017). Noise pollution is pervasive in US protected areas. *Science*, *356*, 531–533. https://doi.org/10.1126/science.aah4783

Chalfoun, A. D., & Martin, T. E. (2007). Assessments of habitat preferences and quality depend on spatial scale and metrics of fitness. *Journal of Applied Ecology*, *44*, 983–992. https://doi.org/10.1111/j.1365-2664.2007.01352.x

Cinto Mejia, E., McClure, C. J. W., & Barber, J. R. (2019). Data from: Large-scale manipulation of the acoustic environment can alter the abundance of breeding birds: Evidence from a phantom natural gas field. *Dryad Digital Repository*, https://doi.org/10.5061/dryad.7d069p5

Dooling, R. J. (2011). The effects of noise on birds. *The Journal of the Acoustical Society of America*, *129*, 2395–2395. https://doi.org/10.1121/1.3587789

Dziak, R., Haxel, J., Matsumoto, H., Meinig, C., Delich, N., Osse, J., & Wetzler, M. (2015). Deployment and recovery of a full-ocean depth mooring at Challenger Deep, Mariana Trench. In *OCEANS'15 MTS/IEEE*, Washington (pp. 1–9). IEEE. https://doi.org/10.23919/OCEANS.2015.7401902

Francis, C. D. (2015). Vocal traits and diet explain avian sensitivities to anthropogenic noise. *Global Change Biology*, *21*, 1809–1820. https://doi.org/10.1111/gcb.12862

Francis, C. D., & Barber, J. R. (2013). A framework for understanding noise impacts on wildlife: An urgent conservation priority. *Frontiers in Ecology and the Environment*, *11*, 305–313. https://doi.org/10.1890/120183

Francis, C. D., Kleist, N. J., Ortega, C. P., & Cruz, A. (2012). Noise pollution alters ecological services: Enhanced pollination and disrupted seed dispersal. *Proceedings of the Royal Society B*, *279*, 2727–2735. https://doi.org/10.1098/rspb.2012.0230

Francis, C. D., Ortega, C. P., & Cruz, A. (2009). Noise pollution changes avian communities and species interactions. *Current Biology*, *19*, 1415–1419. https://doi.org/10.1016/j.cub.2009.06.052

Francis, C. D., Paritsis, J., Ortega, C. P., & Cruz, A. (2011). Landscape patterns of avian habitat use and nest success are affected by chronic gas well compressor noise. *Landscape Ecology*, *26*, 1269–1280. https://doi.org/10.1007/s10980-011-9609-z

Gilbert, M. M., & Chalfoun, A. D. (2011). Energy development affects populations of sagebrush songbirds in Wyoming. *Journal of Wildlife Management*, *75*, 816–824. https://doi.org/10.1002/jwmg.123

Grade, A. M., & Sieving, K. E. (2016). When the birds go unheard: Highway noise disrupts information transfer between bird species. *Biology Letters*, *12*, 20160113. https://doi.org/10.1098/rsbl.2016.0113

Greenfield, M. D. (2014). *Insect hearing and acoustic communication* (Vol 1). https://doi.org/10.1007/978-3-642-40462-7

Halfwerk, W., Bot, S., Buikx, J., van der Velde, M., Komdeur, J., ten Cate, C., & Slabbekoorn, H. (2011). Low-frequency songs lose their potency in noisy urban conditions. *Proceedings of the National Academy of Sciences of the United States of America*, *108*, 14549–14554. https://doi.org/10.1073/pnas.1109091108

Hanni, D. J., White, C. M., & Van Lanen, N. J.,Birek, J. J., Berven, J. M., & McLaren, M. A. (2014). Unpublished report Rocky Mountain Bird Observatory.

Hidaka, T., Beranek, L. L., & Okano, T. (1995). Interaural cross-correlation, lateral fraction, and low-and high-frequency sound levels as measures of acoustical quality in concert halls. *The Journal of the Acoustical Society of America*, *98*, 988–1007. https://doi.org/10.1121/1.414451

Keyel, A., Reed, S., Nuessly, K., Cinto-Mejia, E., Barber, J., & Wittemyer, G. (2018). Modeling anthropogenic noise impacts on animals in natural areas. *Landscape and Urban Planning*, *180*, 76–78. https://doi.org/10.1016/j.landurbplan.2018.08.011

Kleist, N., Guralnick, R., Cruz, A., & Francis, C. (2016). Anthropogenic noise weakens territorial response to intruder's songs. *Ecosphere*, *7*, e01259. https://doi.org/10.1002/ecs2.1259

Kleist, N., Guralnick, R., Cruz, A., Lowry, C., & Francis, C. D. (2018). Chronic anthropogenic noise disrupts glucocorticoid signaling and has multiple effects on fitness in an avian community. *Proceedings of the National Academy of Sciences*, *8*, 201709200. https://doi.org/10.1073/pnas.1709200115

Knick, S. T., Dobkin, D. S., Rotenberry, J. T., Schroeder, M. A., Vander Haegen, W. M., & van Riper, C. (2003). Teetering on the edge or too late? Conservation and research issues for avifauna of sagebrush habitats. *The Condor, 105*, 611–634. https://doi.org/10.1650/7329

Koper, N., Leston, L., Baker, T. M., Curry, C., & Rosa, P. (2016). Effects of ambient noise on detectability and localization of avian songs and tones by observers in grasslands. *Ecology and Evolution, 6*, 245–555. https://doi.org/10.1002/ece3.1847

Lynch, E., Joyce, D., & Fristrup, K. (2011). An assessment of noise audibility and sound levels in US National Parks. *Landscape Ecology., 26*, 1297. https://doi.org/10.1007/s10980-011-9643-x

Mason, J. T., McClure, C. J. W., & Barber, J. R. (2016). Anthropogenic noise impairs owl hunting behaviour. *Biological Conservation, 199*, 29–32. https://doi.org/10.1016/j.biocon.2016.04.009

McClure, C. J. W., Korte, A. C., Heath, J. A., & Barber, J. R. (2015). Pavement and riparian forest shape the bird community along an urban river corridor. *Global Ecology and Conservation, 4*, 291–310. https://doi.org/10.1016/j.gecco.2015.07.004

McClure, C. J. W., Ware, H. E., Carlisle, J. D., & Barber, J. R. (2016). Noise from a phantom road experiment alters the age structure of a community of migrating birds. *Animal Conservation, 20*(2), 164–172. https://doi.org/10.1111/acv.12302

McClure, C. J. W., Ware, H. E., Carlisle, J., Kaltenecker, G., & Barber, J. R. (2013). An experimental investigation into the effects of traffic noise on distributions of birds: Avoiding the phantom road. *Proceedings of the Royal Society B, 280*, 1773. https://doi.org/10.1098/rspb.2013.2290

McDonald, R. I., Fargione, J., Kiesecker, J., Miller, W. M., & Powell, J. (2009). Energy sprawl or energy efficiency: Climate policy impacts on natural habitat for the United States of America. *PLoS ONE, 4*(8), e6802. https://doi.org/10.1371/journal.pone.0006802

Mennitt, D. J., & Fristrup, K. M. (2012). Obtaining calibrated sound pressure levels from consumer digital audio recorders. *Applied Acoustics., 73*, 1138–1145. https://doi.org/10.1016/j.apacoust.2012.05.006

Montgomerie, R., & Weatherhead, P. J. (1997). How robins find worms. *Animal Behavior, 54*, 143–151. https://doi.org/10.1006/anbe.1996.0411

Motriuk, R. W. (2000). How to design and operate quiet centrifugal compressor system. In *2000 3rd International Pipeline Conference* (p. V002T09A005). American Society of Mechanical Engineers.

Northrup, J. M., & Wittemyer, G. (2013). Characterizing the impacts of emerging energy development on wildlife, with an eye towards mitigation. *Ecology Letters, 16*, 112–125. https://doi.org/10.1111/ele.12009

Ortega, C. P., & Francis, C. D. (2012). Effects of gas-well-compressor noise on the ability to detect birds during surveys in northwest New Mexico. *Ornithological Monographs, 74*, 74–78. https://doi.org/10.1525/om.2012.74.1.78

Pacifici, K., Simons, T. R., & Pollock, K. H. (2008). Effects of vegetation and background noise on the detection process in auditory avian Point-Count surveys. *The Auk, 125*, 600–607. https://doi.org/10.1525/auk.2008.07078

R CoreTeam. (2000). *R language definition*. Vienna, Austria: R foundation for statistical computing.

Reed, S., Boggs, J., & Mann, J. (2010). *SPreAD-GIS: An ArcGIS toolbox for modeling the propagation of engine noise in a wildland setting. Version 2.0*. San Francisco, CA: The Wilderness Society.

Roy, A. A., Adams, P. J., & Robinson, A. L. (2014). Air pollutant emissions from the development, production, and processing of Marcellus Shale natural gas. *Journal of the Air and Waste Management Association, 64*, 19–37. https://doi.org/10.1080/10962247.2013.826151

Sauer, J. R., Peterjohn, B. G., & Link, W. A. (1994). Observer differences in the North-American breeding bird survey. *The Auk, 111*, 50–62. https://doi.org/10.2307/4088504

Shannon, G., McKenna, M. F., Angeloni, L. M., Crooks, K. R., Fristrup, K. M., Brown, E., ... Wittemyer, G. (2016). A synthesis of two decades of research documenting the effects of noise on wildlife. *Biological Reviews, 91*, 982–1005. https://doi.org/10.1111/brv.12207

Simons, T. R., Alldredge, M. W., Pollock, K. H., & Wettroth, J. M. (2007). Experimental analysis of the auditory detection process on avian point counts. *The Auk, 124*, 986–999. https://doi.org/10.1642/00048038(2007)124[986:EAOTAD]2.0.CO;2

The White House (2017, March 28). Retrieved from https://www.whitehouse.gov/the-press-office/2017/03/28/presidential-executive-order-promoting-energy-independence-and-economi-1

U.S. Energy Information Administration. (2007, November 1–12). *Natural gas compressor stations on the interstate pipeline network: Developments since 1996*. Energy Information Administration Office of Oil and Gas.

Ware, H. E., McClure, C. J. W., Carlisle, J. D., & Barber, J. R. (2015). A phantom road experiment reveals traffic noise is an invisible source of habitat degradation. *Proceedings of the National Academy of Sciences, 112*, 12105–12109. https://doi.org/10.1073/pnas.1504710112

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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The costs of chronic noise exposure for terrestrial organisms

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Growth in transportation networks, resource extraction, motorized recreation and urban development is responsible for chronic noise exposure in most terrestrial areas, including remote wilderness sites. Increased noise levels reduce the distance and area over which acoustic signals can be perceived by animals. Here, we review a broad range of findings that indicate the potential severity of this threat to diverse taxa, and recent studies that document substantial changes in foraging and anti-predator behavior, reproductive success, density and community structure in response to noise. Effective management of protected areas must include noise assessment, and research is needed to further quantify the ecological consequences of chronic noise exposure in terrestrial environments.

Anthropogenic noise and acoustic masking

Habitat destruction and fragmentation are collectively the major cause of species extinctions [1,2]. Many current threats to ecological integrity and biodiversity transcend political and land management boundaries; climate change, altered atmospheric and hydrologic regimes and invasive species are prominent examples. Noise also knows no boundaries, and terrestrial environments are subject to substantial and largely uncontrolled degradation of opportunities to perceive natural sounds. Noise management is an emergent issue for protected lands, and a potential opportunity to improve the resilience of these areas to climate change and other forces less susceptible to immediate remediation.

Why is chronic noise exposure a significant threat to the integrity of terrestrial ecosystems? Noise inhibits perception of sounds, an effect called masking (see Glossary) [3]. Birds, primates, cetaceans and a sciurid rodent have been observed to shift their vocalizations to reduce the masking effects of noise [4–7]. However, compromised hearing affects more than acoustical communication. Comparative evolutionary patterns attest to the alerting function of hearing: (i) auditory organs evolved before the capacity to produce sounds intentionally [8], (ii) species commonly hear a broader range of sounds than they are capable of producing [9], (iii) vocal activity does not predict hearing performance across taxa [9,10], (iv) hearing continues to function in sleeping [11] and hibernating [12] animals; and (v) secondary loss of vision is more common than is loss of hearing [13].

Masking is a significant problem for the perception of adventitious sounds, such as footfalls and other byproducts of motion. These sounds are not intentionally produced and natural selection will typically favor individuals that minimize their production. The prevalence and characteristics of adventitious sounds have not been widely studied [14–16], although their role in interactions

Glossary

Alerting distance: the maximum distance at which a signal can be perceived. Alerting distance is pertinent in biological contexts where sounds are monitored to detect potential threats.
Atmospheric absorption: the part of transmission loss caused by conversion of acoustic energy into other forms of energy. Absorption coefficients increase with increasing frequency, and range from a few dB to hundreds of dB per kilometer within the spectrum of human audibility.
Audible: a signal that is perceptible to an attentive listener.
A-weighting: A method of summing sound energy across the frequency spectrum of sounds audible to humans. A-weighting approximates the inverse of a curve representing sound intensities that are perceived as equally loud (the 40 phon contour). It is a broadband index of loudness in humans in units of dB(A) or dBA. A-weighting also approximates the shapes of hearing threshold curves in birds [20].
Decibel (dB): a logarithmic measure of acoustic intensity, calculated by 10 $\log_{10}$(sound intensity/reference sound intensity). 0 dB approximates the lowest threshold of healthy human hearing, corresponding to an intensity of 10^{-12} Wm^{-2}. Example sound intensities: −20 dB, sound just audible to a bat, owl or fox; 10 dB, leaves rustling, quiet respiration; 60 dB, average human speaking voice; 80 dB, motorcycle at 15 m.
Frequency (Hz and kHz): for a periodic signal, the maximum number of times per second that a segment of the signal is duplicated. For a sinusoidal signal, the number of cycles (the number of pressure peaks) in one second (Hz). Frequency equals the speed of sound (~340 ms^{-1}) divided by wavelength.
Ground attenuation: the part of transmission loss caused by interaction of the propagating sound with the ground.
Listening area: the area of a circle whose radius is the alerting distance. Listening area is the same as the 'active space' of a vocalization, with a listener replacing the signaler as the focus, and is pertinent for organisms that are searching for sounds.
Masking: the amount or the process by which the threshold of detection for a sound is increased by the presence of the aggregate of other sounds.
Noticeable: a signal that attracts the attention of an organism whose focus is elsewhere.
Scattering loss: the part of transmission loss resulting from irregular reflection, diffraction and refraction of sound caused by physical inhomogeneities along the signal path.
Spectrum, power spectrum and spectral profile: the distribution of acoustic energy in relation to frequency. In graphical presentations, the spectrum is often plotted as sound intensity against sound frequency (Figure 1, main text).
1/3 octave spectrum: acoustic intensity measurements in a sequence of spectral bands that span 1/3 octave. The International Standards Organization defines 1/3rd octave bands used by most sound level meters (ISO 266, 1975). 1/3rd octave frequency bands approximate the auditory filter widths of the human peripheral auditory system.
Spreading loss: more rigorously termed divergence loss. The portion of transmission loss attributed to the divergence of sound energy, in accordance with the geometry of environmental sound propagation. Spherical spreading losses in dB equal $20*\log10(R/R_0)$, and result when the surface of the acoustic wavefront increases with the square of distance from the source.
White noise: noise with equal energy across the frequency spectrum.

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Box 1. Geographic extent of transportation noise in the USA

Transportation noise is a near ubiquitous component of the modern acoustical landscape. The method used here to estimate the geographic extent of airway (Figure Ia,b), railway (Figure Ic) and roadway (Figure Id) noise in the continental USA is calculated using the average human 'noticeability' of noise. Noise was deemed noticeable when the modeled noise intensity from transportation [in dB(A)] exceeded the expected noise intensity as predicted from population density [also dB(A)]. Although noticeability is a conservative metric of the geographic extent of transportation noise, this analysis only indicates the potential scope of the problem. How anthropogenic noise changes the temporal and spectral properties of naturally-occurring noise (Figure 1, main text) and the life histories of individual species will be crucial components of a more thorough analysis.

The maps in Figure I reflect the following calculations: (i) noise calculations are county-by-county for a typical daytime hour; (ii) county population density is transformed into background sound level using an EPA empirical formula (see Ref. [84]); higher density implies higher background sound levels; (iii) the geographic extent of transportation noise is determined by calculating the distance from the vehicle track at which the transportation noise falls below the background sound level, multiplying twice that distance by the length of the transportation corridor in the county (giving a noticeability area), and comparing that area with the total area in the county to compute the percentage land area affected. A low percentage noticeability can result if either the population density is high or the number of transportation segments is low in the county. This analysis indicates that transportation noise is audible above the background of other anthropogenic noise created by local communities in most counties in continental USA. See Ref. [84] for more details.

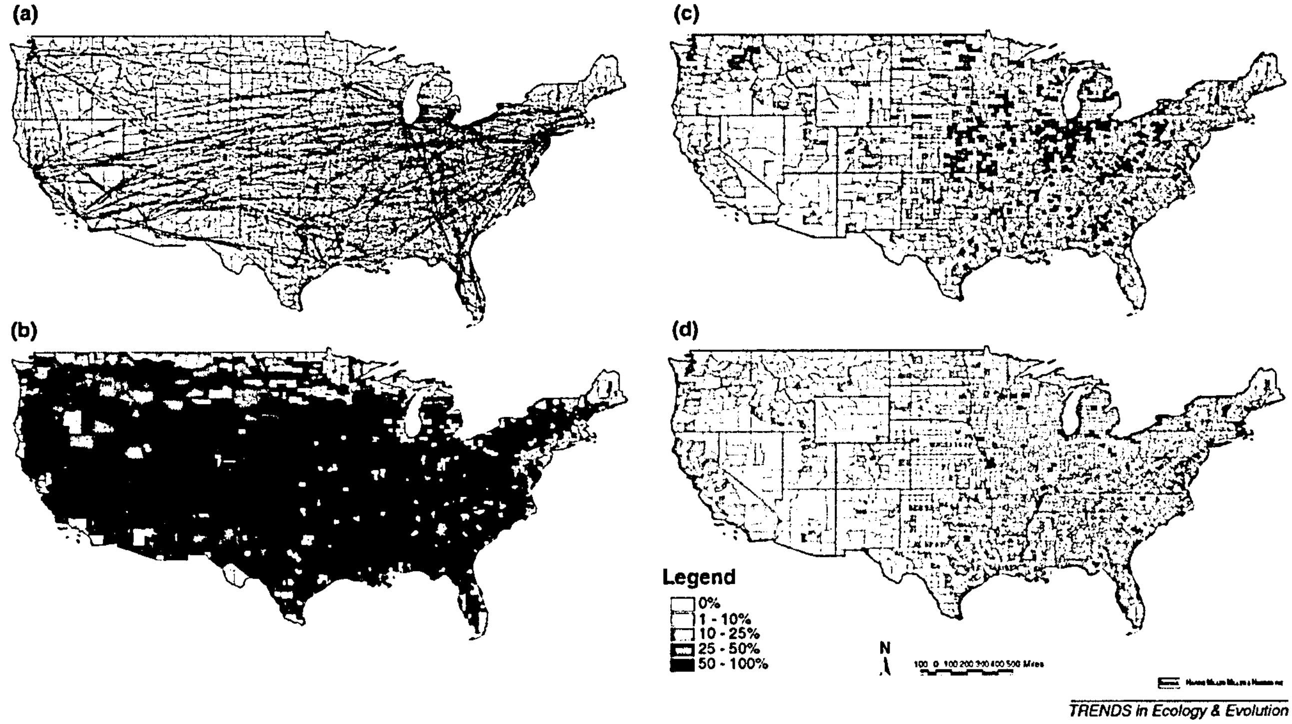


Figure I. Percent of US county areas in which transportation noise is noticeable. (a) Jet departures that occurred between 3 and 4 pm on Oct. 17, 2000, tracked to first destination. (b) Data from (a) were used to estimate the geographic extent of high altitude airway noise in the USA. The geographic extent of noise from railway and highway networks is depicted in (c) and (d), respectively. The color-coded divisions (see legend; divisions increase in size as the percent increases) were chosen assuming that, as noticeability increases, so do estimate errors due to noticeability area overlap from different transportation segments. Adapted with permission from Ref. [84].

among predators and prey is unquestionable. In animal communication systems, both the sender and receiver can adapt to noise masking, but for adventitious sounds the burden falls on listeners.

Anthropogenic disturbance is known to alter animal behavioral patterns and lead to population declines [17,18]. However, animal responses probably depend upon the intensity of perceived threats rather than on the intensity of noise [19]. Deleterious physiological responses to noise exposure in humans and other animals include hearing loss [20], elevated stress hormone levels [21] and hypertension [22]. These responses begin to appear at exposure levels of 55–60 dB(A), levels that are restricted to relatively small areas close to noise sources [20].

The scale of potential impact

The most spatially extensive source of anthropogenic noise is transportation networks. Growth in transportation is increasing faster than is the human population. Between 1970 and 2007, the US population increased by approximately one third (http://www.census.gov/compendia/statab). Traffic on US roads nearly tripled, to almost 5 trillion vehicle kilometers per year (http://www.fhwa.dot.gov/ohim/tvtw/tvtpage.cfm). Several measures of aircraft traffic grew by a factor of three or more between 1981 and 2007 (http://www.bts.gov/programs/airline_information/air_carrier_traffic_statistics/airtraffic/annual/1981_present.html). Recent reviews of the effects of noise on marine mammals have identified similar trends in shipping noise (e.g. Refs [23,24]). In addition to transportation, resource extraction and motorized recreation are spatially extensive sources of noise on public lands.

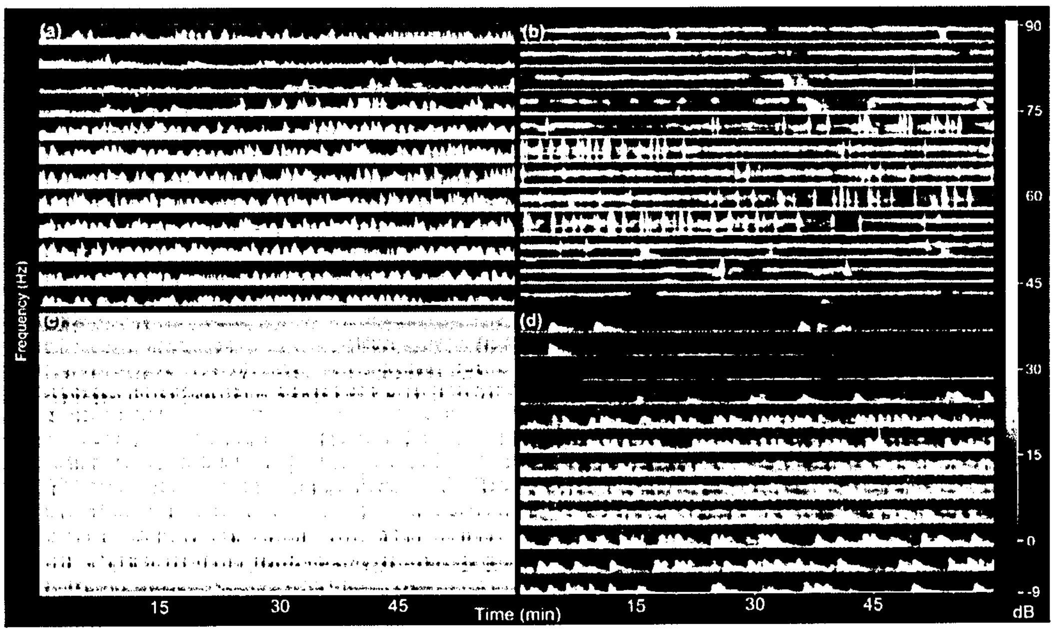
Systematic monitoring by the Natural Sounds Program of the US National Park Service (http://www.nature.nps.gov/naturalsounds) confirms the extent of noise intrusions. Noise is audible more than 25% of the hours between 7am and 10pm at more than half of the 55 sites in 14 National Parks that have been studied to date; more than a dozen sites have hourly noise audibility percentages exceeding 50% (NPS, unpublished). Remote wilderness areas are not immune, because air transportation noise is widespread, and high traffic corridors generate substantial noise increases on the ground (Box 1). For example, anthropogenic sound is audible at the Snow Flats site in Yosemite National Park nearly 70% of the time during peak traffic hours. Figure 1 shows that typical noise levels exceed natural ambient sound levels by an order of magnitude or more.

Roads are another pervasive source of noise: 83% of the land area of the continental US is within 1061 m of a road [25]. At this distance an average automobile [having a noise source level of 68 dB(A) measured at 15 m] will project a noise level of 20 dB(A). This exceeds the median natural levels of low frequency sound in most environments. Trucks and motorcycles will project substantially more noise: up to 40 dB(A) at 1 km. Box 2 provides a physical model of the reduced listening area that can be imposed by these louder background sound levels.

Acoustical ecology

Intentional communication, such as song, is the best studied component of the acoustical world, and these signals are often processed by multiple receivers. These communication networks enable female and male songbirds, for example, to assess multiple individuals simultaneously for mate choice, extra-pair copulations and rival assessment [26]. Acoustic masking resulting from increasing background sound levels will reduce the number of individuals that comprise these communication networks and have unknown consequences for reproductive processes [27].

Reproductive and territorial messages are not the only forms of acoustical communication that operate in a network. Social groups benefit by producing alarm calls to warn of approaching predators [28] and contact calls to maintain group cohesion [29]. A reduction in signal transmission distance created by anthropogenic noise might decrease the effectiveness of these social networks. The inability to hear just one of the alarm calling individuals can result in animals underestimating the urgency of their response [30].



TRENDS in Ecology & Evolution

Figure 1. 24-hour spectrograms of Indian Pass in Lake Mead National Recreation Area (a), Madison Junction in Yellowstone National Park (b), Trail Ridge Road in Rocky Mountain National Park (c), and Snow Flats in Yosemite National Park (d). Each panel displays 1/3 octave spectrum sound pressure levels, with two hours represented horizontally in each of 12 rows. The first three rows in each panel represent the quietest hours of each day, from midnight to 6 am. Frequency is shown on the y axis as a logarithmic scale extending from 12.5 Hz to 20 kHz, with the vertical midpoint in each row corresponding to 500 Hz. The z axis (color) describes sound pressure levels in dB (unweighted); the color scaling used for all four panels is indicated by the color bar on the right hand edge. The lowest 1/3 octave levels are below 0 dB, the nominal threshold of human hearing. White dots at the upper edge of some rows in the panels on the right side denote missing seconds of data. Low-frequency, broadband signatures from high altitude jets are present in all four panels. Distinct examples are present just before 6 am in (a), near 12:45 am in (b) and (c), and between midnight and 12:30 am in (d). Fixed wing aircraft signatures (tonal contours with descending pitch) are present in (a) and (d), with a good example at 1:15 am in (d). Broadband signatures with very low frequency tonal components in (a) are due to low-altitude helicopters, that are prominent from ~7 am until 8 pm. Another prominent helicopter signature is at 11:30 am in (d). (b) illustrates snowmobile and snowcoach sounds recorded ~30 m from the West Entrance Road in Yellowstone. (c) illustrates traffic noise recorded 15 m from Trail Ridge Road in Rocky Mountain National Park, during a weekend event featuring high levels of motorcycle traffic. Background sound levels at the Rocky Mountain site were elevated by sounds from the nearby river.

Box 2. Physical model of reduced listening area in noise

The maximum detection distance of a signal decreases when noise elevates the masked hearing threshold. The masked detection distance: original detection distance ratio will be the same for all signals in the affected frequency band whose detection range is primarily limited by spreading losses. For an increase of N dB in background sound level, the detection distance ratio is: $k = 10^{-N/20}$. The corresponding fraction of original listening area is: $k = 10^{-N/10}$. A 1-dB increase in background sound level results in 89% of the original detection distance, and 79% of the original listening area. These formulae will overestimate the effects of masking on alerting distance and listening area for signals that travel far enough to incur significant absorptive and scattering losses. More detailed formulae would include terms that depend upon the original maximum range of detection.

Figure I illustrates the expected noise field of a road treated as a line source (equal energy generated per 10 m segment). An animal track is marked by ten circular features, that depict the listening area of a signal whose received level (expressed as a grey-scaled value for each possible source location) decreases with the inverse square of distance from the listener. The apparent shrinkage of the circles is due to masking by the increasingly dark background of sound projected from the road, just as noise would shrink the listening area. The circles span 9 dB in road noise level, in 1-dB steps from the quietest location (upper right) to the noisiest (at the crossing).

Masking effects are reduced with increasing spectral separation between noise and signal. The model presumes that the original conditions imposed masked hearing thresholds, so organisms that are limited by their hearing thresholds will not be as affected by masking. A diffuse noise source is illustrated, but the same results would be obtained if some spatial release from masking were possible, so long as the original conditions implied masked hearing thresholds (see Ref. [85] for a review of release strategies).

These measures of lost listening opportunity are most pertinent for chronic exposures. They imply substantial losses in auditory awareness for seemingly modest increases in noise exposure. Analyses of transportation noise impacts based on perceived loudness often assert that increases of up to three dB have negligible effects; this corresponds to a 50% loss of listening area.

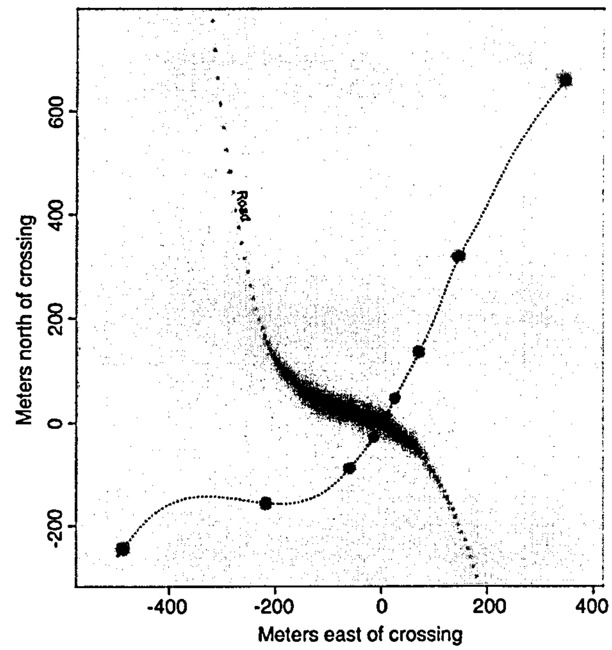


Figure I. A physical model of reduced listening area as an animal approaches a road.

Many vertebrate and invertebrate species are known to listen across species' boundaries to one another's sexual (e.g. Ref. [31]), alarm (e.g. Ref. [32]) and other vocalizations. Recent examples include gray squirrels, *Sciurus carolinensis*, listening in on the communication calls of blue jays, *Cyanocitta cristata*, to assess site-specific risks of cache pilfering [33]; and nocturnally migrating songbirds [34] and newts (Ref. [35] and Refs therein) using heterospecific calls to make habitat decisions. Reduced listening area imposed by increased sound levels is perhaps more likely to affect acoustical eavesdropping than to interfere with deliberate communication. The signaler is under no selective pressure to ensure successful communication to eavesdroppers and any masking compensation behaviors will be directed at the auditory system and position of the intended receiver rather than of the eavesdropper.

Acoustical communication and eavesdropping comprise most of the work in bioacoustics, but the parsimonious scenario for the evolution of hearing involves selection for auditory surveillance of the acoustical environment, with intentional communication evolving later [8]. Adventitious sounds are inadequately studied, in spite of their documented role in ecological interactions. Robins can use sound as the only cue to find buried worms [36]; a functional group of bats that capture prey off surfaces, gleaners, relies on prey-generated noises to localize their next meal [37]; barn owls (*Tyto alba*; [38]), marsh hawks (*Circus cyaneus*; [39]), and grey mouse lemurs (*Microcebus murinus*; [15] have been shown to use prey rustling sounds to detect and localize prey; big brown bats, *Eptesicus fuscus*, have the ability to use low-frequency insect flight sounds to identify insects and avoid protected prey [40]. In addition to prey localization, spectrally unstructured movement sounds are also used to detect predators. White-browed scrubwren (*Sericornis frontalis*) nestlings become silent when they hear the playback of footsteps of pied currawong, *Strepera graculina*, their major predator [41]; and tungara frogs, *Physalaemus pustulosus* avoid the wingbeat sounds of an approaching frog-eating bat, *Trachops cirrhosus* [42]. We are aware of only one study that has examined the role of adventitious sounds other than movement noises; African reed frogs, *Hyperolius nitidulus* flee from the sound of fire [43]. It is likely that other ecological sounds are functionally important to animals.

It is clear that the acoustical environment is not a collection of private conversations between signaler and receiver but an interconnected landscape of information networks and adventitious sounds; a landscape that we see as more connected with each year of investigation. It is for these reasons that the masking imposed by anthropogenic noise could have volatile and unpredictable consequences.

Separating anthropogenic disturbance from noise impacts

Recent research has reinforced decades of work [44,45] showing that human activities associated with high levels of anthropogenic noise modify animal ecology: for example, the species richness of nocturnal primates, small ungulates and carnivores is significantly reduced within ~ 30 m of roads in Africa [46]; anuran species richness in Ottawa, Canada is negatively correlated with traffic density [47]; aircraft overflights disturb behavior and alter time budgets in harlequin ducks (*Histrionicus histrionicus*; [48]) and mountain goats (*Oreamnos americanus*; [49]); snowmobiles and off-road vehicles change ungulate vigilance behavior and space use, although no evidence yet links these responses to population consequences [50,51]; songbirds show greater nest desertion and abandonment, but reduced predation, within 100 m of off-road vehicle trails [52]; and both greater sage-grouse (*Centrocercus urophasianus*; [53]) and mule deer (*Odocoileus hemionus*; [54]) are significantly more likely to select habitat away from noise-producing oil and gas developments. Thus, based on these studies alone, it seems clear that activities associated with high levels of anthropogenic noise can re-structure animal communities; but, because none of these studies, nor the disturbance literature in general, isolates noise from other possible forces, the independent contribution of anthropogenic noise to these effects is ambiguous.

Other evidence also implicates quiet, human-powered activities, such as hiking and skiing, in habitat degradation. For example, a paired comparison of 28 land preserves in northern California that varied substantially in the number of non-motorized recreationists showed a five-fold decline in the density of native carnivores in heavily used sites [55]. Further evidence from the Alps indicates that outdoor winter sports reduce alpine black grouse, *Tetrao tetrix* populations [17] and data from the UK link primarily quiet, non-motorized recreation to reduced woodlark, *Lullula arborea* populations [18]. A recent meta-analysis of ungulate flight responses to human disturbance showed that humans on foot produced stronger behavioral reactions than did motorized disturbance [45]. These studies strengthen a detailed foundational literature suggesting that anthropogenic disturbance events are perceived by animals as predation risk, regardless of the associated noise levels. Disturbance evokes anti-predator behaviors, interferes with other activities that enhance fitness and, as the studies above illustrate, can lead to population decline [44]. Although increased levels of noise associated with the same disturbance type appear to accentuate some animal responses (e.g. Refs [44,48]), it is difficult to distinguish reactions that reflect increasingly compromised sensory awareness from reactions that treat greater noise intensity as an indicator of greater risk.

To understand the functional importance of intact acoustical environments for animals, experimental and statistical designs must control for the influence of other stimuli. Numerous studies implicating noise as a problem for animals have reported reduced bird densities near roadways (reviewed in Ref. [56]). An extensive study conducted in the Netherlands found that 26 of 43 (60%) woodland bird species showed reduced numbers near roads [57]. This research, similar to most road ecology work, could not isolate noise from other possible factors associated with transportation corridors (e.g. road mortality, visual disturbance, chemical pollution, habitat fragmentation, increased predation and invasive species along edges). However, these effects extended for over a mile into the forest, implicating noise as one of the most potent forces driving road effects [58]. Later work, with a smaller sample size, confirmed these results and contributed a significant finding: birds with higher frequency calls were less likely to avoid roadways than birds with lower frequency calls [59]. Coupled with the mounting evidence that several animals shift their call frequencies in anthropogenic noise [4–7], these data are suggestive of a masking mechanism.

A good first step towards disentangling disturbance from noise effects is exemplified by small mammal translocation work performed across roadways that varied greatly in traffic amount. The densities of white-footed mice, *Peromyscus leucopus* and eastern chipmunks *Tamias striatus* were not lower near roads and both species were significantly less likely to cross a road than cover the same distance away from roads, but traffic volume (and noise level) had no influence on this finding [60]. Thus, for these species, the influence of the road surface itself appears to outweigh the independent contributions of direct mortality and noise.

Recent findings on the effects of anthropogenic noise

Two research groups have used oil and gas fields as 'natural experiments' to isolate the effects of noise from other confounding variables. Researchers in Canada's boreal forest studied songbirds near noisy compressor stations [75–90 dB(A) at the source, 24 hrs a day, 365 days a year] and nearly identical (and much quieter) well pads. Both of these installations were situated in two to four ha clearings with dirt access roads that were rarely used. This design allowed for control of edge effects and other confounding factors that hinder interpretation of road impact studies. The findings from this system include reduced pairing success and significantly more first time breeders near loud compressor stations in ovenbirds (*Seiurus aurocapilla*; [61]), and a one-third reduction in overall passerine bird density [62]. Low territory quality in loud sites might explain the age structuring of this ovenbird population and, if so, implicates background sound level as an important habitat characteristic. In addition to the field data above, weakened avian pair preference in high levels of noise has been shown experimentally in the lab [63]. These data suggest masking of communication calls as a possible underlying mechanism; however the reduced effectiveness of territorial defense songs, reduced auditory awareness of approaching predators (see Box 3 for a discussion of the foraging/vigilance tradeoff in noise), or reduced capacity to detect acoustic cues in foraging, cannot be excluded as explanations of the results.

A second research group, working within natural gas fields in north-west New Mexico, US, used pinyon, *Pinus edulis*-juniper, *Juniperus osteosperma* woodlands adjacent to compressor stations as treatment sites and woodlands adjacent to gas wells lacking noise-producing compressors as quiet control sites [64]. The researchers were able to turn off the loud compressor stations to perform bird counts, relieving the need to adjust for detection differences in noise [62]. This group found reduced nesting species richness but in contrast to Ref.

Box 3. Do rising background sound levels alter vigilance behavior?

Predation risk and human disturbance increase vigilance behaviors (e.g. Refs [50,86]), at a cost to foraging efficiency [87,88]. Habitat features that influence predator detection, such as vegetation height, predict predation risk [88]. If background sound level interferes with the ability of an animal to detect predators, risk can increase. Do animals perceive background sound level as a habitat characteristic that predicts predation risk? Two recent studies document increased vigilance behaviors in high levels of noise (Figure I). It seems probable that these increased anti-predator behaviors are the result of attempted visual compensation for lost auditory awareness. Evidence from ungulates near roads suggests this is the case (Figure II); however, the distinct contributions of traffic as perceived threat and traffic noise as a sensory obstacle are confounded in road studies. Experimental research with birds and mammals suggests that lost visual awareness owing to habitat obstruction reduces food-searching bouts and increases vigilance (reviewed in Ref. [89]). Although no evidence exists (but see Ref. [64]), if noise shifts the spatial distribution of foraging effort, then plant growth and seed dispersal could also be altered.

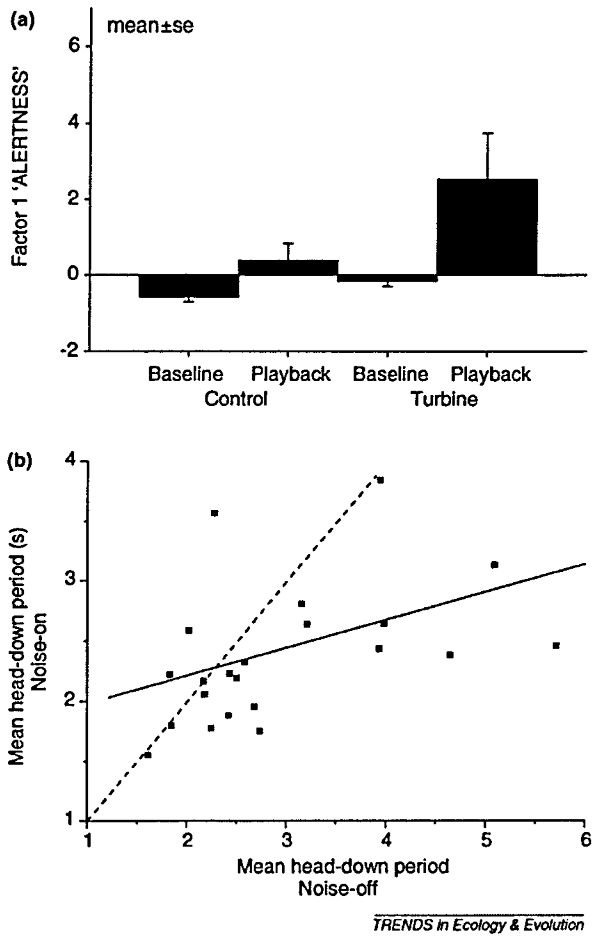


Figure I. Examples of increased vigilance behavior in noise. (a) When predator-elicited alarm calls are played back to California ground squirrels (*Spermophilus beecheyi*), adults show a greater increase in vigilance behavior at a site heavily impacted by anthropogenic noise, under power-generating wind turbines, than in a quiet control site [67]. (b) Further work on vigilance behaviors in noise comes from controlled, laboratory work with foraging chaffinches (*Fringilla coelebs*). In noise these birds decrease the interval between head-up scanning bouts, which results in fewer pecks and, thus, reduced food intake [90]. Dots depict the mean head-down period for each individual with and without white noise playback. Points below the dashed line (slope = 1) document individuals who increased scanning effort in noise. The solid regression line shows that the general trend was a more dramatic response from individuals with the lowest scanning effort. (a) adapted and (b) reproduced, with permission from Refs [67] and [90], respectively.

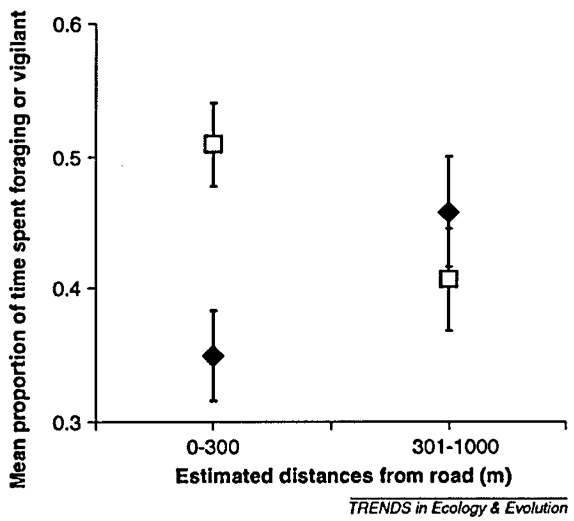


Figure II. An example of the foraging-vigilance tradeoff. Pronghorn (*Antilocapra Americana*) spend more time being vigilant (squares) and less time foraging (diamonds) within 300 meters of a road [86]. Future experiments should attempt to separate the roles of traffic as perceived threat and reduced auditory awareness on these tradeoffs. Reproduced, with permission, from Ref. [86].

[62], no reduction in overall nesting density. Unexpectedly, nest success was higher and predation levels lower in loud sites (also see Ref. [52]). The change in bird communities between loud and quiet sites appears to be driven by site preference; the response to noise ranged from positive to negative, with most responses being negative (e.g. three species nested only in loud sites and 14 species nested only in quiet, control sites). However, given the change in community structure, habitat selection based on background sound level is not the only interpretation of these data, as birds might be using cues of reduced competition pressure or predation risk to make habitat decisions [64]. The major nest predator in the study area, the western scrub jay, *Aphelocoma californica*, was significantly more likely to occupy quiet sites, which might explain the nest predation data [64]. It is probable that nest predators rely heavily on acoustic cues to find their prey. The study also found that the two bird species most strongly associated with control sites produce low-frequency communication calls. These observations suggest masking as an explanatory factor for these observed patterns. This work highlights the potential complexity of the relationship between noise exposure and the structure and function of ecological systems.

Adjusting temporal, spectral, intensity and redundancy characteristics of acoustic signals to reduce masking by noise has been demonstrated in six vertebrate orders [4–7,65]. These shifts have been documented in a variety of signal types: begging calls of bird chicks [66], alarm signals in ground squirrels [67], contact calls of primates [68], echolocation cries of bats [65] and sexual communication signals in birds, cetaceans and anurans [4–7,69]. Vocal adjustment probably comes at a cost to both energy balance and information transfer; however, no study has addressed receivers.

Masking also affects the ability of animals to use sound for spatial orientation. When traffic noise is played back to grey treefrog, *Hyla chrysoscelis* females as they attempt to localize male calls, they take longer to do so and are significantly less successful in correctly orienting to the male signal [70]. Similar studies with the European tree frog, *Hyla arborea* show decreased calling activity in played back traffic noise [71]. *H. arborea* individuals appear to be unable to adjust the frequency or duration of their calls to increase signal transmission, even at very high noise intensities (88 dB(A), [71]); although other frogs have been shown to slightly shift call frequencies upward in response to anthropogenic noise [69]. These are particularly salient points. It is likely that some species are unable to adjust the structure of their sounds to cope with noise even within the same group of organisms. These differences in vocal adaptability could partially explain why some species do well in loud environments and others do poorly [5,7,72].

Under many conditions, animals will minimize their movement sounds. For example, mice preferentially select quieter substrates on which to move [73]. Adventitious sounds of insects walking contain appreciable energy at higher frequencies (main energy ~3–30 kHz [16]) and are thus unlikely to be fully masked by most anthropogenic noise (<2 kHz [4–7]) but the spectral profile near many noise sources contains significant energy at higher frequencies (e.g. Ref [74]). Foundational work with owls and bats has shown that frequencies between approximately three and eight kHz are crucial for passive sound localization accuracy [38,75]. In fact, a recent laboratory study demonstrated that gleaning bats avoided hunting in areas with played back road noise that contained energy within this spectral band ([74]; Box 4).

Adapting to a louder world

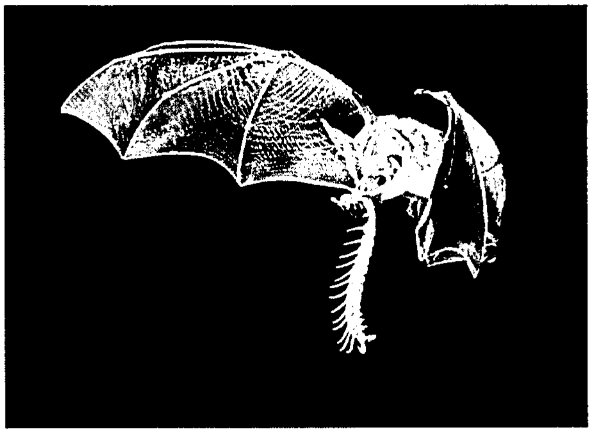
Animals have been under constant selective pressure to distinguish pertinent sounds from background noise. Two

Box 4. Effects of acoustic masking on acoustically specialized predators

Laboratory work has demonstrated that gleaning bats (who use prey-generated sounds to capture terrestrial prey; Figure Ia) avoid noise when foraging (Figure Ib). Interestingly, treefrogs, a favorite prey of some neotropical gleaning bats, tend to call from sites with high ambient noise levels (primarily from waterfalls) and bats prefer frog calls played back in quieter locations [91]. Extinction risk in bats correlates with low wing aspect ratios (a high cost and low wing-loading morphology), a trait that all gleaning bats share [92]. A recent analysis indicates that urbanization most strongly impacts bats with these wing shapes [93]. However, low wing aspect ratio is also correlated with habitat specialization, edge intolerance and low mobility [92,93], obscuring the links between a gleaning lifestyle, louder background sound levels and extinction risk as urbanization reduces available habitat, fragments landscapes and generates noise concomitantly.

A radio-tag study showed that a gleaning bat, *Myotis bechsteinii*, was less likely to cross a roadway (three of 34 individuals) than was a sympatric open-space foraging bat, *Barbastella barbastellus* (five out of six individuals; [94]), implicating noise as a fragmenting agent for some bats. The latter species hunts flying insects using echolocation (an auditory behavior that uses ultrasonic signals above the spectrum of anthropogenic noise) [94]. Similar findings suggest acoustically mediated foragers are at risk: terrestrial insectivores were the only avian ecological guild to avoid road construction in the Amazon [95] and human-altered landscapes limited provisioning rates of saw-whet owls [96]. That these animals plausibly rely on sound for hunting might not be coincidental.

(a)



(b)

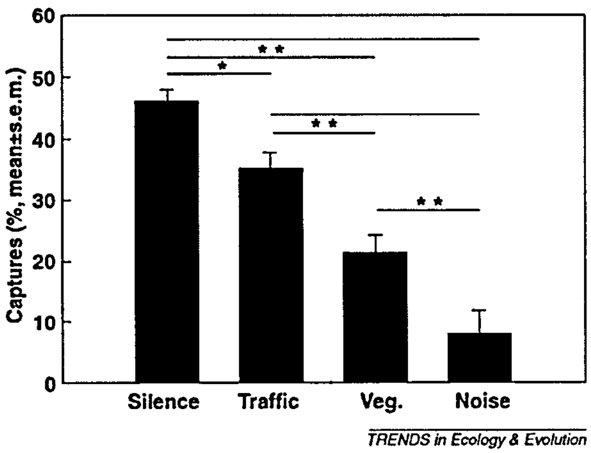


Figure I. Gleaning bats avoid hunting in noise. The pallid bat, *Antrozous pallidus* (a), relies upon prey-generated movement sounds to localize its terrestrial prey. Recent work demonstrates that another gleaning bat, the greater mouse-eared bat, *Myotis myotis*, avoids foraging in noise [74]. (b) A laboratory two-compartment choice experiment showed that this bat preferred to forage in the compartment with played-back silence versus the compartment with played-back traffic, wind-blown vegetation or white noise. This pattern held true whether the percentage of flight time, compartment entering events, the first 25 captures per session or overall capture percentage were compared across silent and noise playback compartments. Asteriks indicate the results of post repeated-measure ANOVA, paired t-tests (**$P<0.01$, *$P<0.05$, N=7 bats). The differences between noise types (traffic, vegetation and white noise) probably reflect increased spectral overlap between prey-generated movement sounds and the spectral profile of the noise. Reproduced with permission from Scott Altenbach (a) and Ref. [74] (b).

Box 5. Outstanding questions

- Multiple studies with birds have demonstrated signal shifts in anthropogenic noise that does not substantially overlap in frequency with the birds' song [4–7,72]. To what extent does low-frequency anthropogenic noise inhibit perception of higher frequency signals? Mammals appear more prone to the 'upward spread' of masking than do birds [85,97]. Noise commonly elevates low frequency ambient sound levels by 40 dB or more, so small amounts of spectral 'leakage' can be significant. Laboratory studies should be complimented by field studies that can identify the potential for informational or attentional effects [98]. This work should use anthropogenic noise profiles and not rely on artificial white noise as a surrogate. Furthermore, we suggest that future studies measure or model sound levels (both signal and background) at the position of the animal receiver (*sensu* Ref. [23]).
- What roles do behavioral and cognitive masking release mechanisms [85] have in modifying the capacity of free-ranging animals to detect and identify significant sounds? Only one study has examined the masked hearing thresholds of natural vocal signals in anthropogenic noise [97]. This work found that thresholds for discrimination between calls of the same bird species were consistently higher than were detection thresholds for the same calls [97]. This highlights the lack of knowledge concerning top-down cognitive constraints on signal processing in noise. Can noise divide attention and reduce task accuracy by forcing the processing of multiple streams of auditory information simultaneously [99]?
- Do animals exploit the temporal patterning of anthropogenic noise pollution (see Ref. [4])? Alternatively, what constitutes a chronic exposure and how does this vary in relation to diel activity schedules?
- Does noise amplify the barrier effects of fragmenting agents, such as roads [94,100]?
- What routes (exaptation, behavioral compensation, phenotypic plasticity and/or contemporary evolution) lead to successful tolerance of loud environments?
- What role does audition have in vigilance behaviors? Are visually mediated predators at an advantage in loud environments when prey animals rely upon acoustical predator detection?
- Do animals directly perceive background sound level as a habitat characteristic related to predation risk? A noise increase of 3 dB(A) is often identified as 'just perceptible' for humans, and an increase of 10 dB(A) as a doubling of perceived loudness. These correspond to 30% and 90% reductions in alerting distance, respectively. Do organisms assess reduced alerting distance by monitoring other acoustical signals?

examples include penguin communication systems being shaped by wind and colony noise [76] and frog systems driven to ultrasonic frequencies by stream noise [77]. A meta-analysis of the acoustic adaptation hypothesis for birdsong (the idea that signals are adapted to maximize propagation through the local habitat) found only weak evidence for this claim [78]. Physiological constraints and selective forces from eavesdropping could explain this weak relationship [78], in addition to variation of noise profiles across nominally similar habitat types (e.g. insect noise, [79]).

Phenotypic plasticity enables one adaptation to anthropogenic noise. The open-ended song learning documented in great tits, *Parus major* helps explain the consistent song shifts observed in all ten comparisons between urban and rural populations [72]. Contemporary evolution (fewer than a few hundred generations) has now been quantified in several systems [80] and we might anticipate similar microevolutionary changes in many species with rapid generation times that consistently experience acoustical environments dominated by noise, particularly in increasingly fragmented landscapes.

Perhaps the greatest predictors of the ability of a given species to succeed in a louder world will be the degree of temporal and spectral overlap of biologically crucial signals with anthropogenic noise (Figure 1), and their flexibility to compensate with other sensory modalities (e.g. vision) when auditory cues are masked. Given known sensory biases in learning [81], many animals will be constrained in their ability to shift from acoustical inputs to other sensory cues for dynamic control of complex behavioral sequences.

Conclusions and recommendations

The constraints on signal reception imposed by background sound level have a long history of being researched in bioacoustics, and it is increasingly clear that these constraints underlie crucial issues for conservation biology. Questions have been raised about the value of behavioral studies for conservation practice (for a review see Ref [82]), but ethological studies of auditory awareness and the consequences of degraded listening opportunities are essential to understanding the mechanisms underlying ecological responses to anthropogenic noise (Box 5). These studies are more challenging to execute than observation of salient behavioral responses to acute noise events, but they offer opportunities to explore fundamental questions regarding auditory perception in natural and disturbed contexts.

Chronic noise exposure is widespread. Taken individually, many of the papers cited here offer suggestive but inconclusive evidence that masking is substantially altering many ecosystems. Taken collectively, the preponderance of evidence argues for immediate action to manage noise in protected natural areas. Advances in instrumentation and methods are needed to expand research and monitoring capabilities. Explicit experimental manipulations should become an integral part of future adaptive management plans to decisively identify the most effective and efficient methods that reconcile human activities with resource management objectives [83].

The costs of noise must be understood in relation to other anthropogenic forces, to ensure effective mitigation and efficient realization of environmental goals. Noise pollution exacerbates the problems posed by habitat fragmentation and wildlife responses to human presence; therefore, highly fragmented or heavily visited locations are priority candidates for noise management. Noise management might also offer a relatively rapid tool to improve the resilience of protected lands to some of the stresses imposed by climate change. Shuttle buses and other specialized mass transit systems, such as those used at Zion and Denali National Parks, offer promising alternatives for visitor access that enable resource managers to exert better control over the timing, spatial distribution, and intensity of both noise and human disturbance. Quieting protected areas is a prudent precaution in the face of sweeping environmental changes, and a powerful affirmation of the wilderness values that inspired their creation.

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References

1 Wilcove, D.S. *et al.* (1998) Quantifying threats to imperiled species in the United States. *Bioscience* 48, 607–615
2 Crooks, K.R. and Sanjayan, M., eds (2006) *Connectivity Conservation*, Cambridge University Press
3 Klump, G.M. (1996) Bird communication in a noisy world. In *Ecology and Evolution of Acoustic Communication in Birds* (Kroodsma, D.E. and Miller, E.H., eds), pp. 321–328, Cornell University Press
4 Brumm, H. and Slabbekoorn, H. (2005) Acoustic communication in noise. *Adv. Stud. Behav.* 35, 151–209
5 Patricelli, G.L. and Blickley, J.L. (2006) Avian communication in urban noise: causes and consequences of vocal adjustment. *Auk* 123, 639–649
6 Warren, P.S. *et al.* (2006) Urban bioacoustics: it's not just noise. *Anim. Behav.* 71, 491–502
7 Slabbekoorn, H. and Ripmeester, E.A. (2008) Birdsong and anthropogenic noise: implications and applications for conservation. *Mol. Ecol.* 17, 72–83
8 Fay, R.R. and Popper, A.N. (2000) Evolution of hearing in vertebrates: inner ears and processing. *Hearing Res.* 149, 1–10
9 Fay, R.R. (1988) *Hearing in Vertebrates: A Psychophysics Databook*, Hill-Fay Associates
10 Bradbury, J.W. and Vehrencamp, S.L. (1998) *Principles of Acoustic Communication*, Sinauer
11 Rabat, A. (2007) Extra-auditory effects of noise in laboratory animals: the relationship between noise and sleep. *J. Am. Assoc. Lab. Anim. Sci.* 46, 35–41
12 Lyman, C.P. and Chatfield, P.O. (1955) Physiology of hibernation in mammals. *Physiol. Rev.* 35, 403–425
13 Fong, D.W. *et al.* (1995) Vestigialization and loss of nonfunctional characters. *Annu. Rev. Ecol. Syst.* 26, 249–268
14 Siemers, B.M. and Güttinger, R. (2006) Prey conspicuousness can explain apparent prey selectivity. *Curr. Biol.* 16, R157–R159
15 Goerlitz, H.R. and Siemers, B.M. (2007) Sensory ecology of prey rustling sounds: acoustical features and their classification by wild grey mouse lemurs. *Funct. Ecol.* 21, 143–153
16 Goerlitz, H.R. *et al.* (2008) Cues for acoustic detection of prey: insect rustling sounds and the influence of walking substrate. *J. Exp. Biol.* 211, 2799–2806
17 Patthey, P. *et al.* (2008) Impact of outdoor winter sports on the abundance of a key indicator species of alpine ecosystems. *J. Appl. Ecol.* 10, 2–8
18 Mallord, J.W. *et al.* (2007) Linking recreational disturbance to population size in a ground-nesting passerine. *J Appl. Ecol.* 44, 185–195
19 Bowles, A.E. (1995) Responses of wildlife to noise. In *Wildlife and Recreationists: Coexistence through Management and Research* (Knight, R.L. and Gutzwiller, J., eds), pp. 109–156, Island Press
20 Dooling, R.J. and Popper, A.N. (2007) The effects of highway noise on birds. Report to California Department of Transportation, contract 43A0139. (http://www.dot.ca.gov/hq/env/bio/avian_bioacoustics.htm)
21 Babisch, W. (2003) Stress hormones in the research on cardiovascular effects of noise. *Noise Health* 5, 1–11
22 Jarup, L. *et al.* (2008) Hypertension and exposure to noise near airports: the HYENA study. *Environ. Health Persp.* 116, 329–333
23 Nowacek, D.P. *et al.* (2007) Responses of cetaceans to anthropogenic noise. *Mammal Rev.* 37, 81–115
24 Weilgart, L.S. (2007) The impacts of anthropogenic noise on cetaceans and implications for management. *Can. J. Zool.* 85, 1091–1116
25 Ritters, K.H. and Wickham, J.D. (2003) How far to the nearest road? *Front. Ecol. Environ.* 1, 125–129
26 McGregor, P. (ed.) (2005) *Animal Communication Networks*, Cambridge University Press
27 Hansen, I.J.K. *et al.* (2005) Communication breakdown? Habitat influences on black-capped chickadee dawn choruses. *Acta Ethol.* 8, 111–120
28 Caro, T. (2005) *Antipredator Defenses in Birds and Mammals*, The University of Chicago Press
29 Marler, P. (2004) Bird calls: a cornucopia for communication. In *Nature's Music: The Science of Birdsong* (Marler, P. and Slabbekoorn, H., eds), pp. 132–176, Elsevier
30 Sloan, J.L. and Hare, J.F. (2008) The more the scarier: adult Richardson's ground squirrels (*Spermophilus richardsonii*) assess response urgency via the number of alarm signalers. *Ethology* 114, 436–443
31 Zuk, M. and Kolluru, G.R. (1998) Exploitation of sexual signals by predators and parasitoids. *Q. Rev. Biol.* 73, 415–438
32 Ridley, A.R. *et al.* (2007) Interspecific audience effects on the alarm-calling behavior of a kleptoparasitic bird. *Biol. Lett.* 3, 589–591
33 Schmidt, K.A. and Ostefeld, R.S. (2008) Eavesdropping squirrels reduce their future value of food under the perceived presence of cache robbers. *Am. Nat.* 171, 388–393
34 Mukhin, A. *et al.* (2008) Acoustic information as a distant cue for habitat recognition by nocturnally migrating passerines during landfall. *Behav. Ecol.* 19, 716–723
35 Slabbekoorn, H. and Bouton, N. (2008) Soundscape orientation: a new field in need of a sound investigation. *Anim. Behav.* 76, e5–e8
36 Montgomerie, R. and Weatherhead, P.J. (1997) How robins find worms. *Anim. Behav.* 54, 143–151
37 Neuweiler, G. (1989) Foraging ecology and audition in echolocating bats. *Trends Ecol. Evo.* 4, 160–166
38 Knudsen, E.I. and Konishi, M. (1979) Mechanisms of sound localization in the barn owl (*Tyto alba*). *J. Comp. Physiol. A* 133, 13–21
39 Rice, W.R. (1982) Acoustical location of prey by the marsh hawk: adaptation to concealed prey. *Auk* 99, 403–413
40 Hamr, J. and Bailey, E.D. (1985) Detection and discrimination of insect flight sounds by big brown bats (*Eptesicus fuscus*). *Biol. Behav.* 10, 105–121
41 Magrath, R.D. *et al.* (2007) How to be fed but not eaten: nestling response to parental food calls and the sound of a predator's footsteps. *Anim. Behav.* 74, 1117–1129
42 Bernal, X.E. *et al.* (2007) Sexual differences in the behavioral response of túngara frogs, *Physalaemus pustulosus*, to cues associated with increased predation risk. *Ethology* 755–763
43 Grafe, T.U. *et al.* (2002) Frogs flee from the sound of fire. *Proc. R. Soc. Lond. B* 269, 999–1003
44 Frid, A. and Dill, L. (2002) Human-caused disturbance stimuli as a form of predation risk. *Conserv. Ecol.* 6 In: http://www.ecologyandsociety.org/vol6/iss1/art11/main.html
45 Stankowich, T. (2008) Ungulate flight responses to human disturbance: a review and meta-analysis. *Biol. Conserv.* 141, 2159–2173
46 Laurance, W.F. *et al.* (2008) Impacts of roads, hunting, and habitat alteration of nocturnal mammals in African rainforests. *Conserv. Biol.* 22, 721–732
47 Eigenbrod, F. *et al.* (2008) The relative effects of road traffic and forest cover on anuran populations. *Biol. Conserv.* 141, 35–46
48 Goudie, R.I. (2006) Multivariate behavioural response of harlequin ducks to aircraft disturbance in Labrador. *Environ. Conserv.* 33, 28–35
49 Goldstein, M.I. *et al.* (2005) Mountain goat response to helicopter overflights in Alaska. *Wildlife Soc. B.* 33, 688–699
50 Borkowski, J.J. *et al.* (2006) Behavioral responses of bison and elk in Yellowstone to snowmobiles and snow coaches. *Ecol. Appl.* 16, 1911–1925
51 Preisler, H.K. *et al.* (2006) Statistical methods for analyzing responses of wildlife to human disturbance. *J. Appl. Ecol.* 43, 164–172
52 Barton, D.C. and Holmes, A.L. (2007) Off-highway vehicle trail impacts on breeding songbirds in northeastern California. *J. Wildl. Manage.* 71, 1617–1620
53 Doherty, K.E. *et al.* (2008) Greater sage-grouse winter habitat selection and energy development. *J. Wildl. Manage.* 72, 187–195

54 Sawyer, H. *et al.* (2006) Winter habitat selection of mule deer before and during development of a natural gas field. *J. Wildl. Manage.* 70, 396–403
55 Reed, S.E. and Merenlender, A.M. (2008) Quiet, nonconsumptive recreation reduces protected area effectiveness. *Conserv. Lett.* 1, 146–154
56 Reijnen, R. and Foppen, R. (2006) Impact of road traffic on breeding bird populations. In *The Ecology of Transportation: Managing Mobility for the Environment* (Davenport, J. and Davenport, J.L., eds), pp. 255-274, Springer
57 Reijnen, R. *et al.* (1995) The effects of car traffic on breeding bird populations in Woodland. III. Reduction of density in relation to the proximity of main roads. *J. Appl. Ecol* 32, 187–202
58 Forman, R.T.T. and Alexander, L.E. (1998) Roads and their major ecological effects. *Ann. Rev. Ecol. Syst.* 29, 207–231
59 Rheindt, F.E. (2003) The impacts of roads on birds: Does song frequency play a role in determining susceptibility to noise pollution? *J. Ornithol.* 144, 295–306
60 McGregor, R.L. *et al.* (2007) Do small mammals avoid roads because of the traffic? *J. Appl. Ecol.* 45, 117–123
61 Habib, L. *et al.* (2007) Chronic industrial noise affects pairing success and age structure of ovenbirds *Seiurus aurocapilla*. *J. Appl. Ecol.* 44, 176–184
62 Bayne, E.M. *et al.* (2008) Impacts of chronic anthropogenic noise from energy-sector activity on abundance of songbirds in the boreal forest. *Conserv. Biol.* 22, 1186–1193
63 Swaddle, J.P. and Page, L.C. (2007) High levels of environmental noise erode pair preferences in zebra finches: implications for noise pollution. *Anim. Behav.* 74, 363–368
64 Francis, C.D. *et al.* (2009) Noise pollution changes avian communities and species interactions. *Curr. Biol.* 19, 1415–1419
65 Gillam, E.H. and McCracken, G.F. (2007) Variability in the echolocation of *Tadarida brasiliensis*: effects of geography and local acoustic environment. *Anim. Behav.* 74, 277–286
66 Leonard, M.L. and Horn, A.G. (2008) Does ambient noise affect growth and begging call structure in nestling birds? *Behav. Ecol.* 19, 502–507
67 Rabin, L.A. *et al.* (2006) The effects of wind turbines on antipredator behavior in California ground squirrels (*Spermophilus beecheyi*). *Biol. Conserv.* 131, 410–420
68 Egnor, S.E.R. *et al.* (2007) Tracking silence: adjusting vocal production to avoid acoustic interference. *J. Comp. Physiol. A* 193, 477–483
69 Parris, K.M. *et al.* (2009) Frogs call at a higher pitch in traffic noise. *Ecol. Soc.* 14, 25 In: http://www.ecologyandsociety.org/vol14/iss1/art25
70 Bee, M.A. and Swanson, E.M. (2007) Auditory masking of anuran advertisement calls by road traffic noise. *Anim. Behav.* 74, 1765–1776
71 Lengagne, T. (2008) Traffic noise affects communication behaviour in a breeding anuran, *Hyla arborea*. *Biol. Conserv* 141, 2023–2031
72 Slabbekoorn, H. and den Boer-Visser, A. (2006) Cities change the songs of birds. *Curr. Biol.* 16, 2326–2331
73 Roche, B.E. *et al.* (1998) Route choice by deer mice (*Peromyscus maniculatus*): reducing the risk of auditory detection by predators. *Am. Midl. Nat.* 142, 194–197
74 Schaub, A. *et al.* (2008) Foraging bats avoid noise. *J. Exp. Biol.* 211, 3174–3180
75 Fuzessery, Z.M. *et al.* (1993) Passive sound localization of prey by the pallid bat (*Antrozous p. pallidus*). *J. Comp. Physiol. A* 171, 7667–7777
76 Aubin, T. and Jouventin, P. (2002) How to vocally identify kin in a crowd: the penguin model. *Adv. Stud. Behav.* 31, 243–277
77 Arch, V.S. and Narins, P.M. (2008) 'Silent' signals: selective forces acting on ultrasonic communication systems in terrestrial vertebrates. *Anim. Behav.* 76, 1423–1428
78 Boncoraglio, G. and Saino, N. (2007) Habitat structure and the evolution of bird song: a meta-analysis of the evidence for the acoustic adaptation hypothesis. *Funct. Ecol.* 21, 134–142
79 Kirschel, A.N.G. *et al.* (2009) Birdsong tuned to the environment: green hylia song varies with elevation, tree cover, and noise. Behav. Ecol. Published online July 14, 2009
80 Stockwell, C.A. *et al.* (2003) Contemporary evolution meets conservation biology. *Trends Ecol. Evol.* 18, 94–100
81 Garcia, J. *et al.* (1974) Behavioral regulation of the milieu interne in man and rat. *Science* 185, 824–831
82 Angeloni, L. *et al.* (2008) A reassessment of the interface between conservation and behavior. *Anim. Behav.* 75, 731–737
83 Blickley J.L. and Patricelli, G.L., Impacts of anthropogenic noise on wildlife: Research priorities for the development of standards and mitigation. *J Int. Wildlife Law Policy.* (in press)
84 Miller, N.P. (2003) Transportation Noise and Recreational Lands. *Noise/News International* 11(1), 1-20, International Institute of Noise Control Engineering, (http://www.hmmh.com/presentations-papers.html)
85 Moore, B.C.J. (2003) *An Introduction to the Psychology of Hearing*, (5th edn), Academic Press
86 Gavin, S.D. and Komers, P.E. (2006) Do pronghorn (*Antilocapra Americana*) perceive roads as predation risk? *Can. J. Zool.* 84, 1775–1780
87 Fortin, D. *et al.* (2004) Foraging costs of vigilance in large mammalian herbivores. *Oikos* 107, 172–180
88 Verdolin, J.L. (2006) Meta-analysis of foraging and predation risk trade-offs in terrestrial systems. *Behav. Ecol. Sociobiol.* 60, 457–464
89 Bednekoff, P.A. and Blumstein, D.T. (2009) Peripheral obstructions influence marmot vigilance: integrating observational and experimental results. Behav. Ecol. Published online July 16, 2009
90 Quinn, J.L. *et al.* (2006) Noise, predation risk compensation and vigilance in the chaffinch *Fringilla coelebs*. *J. Avian Biol.* 37, 601–608
91 Tuttle, M.D. and Ryan, M.J. (1982) The role of synchronized calling, ambient light, and ambient noise, in anti-bat-predator behavior of a treefrog. *Behav. Ecol. Sociobiol.* 11, 125–131
92 Jones, K.E. *et al.* (2003) Biological correlates of extinction risk in bats. *Am. Nat.* 161, 601–614
93 Duchamp, J.E. and Swihart, R.K. (2008) Shifts in bat community structure related to evolved traits and features of human-altered landscapes. *Landsc. Ecol.* 23, 849–860
94 Kerth, G. and Melber, M. (2009) Species-specific barrier effects of a motorway on the habitat use of two threatened forest-living species. *Biol. Conserv.* 142, 270–279
95 Canaday, C. and Rivadeneyra, J. (2001) Initial effects of petroleum operation on Amazonian birds: terrestrial insectivores retreat. *Biodiv. Conserv.* 10, 567–595
96 Hinam, H.L. and St. Clair, C.C. (2008) High levels of habitat loss and fragmentation limit reproductive success by reducing home range size and provisioning rates of Northern saw-whet owls. *Biol. Conserv.* 141, 524–535
97 Lohr, B. *et al.* (2003) Detection and discrimination of natural calls in masking noise by birds: estimation of the active space of a signal. *Anim. Behav.* 65, 763–777
98 Gutschalk, A. *et al.* (2008) Neural correlates of auditory perceptual awareness under informational masking. *PLoS Biol* 6, 1156–1165
99 Barber, J.R. *et al.* (2003) Can two streams of auditory information be processed simultaneously? Evidence from the gleaning bat *Antrozous pallidus*. *J. Comp. Physiol. A* 189, 843–855
100 St. Clair, C.C. (2003) Comparative permeability of roads, rivers, and meadows to songbirds in Banff National Park. *Conserv. Biol.* 17, 1151–1160

The Effect of Human Activities and Their Associated Noise on Ungulate Behavior

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Abstract

Background: The effect of anthropogenic noise on terrestrial wildlife is a relatively new area of study with broad ranging management implications. Noise has been identified as a disturbance that has the potential to induce behavioral responses in animals similar to those associated with predation risk. This study investigated potential impacts of a variety of human activities and their associated noise on the behavior of elk (*Cervus elaphus*) and pronghorn (*Antilocapra americana*) along a transportation corridor in Grand Teton National Park.

Methodology/Principal Findings: We conducted roadside scan surveys and focal observations of ungulate behavior while concurrently recording human activity and anthropogenic noise. Although we expected ungulates to be more responsive with greater human activity and noise, as predicted by the risk disturbance hypothesis, they were actually less responsive (less likely to perform vigilant, flight, traveling and defensive behaviors) with increasing levels of vehicle traffic, the human activity most closely associated with noise. Noise levels themselves had relatively little effect on ungulate behavior, although there was a weak negative relationship between noise and responsiveness in our scan samples. In contrast, ungulates did increase their responsiveness with other forms of anthropogenic disturbance; they reacted to the presence of pedestrians (in our scan samples) and to passing motorcycles (in our focal observations).

Conclusions: These findings suggest that ungulates did not consistently associate noise and human activity with an increase in predation risk or that they could not afford to maintain responsiveness to the most frequent human stimuli. Although reduced responsiveness to certain disturbances may allow for greater investment in fitness-enhancing activities, it may also decrease detections of predators and other environmental cues and increase conflict with humans.

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Introduction

Anthropogenic noise can impact animals in ways that are only beginning to be explored [1]. Noise is pervasive in both developed and natural areas [2,3] and can be deleterious to an animal's physiology and behavior. If chronic, it may affect an animal's auditory system [4], increase cardiac and stress levels [5,6], and impair communication [7–11]. Noise can also alter pairing and reproduction [9,12], age structuring [9], and density and occupancy patterns [13–15].

Noise has also been identified as a disturbance that could induce behavioral responses similar to those associated with predation risk [16]. The risk-disturbance hypothesis predicts that animals exposed to anthropogenic disturbance, such as noise, will exhibit antipredator behavior that takes time and energy away from fitness-enhancing activities [16]. Indeed, prior studies have documented behavioral responses, such as vigilance, avoidance, and flight, to anthropogenic noise for a variety of taxa [5,17–20]. An increase in vigilance may be costly if it results in a decrease in maintenance activities such as foraging [21,22], and displacement or flight may expend valuable amounts of energy [23–25]. Thus, noise can affect habitat selection, foraging patterns, and overall energy budgets [26,27], with potential population-level effects. However, noise may not have lasting negative effects if animals habituate to the disturbance, that is exhibit reduced responsiveness over time after repeated exposure without consequence [28]; e.g., [5,29–31]. In some cases animals may even be attracted to and benefit from noisy disturbed areas, for example if they provide shelter from predators [32–35].

Large mammals, such as ungulates, may be particularly sensitive to anthropogenic disturbance [36,37], including human activities associated with recreation, transportation, ecotourism and the noise they produce [33,38–40]. Recreational activities such as snowmobiling, skiing, biking and hiking can alter the behavior of ungulates [24,41–48]. Roadways can also induce a range of behavioral responses in ungulates, which in some cases seem attracted to or unaffected by road activity [32,41] but more commonly exhibit risk-avoidance behavior in response to roads [25,33,39,40,49–53]. Although the degree to which animals are responding to visual or acoustic disturbances generated by these recreational and transportation activities remains largely unexplored, there is some evidence for the independent effect of noise, reviewed in [1,2,7]; but see [54].

The goal of this research was to quantify the behavioral response of ungulates to a variety of human activities and their associated noise along the primary travel corridor in Grand Teton National Park, USA. We evaluated the effect of human activities and concurrent sound properties on ungulate behavior along this corridor. If, according to the risk disturbance hypothesis [16], activities of park visitors represent a form of predation risk to ungulates, then we predicted ungulates would display heightened responsive behavior with increasing levels of anthropogenic stimuli, including both noise and human activity. Alternatively, the behavior of ungulates along the travel corridor could be unaffected by the level of noise and human activity if they have habituated to human disturbance over time or if sensitive individuals have been previously displaced from this location [55].

Methods

Study area

We conducted the study in summer 2008 along 22 km of Teton Park Road in Grand Teton National Park in northwestern Wyoming, USA (43–50′00″ N, 110–42′03″ W; Figure 1). Teton Park Road is located at the eastern base of the Teton Range and traverses the valley floor from north to south through a predominantly open sage-brush community where large ungulates congregate and visitors often stop to view wildlife. The study area included a stretch of Teton Park Road from its junction with Spalding Bay Drive to its junction with the town of Moose (Figure 1). Our research focused on the two ungulate species most prevalent along the road, elk (*Cervus elaphus*) and pronghorn (*Antilocapra americana*). Large numbers of elk (~2,500–4,500 [56]) and pronghorn (~200 [57]) spend the summer in Grand Teton National Park with the potential to move into and out of our study area. The behavior of both species may be influenced by predation risk in this system given the presence of carnivores within the park, including grizzly bear (*Ursus arctos*), black bear (*Ursus americanus*), gray wolf (*Canis lupus*), and mountain lion (*Puma concolor*), although these predators were only rarely observed in our study area. These ungulates also have the potential to experience hunting by humans, particularly when they venture outside our study area during the fall archery and rifle hunting seasons.

Behavioral Observations

Scan sampling. We recorded the behavior of individuals in ungulate herds through scan sampling at 42 points along Teton Park Road (Figure 1) from 14 June 2008 to 18 October 2008. We selected sampling points every 160 to 650 meters to standardize search efforts over space and time and to maximize visible area from the road in an attempt to include the entire viewshed along this stretch of Teton Park Road. Scan sampling occurred during both daytime and crepuscular hours, with staggered starting times to balance sampling effort across periods, allowing at least twelve hours between surveys.

To conduct scan sampling, we drove along Teton Park Road starting at either the northern or southern end of the study area and stopped at each sampling point to scan for ungulate herds with binoculars and a spotting scope. A herd was defined as ≥1 animal present, and a distance of 100 meters was used to delineate different herds, following Childress and Lung [21] who described this as the maximum distance at which elk respond to conspecific vocalizations. Once a herd was sighted, we noted the time of day and counted the number of individuals in the herd. We visually estimated whether the herd was clustered, with most individuals within 25 meters of a nearest neighbor, or dispersed, with most individuals greater than 25 meters from a nearest neighbor; we selected this threshold because it was relatively easy to detect visually and it divided our herds roughly evenly into clustered and dispersed categories. We used laser rangefinders to measure the distance to the center of the herd from the road (our vehicle) and the distance to closest vegetation cover, categorized as near or far to cover (using 100 m as the threshold, a distance across which elk vigilance patterns are known to change [58]).

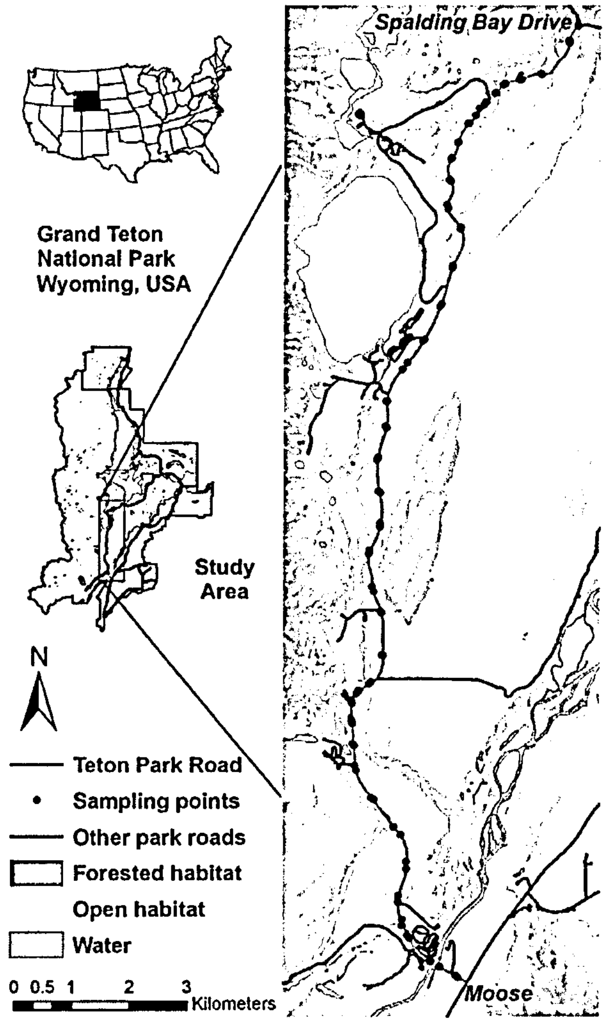

Figure 1. Map of study area.
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Once the initial herd data were collected, we recorded behavior only if the herd was within 500 meters of the sampling point to ensure accuracy of behavioral observations. One observer scanned the herd from left to right recording the behavioral category of each individual, following [21,47]: feeding, grooming (licking or scratching), bedded, mating (sparring or bugling), traveling (walking), fleeing (running), scanning (standing with head above shoulder level), vigilant (displaying alarm or acute attention toward stimuli), and defensive (kicking, biting, charging). Scan surveys lasted approximately 1 minute. It is important to note that ungulates were not tagged or individually identified in our study area; thus, although we can be confident that we sampled unique individuals within each sampling bout as we moved along Teton Park Road, we cannot rule out the possibility that we observed the same individuals on multiple occasions across our scan and focal (described below) sampling bouts.

While ungulate behavioral data were collected, a second observer simultaneously conducted a scan sample to count different kinds of human activity within 200 meters of the sampling point. Ungulates have been shown to be sensitive to the approach speed and direction of anthropogenic stimuli [36]; therefore we categorized vehicles as moving versus stopped. Ungulates can also be particularly responsive to the human form [36]; therefore we also recorded the number of pedestrians along the road. Human activities recorded during scan samples included the number of automobiles (autos) passing, the number of autos stopped (including our own vehicle), and the number of pedestrians at each sampling point. Observers strove to remain in the vehicle to reduce potential observer effects, but on rare occasions when it was necessary to exit the vehicle during a scan observation (e.g., to see a herd that was partially obscured from view), we recorded the observer as a pedestrian to account for our presence and potential influence. We also recorded whether motorcycles, trucks (including recreational vehicles and large commercial and construction vehicles), and bicycles were passing but rarely recorded these activities during our scan samples. Consequently, we did not analyze these three activities separately, but rather grouped passing motorcycles, trucks, and autos into an additional category (total vehicles passing) and omitted passing bicycles from the analyses.

Concurrent with the ungulate and human behavioral observations, we used a portable recording device to sample noise. The recorder (iAudio 7, Cowan America, Irvine, California) was attached to PA3 microphones and a horn lens. The device was mounted on our research vehicle approximately 1.5 meters off the ground and microphones were spaced 2 meters apart pointing in opposite directions. The consistently close proximity of the recorder to the road allowed us to effectively record motorized vehicles, road noise, bicycles, and pedestrians (i.e., human voices). We used a sampling rate of 64 bits per second and recordings were saved as uncalibrated WMA files that could be analyzed for relative metrics of sound. We produced waveforms using SWITCH sound file converter (NCH Software, Canberra, Australia) and spectrograms using RAVEN PRO 1.4 (Cornell University, Ithaca, New York) to quantify relative sound metrics. As the perception of loudness depends on both the amplitude and frequency of sound waves, we measured average power, or the mean relative amplitude over the entire observation, and peak frequency, or the frequency at which the maximum power occurred.

Focal Animal Sampling. In addition to scan sampling, we conducted extended behavioral observations of individual focal animals. We initiated focal animal sampling opportunistically, between scan sampling events, as well as systematically, during scheduled daytime and crepuscular focal animal sessions. Observers drove the length of the study area searching for ungulate herds. When a herd was sighted within 500 meters of the road, we recorded its dispersion and location. We randomly selected a focal animal within a herd by counting individuals in the herd from left to right until reaching a chosen random number, and we recorded its sex classification (adult male, adult female or adult female with calf, if a female was in close proximity to or seen tending to a calf). The focal animal observer continuously recorded the behavioral state (same categories as described above) and the timing of any changes in behavioral state for up to 50 minutes or until the focal animal bedded or moved out of view. We excluded focal animal samples with a duration less than 3 minutes (following Childress and Lung [21]) resulting in an average sample duration of 14.6 minutes (SE = 0.8, n = 113).

As with scan samples, we continuously recorded sound for the duration of the focal sample to measure average power and peak frequency. Simultaneously, a second observer alternated between conducting scan samples of behavior for all individuals within the herd and conducting scan samples to count human activities in the vicinity (within 200 meters of the observers). The alternating herd and human activity scans continued throughout the duration of the focal animal sample, with repeated intervals of approximately 45 seconds to 3 minutes; the duration and frequency of scan samples were dependent on herd size and amount of human activity in the vicinity. The herd behavioral scans were conducted for a concurrent study (Hardy, unpublished data); we use only the human activity data here. Anthropogenic activities recorded during focal samples included the number of autos, motorcycles, trucks, and bicycles passing; the number of autos stopped; and the number of pedestrians present.

Data Analysis

Scan sampling. We developed a candidate set of nonlinear mixed models with a binomial distribution (Proc NLMixed, SAS 9.1) to evaluate if and how acoustic variables and human activities predicted the probability that each individual within a herd was responding or not responding, expressed as a binary, categorical variable. Individuals were classified as 'responding' if they were vigilant, if they displayed defensive behavior, or if they were fleeing or traveling [47,59]. Although animals may travel for a variety of reasons, human activity has been observed to provoke movement in general [24,60] and walking in particular [41,61–63] in a variety of ungulates, including elk within this Greater Yellowstone Ecosystem [47,64].

Our candidate models included all combinations of five acoustic and human activity predictor variables (average power, peak frequency, total vehicles passing, autos stopped, and pedestrians present). Each model additionally included all of the following covariates that have been shown to influence responsive behavior in ungulates [36,39,58,65,66]: distance to road, distance to cover, dispersion (clustered versus dispersed), herd size, species (pronghorn or elk), Julian date, and time of day (crepuscular: ≤ 1 hour after dawn or prior to dusk, or daytime: >1 hour after dawn or prior to dusk, as determined by regional sunrise and sunset tables). We also included the herd ID (a number from 1 to 161 assigned to each scan sample) as a random effect in each model to avoid statistical issues related to pseudoreplication, since an individual's behavior within a scan sample may be correlated with the behavior of the other animals scanned within the same herd. Our candidate model set included an intercept-only model, a covariate model, and models with all subsets of acoustic and human activity predictors in addition to the covariates.

AIC_c (Akaike Information Criterion adjusted for small sample size) [67] based on likelihood values were calculated for each model of ungulate herd responsiveness. We reported model weights (w_i) and AIC_c differences (Δ), measuring the information loss between models given the data, to compare model ranking. Because our model set was balanced by including all combinations of acoustic and human activity variables, we were able to calculate relative variable importance weights (sum of model weights for all models containing that specific variable) to determine which of these variables were the strongest predictors of ungulate responsiveness [67,68]. For each predictor, we also calculated model-averaged parameter estimates and their associated 95% confidence intervals to account for model selection uncertainty and to provide unconditional estimates not dependent on a single model [67]. However, because model-averaging might not reliably assess the effect of a single predictor variable [69,70], we also reported parameter estimates for the predictors in the top model, which necessarily provide conditional estimates, and we calculated estimates from the relationship between each sole predictor and responsiveness, which produce estimates that are not conditional on other predictors.

Focal animal sampling. We used linear regressions (Proc Genmod, SAS 9.1) to evaluate the relationship between behavioral budgets of individual animals in the focal observations and acoustic and human activity. For these analyses, the sampling unit was the focal animal and our response variable was the proportion of time spent responding (i.e., vigilant, defensive, fleeing, traveling). Proportionate data was square root arcsine transformed to normalize variance prior to analyses. We calculated overall rates for human activity variables, averaged across all human scans that occurred during a focal observation (i.e., mean number of activities per scan), to adjust for variation in the number of human activity scans conducted while observing focal animals.

To predict focal animal responsiveness, we created candidate models with all combinations of acoustic and human activity predictors (in addition to an intercept-only model and a model with just the covariates), using similar variables as for the scan samples. However, we separated the total passing vehicles into passing autos and motorcycles, and we also included passing bicycles as a distinct predictor, because they were recorded in sufficient frequency in our focal samples due to their longer duration; this resulted in a total of seven acoustic and human activity predictors. All candidate models included the same covariates as in the scan samples, including distance to road, distance to cover, dispersion, herd size, species, Julian date, and time of day. Past studies suggest the sex of an individual may also affect responsiveness [71,72]; thus we additionally included the focal animal's sex classification. As with the scan samples, we reported AIC_c values, model weights, and parameter estimates and confidence intervals from the top model, from model averaging, and from a model where each variable was the sole predictor; variable importance weights were also calculated to determine which acoustic and human activity variables were the strongest predictors of ungulate responsiveness.

Results

Scan Samples

Across 161 scan samples, we observed a total of 334 autos stopped, 265 total vehicles passing (including 245 autos, 11 trucks, 9 motorcycles), 135 pedestrians, and 4 bicycles passing. Our uncalibrated measures of average power during scan samples ranged from 37.8 dB to 80.9 dB (mean =64.9, SE = 0.9). Peak frequency ranged from 172 to 4307 Hz, falling within the hearing range of ungulates [73], and averaged 958 Hz (SE = 41), consistent with the low frequency of traffic noise [74]. Of all human activities measured, the number of autos passing was most strongly correlated with average power measurements during scan samples ($r = 0.37$), further pointing to traffic as a dominant source of noise. Of 1013 ungulates scanned across all scan samples, 234 (23%) were engaged in responsive behavior (14% traveling, 7% vigilant, 2% fleeing, and 0.2% defensive).

When comparing our candidate models predicting ungulate responsiveness, there was some model selection uncertainty (Table 1) with substantial support for the top 3 models (out of 33) that fell within 2.0 ΔAIC_c [67]; these top models contained all acoustic and human activity predictors except peak frequency. Based on the magnitude and direction of parameter estimates, ungulates were more likely to respond when there were more pedestrians present and less likely to respond when there were high levels of traffic, with traffic having a greater effect than pedestrians (Table 2). The 95% confidence intervals around the parameter estimates for total vehicles passing and pedestrians did not overlap zero in the top model or from model averaging, further suggesting that they both influenced responsiveness. The parameter estimate for average power was relatively small, and its 95% confidence interval overlapped zero when model averaging but not when average power was the sole predictor, suggesting only a weak negative relationship between noise and responsiveness. The parameter estimates for autos stopped and peak frequency were also small, with confidence intervals overlapping zero both from model averaging and when they were the only predictors (Table 2). Comparing the importance weights of the acoustic and human activity variables confirmed that the number of vehicles passing and pedestrians were relatively more important predictors of ungulate responsiveness than average power, the numbers of autos stopped, and peak frequency (Table 2). Based on the magnitude and directions of parameter estimates for the covariates, ungulates were more likely to respond when herds were dispersed, were closer to the road, and were composed of pronghorn, with at least one confidence interval that did not overlap zero from the top model, model averaging, or the model with a single predictor (Table 2).

Focal Samples

We conducted 113 focal samples throughout the field season generating 1,632 minutes of individual observations. We observed 3,275 autos stopped, 3,040 vehicles passing (including 2,786 autos, 171 trucks, 83 motorcycles), 1,047 pedestrians, and 41 bicycles passing summed over 2,172 human activity scans that were concurrent with the 113 focal observations. Our uncalibrated measures of average power during focal samples ranged between 57.0 dB and 77.0 dB (mean =69.2, SE = 0.4), while peak frequency ranged between 172 and 11,887 Hz (mean =958, SE = 74.1). Of the human activities measured, the number of autos passing was most strongly correlated with average power during focal samples ($r = 0.54$), again implicating auto traffic as a major source of noise. On average, focal ungulates spent 25% (SE = 2%) of their time engaged in responsive behavior (13% traveling, 8% vigilant, 4% fleeing, 0.1% defensive).

When comparing our candidate models predicting ungulate responsiveness, there was considerable model selection uncertainty (Table 3), with substantial support for the top 8 models (out of 129) that fell within 2.0 ΔAIC_c [67]; these top models contained all acoustic and human activity predictors. Based on the magnitude and direction of parameter estimates in the most strongly supported models, focal animals increased their responsiveness with increasing motorcycle traffic and decreased their responsiveness with increasing auto traffic, with motorcycles having a larger effect size than autos (Table 4). The 95% confidence intervals around the parameter estimates for these two predictors did not overlap zero in the top model, further suggesting they influenced responsiveness. In contrast, the parameter estimates for the other acoustic and human activity variables in the top model (average

Table 1. AIC$_c$ model selection results where acoustic and human activity variables were used to explain whether or not individuals were responsive during scan samples.

Model[a]	K[b]	ΔAIC$_c$	Model weight (w_i)
total vehicles passing, pedestrians	11	0.0	0.214
total vehicles passing, pedestrians, autos stopped	12	1.8	0.087
total vehicles passing, pedestrians, average power	12	2.0	0.079
total vehicles passing	10	2.2	0.071
total vehicles passing, pedestrians, peak frequency	12	2.4	0.065
total vehicles passing, autos stopped	11	3.0	0.048
pedestrians, average power	11	3.3	0.041
pedestrians	10	3.5	0.037
total vehicles passing, pedestrians, average power, autos stopped	13	3.8	0.032

Covariates (distance to road, distance to cover, dispersion, herd size, species, Julian date, time of day) and a random effect (Herd ID) were also included in each model.
[a]The top 9 models (out of 33) that fell within 4 AIC$_c$ of the top model (holding 67% of the total model weight) are presented.
[b]Parameter count for the model (including intercept and variance).
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power and pedestrians) were relatively small, with confidence intervals that overlapped zero (Table 4). All model-averaged parameter estimates of acoustic and human activity variables were smaller than those from the highest-ranking models, with confidence intervals overlapping zero, suggesting that they did not strongly influence responsiveness, though this could be attributed to averaging over many models with high uncertainty, which may reduce the ability to correctly estimate the effect of a single predictor [69,70]. Comparing the relative importance weights of the acoustic and human activity predictors revealed that the number of autos passing was the most important predictor of ungulate responsiveness followed by the number of motorcycles passing. Average power, pedestrians, autos stopped, peak frequency, and bicycles passing were relatively less important (Table 4). Further, based on the magnitude and directions of parameter estimates for the covariates (with at least one confidence interval that did not overlap zero from model averaging or the single-predictor model), ungulates were more responsive in smaller herds and during daytime hours, and cows with a calf were more responsive than males or females without a calf (Table 4).

Discussion

The risk-disturbance hypothesis states that anthropogenic disturbance such as human-related presence, objects, or sounds will elicit antipredator behavior [16]. Thus, we expected ungulates

Table 2. Relative variable importance weights (for acoustic and human activity variables) and parameter estimates with 95% confidence intervals (for all variables, including covariates) from models predicting ungulate responsiveness in our scan samples.

Variable	Relative importance weight	Estimate from top model (lower/upper CL)	Estimate from model averaging (lower/upper CL)	Estimate from model with one predictor (lower/upper CL)
Acoustic or human activity predictor:				
total vehicles passing	0.76	−0.23 (−0.41/−0.05)*	−0.15 (−0.20/−0.11)*	−0.16 (−0.33/0.004)
pedestrians	0.70	0.11 (0.01/0.21)*	0.09 (0.05/0.12)*	0.09 (−0.01/0.20)
average power	0.33		−0.01 (−0.03/0.02)	−0.03 (−0.06/−0.01)*
autos stopped	0.33		−0.01 (−0.04/0.02)	0.07 (−0.06/0.21)
peak frequency	0.24		0 (−0.0001/0.0001)	0.0002 (−0.001/0.001)
Covariate:				
distance to road		−0.01 (−0.003/0.001)	−0.001 (−0.002/0.002)	−0.002 (−0.004/−0.0003)*
distance to cover		−0.001 (−0.33/0.004)	−0.001 (−0.004/0.002)	−0.30 (−1.38/0.78)
dispersion		1.34 (0.62/2.07)*	1.19 (0.44/1.93)*	1.08 (0.37/1.79)*
herd size		0.02 (−0.01/0.05)	0.01 (−0.03/0.05)	−0.01 (−0.03/0.01)
species		−1.02 (−1.78/−0.26)*[a]	−0.92 (−2.18/0.96)	−0.60 (−1.29/0.09)
Julian date		0.002 (−0.01/0.01)	0.002 (−0.01/0.01)	0.001 (−0.01/0.01)
time of day		0.56 (−0.22/1.34)	0.53 (−0.73/1.78)	0.58 (−0.18/1.34)

Parameter estimates and confidence intervals are presented for variables in the top model, for all variables based on model averaging across all 33 models, and from models containing each variable as a sole predictor of ungulate responsiveness.
*Confidence interval not overlapping zero.
[a]Indicates greater responsiveness of pronghorn than elk.
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Table 3. AIC_c model selection results where acoustic and human activity variables were used to explain the proportion of time individual focal animals were responsive.

Model[a]	K[b]	ΔAIC_c	Model weight (w_i)
autos passing, motorcycles passing, average power, pedestrians	15	0.0	0.070
autos passing, motorcycles passing, average power	14	0.0	0.069
autos passing, motorcycles passing, pedestrians	14	0.6	0.053
autos passing, motorcycles passing	13	0.7	0.049
autos passing, motorcycles passing, average power, autos stopped	15	1.4	0.034
autos passing, motorcycles passing, autos stopped	14	1.6	0.031
autos passing, motorcycles passing, average power, bicycles passing	15	1.8	0.028
autos passing, motorcycles passing, average power, pedestrians, peak frequency	16	2.0	0.026
autos passing, motorcycles passing, average power, pedestrians, bicycles passing	16	2.1	0.024
autos passing, average power	13	2.3	0.022
autos passing	12	2.3	0.022
autos passing, motorcycles passing, pedestrians, peak frequency	15	2.4	0.021
autos passing, pedestrians	13	2.6	0.019
autos passing, average power, pedestrians	14	2.7	0.018
autos passing, motorcycles passing, average power, peak frequency	15	2.7	0.018
autos passing, motorcycles passing, average power, pedestrians, autos stopped	16	2.7	0.018
motorcycles passing, autos stopped	13	2.8	0.018
autos passing, motorcycles passing, bicycles passing	14	2.9	0.016
autos stopped	12	3.0	0.016
autos passing, motorcycles passing, pedestrians, bicycles passing	15	3.0	0.015
autos passing, motorcycle passing, pedestrians, autos stopped	15	3.2	0.014
pedestrians	12	3.2	0.014
motorcycles passing, pedestrians	13	3.3	0.014
autos passing, motorcycles passing, peak frequency	14	3.3	0.014
autos passing, autos stopped	13	3.4	0.013
autos passing, motorcycles passing, average power, autos stopped, bicycles passing	16	3.5	0.012
autos passing, average power, autos stopped	14	3.8	0.011
autos passing, motorcycles passing, average power, autos stopped, peak frequency	16	3.8	0.010
autos passing, motorcycles passing, autos stopped, peak frequency	15	3.8	0.010

Covariates (distance to road, distance to cover, dispersion, herd size, species, Julian date, time of day, and sex) were also included in each model.
[a]The top 29 models (out of 129) that fell within 4 AIC_c of the top model (holding 70% of the total model weight) are presented.
[b]Parameter count for the model (including intercept and variance).
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to exhibit heightened levels of responsive behavior in the presence of human activities and noise along Teton Park Road in Grand Teton National Park. The results suggest that human activities can alter responsive behaviors in ungulates. Contrary to our predictions, however, ungulates were not more likely to respond, but rather less likely to respond to increased vehicle traffic, which was the human activity most closely associated with noise. Though noise levels themselves did not have a strong effect on ungulate behavior, there was a weak negative relationship between average power and responsiveness in our scan samples.

One possible explanation for these findings is that ungulates in our study area did not perceive traffic and its associated noise as a form of predation risk, perhaps because individuals sensitive to these stimuli have been displaced over time or because the individuals that remain have habituated over time to these frequent stimuli. Ungulates are known to habituate to regular exposure to noise [5,31] and other non-lethal human activities [36] and to display individual variation within populations in their avoidance or tolerance of roads [62]. Elk in particular exhibit behavioral patterns that suggest habituation along roads and other areas disturbed by human activities [75–77]. This tolerance would explain a lack of effect of traffic on responsiveness, but does not seem sufficient to explain the finding that increasing traffic caused ungulates to be *less* responsive.

The decrease in responsiveness with increasing traffic could indicate that passing vehicles provide a refuge from predators, such that ungulates have come to perceive reduced predation risk when traffic and their associated noise levels are high. Previous studies have demonstrated direct benefits of human activity to prey through reduced predator abundance [14,32–35], and it is possible that this could also translate to indirect benefits through reduced investment in vigilance and other forms of antipredator behavior. Alternatively, another explanation for our findings is that traffic disturbances are actually perceived as a form of predation risk by ungulates, but they cannot afford to maintain high levels of responsiveness to such a continuous and pervasive form of disturbance. Specifically, the risk allocation hypothesis [78] suggests that animals will devote a larger proportion of risky

Table 4. Relative variable importance weights (for acoustic and human activity variables) and parameter estimates with 95% confidence intervals (for all variables, including covariates) from models predicting ungulate responsiveness in our focal observations.

Variable	Relative importance weight	Estimate from top model (lower/upper CL)	Estimate from model averaging (lower/upper CL)	Estimate from model with one predictor (lower/upper CL)
Acoustic or human activity predictor:				
autos passing	0.80	−0.08 (−0.14/−0.02)*	−0.05 (−0.19/0.08)	−0.06 (−0.11/−0.01)*
motorcycles passing	0.69	0.57 (0.06/1.09)*	0.37 (−0.09/0.82)	0.35 (−0.15/0.85)
average power	0.50	0.01 (−0.002/0.03)	0.005 (−0.01/0.02)	−0.0001 (−0.01/0.01)
pedestrians	0.46	−0.04 (−0.09/0.01)	−0.02 (−0.09/0.05)	−0.04 (−0.10/0.01)
autos stopped	0.34		−0.01 (−0.06/0.04)	−0.04 (−0.08/−0.002)*
peak frequency	0.25		−0.0003 (−0.01/0.01)	0 (−0.0001/0.01)
bicycles passing	0.24		0.04 (−0.44/0.53)	−0.48 (−1.37/0.42)
Covariate:				
distance to road		−0.0001 (−0.001/0.0004)	−0.0001 (−0.001/0.001)	−0.0001 (−0.001/0.0003)
distance to cover		0.34 (−0.09/0.77)	0.35 (−0.54/1.25)	0.13 (−0.41/0.68)
dispersion		0.03 (−0.07/0.14)	0.03 (−0.09/0.15)	0.04 (−0.07/0.15)
herd size		−0.005 (−0.01/0.0004)	−0.11 (−0.12/−0.10)*	−0.006 (−0.01/−0.0004)*
species		0.09 (−0.05/0.23)	0.08 (−0.14/0.30)	−0.06 (−1.04/0.92)
Julian date		−0.0002 (−0.002/0.001)	−0.0004 (−0.002/0.002)	−0.0005 (−0.002/0.001)
time of day		0.11 (−0.002/0.22)	0.09 (−0.15/0.33)	0.11 (0.01/0.22)*[a]
sex		−0.12 (−0.24/0.01)	−0.11 (−0.36/0.14)	−0.16 (−0.27/−0.04)*[b]

Parameter estimates and confidence intervals are presented for variables in the top model, for all variables based on model averaging across all 129 models, and from models containing each variable as a sole predictor of ungulate responsiveness.
*Confidence interval not overlapping zero.
[a]Indicates greater responsiveness during daytime hours than crepuscular hours.
[b]Indicates greater responsiveness of females with calf than males or females without a calf.
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intervals to antipredator behavior, when those intervals are brief and infrequent. In contrast, when periods of risk are lengthy and more frequent, animals will devote a reduced proportion of those risky intervals to antipredator behavior in order to avoid the high cost of lost foraging. In the context of anthropogenic disturbance, Miller et al. [79] found certain human activities, when infrequent and unpredictable, were related to heightened levels of flush distance in ungulates. In our study, auto traffic, with its associated noise, was the most prevalent anthropogenic disturbance; thus, high traffic levels may have reduced responsiveness due to risk allocation decisions. In comparison, pedestrians, a less frequent form of disturbance, were more likely to elicit responsive behavior in our scan samples, consistent with prior studies implicating the human form as an importance source of disturbance for ungulates [36]. Similarly, responsiveness was greater in response to the least common form of disturbance, motorcycle traffic, as would be predicted by the risk allocation hypothesis. Interestingly, bicycles, which are quieter but similar in shape to motorcycles, were not an important predictor of responsive behavior, suggesting that the loud noise generated by motorcycles in particular may be a disturbance stimulus.

Although the goal of this study was to evaluate whether anthropogenic disturbances affected ungulate behavior, we also measured a variety of covariates for inclusion in our models. The directions of their effects on responsiveness supports earlier findings that ungulates were more responsive when they were in smaller herds, when they were dispersed rather than clustered, and when they were closer to roads, further suggesting they were not completely tolerant of human activity [36,39,58,66]. Our results also suggest that ungulates may be more responsive during daytime hours; this adds to prior findings that time of day influences responsiveness, though the direction of the effect varies across ungulate species and populations, including elk [36,64]. Pronghorn were more responsive than elk, and females with young were more responsive than adult males and adult females without young, again consistent with prior studies demonstrating the sensitivity of pronghorn [39,71,80] and of females with young [21,71,81] to disturbance.

Understanding the behavioral responses of wildlife to anthropogenic disturbance can have important conservation and management implications [82–86]. Our results highlight an interesting effect of human disturbance on behavior. Except in the case of motorcycles, which are relatively infrequent disturbance events, ungulates spent less time responding with increased vehicle traffic and its associated noise, allowing more time for maintenance activities such as feeding. Presumably, increased levels of energy enhancing activities can positively affect fitness, suggesting a benefit of reduced responsiveness to traffic. However, we urge caution with this interpretation, since unresponsive behavior also could have negative implications, for example by reducing their ability to visually detect predators and other cues in the environment, potentially adding to any masking of acoustic cues caused by the anthropogenic noise itself [1]. Reduced responsiveness of ungulates to road traffic could also lead to increased human conflict such as negative encounters with recreationists or collisions with vehicles [33,87], major concerns for park managers [88]. Finally, it is important to emphasize that noise can have negative impacts on fitness and population persistence in ways that may not be reflected by individual behavioral responsiveness [89]. Thus, although anthropogenic noise did not appear to detract from fitness-enhancing behaviors in this system, we suggest continued investigation of possible population-level noise impacts.

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Author Contributions

Conceived and designed the experiments: CLB ARH JRB KMF KRC LMA. Performed the experiments: CLB ARH. Analyzed the data: CLB ARH JRB KMF KRC LMA. Contributed reagents/materials/analysis tools: CLB ARH JRB KMF KRC LMA. Wrote the paper: CLB ARH JRB KMF KRC LMA.

References

1. Barber JR, Crooks KR, Fristrup KM (2010) The costs of chronic noise exposure for terrestrial organisms. Trends in Ecology and Evolution 25: 180–189.
2. Barber JR, Burdett CL, Reed SE, Warner KA, Formichella C, et al. (2011) Anthropogenic noise exposure in protected natural areas: estimating the scale of ecological consequences. Landscape Ecology 26: 1281–1295.
3. Lynch E, Joyce D, Fristrup K (2011) An assessment of noise audibility and sound levels in U.S. National Parks. Landscape Ecology 26: 1297–1309.
4. Henderson D, Hamernik RP, Dosanjh DS, Mills JH (1976) Effects of noise on hearing. New York: Raven Press. 565 p.
5. Weisenberger ME, Krausman PR, Wallace MC, De Young DW, Maughan OE (1996) Effects of simulated jet aircraft noise on heart rate and behavior of desert ungulates. Journal of Wildlife Management 60: 52–61.
6. Owen MA, Swaisgood RR, Czekala NM, Steinman K, Lindburg DG (2004) Monitoring stress in captive giant pandas (*Ailuropoda melanoleuca*): behavioral and hormonal responses to ambient noise. Zoo Biology 23: 147–164.
7. Warren PS, Katti M, Ermann M, Brazel A (2006) Urban bioacoustics: it's not just noise. Animal Behaviour 71: 491–502.
8. Bee MA, Swanson EM (2007) Auditory masking of anuran advertisement calls by road traffic noise. Animal Behaviour 74: 1765–1776.
9. Habib L, Bayne EM, Boutin S (2007) Chronic industrial noise affects pairing success and age structure of ovenbirds *Seiurus aurocapilla*. Journal of Applied Ecology 44: 176–184.
10. Lengagne T (2008) Traffic noise affects communication behaviour in a breeding anuran, *Hyla arborea*. Biological Conservation 141: 2023–2031.
11. Slabbekoorn H, Ripmeester EAP (2008) Birdsong and anthropogenic noise: implications and applications for conservation. Molecular Ecology 17: 72–83.
12. Halfwerk W, Holleman LJM, Lessells CM, Slabbekoorn H (2011) Negative impact of traffic noise on avian reproductive success. Journal of Applied Ecology 48: 210–219.
13. Bayne EM, Habib L, Boutin S (2008) Impacts of Chronic Anthropogenic Noise from energy-sector activity on abundance of songbirds in the boreal forest. Conservation Biology 22: 1186–1193.
14. Francis CD, Ortega CP, Cruz A (2009) Noise pollution changes avian communities and species interactions. Current Biology 19: 1415–1419.
15. Francis CD, Paritsis J, Ortega CP, Cruz A (2011) Landscape patterns of avian habitat use and nest success are affected by chronic gas well compressor noise. Landscape Ecology 26: 1269–1280.
16. Frid A, Dill LM (2002) Human-caused disturbance stimuli as a form of predation risk. Conservation Ecology 6: 11.
17. Quinn JL, Whittingham MJ, Butler SJ, Cresswell W (2006) Noise, predation risk compensation and vigilance in the chaffinch *Fringilla coelebs*. Journal of Avian Biology 37: 601–608.
18. Rabin LA, Coss RG, Owings DH (2006) The effects of wind turbines on antipredator behavior in California ground squirrels (*Spermophilus beecheyi*). Biological Conservation 131: 410–420.
19. Nowacek DP, Thorne LH, Johnston DW, Tyack PL (2007) Responses of cetaceans to anthropogenic noise. Mammal Review 37: 81–115.
20. Maier JAK, Murphy SM, White RG, Smith MD (1998) Responses of caribou to overflights by low-altitude jet aircraft. Journal of Wildlife Management 62: 752–766.
21. Childress MJ, Lung MA (2003) Predation risk, gender and the group size effect: does elk vigilance depend upon the behaviour of conspecifics? Animal Behaviour 66: 389–398.
22. Fortin D, Boyce MS, Merrill EH, Fryxell JM (2004) Foraging costs of vigilance in large mammalian herbivores. Oikos 107: 172–180.
23. Ydenberg RC, Dill LM (1986) The economics of fleeing from predators. Advances in the Study of Behavior 16: 229–249.
24. Cassirer EF, Freddy DJ, Ables ED (1992) Elk responses to disturbance by cross-country skiers in Yellowstone National Park. Wildlife Society Bulletin 20: 375–381.
25. Rumble MA, Benkobi L, Gamo RS (2005) Elk responses to humans in a densely roaded area. Intermountain Journal of Sciences 11: 10–24.
26. Stockwell CA, Bateman GC, Berger J (1991) Conflicts in national parks: a case study of helicopters and bighorn sheep time budgets at the Grand Canyon. Biological Conservation 56: 317–328.
27. Bradshaw CJA, Boutin S, Hebert DM (1998) Energetic implications of disturbance caused by petroleum exploration to woodland caribou. Canadian Journal of Zoology 76: 1319–1324.
28. Thorpe WH (1963) Learning and instinct in animals. London: Methuen. 558 p.
29. Harms CA, Fleming WJ, Stoskopf MK (1997) A technique for dorsal subcutaneous implantation of heart rate biotelemetry transmitters in black ducks: Application in an aircraft noise response study. The Condor 99: 231–237.
30. Delaney DK, Grubb TG, Beier P, Pater LL, Reiser MH (1999) Effects of helicopter noise on Mexican spotted owls. Journal of Wildlife Management 63: 60–76.
31. Waynert DF, Stookey JM, Schwartzkopf-Genswein KS, Watts JM, Waltz CS (1999) The response of beef cattle to noise during handling. Applied Animal Behviour Science 62: 27–42.
32. Berger J (2007) Fear, human shields and the redistribution of prey and predators in protected areas. Biology Letters 3: 620–623.
33. Fahrig L, Rytwinski T (2009) Effects of roads on animal abundance: an empirical review and synthesis. Ecology and Society 14: 21.
34. Leighton PA, Horrocks JA, Kramer DL (2010) Conservation and the scarecrow effect: Can human activity benefit threatened species by displacing predators? Biological Conservation 143: 2156–2163.
35. Muhly TB, Semeniuk C, Massolo A, Hickman L, Musiani M (2011) Human activity helps prey win the predator-prey space race. PLoS ONE 6: e17050.
36. Stankowich T (2008) Ungulate flight responses to human disturbance: A review and meta-analysis. Biological Conservation 141: 2159–2173.
37. Bolger TD, Newmark D, Morrison TA, Doak DF (2008) The need for integrative approaches to understand and conserve migratory ungulates. Ecology Letters 11: 63–77.
38. Duchesne M, Côté SD, Barrette C (2000) Responses of woodland caribou to winter ecotourism in the Charlevoix Biosphere Reserve, Canada. Biological Conservation 96: 311–317.
39. Gavin SD, Komers PE (2006) Do pronghorn (*Antilocapra americana*) perceive roads as a predation risk? Canadian Journal of Zoology 84: 1775–1780.
40. St. Clair CC, Forrest A (2009) Impacts of vehicle traffic on the distribution and behaviour of rutting elk, *Cervus elaphus*. Behaviour 146: 393–413.
41. Schultz RD, Bailey JA (1978) Responses of national park elk to human activity. Journal of Wildlife Management 42: 91–100.
42. Freddy DJ, Bronaugh WM, Fowler MC (1986) Responses of mule deer to disturbance by persons afoot and snowmobiles. Wildlife Society Bulletin 14: 63–68.
43. Knight RL, Cole DN (1995) Wildlife responses to recreationists. In: Knight RL, Gutzwiller K, editors. Wildlife and recreationists: Coexistence through management and research. Washington, DC: Island Press. 51–70.
44. Phillips GE, Alldredge AW (2000) Reproductive success of elk following disturbance by humans during calving season. Journal of Wildlife Management 64: 521–530.
45. Manor R, Saltz D (2003) Impact of human nuisance disturbance on vigilance and group size of a social ungulate. Ecological Applications 13: 1830–1834.
46. Taylor AR, Knight RL (2003) Wildlife responses to recreation and associated visitor perceptions. Ecological Applications 13: 951–963.
47. Borkowski JJ, White PJ, Garrott RA, Davis T, Hardy AR, et al. (2006) Behavioral responses of bison and elk in Yellowstone to snowmobiles and snow coaches. Ecological Applications 16: 1911–1925.
48. Setsaas TH, Holmern T, Mwakalebe G, Stokke S, Røskaft E (2007) How does human exploitation affect impala populations in protected and partially protected areas? – A case study from the Serengeti ecosystem, Tanzania. Biological Conservation 136: 563–570.
49. Rost GR, Bailey JA (1979) Distribution of mule deer and elk in relation to roads. Journal of Wildlife Management 43: 634–641.
50. Pedevillano C, Wright RG (1987) The influence of visitors on mountain goat activities in Glacier National Park, Montana. Biological Conservation 39: 1–11.

51. Czech B (1991) Elk behavior in response to human disturbance at Mount St. Helens National Volcanic Monument. Applied Animal Behaviour Science 29: 269–277.
52. Rowland MM, Wisdom MJ, Johnson BK, Kie JG (2000) Elk distribution and modeling in relation to roads. Journal of Wildlife Management 64: 672–684.
53. Rumble MA, Gamo RS (2011) Resource selection by elk at two spatial scales in the Black Hills, South Dakota. Prairie Naturalist 43: 3–13.
54. Summers PD, Cunnington GM, Fahrig L (2011) Are the negative effects of roads on breeding birds caused by traffic noise? Journal of Applied Ecology 48: 1527–1534.
55. Bejder L, Samuels A, Whitehead H, Finn H, Allen S (2009) Impact assessment research: use and misuse of habituation, sensitisation and tolerance in describing wildlife responses to anthropogenic stimuli. Marine Ecology Progress Series 395: 177–185.
56. Smith BL (2007) Migratory behavior of hunted elk. Northwest Science 81: 251–264.
57. Berger J (2003) Is it acceptable to let a species go extinct in a National Park? Conservation Biology 17: 1451–1454.
58. Liley S, Creel S (2008) What best explains vigilance in elk: characteristics of prey, predators, or the environment? Behavioral Ecology 19: 245–254.
59. Goldstein MI, Poe AJ, Cooper E, Youkey D, Brown BA, et al. (2005) Mountain goat response to helicopter overflights in Alaska. Wildlife Society Bulletin 33: 688–699.
60. Dorrance MJ, Savage PJ, Huff DE (1975) Effects of snowmobiles on white-tailed deer. Journal of Wildlife Management 39: 563–569.
61. Tyler NJC (1991) Short-term behavioural responses of Svalbard reindeer *Rangiger tarandus platyrhynchus* to direct provocation by a snowmobile. Biological Conservation 56: 179–194.
62. Papouchis CM, Singer FJ, Sloan WB (2001) Responses of desert bighorn sheep to increased human recreation. Journal of Wildlife Management 65: 573–582.
63. Fortin D, Andruskiw M (2003) Behavioral response of free-ranging bison to human disturbance. Wildlife Society Bulletin 31: 804–813.
64. Cleveland SM (2010) Human predation risk infuences elk behavior in heterogeneous landscapes. MS Thesis. University of Montana. Missoula. 92 p. Available: http://www.mhfj.org/MissoulaElkHerds/PDFs/ClevelandThesis 2010.pdf. Accessed 2012 Jun 18.
65. Roberts G (1996) Why individual vigilance declines as group size increases. Animal Behaviour 51: 1077–1086.
66. Frid A (1997) Vigilance by female Dall's sheep: Interactions between predation risk factors. Animal Behaviour 53: 799–808.
67. Burnham KP, Anderson DR (2002) Model selection and multimodel inference: a practical information-theoretic approach. New York: Springer-Verlag. 496 p.
68. Doherty PF, White GC, Burnham KP (2010) Comparison of model building and selection strategies. Journal of Ornithology 152: S317–S323.
69. Richards SA, Whittingham MJ, Stephens PA (2011) Model selection and model averaging in behavioural ecology: the utility of the IT-AIC framework. Behavioural Ecology and Sociobiology 65: 77–89.
70. Symonds MRE, Moussalli A (2011) A brief guide to model selection, multimodal inference and model averaging in behavioural ecology using Akaike's information criterion. Behavioural Ecology and Sociobiology 65: 13–21.
71. Lipetz VE, Bekoff M (1982) Group-size and vigilance in pronghorns. Journal of Comparative Ethology 58: 203–216.
72. Lima SL (1998) Stress and decision making under the risk of predation: Recent developments from behavioral, reproductive, and ecological perspectives. Advances in the Study of Behavior 27: 215–290.
73. D'Angelo GJ, De Chicchis AR, Osborn DA, Gallagher GR, Warren RJ, et al. (2007) Hearing range of white-tailed deer as determined by auditory brainstem response. Journal of Wildlife Management 71: 1238–1242.
74. Dooling RJ, Popper AN (2007) The effects of highway noise on birds. Environmental BioAcoustics Report. California Department of Transportation website. Available: http://www.caltrans.ca.gov/hq/env/bio/files/caltrans_birds_10-7-2007b.pdf. Accessed 2012 Jun 18.
75. Lyon LJ, Ward AL (1982) Elk and land management. In: Thomas JW, Toweill DE, editors. Elk of North America: Ecology and management. Harrisburg: Stackpole Books. 442–477.
76. Morrison JR, De Vergie WJ, Alldredge AW, Byrne AE, Andree WW (1995) The effects of ski area expansion on elk. Wildlife Society Bulletin 23: 481–489.
77. Thompson MJ, Henderson RE (1998) Elk habituation as a credibility challenge for wildlife professionals. Wildlife Society Bulletin 26: 477–483.
78. Lima SL, Bednekoff PA (1999) Temporal variation in danger drives antipredator behavior: the predation risk allocation hypothesis. American Naturalist 153: 649–659.
79. Miller SG, Knight RL, Miller CK (2001) Wildlife responses to pedestrians and dogs. Wildlife Society Bulletin 29: 124–132.
80. Berger J, Daneke D, Johnson J, Berwick SH (1983) Pronghorn foraging economy and predator avoidance in a desert ecosystem: Implications for the conservation of large mammalian herbivores. Biological Conservation 25: 193–208.
81. Wolff JO, Van Horn T (2003) Vigilance and foraging patterns of American elk during the rut in habitats with and without predators. Canadian Journal of Zoology 81: 266–271.
82. Buchholz R (2007) Behavioural biology: an effective and relevant conservation tool. Trends in Ecology and Evolution 22: 401–407.
83. Caro T (2007) Behavior and conservation: a bridge too far? Trends in Ecology and Evolution 22: 394–400.
84. Angeloni L, Crooks KR, Blumstein DT (2010) Conservation and behavior: Introduction. In: Breed MD, Moore J, editors. Encyclopedia of animal behavior, Volume 1. Oxford: Academic Press. 377–381.
85. Angeloni L, Schlaepfer MA, Lawler JJ, Crooks KR (2008) A reassessment of the interface between conservation and behaviour. Animal Behaviour 75: 731–737.
86. Blumstein DT, Fernández-Juricic E (2010) A primer of conservation behavior. Sunderland: Sinauer Associates. 224 p.
87. Conover MR (2002) Resolving human-wildlife conflicts: the science of wildlife damage management. Boca Raton: CRC Press. 440 p.
88. Ament R, Clevenger AP, Yu O, Hardy A (2008) An assessment of road impacts on wildlife populations in US National Parks. Environmental Management 42: 480–496.
89. Gill JA, Norris K, Sutherland WJ (2001) Why behavioural responses may not reflect the population consequences of human disturbance. Biological Conservation 97: 265–268.

EPA
VICTORIA

ENVIRONMENTAL GUIDELINES FOR THE CONCRETE BATCHING INDUSTRY

Environment Protection Authority
State Government of Victoria

June 1998

ENVIRONMENTAL GUIDELINES FOR THE CONCRETE BATCHING INDUSTRY

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FOREWORD

This Best Practice Environmental Management (BPEM) Guideline was developed in consultation with the concrete batching industry and describes a forward looking approach to waste management issues for this industry. It builds on steps already taken by the industry to improve its environmental performance and seeks to integrate economic and environmental objectives. EPA acknowledges the contribution of the Australian Pre-Mixed Concrete Association to these Guidelines.

The philosophy behind BPEM is that of continual improvement. As industry looks for better ways to operate, it should also seek better ways to protect the environment.

Industry is encouraged to adopt the BPEM practices outlined in this BPEM Guideline so that both the industry and the environment can improve.

EPA will be pleased to receive comments on these guidelines from the concrete batching industry. Comments will, where appropriate, be incorporated in future editions.

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Acknowledgment

These guidelines were drafted by Gregory M Haywood (Deakin University)

Contents

TABLES

1 INTRODUCTION

This publication is intended to help the concrete batching industry operate without causing adverse environmental impacts.

Poorly controlled concrete batching plants may discharge highly alkaline wastewater, dust and excess noise, but plants operated in accordance with these guidelines should operate in harmony with the environment and neighbouring communities.

Best practice environmental management (BPEM) is synonymous with best practice business management. Both aim to maximise the efficiency of raw material usage, while minimising waste generation and the consumption of energy, water and auxiliary chemicals.

BPEM is not driven by regulatory compliance, but by the recognition that efficient resource usage results in increased productivity as well as reduced environmental impact.

1.1 OBJECTIVE

These guidelines will assist the concrete batching industry to achieve the best practical environmental outcome, while allowing flexibility as to how this will be achieved. Thus, the guidelines provide the industry and regulators with:

- a statement of the potential impacts of concrete batching operations on each element of the environment
- a clear environmental performance objective for each element of the environment
- suggested measures to avoid adverse environmental impacts and thus meet the performance objective
- the flexibility to meet the environmental objectives by other measures, as long as they achieve equivalent or better outcomes.

1.2 SCOPE OF THE GUIDELINES

These guidelines will assist concrete batching plant managers and operators to:

- comply with the legislative requirements of the Victorian Government
- use and maintain appropriate technology to minimise the impact of their operations on the environment and the amenity of the local community
- identify potential environmental problems and the tools to monitor and solve these problems
- understand their plant management responsibilities.

These guidelines apply to concrete batching plants of all scale – regardless of whether they are subject to EPA works approval.

The guidelines permit and encourage innovative, effective and improved solutions for the environmental management of concrete batching.

A checklist is provided in Appendix 1 to enable the manager of the facility to check that all relevant environmental issues have been addressed in accordance with these guidelines. This checklist is derived from one developed by the Environmental Sub-Committee (Victoria) of the peak body – the Australian Pre-Mixed Concrete Association – to determine the winner of the industry's annual Environmental Performance Award.

1.3 BEST PRACTICE ENVIRONMENTAL MANAGEMENT

BPEM means managing an organisation or activity to achieve a high level of environmental performance which is sustainable, continuously improves and is consistent with business or economic objectives. BPEM needs to be integrated with overall management philosophy and practice.

The BPEM publication series comprises guidelines and codes of practice for industry sectors or activities, which outline what is needed to achieve optimum environmental outcomes, consistent with the industry's economic viability.

BPEM may encompass:

- site selection
- process design
- technology choice
- key operating parameters and procedures
- contingency arrangements
- monitoring and auditing aspects.

BPEM publications outline key environmental objectives relevant to the industry or activity, and provide suggested measures to achieve these objectives. Satisfactory implementation of the suggested measures will be deemed to achieve compliance with the objectives. However, operators are encouraged to consider alternative ways to meet the objectives and to apply the best site-specific solution equivalent to, or better than, the suggested measure. Thus, innovation is not stifled and flexibility is provided, while those seeking greater direction or certainty can simply apply the suggested measures.

The underlying philosophy of BPEM guidelines and codes is to provide a forward looking approach, rather than simply reflect what is presently the norm. Where problems or issues occur within the industry, a direction or solution to these will be included.

A comprehensive environmental management system – preferably in accordance with the principles outlined in the International Organisation for Standardisation (ISO) 14000 series – is an integral part of BPEM. These principles include the determination of all environmental aspects associated with the company's activities, and a process of continual improvement in environmental performance.

BPEM provides the opportunity to harness the following benefits:

- reduction in unit costs
- opportunities for eco-marketing
- possible preferred supplier status
- potential reduction in resource consumption
- sustainable improvements in environmental performance
- improved community perceptions and relations
- increased compliance with regulatory requirements
- reduced exposure to risk (occupational safety and health as well as environmental).

A BPEM guideline or code is not of itself mandatory, but the potential exists to call up such a document in approvals, licences or permits. Regulatory authorities generally expect forward-looking manufacturers, committed to continuous improvement through a total quality management approach, to voluntarily adopt BPEM guidelines and codes.

2 CONCRETE BATCHING INDUSTRY

2.1 DEFINITION

A mixture of cement, water, sand and aggregate is called concrete. The product is named 'Portland Cement' because after hardening the product resembles a natural limestone quarried at Portland, England.

Components of concrete

The process for making Portland Cement is relatively simple, but the chemistry of cement manufacture is complex.

The components of concrete include calcium, silica, alumina, magnesia, iron oxide and sulfur dioxide compounds along with:

- fly ash – a glass-like substance used in good quality cement products
- aggregates consisting of gravel and sand, which comprise the major raw material of concrete (aggregates are graded according to their size and character)
- admixtures – compounds added to the concrete in small quantities to modify its properties.

The amount of water required to chemically combine the cement is about 16% by weight, but for more efficient mixing a greater amount is used. Adding more water weakens the concrete, but makes it easier to work with.

In a concrete batching plant, the raw materials are mixed in one of the ways discussed below.

2.2 FRONT END LOADER CONCRETE BATCHING

In front end loader plants, a front end loader is used to transport coarse and fine aggregates from a ground level storage bin to an aggregate weigh hopper. The aggregate is then added to an agitator. Cement and fly ash are weighed in a separate hopper and transferred to the agitator. The correct proportion of water is added to the agitator. The concrete is mixed, ready for final slumping, inspection and transportation to the customer.

2.3 OVERHEAD BIN CONCRETE BATCHING

In overhead bin batching plants, coarse and fine aggregates are stored in separate bins. Aggregates are transported from the bins to a compartmentalised overhead storage hopper by conveyor belts. A weigh hopper is situated directly beneath the overhead storage hopper, where aggregate is weighed and transferred to the agitator.

Cement and fly ash are stored in separate overhead silos. They are weighed in a separate hopper and dropped into the agitator. The correct proportion of water is added, along with any required admixtures and the concrete is mixed, ready for final slumping, inspection and transportation to the building site.

3 STATUTORY REQUIREMENTS

Legislation

The *Environment Protection Act 1970* provides for the control of water, air and land pollution, industrial waste and noise. The Act is administered by EPA.

Under the Act, discharges of wastes into the environment must accord with State environment protection policies (SEPPs), which identify beneficial uses for particular segments of the environment, and establish ambient objectives and discharge limits.

Policies

The *Industrial Waste Management Policy (Waste Minimisation) 1990,* specifies objectives for minimising industrial waste generation through avoidance and reduction in preference to recycling and reclamation. Best available technology can be required for priority wastes. EPA can require industry to conduct waste audits and prepare waste management plans.

The *State Environment Protection Policy (The Air Environment),* which applies to Victoria's air environment, sets out:

- beneficial uses
- air quality objectives
- design ground level concentrations
- plume calculation (dispersion modelling) procedures
- control requirements for specific industry groups.

Schedules in the SEPP set out the control requirements for specific industries. Schedule F-2 describes minimum requirements to control discharges of waste to air from concrete batching plants.

EPA has discretion to exempt operations from compliance with Schedule F in certain circumstances. These include situations where compliance would preclude innovative control or energy saving technologies. This is discussed further in section 5.3.

The *State Environment Protection Policy (Waters of Victoria)* applies to all surface waters within Victoria. The policy defines:

- segments of the environment
- beneficial uses
- water quality indicators and objectives
- emission limits for waste discharges to surface waters – including a requirement that the pH of discharges be in the range 6.0 to 9.0.

The *State Environment Protection Policy (Control of Noise from Commerce, Industry and Trade) No. N-1*, specifies noise limits in noise sensitive areas (for example, dwellings, hospitals, hotels, motels), based on land use, planning zones, background noise levels, plant operating periods and the nature of the noise source. The policy applies in the Melbourne metropolitan area, but is used as a guide elsewhere.

Regulations

The *Environment Protection (Scheduled Premises and Exemptions) Regulations 1996* describe premises which are scheduled, and are thus required to comply with the licensing and works approval provisions of the *Environment Protection Act 1970.* Specific discharges which are exempt from the licensing provisions are also listed.

Concrete batching plants with a design throughput of at least 100 tonnes per week are scheduled and require a works approval from the EPA before they are constructed or undergo major modification. Licences are not required to operate concrete batching plants, but plants must accord with Policy requirements.

The *Environment Protection (Prescribed Waste) Regulations 1998* classify certain industrial and domestic wastes as prescribed waste. Prescribed waste can only be removed from a site by an approved waste transporter. Concrete batching plants may generate prescribed waste (for example, waste oil and alkaline sludges). Operators should confirm the status of specific waste streams and their responsibilities with EPA.

4 WASTE MINIMISATION

Waste minimisation is an integral part of BPEM. By focussing on waste avoidance and reduction through the use of better processes and practices, pollution control and waste disposal costs can be lowered.

4.1 WASTE MINIMISATION

The *Waste Minimisation Policy* sets out the following hierarchy for industrial waste management options:

- waste avoidance/reduction
- reuse, recycling and reclamation
- waste treatment
- waste disposal.

Preference should be given to waste avoidance or reduction, ahead of recycling and reuse. Treatment and the least preferred alternative of waste disposal should only be considered if these actions are not possible.

Waste minimisation includes good housekeeping practices and staff attitudes, as well as technical factors. Actions as simple as reducing the volume of water used during washouts may significantly reduce waste generation. The potential impact of such straightforward measures should not be underestimated.

Some of the smaller incremental improvements are easy to gain, but difficult to maintain. Teamwork and commitment from production staff, supported by strong management and effective management systems, should enable sustainable and continuous performance improvement.

Another essential part of waste minimisation is understanding what wastes are being produced and the processes which generate them. As well as establishing a baseline against which improvements can be assessed, this data will allow waste reduction options to be evaluated.

4.2 IMPLEMENTING WASTE MINIMISATION

In the concrete batching industry, waste minimisation principles can be applied to water, cement, aggregate and all other inputs. Significant cost savings have been achieved by plants using this approach.

A useful starting point for a waste minimisation program is to prepare a waste management plan (WMP). The first step to preparing a WMP is a waste audit, which involves identifying the sources, types and quantities of wastes generated by a concrete batching plant. The waste audit should:

- identify all waste streams
- quantify and characterise them
- establish how each waste stream is generated.

After the waste audit is completed, a waste assessment is conducted. This involves identifying the options available to minimise each of the waste streams.

A technical and economic feasibility analysis is then conducted to determine which of the identified waste minimisation opportunities should be adopted.

The WMP contains an implementation timetable and description of the method of implementation, and the anticipated costs and environmental benefits.

The waste minimisation program should not be a one-off activity. It should be periodically reviewed to ensure the WMP is being adhered to, and to identify any new waste minimisation opportunities.

The waste minimisation program should be an integral part of the company's approach to environmental management: it should be a key element when an environmental management system is established.

Further guidance on specific waste minimisation measures can be found in sections 5.2, 5.3 and 5.5.

More information can be found in:

- *Guidelines for Preparing Waste Assessments – A Practical Guide Towards Cleaner Production* (EPA Publication 277)
- *Guidelines for Preparation of Waste Management Plans* (EPA Publication 383)
- *Waste Minimisation, Assessments and Opportunities for Industry* (EPA Publication 351).

WASTE MINIMISATION

Objective

To minimise waste generation and maximise economic benefits.

Suggested measures

- Establish a management policy supporting waste minimisation.
- Establish a waste management team.
- Conduct a waste audit.
- Assess viable waste minimisation projects.
- Prepare and implement a WMP.
- Monitor and evaluate the effectiveness of the WMP.

5 ENVIRONMENTAL ELEMENTS

Environmental issues relating to the concrete batching industry – such as plant location, water quality, air quality, noise and solid waste – are set out in the following sections.

5.1 SITE CONSIDERATIONS

Concrete batching plants must be located in an area where they will not pose a hazard to the environment or the amenity of the local community.

Highly alkaline wastewater, dust emissions and noise are the key potential impacts associated with concrete batching plants. These problems need to be considered when planning new operations and major upgrades of existing sites. Plants should be located so that contaminated stormwater and process wastewater can be retained on-site. The land should not be flood-prone (it should have a flood average recurrence interval less than 100 years). These measures will help to ensure that wastewater is not discharged to waterways.

Dust problems can be minimised by siting the concrete batching plant out of prevailing high winds. The prevailing wind direction should be considered during the planning proposal, to ensure that bunkers and conveyors are sited in the leeward direction to minimise the effects of the wind. The provision of natural or artificial wind barriers – such as trees, fences and landforms – to help control the emission of dust from the plant should be considered during the planning process.

To protect amenity, buffers should be provided between batching plants and sensitive land uses. Buffers are designed to minimise any potential impacts due to accidental or fugitive air emissions. They assume that good control practices will be followed and do not eliminate the need for effective point source emission control.

A minimum buffer distance of 100 metres between batching plants and sensitive land uses is included in *Recommended Buffer Distances for Industrial Residual Air Emissions* (EPA Publication AQ 2/86 – as revised in July 1990). Sensitive land uses include residential areas and zones, hospitals, schools, caravan parks or other similar uses.

Access and exit routes for heavy transport vehicles should be planned to minimise impacts on the environment and amenity of the locality.

Thoughtful site selection and planning will mean fewer problems for future environmental management.

SITING

Objective

To minimise environmental impacts by appropriate site selection.

Suggested measures

- Batching plants should be sited on land that is not flood prone.
- Consider the current and future proximity of sensitive land uses.
- Establish and maintain buffer distances >100 metres.
- Provide vehicle access routes which minimise impacts.

5.2 WATER QUALITY

Potential pollutants in batching plant wastewater include cement, sand, aggregates and petroleum products. These substances can adversely affect the environment by:

- increasing soil and water pH
- increasing the turbidity of waterways (turbidity is a measure of the cloudiness of a suspension).

Increased turbidity results in less light entering an aquatic environment. This in turn affects the rate of photosynthesis by plants, and reduces the visibility of aquatic organisms. Turbidity can also clog fish gills, smother bottom feeding flora and fauna and generally decrease the amenity of an area.

Wastewater management – principles

Using the waste minimisation approach, the keys to avoiding adverse impacts on water quality are to minimise wastewater generation and to recycle the wastewater which is generated. These steps require that:

- the area of the site which generates contaminated stormwater is minimised
- separate dedicated drainage systems are provided for contaminated and clean stormwater
- all contaminated stormwater and process wastewater is collected and recycled.

Wastewater generation

The main sources of wastewater at batching plants are:

- contaminated stormwater runoff
- dust control sprinklers
- the agitator washout station
- the agitator charging station
- the slumping station
- cleaning and washing.

The site should be designed to minimise the areas which are contaminated with cement dust and thus have the potential to generate contaminated stormwater runoff.

Clean stormwater runoff – such as that from office buildings and staff car parks – should be separated from contaminated stormwater, or it will add to the volume of wastewater needing management. Separate drains should be provided for clean stormwater runoff.

All contaminated stormwater and process wastewater should be collected and retained on site. All sources of wastewater should be paved and bunded. (A bund is a small wall of concrete or another impervious material, similar to the curb beside a bitumen road. Bunds serve the dual purpose of ensuring all wastewater is captured and excluding clean stormwater runoff.)

The specific areas that should be paved and bunded include:

- the agitator washout area
- the truck washing area
- the concrete batching area
- any other area that may generate stormwater contaminated with cement dust or residues.

Wastewater capture and reuse

Contaminated stormwater and process wastewater should be captured and recycled by a system with the following specifications.

- The system's storage capacity must be sufficient to store the runoff from the bunded areas generated by 20 mm of rain.
- Water captured by the bunds should be diverted to a collection pit and then pumped to a storage tank for recycling.
- An outlet (overflow drain) in the bund, one metre upstream of the collection pit, should divert excess rainwater from the bunded area when the pit fills due to heavy rain (more than 20 mm of rain over 24 hours).
- Collection pits should contain a sloping sludge interceptor, to separate water and sediments. The sloping surface enables easy removal of sludge and sediments.
- Wastewater should be pumped from the collection pit to a recycling tank. The pit should have an primary pump triggered by a float switch and a backup pump which automatically activates if the primary fails.
- Collection pits should be provided with two visual alarms. The first should activate when the primary pump fails. The second should activate when water reaches the high level mark in the pit. Both alarms should activate warning devices on the operator's console.

Wastewater stored in the recycling tank needs to be reused at the ***earliest possible*** opportunity. This will restore the system's storage capacity, ready to deal with wastewater generated by the next rainfall event.

Many of the problems with wastewater management at batching plants have been caused by failure to recycle stored wastewater as quickly as possible. Uses for recycling tank water include concrete batching, spraying over stockpiles for dust control and washing out agitators.

If the water level exceeds the capacity of the recycling tank, the wastewater must be taken to a waste treater licensed by EPA for this type of waste.

As the wastewater system captures and recycles process water, wastewater must not be discharged from concrete batching plants in dry weather.

Runoff after heavy rainfall (more than 20 mm over 24 hours) contains very small quantities of wastes and is unlikely to pose a significant threat to the environment.

As specified in the *State Environment Protection Policy (Waters of Victoria)*, the pH of wet weather discharges must be in the range 6.0 to 9.0, and suspended solids must be less than 80 milligrams per litre.

Whenever wet weather discharges occur, they should be monitored for pH and suspended solids, and records retained. If unacceptable levels are found:

- an investigation should be carried out to determine the causes
- remedial actions should be identified and implemented.

Equipment and training should be provided, so that staff can carry out pH testing and take suspended solids samples for laboratory analysis (turbidity monitoring may also be used to provide an immediate indicator of discharge quality).

WATER QUALITY

Objective

To ensure contaminated wastewater is not discharged from the concrete batching plant to surface waters, groundwater or land.

Suggested measures

- Minimise the area of the site which generates contaminated stormwater runoff.
- Provide a separate dedicated drainage system to discharge clean stormwater from the site.
- Drain all contaminated stormwater and process wastewater to a collection pit for recycling.
- Regularly clean out solids that accumulate in the pit.
- The wastewater recycling system must be able to store the contaminated runoff generated by 20 mm of rain in 24 hours.
- Use wastewater stored in the recycling system at the earliest possible opportunity.
- There must be no dry weather wastewater discharges from the site.
- Monitor wet weather discharges for pH and suspended solids. Retain the records.

5.3 AIR QUALITY

Dust from cement, sand and aggregates is a pollutant. Fine dust particles can enter neighbouring premises and adversely affect amenity. Dust must be controlled so there are no significant emissions from the plant.

The following controls are consistent with those in Schedule F2 of the *State Environment Protection Policy (The Air Environment)*, but they include additional requirements which represent best practice.

Dust emission sources

Potential sources of dust pollution include:

- delivery of raw materials in trucks, trailers and tankers
- storage of raw materials in bunkers and stockpiles
- transfer of raw materials by front end loaders, conveyors, hoppers and agitators
- leakage or spillage of raw materials from silos, inspection covers and duct work.

The best way to avoid offsite dust problems is to prevent the release of the dust through good design and management techniques.

Ground pavement

The entire plant compound traversed by vehicles – including driveways leading into and out of the plant – should be paved with a hard, impervious material.

Unsealed surfaces should be protected with barriers to exclude vehicles. The pavement should be kept clean and dust-free. Spills and leaks must be contained and cleaned up immediately, before dust is generated.

Sand and aggregate stockpiles

Sand and aggregates should be delivered in a dampened state, using covered trucks. If the materials have dried out during transit they should be re-wetted before being dumped into the storage bunker.

Sand and aggregates should be stored in a hopper or bunker which shields the materials from winds. The bunker should enclose the stockpile on three sides. The walls should extend one metre above the height of the maximum quantity of raw material kept on site, and extend two metres beyond the front of the stockpile.

The hopper or bunker should be fitted with water sprays which keep the stored material damp at all times. Monitor the water content of the stockpile to ensure it is maintained in a damp condition.

If a combination of wall height and length coupled with water sprinklers is unable to contain the material, roofing and/or rubber entry curtains should be installed.

In-ground storage bunkers minimise dust emissions from stockpiles. Where these are filled by drive-over deliveries, the bunker should be shielded on two sides by shrouds or walls that are at least 0.5 metres high and extend the entire length of the bunker.

It is still essential to ensure the raw ingredients are damp on receipt and before they are delivered to the in-ground bunkers.

Overhead bins

Overhead storage bins should be totally enclosed. The swivel chute area and transfer point from the conveyor should also be enclosed.

Rubber curtain seals may be needed to protect the opening of the overhead bin from winds.

Conveyor belts and raw material transfer

Conveyor belts which are exposed to the wind and used for raw material transfer should be effectively enclosed, to ensure dust is not blown off the conveyor during transit.

Conveyor transfer points and hopper discharge areas should be fully enclosed. Double rubber curtain seals are recommended for transfer point outlets to prevent dust from raw materials escaping into the atmosphere.

Conveyor belts should be fitted with belt cleaners on the return side of the belt. It is important that any raw material collected by the belt cleaners is contained, so that dust is not discharged.

Aggregate weigh bins

Weigh hoppers at front end loader plants should be roofed and have weigh hoppers shrouded on three sides, to protect the contents from the wind. The raw materials transferred by the front end loader should be damp, as they are taken from a dampened stockpile.

Cement transfer and storage

Store cement in sealed, dust-tight storage silos. All hatches, inspection points and duct work should be dust-tight.

Cement should be delivered in sealed vehicles equipped for pneumatic transfer from the vehicle to the cement storage silo.

Any cement spills should be cleaned up as soon as they are detected.

Cement delivery

The silo feed pipe must be made of material able to withstand the effects of cement. The delivery pipes should be clearly labelled with the silo identification and material stored inside the silo. The silo delivery pipe should be kept locked at all times except when a delivery is in progress.

The infill pipe should be fitted with a fail-safe valve, which is 'tight shut-off', made of wear resistant materials, able to withstand high velocity product delivery. The valve should be located less than one metre above the fill point.

Silo over-fill protection

Silos should be equipped with a high level sensor alarm and an automatic delivery shut-down switch to prevent overfilling.

The high level alarm set point should be at a level which ensures the silo is not overfilled. The following points should be considered when setting the high level alarm:

- silo profile
- maximum fill rate
- the response time of the shut-down system
- volume of delivery vehicles.

An automatic shut-down switch should stop the flow of cement to the silo within 60 seconds of the high level alarm's activation.

Twin radio frequency probes are recommended for high level alarms. The silo over-fill protection system should incorporate a 30 minute reset time delay.

The high level alarm should be audible (or visual only, in areas sensitive to excess noise). There should be a test circuit to test the operation of the high level alarm sensor, which is tested before every delivery of cement to the silo.

Silo dust control

Cement dust emissions from the silo during filling operations must be minimised. The minimum acceptable performance is obtained using a fabric filter dust collector (FFDC). Equivalent or better performance using alternative dust control technology is acceptable.

Whichever technology is employed, it needs to be maintained properly, in accordance with the manufacture's instructions, to ensure adequate performance. A description of an adequate FFDC system follows.

Fabric filter dust collector (FFDC)

- The FFDC should be sized so that the dust collector bags are not subject to clogging. Install an appropriately sized multibag pulse jet filter in the silo, which is fitted and used in accordance with the manufacturer's recommendations. The cloth area of the filter must be adequate for the displaced air volume.
- The FFDC should be completely protected from the weather.
- The FFDC needs to be made of a material which can withstand continuous exposure to cement – such as polyester and polypropylene.
- The filter elements should be cleaned automatically at the end of the silo filling cycle. A source of high pressure, moisture- and oil-free air is required to operate the filters effectively.
- The FFDC should be able to withstand the maximum pressure differential which may be encountered. A differential pressure indicator should be fitted to an alarm to indicate bag filter pressure in excess of 1.0 kPa.
- Silos should be protected against internal pressures exceeding the design pressure. Positive type relief valves set at appropriate pressures should be installed. The relief valve should be ducted to a container on the ground, able to collect dust particles.
- The exhaust air from the silo filters should be ducted to a dust collection container on the ground. Confirm the exhaust discharge points are visible and monitored by the driver during silo filling operations. If dust is discharged from the duct work, the driver must immediately stop filling the silo.
- Burst bag detectors should be installed in all batching plants. The burst bag detector should be connected to the automatic silo overfill protection circuit to stop the flow of cement if a filter bag bursts.
- The FFDC should be inspected at least once a week and any necessary repairs carried out immediately.

Silo discharge

Silo discharge is controlled by an on/off valve. The valve is generally fitted above the weigh hopper. The control valve should be open air sprung, to close on failure of air pressure or electric power. The control valve should be fitted before (upstream of) any flexible joints in the pipe line and as close as possible to the silo outlet point at the base of the silo cone. This ensures that product can be stopped if a flexible joint fails. All flexible connections between the silo and the weigh hoppers must be sleeved in metal.

Silo discharge emergency shut-down

A back-up discharge emergency shut-down valve should be installed to ensure the flow of cement can be stopped if an emergency – such as failure of a flexible joint or failure of the discharge valve – occurs. The emergency shut-down valve should be similar in location and design to the silo discharge valve.

The plant operator should be able to shut-down product discharge by using an override button located at the silo operation area and from inside the control room. The emergency shut-down valve should operate with the silo discharge control valve. The two systems working in tandem provide extra security from accidental product discharge.

Cement weigh hoppers

Dust control

- Totally enclose the cement weigh hopper, to ensure that dust cannot escape to the atmosphere.
- The weigh hopper should be fitted with a dedicated FFDC, or equivalent dust control device, of similar design and specification to the dust control device installed to the silo.

Overfill protection

- Protect the weigh hopper against overfill by installing a radio frequency type high level alarm probe at the top of the hopper.
- The alarm should automatically shut-down the product delivery system to the weigh hopper.

Agitator loading bay

The load point must be fitted with either a:

- telescopic chute (preferred) or
- flexible sleeve.

The chute or sleeve needs to be long enough to enter agitator hatches. A flexible sleeve should be made of material capable of withstanding continuous exposure to concrete ingredients such as cement slurries and abrasive aggregates.

There must be no significant emission of dust particles from the load point. This can be achieved by installing water sprays in the perimeter of the load point, set to start automatically whenever a batch is discharged. Alternatively, an effective dust extraction system can be fitted to the load point.

Ensure the loading bay is roofed and enclosed on at least two sides. Flexible doors should be fitted to the open sides of the loading bay. A drive-through type bay with flexible doors at the entrance and exit is recommended.

It is important to ensure there is no leakage or spillage of cement during either the filling or dispensing of cement from the silo. Any cement product that escapes during the filling process must be cleaned up immediately.

Inspection program

An inspection of all dust control components should be performed routinely – for example, at least weekly. This will help identify any potential problems before a leak or spill occurs. The use of a checklist including the suggested requirements of this guide may be useful. Appendix 1 shows a checklist that can be used as the basis for the inspection.

Alternative technology

As previously noted, Schedule F2 of the *State Environment Protection Policy (The Air Environment)* sets out emission controls for concrete batching plants. However, the Policy allows EPA to exempt sites from compliance with Schedule F, subject to ambient objectives being met.

The Policy identifies the following matters as being relevant when considering exemptions:

- compliance with Schedule F would increase or create waste disposal problems
- compliance would preclude the use of energy saving technology or innovative controls
- compliance cannot be achieved by reasonably available technology
- maximum ground level concentrations will not be exceeded and the discharge will not adversely affect any beneficial use of the environment.

When considering an exemption, EPA will look at how effectively the proposed alternative technology will control emissions compared with the controls set out in Schedule F2.

AIR QUALITY

Objective

To avoid or substantially reduce dust emissions so there is no loss of amenity.

Suggested measures

- Keep sand and aggregates damp.
- Cover or enclose conveyor belts and hoppers.
- Keep pavements and surfaces clean.
- Fit cement silos with high level alarms, multibag pulse jet filters, airtight inspection hatches and automatic cutoff switches on the filler lines.
- Keep duct work airtight.
- Enclose the loading bay.
- Develop and implement an inspection regime for all dust control components.
- Clean up spills immediately.

5.4 NOISE EMISSIONS

Noise is a form of pollution and a potential source of conflict between the operators of a concrete batching plant and the local community. Noise emitted from a concrete batching plant must be managed as carefully as other discharges from the site. Batching plants in the Melbourne metropolitan area must comply with the *State Environment Protection Policy (Control of Noise from Commerce, Industry and Trade) No. N-1.*

Because of the potential for noise to affect residential amenity, management should give high priority to liaising with the local community so that it can be aware of, and resolve, noise issues.

Definition of noise

Noise is unwanted sound. The disturbing effects of noise depend on the level of the noise and its character – such as tones, intermittency, and so on. Higher frequency tones are more disturbing than lower frequency tones, but lower frequency tones are not easily controlled and can penetrate buildings, such as houses. Noise can cause stress in both employees and neighbours of the plant.

Sound levels are measured in units of decibels, dB(A). The 'A' weighting of a measured sound level approximates how the human ear perceives sound. If a sound is intensified by 10 dB(A), human ears would perceive the sound to have doubled in loudness.

Noise sources at concrete batching plants

Major noise sources at batching plants include:

- truck and front end loader engine noise
- hydraulic pumps
- aggregate delivery to bunkers and hoppers
- conveyor belts
- air valves
- truck air brakes
- filters
- alarms
- amplified telephones
- public address system
- compressors
- swinging, scraping, loading devices
- opening and closing gates
- radios
- reverse warning devices.

Noise mitigation measures

Noise abatement can often be achieved by relatively simple measures such as:

- locating noisy equipment away from potential sources of conflict
- locating noisy equipment behind sound barriers or sound absorbers – for example, gravel stockpiles or constructed barriers
- using self cleaning weigh hoppers
- enclosing compressors and pumps
- fitting silencing devices to all pressure operated equipment
- lining hoppers with a sound absorbing material such as rubber
- sealing roads and plant site with concrete or bitumen
- positioning access and exit points away from noise sensitive areas
- fitting efficient muffling devices to all engines
- using visual alarms in preference to audible alarms
- using a personal paging service instead of hooters to gain attention of staff
- relocating sirens to face away from residences
- weighing fine aggregates before coarse aggregates
- ensuring that maintenance is conducted in enclosed sheds, away from sources of conflict
- ensuring an adequate buffer is kept between the plant and neighbours
- erecting screens and barriers to reduce noise transmission
- storing aggregates below ground level where possible
- limiting operations to between 7.00am and 6.00pm Monday to Friday, and 7.00am and 1.00pm on Saturday if other noise mitigation measures are inadequate.

Where noise abatement requires more detailed analysis and control, an acoustic consultant should be used.

Table 1: Typical noise limits for various types of land uses

Land use	Noise limits dB(A) M-F 7am-6pm* Sat 7am-1pm*	All nights 10pm-7am	All other times
Quiet rural areas	45	32	37
Mainly residential	50-54	39-43	44-48
Residential, commercial and industrial	54-59	39-43	48-52
Commercial and industrial	56-59	47-52	58-52
Industrial	63-68	52-56	57-61

* Excludes public holidays.

NOISE

Objective

To ensure no noise nuisance results from the facility.

Suggested measures

- Liaise with the local community to identify noise issues.
- Select quieter equipment.
- Alter or enclose equipment to reduce noise at the source.
- Use sound absorbing materials to prevent the spread of noise by isolating the source.
- Ensure hooters are used for emergencies only.
- Avoid public address systems for paging staff.

5.5 SOLID WASTES

The main solid waste generated by batching plants is waste concrete. Waste minimisation is the preferred approach to dealing with this problem. Careful matching of orders with production could minimise the need to return unused concrete to the batching plant.

It may be possible to use waste concrete for construction purposes at the batching plant. If this is not possible, direct the waste concrete to a fully enclosed pit where it can be dried and collected. It should then be reused, or taken to a recycling facility or licensed landfill site. Producers should satisfy themselves the reuse of such wastes avoids adverse environmental impacts – for example, any reuse as a road base or other beneficial use must avoid situations where there can be significant runoff.

Concrete agitator mixers and chutes must not be rinsed out to the stormwater system or roadways. It may be possible to add water and agitate the mixer during the return trip to the plant – making cleaning easier and enabling excess material to be reused.

It is recommended the driver of the agitator mixer obtain a signature from the purchaser declaring the amount of concrete received. This can be compared with the batch amount originally delivered. All concrete should be accounted for, to ensure proper disposal of the waste product.

Aluminium cans, glass bottles, paper, other office waste and packaging materials such as plastic and cardboard should be considered in the waste minimisation program. Recycling of these materials is part of best practice.

SOLID WASTE REDUCTION

Objective

To minimise solid waste generation and to reuse/recycle wherever possible.

Suggested measures

- Investigate ways to minimise the generation of waste concrete.
- Investigate ways to recycle excess material from agitators.
- Include solid waste streams in the WMP.
- Establish recycling programs for aluminium cans, glass bottles, packaging materials, cardboard and office paper.

6 ENVIRONMENTAL MANAGEMENT

A concrete batching plant must be well managed if it is to achieve consistently sound environmental performance. This is best done by an environmental management system (EMS), which is part of best practice.

6.1 ELEMENTS OF AN EMS

An EMS can be part of a wider quality management system. The EMS and (if applicable) the quality management system may use the International Standards ISO 14001 and ISO 9001 respectively, as guides to good management systems.

Key elements of an EMS are outlined below.

Management commitment

It is essential that senior management demonstrates its commitment to an environmental policy and that the policy is communicated to all staff. The policy should contain clear objectives detailing what the policy aims to achieve. The policy must be evaluated and reviewed regularly.

Environmental review and improvement plan

A thorough review of the plant's environmental impacts should be carried out. A plan – which includes specific objectives and targets – to reduce impacts can then be prepared.

Use *Section 5* as a guide to the range of environmental impacts associated with batching plants and ways to reduce them. *Appendix 1* sets out a checklist which can be used during the review.

Mechanisms to implement improvements

The management system should address responsibilities, communication processes, document control and operational procedures.

A manager at the plant should have the skills, authority and accountability to deal with environmental issues.

Maintenance and monitoring

Systems should be established to regularly maintain operations, and to monitor and review environmental performance. This should include the following.

Water quality

- Bund integrity
- Efficiency of the pumps in the collection pit
- Operation of the warning devices and alarms in the collection pit
- Confirm the collection pit is maintained to ensure adequate capacity is available when rain falls
- Check there is no dry weather flow to storm water
- pH and suspended solids are monitored and recorded during offsite discharges

Air quality

- Aggregates and sand are kept damp
- Pavements and other surfaces are not dust sources
- Warning devices and alarms systems are operating correctly
- Dust control devices are properly maintained and working correctly
- Duct work is airtight

Noise emissions

- Monitor noise impact on the neighbourhood.
- Maintain equipment.

System reviews

The EMS should be regularly reviewed to verify performance and identify areas for improvement.

Commitment to continuous improvement

The principle of continuous improvement is an integral part of good environmental management.

The development and implementation of an EMS is an essential part of best practice. Larger companies which operate a number of sites can develop a company-wide EMS which applies to all sites.

6.2 COMMUNITY LIAISON

A well managed facility should have an open attitude to the community. Industry should establish mechanisms and procedures to liaise with the community on a continuing basis. The scale of this liaison should reflect the impact of the site, the proximity of sensitive land uses and the level of community interest.

A key part of sound community liaison is an effective system to respond to complaints. It is important to document each complaint. The proforma in *Appendix 2* can be used.

The document should include the name and address of the complainant, time and date of the incident. The document must clearly state the problem or complaint, the outcome of the resulting investigation, solutions to the problem and the name of the person dealing with the complaint.

ENVIRONMENTAL MANAGEMENT

Objective

To achieve a consistently high level of environmental performance by good management of the operation.

Suggested measures

- Obtain a commitment to sound environmental management from senior company staff.
- Have an EMS.
- Carry out regular environmental audits which extend to all activities at the site.
- Establish mechanisms for continuing liaison with the community.

APPENDIX 1: ENVIRONMENTAL PERFORMANCE CHECKLIST FOR CONCRETE BATCHING PLANTS

SITING OF THE PLANT

Issue	Requirement
Buffer zone	At least 100 metre buffer between plant and residential zone.
Groundwater	No shallow groundwater in the plant's vicinity.
Winds	Bunkers located out of prevailing winds.
Access	Plant access minimises potential impacts on amenity.
Amenity	Batching plant does not detract from local amenity.

WATER QUALITY

Issue	Requirement
Paving	All working areas are paved in hard non-porous surface.
Bunding	Bunding is able to contain runoff.
Collection pit and recycle tank	Primary and secondary pumps fitted to collection pit.
	Excess water pumped to recycle tank.
	Collection pit empty of water, sand and gravel.
	Level controls working properly.
	Recycle tank large enough to store runoff from 20 mm rainfall event.
Monitoring offsite discharges	Visual alarms on console – to indicate when water is discharged from site – are installed and operable
	pH of offsite wastewater discharges between 6.0 and 9.0.
	Suspended solids levels of wastewater discharges less than 80 mg/L.
Fuel and chemical storage	Chemicals and fuels are stored in a dedicated and adequately protected store.
	Bund around the storage facility is adequate.
	Material Safety Data Sheet available for all chemicals.
	Underground storage tanks tested in accordance with applicable Regulations.

AIR QUALITY

Issue	Requirement
Aggregates	Aggregates are damp at all times.
	Wind shields are in place and offer adequate protection from the wind.
Silos	Filler caps are clearly identified and capped.
	Filler cut-off valve is installed and operating.
	High level alarms are installed and operating.
	Adequate test circuit.
	Hatches are air-tight.
	Dipping points are air-tight.
	Filter vents and silo protection valves are ducted to a ground level collection point.
	Cement discharge valves have fail-safe actuators.
	Flexible joints downstream of valves.
Conveyors	Conveyors covered and protected from winds.
	Transfer points fully enclosed.
	Conveyor spillage control provided.
	Conveyors fitted with belt cleaners.
Filters	Filter system in correct operating condition (service and maintenance records complete).
Weigh hoppers	Separate filters on cement silo and weigh hoppers.
	Overfill protection installed and operational.
Emergency shut-down	Emergency shut-down system operates from console and silo delivery point.
Loading bay	Loading bay is enclosed.

NOISE EMISSIONS

Issue	Requirement
Process equipment	Noisy equipment fitted with suitable enclosures.
	No excess noise emissions apparent.
Warning devices	No excess noise emissions apparent.

SOLID WASTE MANAGEMENT

Issue	Requirement
Waste concrete	All concrete wastes should be returned to the plant.
	Concrete waste return and disposal are monitored and documented.
	Waste concrete is reclaimed or recycled.
	Wastes disposed in storage pit, dried, then removed for recycling or to a licensed landfill.

ENVIRONMENTAL MANAGEMENT

Issue	Requirement
Waste minimisation	WMP developed and implemented.
EMS	Environmental policy developed and widely disseminated to staff.
	EMS developed, implemented and continuously reviewed.
Community liaison	Complaints are recorded, investigated and the complainant is advised of the outcome.
	Mechanisms are in place for community liaison.

APPENDIX 2: ENVIRONMENTAL COMPLAINT OR INCIDENT REPORT

COMPANY NAME: ....

ENVIRONMENTAL INCIDENT OR COMPLAINT REPORT	**Report Nos:**......................
Location: .... Date:	
Incident/Complaint Details:...	
Reported by (PRINT):.. Signed:	
Complainant Name: .... Telephone Nos:	
Address:...	

Incident Ranking (indicate which applies (x))
(EPA notification required for Level 2 to 4; company to nominate officer)

☐ **Level 1**	☐ **Level 2**	☐ **Level 3**	☐ **Level 4**
• Minor incident. • No external activity required. • Instigate clean up as appropriate. • Complete report.	• External contact made (regulator or neighbour) – for example, dust, noise, water, pollution. • Verbally report details to a more senior officer of the company. • Complete report within two days.	• Clean up or potential costs to exceed $5,000. • Immediately report details verbally to a more senior officer of the company. • Complete this report within stipulated timeframe.	• Clean-up or potential costs to exceed $50,000. • Immediately report details verbally to a more senior officer of the company and CEO. • Await directions from those advised.

CORRECTIVE ACTION/S

Short Term: ....

....

....

Long Term:...

....

....

VERIFICATION OF EFFECTIVENESS OF CORRECTIVE ACTION

Reporting Officer:..Date:

Senior Officer: ....Date:

Environmental Officer:..Date:

REFERENCES

AS 3901/ISO 9001, *Quality Systems for Design, Development, Production, Installation and Servicing*

Guidelines for Preparation of Waste Management Plans, EPA Publication 383, August 1993

Guidelines for Preparing Waste Assessments – A Practical Guide Towards Cleaner Production, EPA Publication 277, October 1994

ISO 14001, *Environmental Management Systems – Specification with Guidance for Use*

Recommended Buffer Distances for Industrial Residual Air Emissions, EPA Publication AQ 2/86, July 1990

Technical Guidelines: Concrete Batching Plants, EPA Publication TG 204/91, September 1991

Waste Minimisation, Assessments and Opportunities for Industry, EPA Publication 351, July 1993

Industrial waste management policy

Industrial Waste Management Policy (Waste Minimisation) 1990.

State environment protection policies

State Environment Protection Policy (The Air Environment) (particularly Schedule F2).

State Environment Protection Policy (Groundwaters of Victoria)

State Environment Protection Policy (Control of Noise from Commerce, Industry and Trade).

State Environment Protection Policy (The Waters of Victoria).

State Government Victoria

EPA Publication 628