North American Natural Gas Market and Infrastructure under Different LNG Export Scenarios

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Overview

- We build a mixed complementarity (MCP) model for North America and its interaction with LNG markets.
- We conduct analysis through 2050, investigating the effects of different levels of LNG demand and new LNG export facility construction restrictions on the West Coast of the U.S. and Canada.
- Our key findings are:
  - We find North American markets can significantly scale up LNG exports to satisfy strong Asian demand growth.
  - We observe that even if new export terminals cannot be constructed on the West Coast, LNG exports largely shift to other regions rather than suffer an overall decline.
  - We also find that increasing external demand for LNG puts upward pressure on regional prices in North America, and directs production and pipeline flows toward the regions that export LNG.

Agenda

Problem Motivation and Background

- Shale gas revolutionized the natural gas markets in North America, particularly the U.S., by boosting the production and driving the prices down.
- This shift in supply dynamics enabled the United States to be an LNG exporter, bringing its first liquefaction facility online in 2016.
- China's LNG imports tripled in just six years from 2010 to 2016. By 2040, EIA expects China to triple its 2015 natural gas consumption, supported by roughly 4 Tcf of LNG imports per year.
- This increasing demand brings the question of the possibility of building LNG export facilities on the Pacific Coast of North America, which also raises fierce public and political opposition stemming from resistance to fossil fuel development.

Model

- Mixed complementarity problem (MCP)
- 9 North American regions, 2 LNG demand regions
- 6 types of profit maximizing players, 2 types of aggregated demand structures.
- Discrete-time model with 2 seasons per year: high demand and low demand
- Endogenous capacity investment decisions
- Linear demand functions
- Parameterization is done with publicly available data from government agencies such as EIA and NEB as well as agency and industry reports
- Current pipeline and LNG export projects that are not operational yet but are to be constructed are exogenously defined in the model

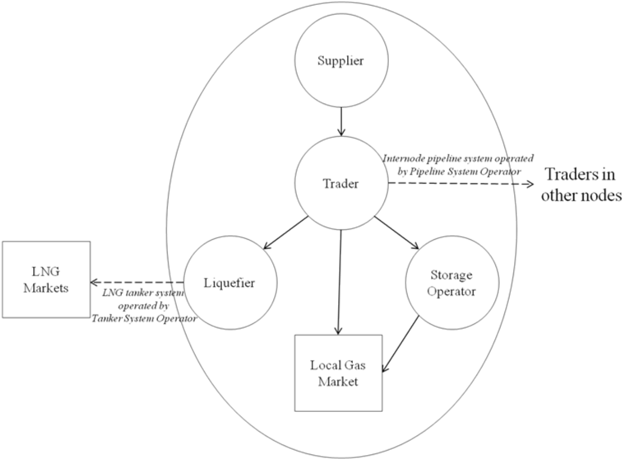
Regions


Western Canada
Eastern Canada
Pacific LNG Market
Western U.S.
Central
Midwest
Northeast
Atlantic LNG Market
Southeast
Southwest
Mexico

Players

Player	**Role**
Suppliers	Extract natural gas from the ground and sells to the trader in their region.
Traders	Buy natural gas from their local supplier or traders in adjacent regions, sells gas to the liquefiers, storage operators and spot market in their region as well as other traders in adjacent regions.
Storage Operators	Buy gas from their local trader in low demand season and sell it to the spot markets in high demand season.
Liquefiers	Buy gas from their local trader, liquefy it and sell to LNG markets.
Pipeline Network Operator	Operates the pipeline network and collects regulatory and congestion fees from traders in exchange for gas transmission between regions.
Tanker Network Operator	Operates the tanker network and collects regulatory and congestion fees from liquefiers in exchange for gas transshipment to LNG markets.

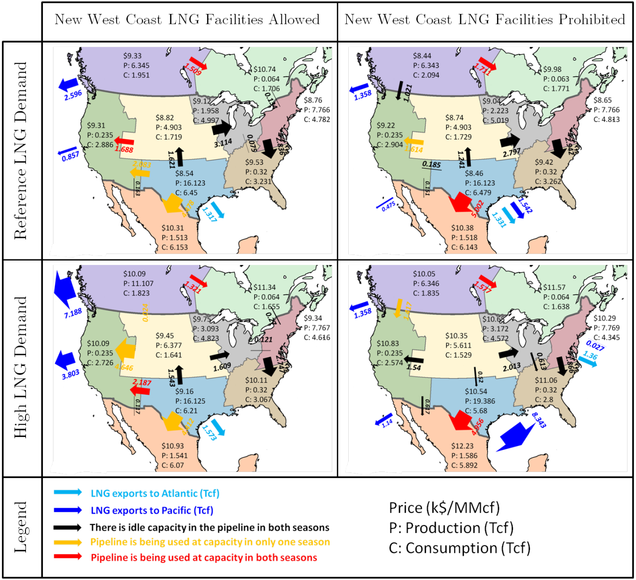
Players


Supplier
Trader
Internode pipeline system operated by Pipeline System Operator
Traders in other nodes
LNG Markets
Liquefier
LNG tanker system operated by Tanker System Operator
Storage Operator
Local Gas Market

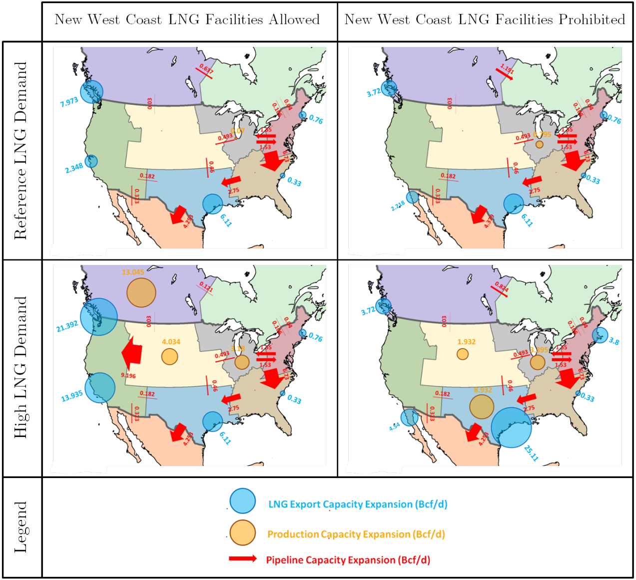
Scenarios

Scenario	Details
Reference (REF)	LNG demand increases by 3% in the Pacific and at 0.3% per year in the Atlantic LNG demand markets. No restriction on where new LNG export terminals can be built.
No West Coast (NWC)	LNG demand growth rates are the same as Reference scenario. New LNG export terminals cannot be built in the U.S. and Canada's west coast.
High LNG Demand (HLN)	LNG demand growth rates are doubled from Reference scenario. No restriction on where LNG export terminals can be built.
No West Coast and High LNG Demand (NWH)	LNG demand growth rates are doubled from Reference scenario. New LNG export terminals cannot be built in the U.S. and Canada's west coast.

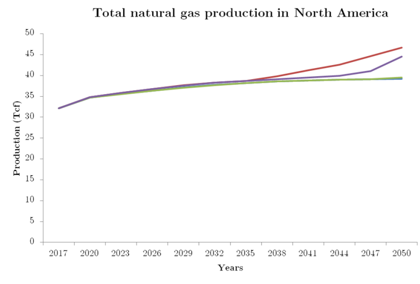
Results (Market)

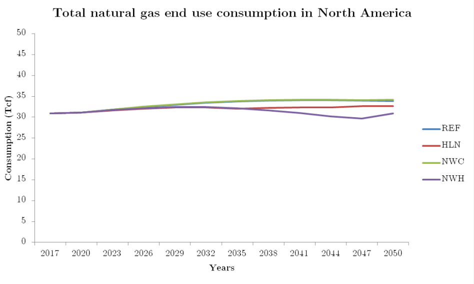


Results (Infrastructure)

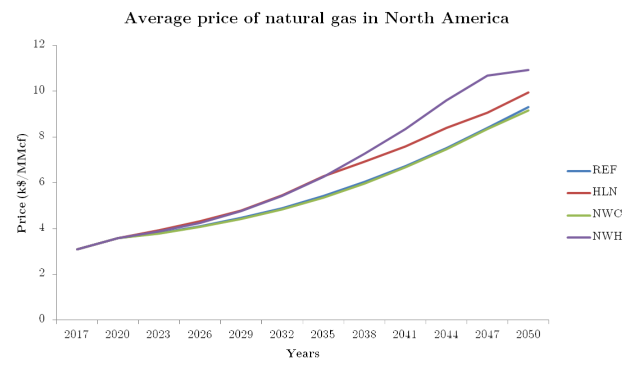


Results (Production and Consumption)

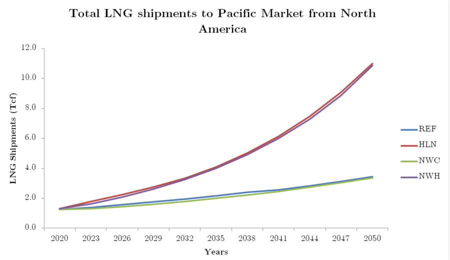


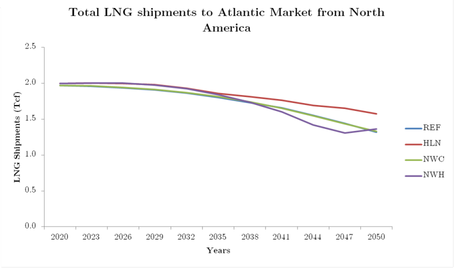


Results (Price)



Results (LNG Shipments)





Conclusions

- Without any restrictions on new LNG export facilities, the Western Canada and Western U.S. regions are well positioned to export LNG to the Pacific market.
- If new LNG export infrastructure cannot be built along the West Coast of the U.S. and Canada, then LNG exports to the Pacific market largely relocate to the Gulf Coast of the U.S. and (to a lesser extent) the Pacific coast of Mexico.
- The total volume of North American LNG exports is thus robust to the possibility that opposition to gas infrastructure development on the West Coast would prevent new facilities from being constructed there.
- Increasing external demand for LNG puts upward pressure on regional prices within North America, an effect which is stronger if infrastructure restrictions concentrate LNG development within fewer regions.

Thank You

References

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Producer's Optimization Problem

Parameters

$Q_{ist}^{n,max}$: Daily production capacity

$V_{i}^{n,prod,max}$: Total reservoir

$CAP_{it}^{n,prod}$: Daily capacity expansion limit

$Days_s$: Number of days in a season

Decision Variables

$q_{ist}^{n,prod}$: Daily production

$\Delta_{it}^{n,prod}$: Daily capacity expansion

$\pi_{st}^{n,wholesale}$: Wholesale price of gas

δ_t^n: Discount factor

Maximize

$$\sum_t \delta_t \left[\sum_s \left(Days_s \left\{ \pi_{st}^{n,wholesale} q_{ist}^{n,prod} - C_{ist}^{n,prod}(.) \right\} \right) - E_{it}^{n,prod}(\Delta_{it}^{n,prod}) \right]$$

s.t.

$$q_{ist}^{n,prod} \leq Q_{ist}^{n,max} + \sum_{t'<t} \Delta_{it'}^{n,prod}, \forall s,t \qquad (\alpha 1_{ist}^n) \quad (1)$$

$$\sum_t \sum_s Days_s q_{ist}^{n,prod} \leq V_i^{n,prod,max} \qquad (\alpha 2_i^n) \quad (2)$$

$$\Delta_{it}^{n,prod} \leq CAP_{it}^{n,prod}, \forall t \qquad (\alpha 3_{it}^n) \quad (3)$$

$$q_{ist}^{n,prod}, \Delta_{it}^{n,prod} \geq 0, \forall s,t \qquad (4)$$

Wholesale Market Clearing Conditions

$$\sum_{i \in suppl(n)} Days_s q_{ist}^{n,prod} = \sum_{k \in trader(n)} v_{kst}^{n,purch,tra} \qquad \forall n, s, t$$

where $\pi_{st}^{n,wholesale}$ is the dual variable

and $v_{kst}^{n,purch,tra}$ denotes the amount of gas bought by the trader.

Producer's KKT Conditions

$$0 \le \delta_t Days_s(-\pi_{st}^{n,wholesale} + \frac{\partial C_{ist}^{n,prod}(.)}{\partial q_{ist}^{n,prod}}) + \alpha 1_{ist}^n + Days_s \alpha 2_i^n$$

$$\perp q_{ist}^{n,prod} \ge 0, \forall n, i, s, t$$

$$0 \le \delta_t \frac{dE_{it}^{n,prod}(\Delta_{it}^{n,prod})}{\Delta_{it}^{n,prod}} + \sum_{t'>t} \delta_{t'} \sum_{s} \frac{\partial C_{ist'}^{n,prod}(.)}{\partial \Delta_{it}^{n,prod}} - \sum_{t'>t} \sum_{s} \alpha 1_{ist'}^n + \alpha 3_{it}^n$$

$$\perp \Delta_{it}^{n,prod} \ge 0, \forall n, i, t \; and \; t' < t$$

$$0 \le Q_{ist}^{n,max} - v_{ist}^{n,prod} + \sum_{t'<t} \Delta_{it'}^{n,prod} \perp \alpha 1_{ist}^n \ge 0, \forall n, i, s, t$$

$$0 \le V_i^{n,prod,max} - \sum_t \sum_s Days_s q_{ist}^{n,prod} \perp \alpha 2_i^n \ge 0, \forall n, i$$

$$0 \le CAP_{it}^{n,prod} - \Delta_{it}^{n,prod} \perp \alpha 3_{it}^n \ge 0, \forall n, i, t$$

Mixed Complementarity Problem

Nonlinear Complementarity Problem

Given a mapping $F : \mathbb{R}^n \to \mathbb{R}^n$, find a vector x such that $0 \leq x \perp F(x) \geq 0$.

Mixed Complementarity Problem is the generalization of Nonlinear Complimentarity Problem which can take upper and lower bounds into account.

Mixed Complementarity Problem

Given a mapping $F : \mathbb{R}^n \to \mathbb{R}^n$, lower values $l_i \in \mathbb{R} \cup \{-\infty\}$ and upper values $u_i \in \mathbb{R} \cup \{\infty\}$ find a vector x such that

- $x_i = l_i, F_i(x) \geq 0$
- $l_i < x_i < u_i, F_i(x) = 0$
- $x_i = u_i, F_i(x) \leq 0$

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