THE SALATA INSTITUTE
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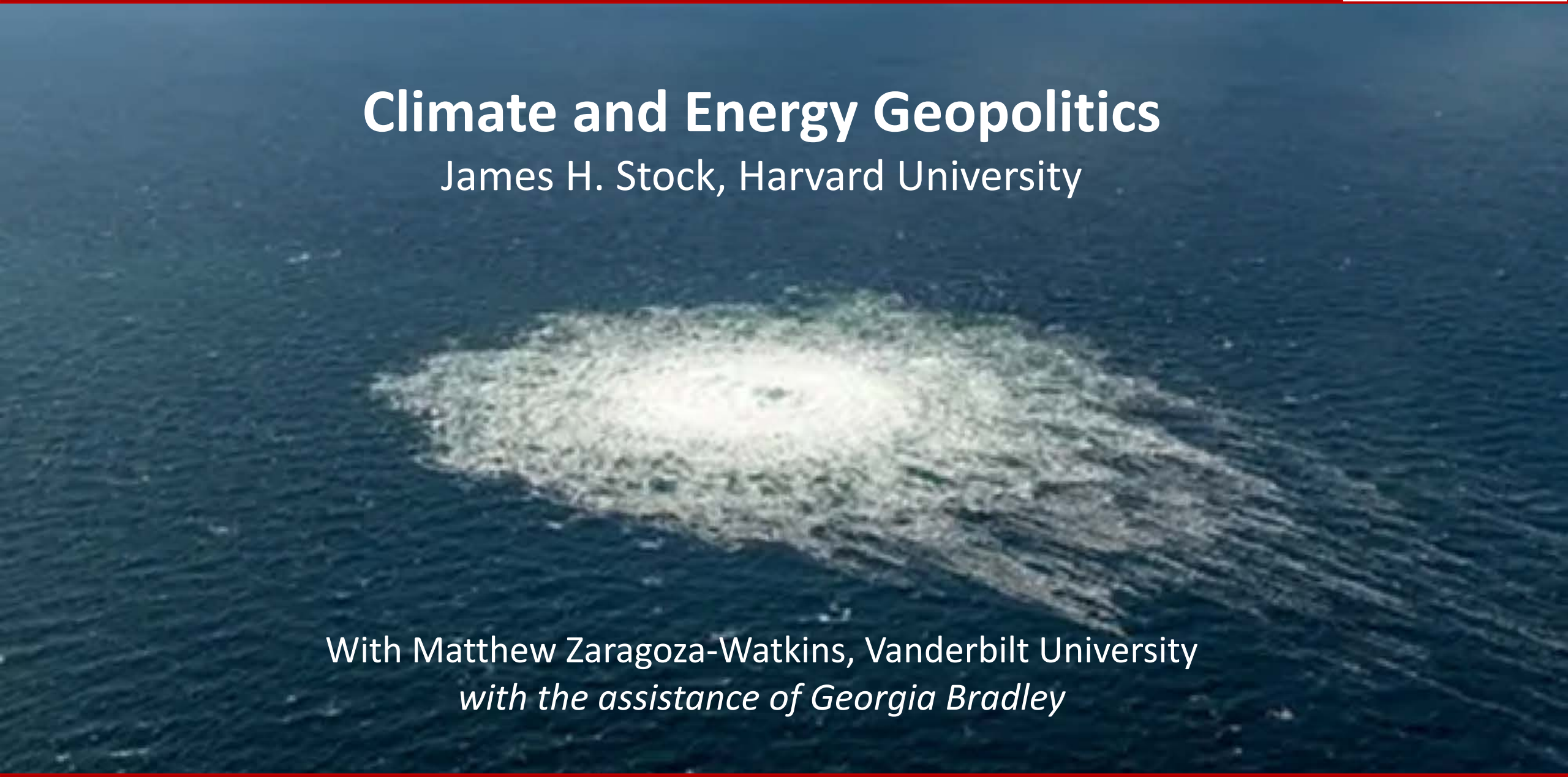
at Harvard University

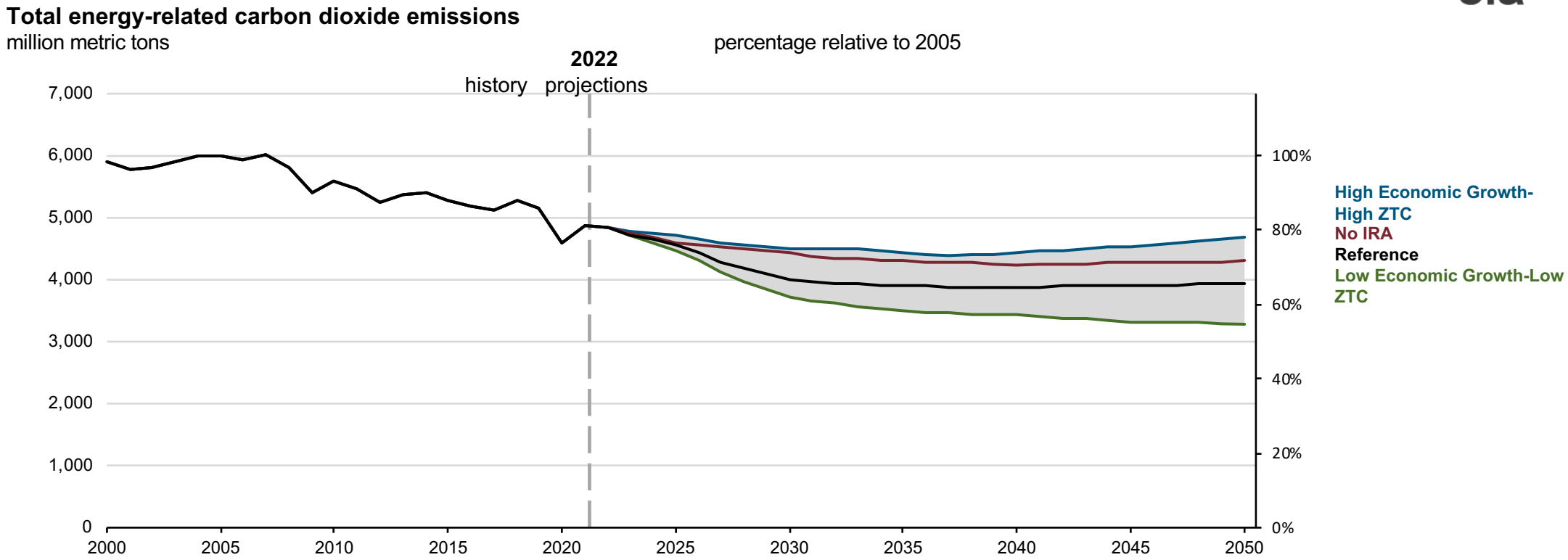


Climate and Energy Geopolitics

James H. Stock, Harvard University

With Matthew Zaragoza-Watkins, Vanderbilt University
with the assistance of Georgia Bradley

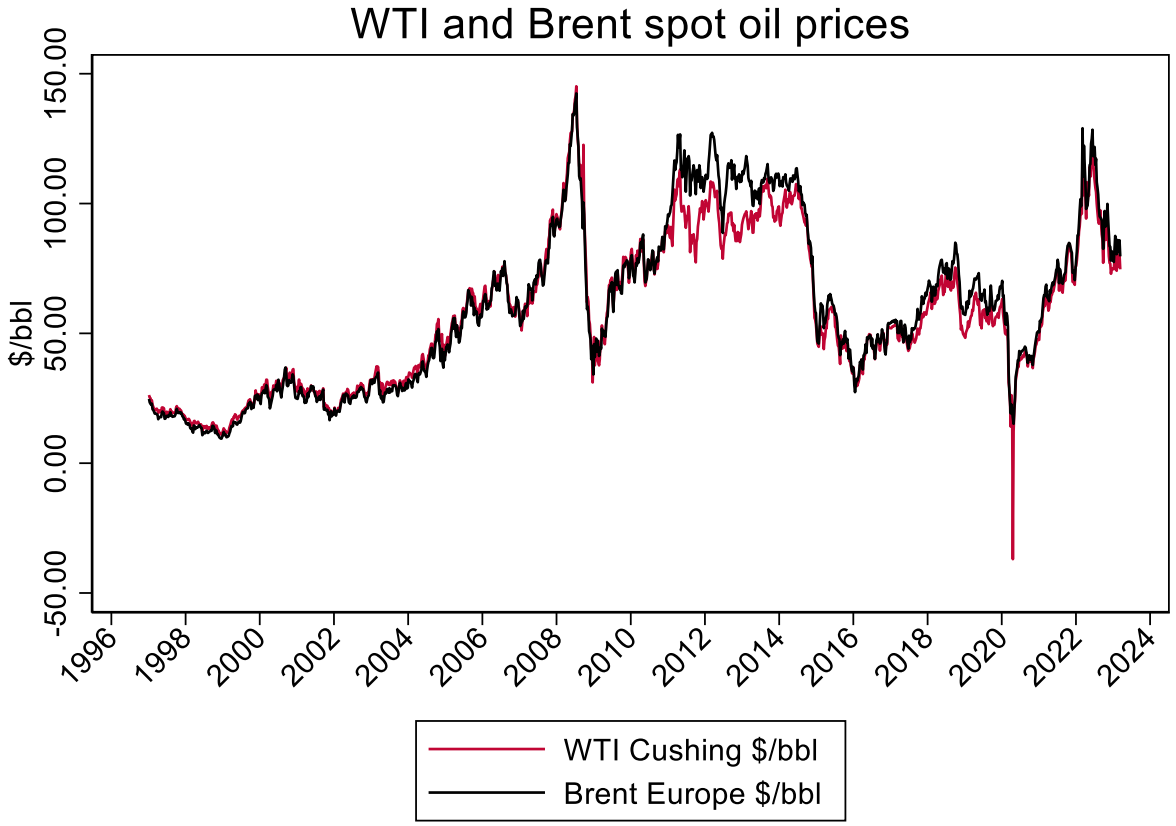
By 2030, energy-related CO_2 emissions fall 25% to 38% below 2005 levels

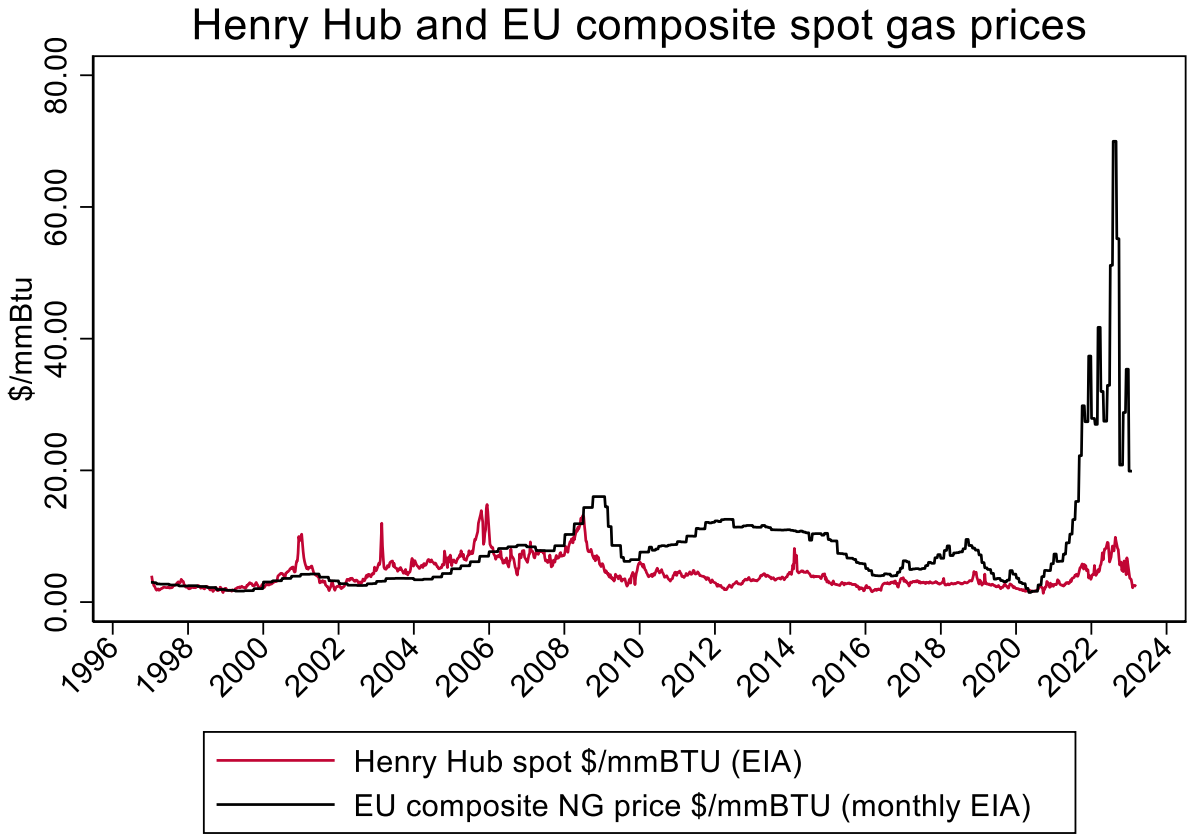


Data source: U.S. Energy Information Administration, *Annual Energy Outlook 2023* (AEO2023)

Note: Shaded regions represent maximum and minimum values for each projection year across the AEO2023 Reference case and side cases. ZTC=Zero-Carbon Technology Cost; IRA=Inflation Reduction Act.

Oil and gas prices

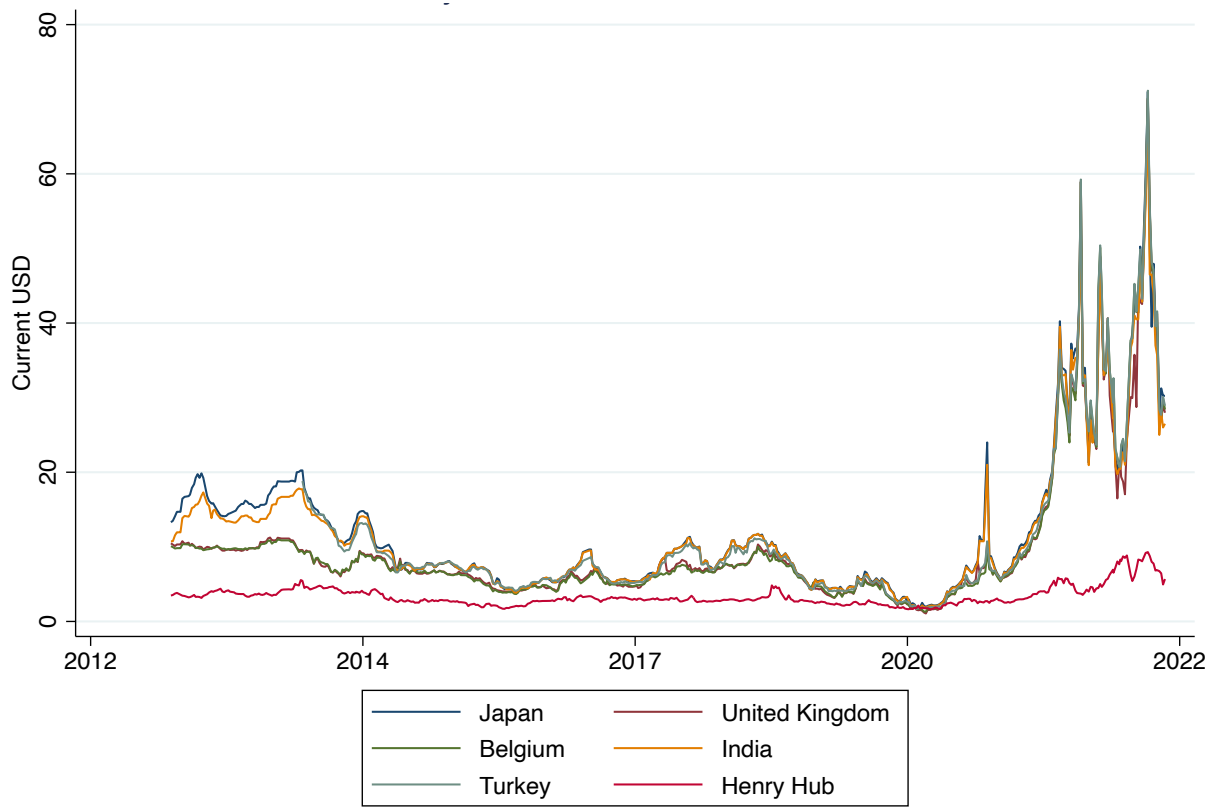


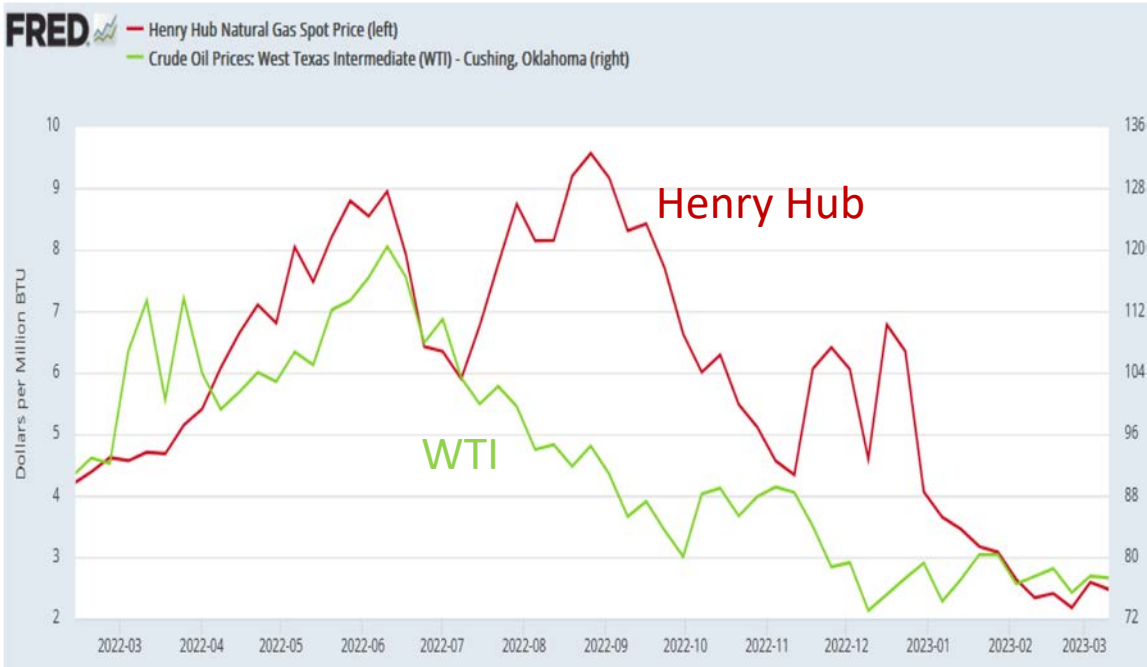


Source: FRED, EIA

C. Brief History: Global demand driving U.S. LNG exporting

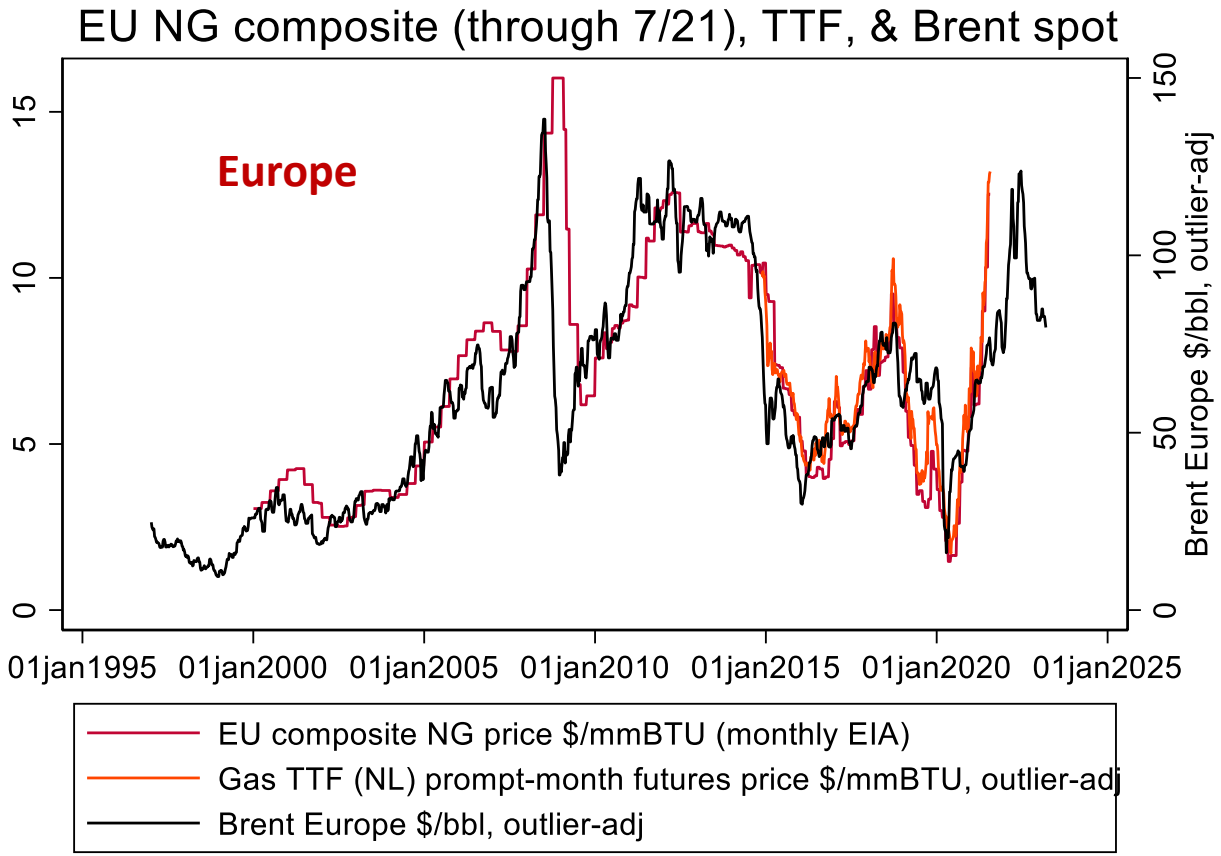
Weekly, 2013 - 2022

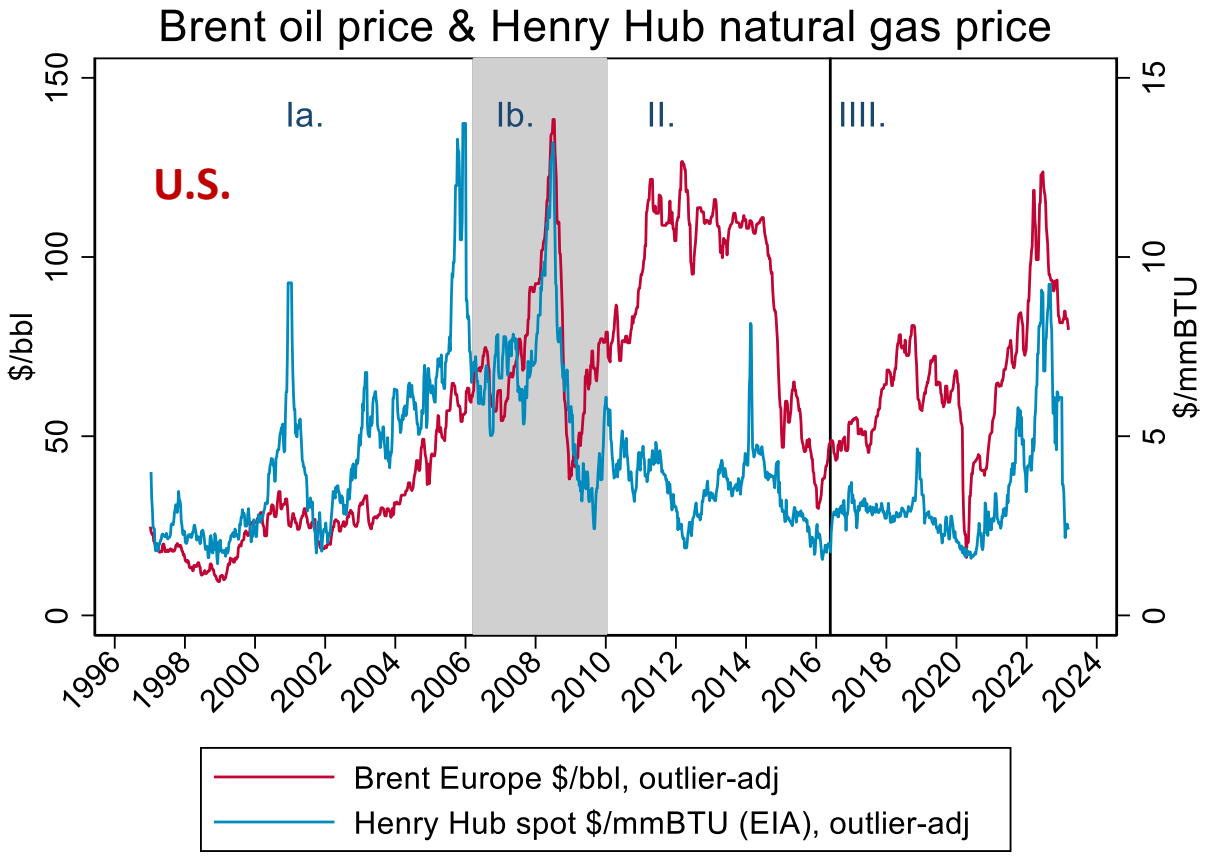




March 2022 – March 2023

Oil and gas prices





Source: FRED, EIA, SNL

A. Natural gas 101

Prices: $/mmBTU

Energy content:

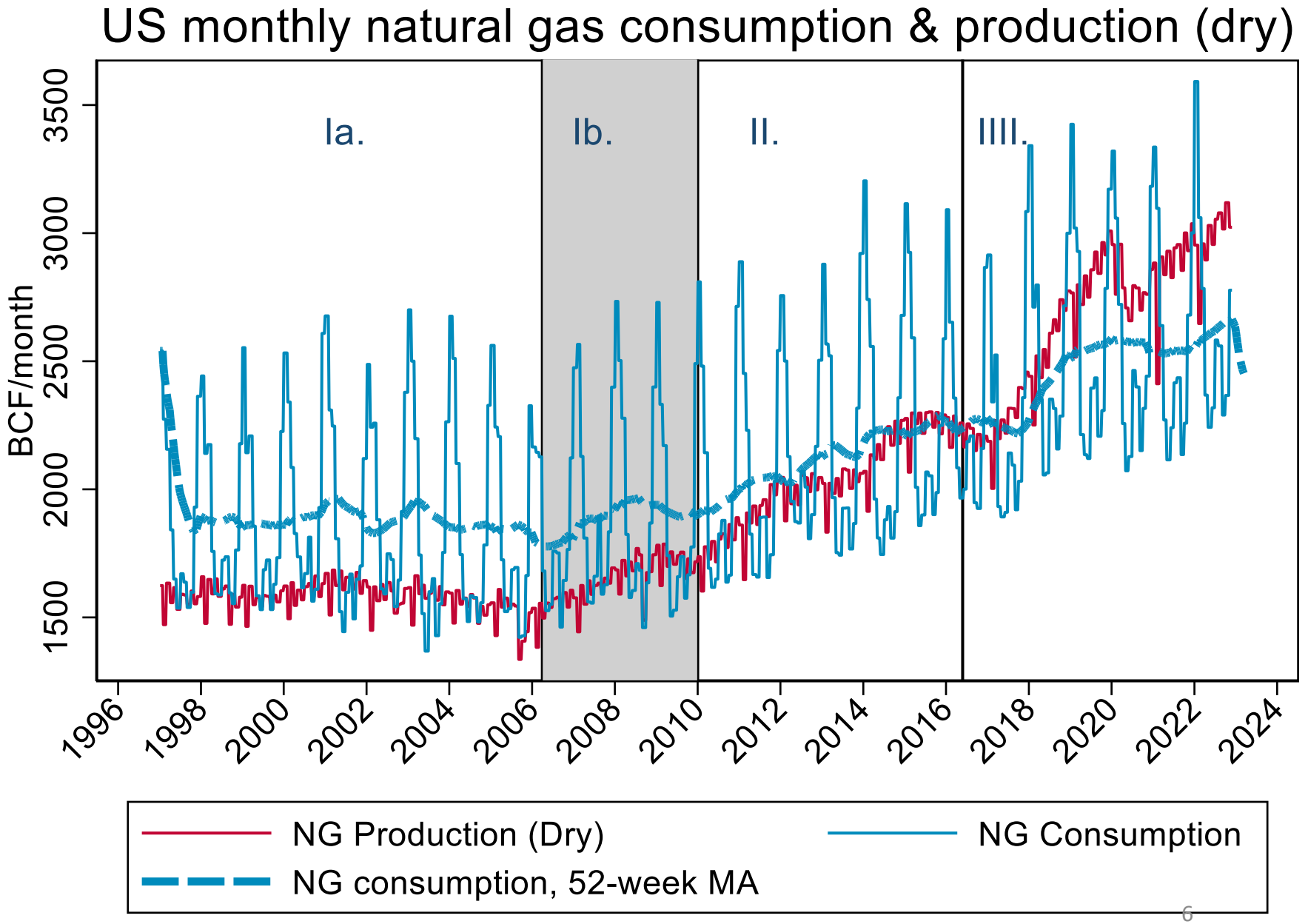
- 1 mmBTU gas = **0.176** bbl oil
- NGCC v. Residual fuel oil steam boiler: 1 mmBtu gas = **0.112** bbl oil

Quantities:

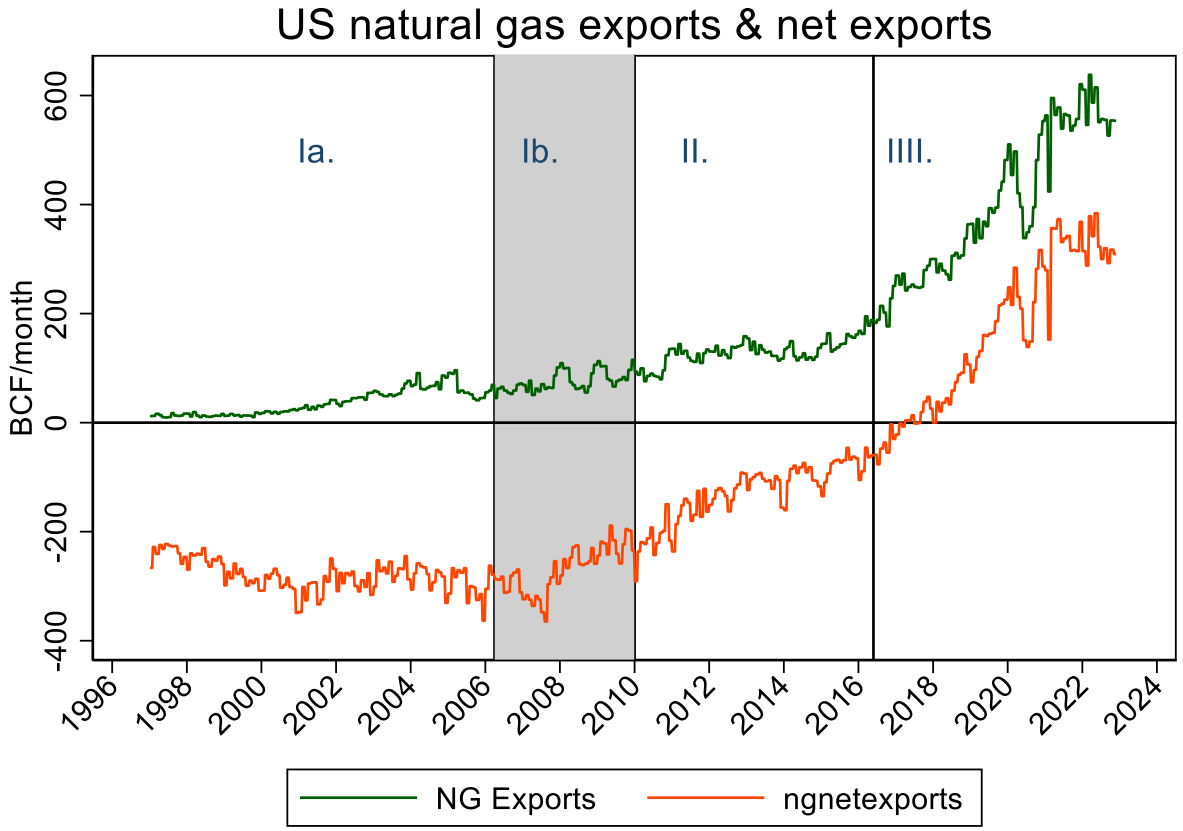
- 1 Mcf (1000 cubic feet) = 1.037 mmBTU

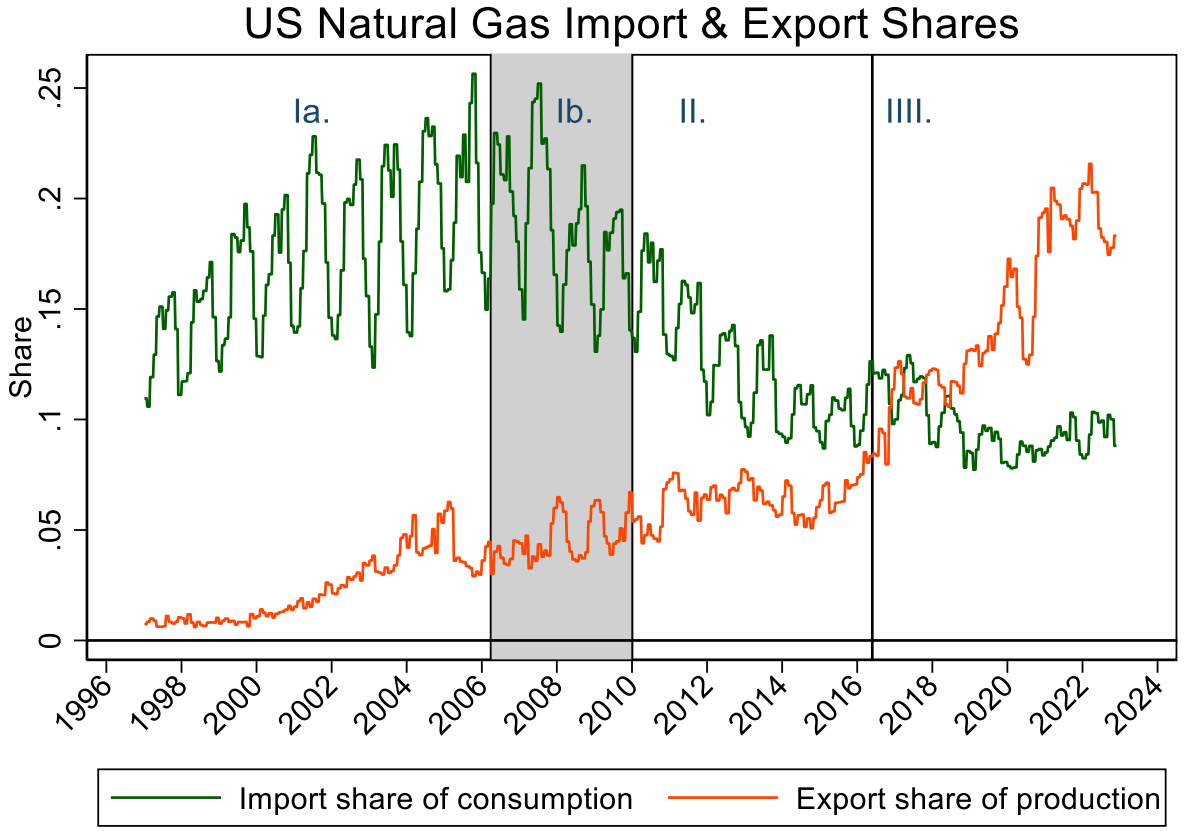
Carbon:

- 53 kgCO2/mmBTU
- $40 carbon tax => $2.12/mmBTU



Three regimes in natural gas prices: Quantities





U.S. natural gas regimes

Ia. ***Burner tip parity****:* < April 2006: growing & large imports, cofiring

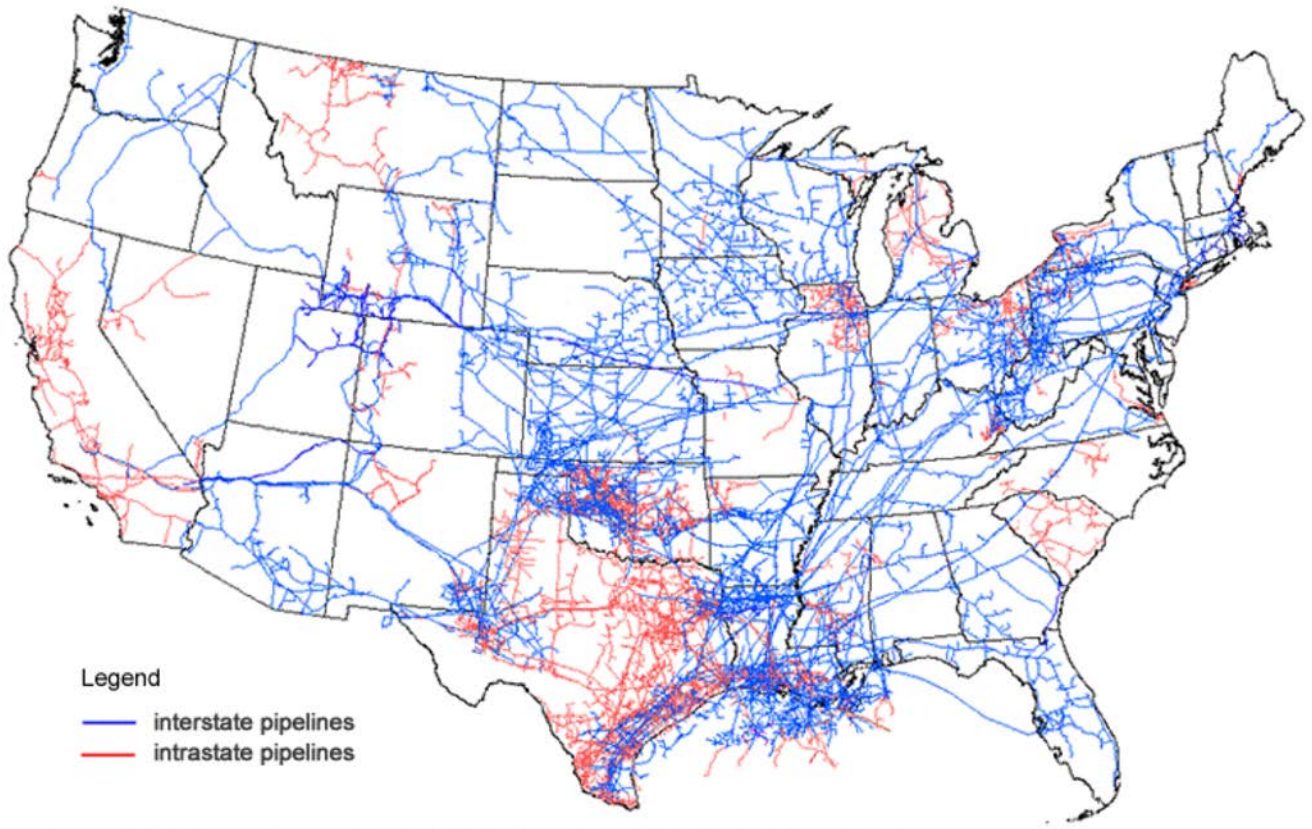
Ib. ***Pre-fracking transition****:* April 2006 – January 2010: high & stable imports, no cofiring

II. ***Fracking, shut-in gas***: 2010 – May 2016: Fracking, product "shut in"

III. ***LNG***: May 2016 – present

U.S. interstate pipelines & LNG terminals

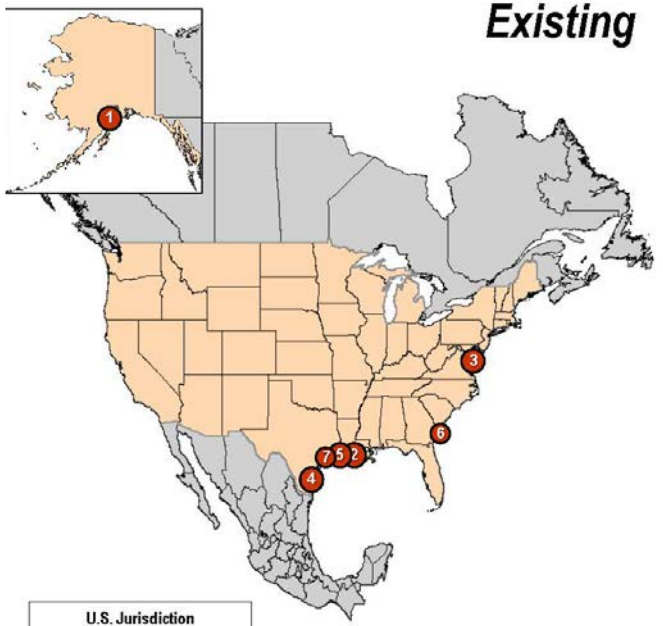
Map of U.S. interstate and intrastate natural gas pipelines



Source: U.S. Energy Information Administration, *About U.S. Natural Gas Pipelines*

North American LNG Export Terminals

Existing



Export Terminals

UNITED STATES

1. **Kenai, AK:** 0.2 Bcfd (Trans-Foreland)
2. **Sabine, LA:** 4.55 Bcfd (Cheniere/Sabine Pass LNG – Trains 1-6)
3. **Cove Point, MD:** 0.82 Bcfd (Dominion–Cove Point LNG)
4. **Corpus Christi, TX:** 2.40 Bcfd (Cheniere – Corpus Christi LNG Trains 1-3)
5. **Hackberry, LA:** 2.15 Bcfd (Sempra–Cameron LNG, Trains 1-3)
6. **Elba Island, GA:** 350 MMcfd (Southern LNG Company Units 1-10)
7. **Freeport, TX:** 2.13 Bcfd (Freeport LNG Dev/Freeport LNG Expansion/FLNG Liquefaction Trains 1-3)

As of February 16, 2022

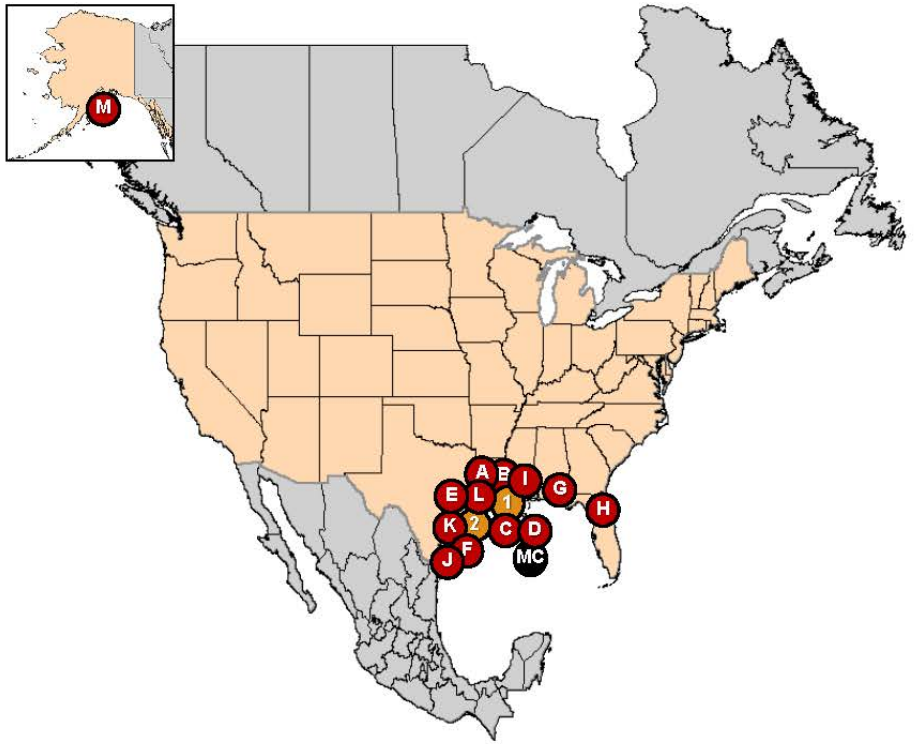
Cheniere Sabine Pass Train 1 was placed into service May 2016.

Approved LNG export facilities

LNG exports require a DOE license

- Section 3 of the Natural Gas Act (as amended) (15 U.S.C. § 717b.
- May 29, 2014 DOE completed EIA and proposed regulations for reviewing LNG export applications

North American LNG Export Terminals
Approved, Not Yet Built



U.S. Jurisdiction & Status

- FERC - Approved, Under Construction
- FERC - Approved, Not Under Construction
- MARAD / U.S. Coast Guard

Export Terminals

UNITED STATES

FERC – APPROVED, UNDER CONSTRUCTION

1. **Cameron Parish, LA:** 1.41 Bcfd (Venture Global Calcasieu Pass) (CP15-550)
2. **Sabine Pass, TX:** 2.26 Bcfd (ExxonMobil – Golden Pass) (CP14-517, CP20-459)

FERC – APPROVED, NOT UNDER CONSTRUCTION

A. **Lake Charles, LA:** 2.2 Bcfd (Lake Charles LNG) (CP14-120)
B. **Lake Charles, LA:** 1.186 Bcfd (Magnolia LNG) (CP14-347)
C. **Hackberry, LA:** 1.41 Bcfd (Sempra - Cameron LNG Trains 4 & 5) (CP15-560)
D. **Calcasieu Parish, LA:** 4.0 Bcfd (Driftwood LNG) (CP17-117)
E. **Port Arthur, TX:** 1.86 Bcfd (Port Arthur LNG Trains 1 & 2) (CP17-20)
F. **Freeport, TX:** 0.72 Bcfd (Freeport LNG Dev Train 4) (CP17-470)
G. **Pascagoula, MS:** 1.5 Bcfd (Gulf LNG Liquefaction) (CP15-521)
H. **Jacksonville, FL:** 0.132 Bcf/d (Eagle LNG Partners) (CP17-41)
I. **Plaquemines Parish, LA:** 3.40 Bcfd (Venture Global Plaquemines) (CP17-66)
J. **Brownsville, TX:** 0.55 Bcfd (Texas LNG Brownsville) (CP16-116)
K. **Brownsville, TX:** 3.6 Bcfd (Rio Grande LNG – NextDecade) (CP16-454)
L. **Corpus Christi, TX:** 1.86 Bcfd (Cheniere Corpus Christi Stage III) (CP18-512)
M. **Nikiski, AK:** 2.63 Bcfd (Alaska Gasline) (CP17-178)

MARAD/USCG – APPROVED, NOT UNDER CONSTRUCTION

MC. **Gulf of Mexico:** 1.8 Bcfd (Delfin LNG)

CANADA - LNG IMPORT AND PROPOSED EXPORT FACILITIES
https://www.nrcan.gc.ca/energy/natural-gas/5683

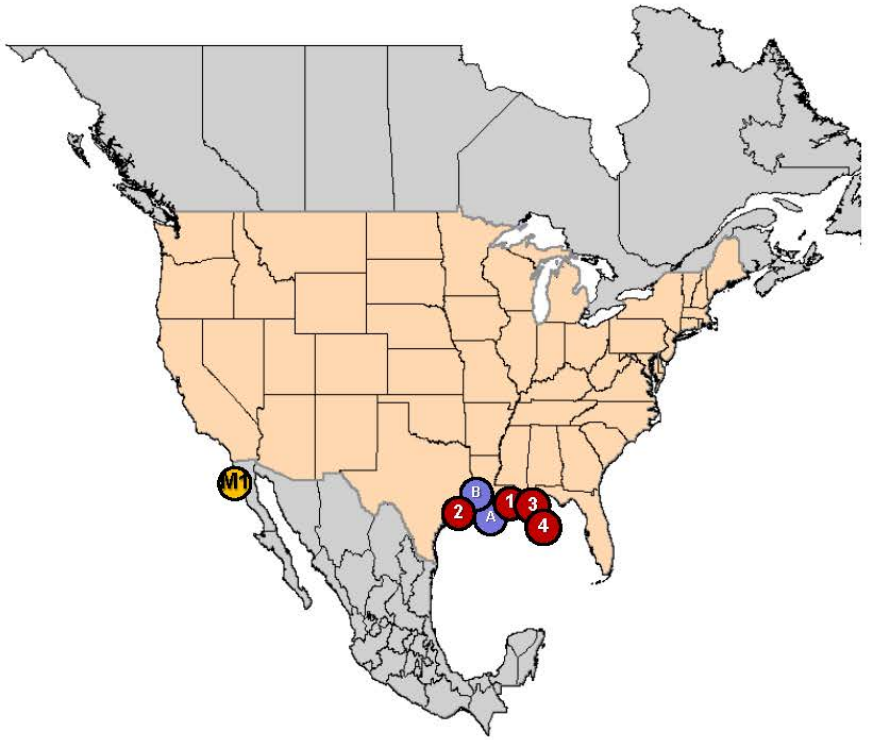
As of February 16, 2022

Brief history of US LNG exporting

LNG exports require a DOE license

- Section 3 of the Natural Gas Act (as amended) (15 U.S.C. § 717b.
- May 29, 2014 DOE completed EIA and proposed regulations for reviewing LNG export applications

North American LNG Export Terminals
Proposed



UNITED STATES

PROPOSED TO FERC
Pending Applications:
1. Cameron Parish, LA: 1.18 Bcfd (Commonwealth, LNG) (CP19-502)
2. Port Arthur, TX: 1.86 Bcfd (Sempra - Port Arthur LNG Trains 3 & 4) (CP20-55)
3. Cameron Parish, LA: 1.45 Bcfd (Venture Global CP2 Blocks 1-9) (CP22-21)
4. Cameron Parish, LA: .057 Bcfd (Venture Global Calcasieu Pass) (CP22-25)

Projects in Pre-filing:
A. LaFourche Parish, LA: 0.65 Bcfd (Port Fourchon LNG) (PF17-9)
B. Plaquemines Parish, LA: 2.76 Bcfd (Delta LNG - Venture Global) (PF19-4)

CANADA
For Canadian LNG Import and Proposed Export Facilities:

https://www.nrcan.gc.ca/energy/natural-gas/5683

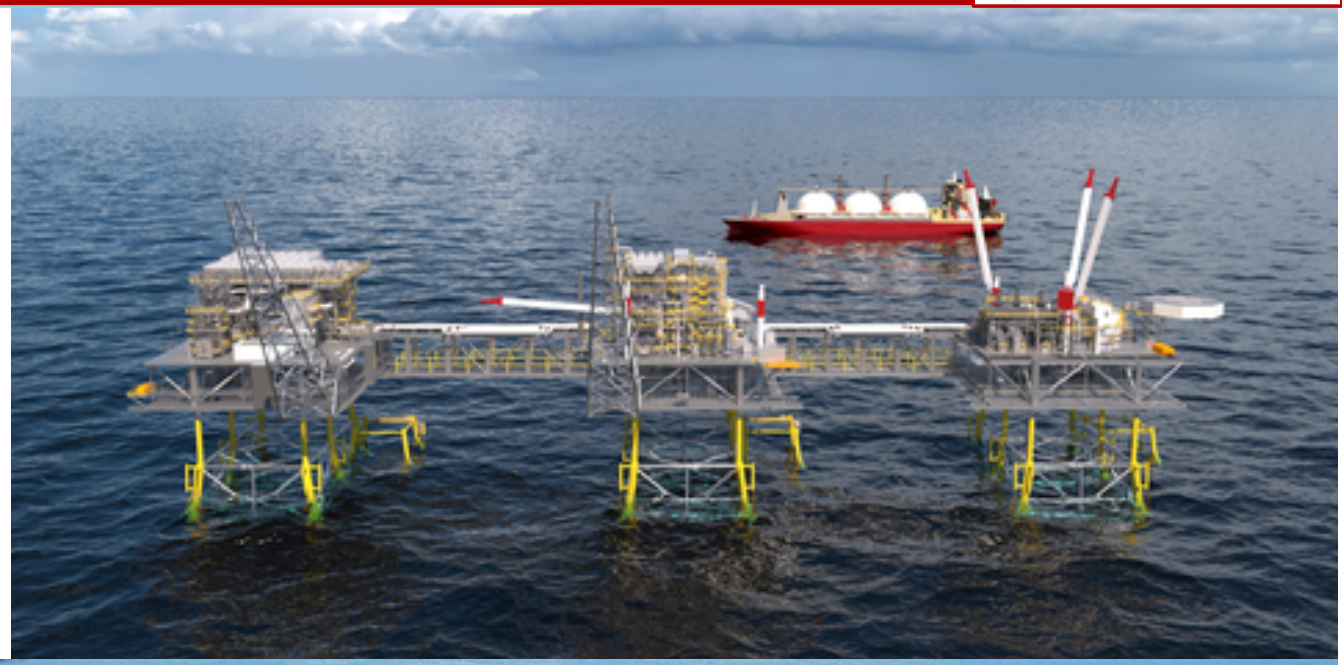
MEXICO (Projects in advanced planning/development stages)
M1. Baja California, MX: 0.4 Bcfd (Sempra – Energía Costa Azul Phase 1)

As of February 16, 2022

Fast LNG export facilities

"Fast LNG" and Floating Shipborne Regasification Units (FSRUs)

- Fast LNG repurposes offshore rigs, mainly jackup rigs, to provide a seaborne liquefaction facility
  - 6 exist so far; 5 under construction
  - Estimated ~160 jackup rigs > 30 yrs old available for Fast Gas repurposing
  - Typical 1.4 MPTA capacity/facility (0.2 Bcf/d)
  - Takes ~18 months to complete

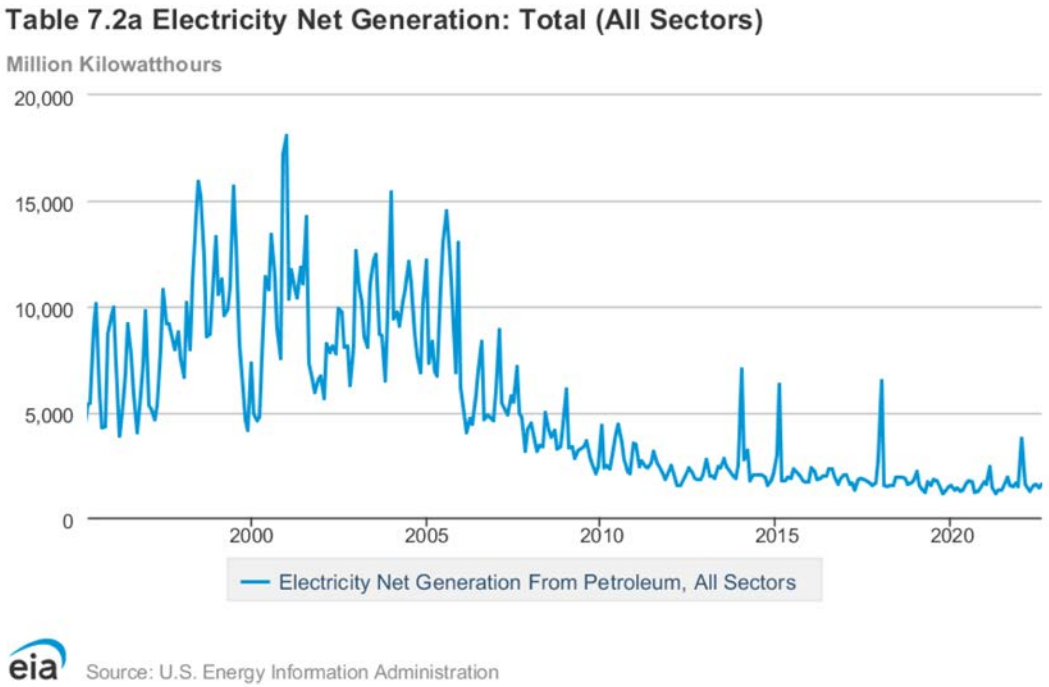


Floating Storage & Regasification Units (FSRUs)

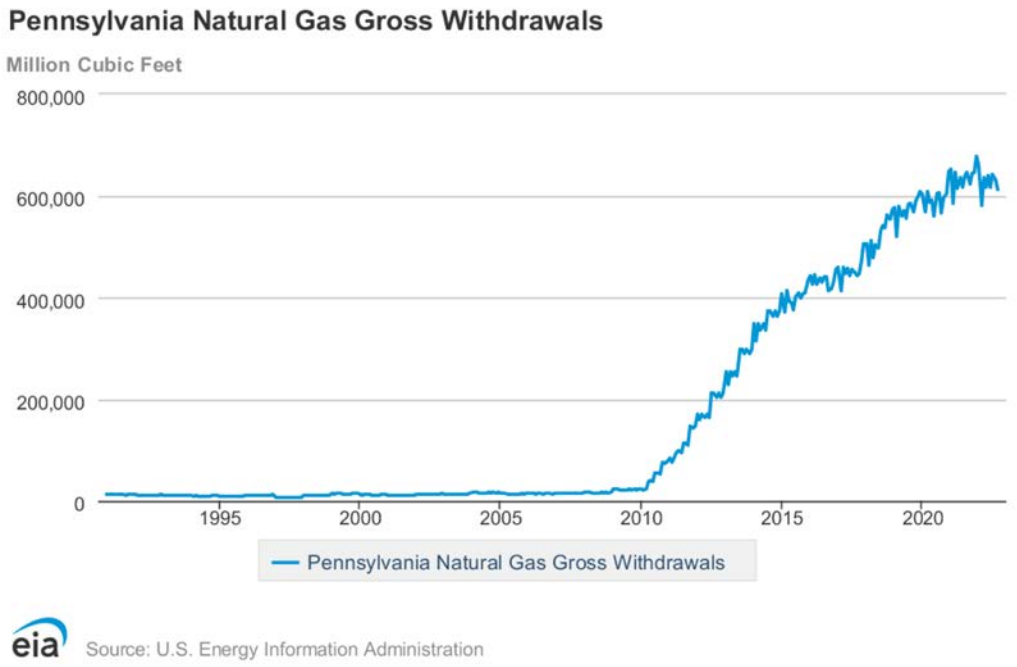
- Modified tankers/LNG vessels capable of regasification
  - Mobile

NG History: Some key events & dates

~April 2006: End of oil-gas co-firing



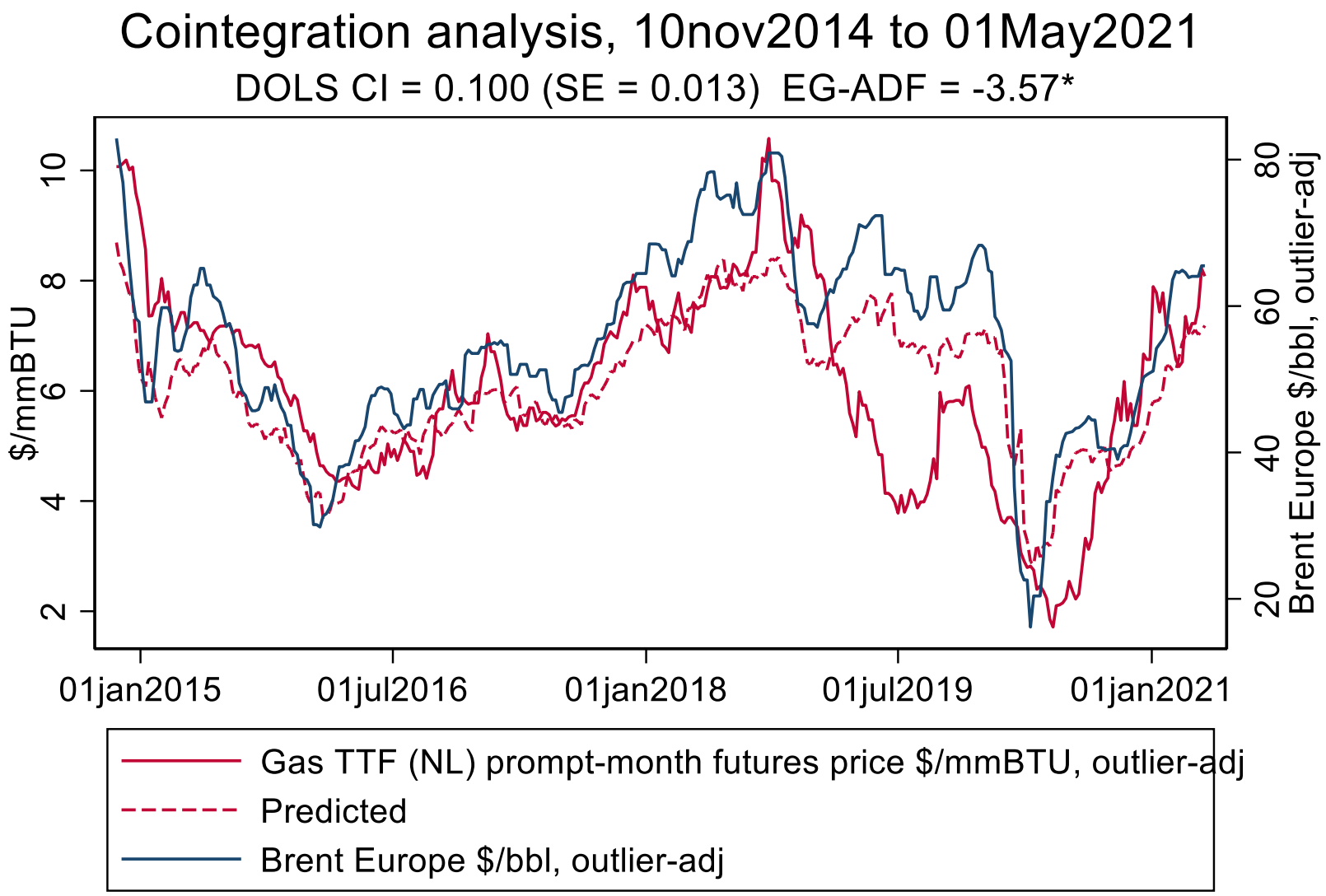
~January 2010: Start of fracking



May 2016: LNG exports begin

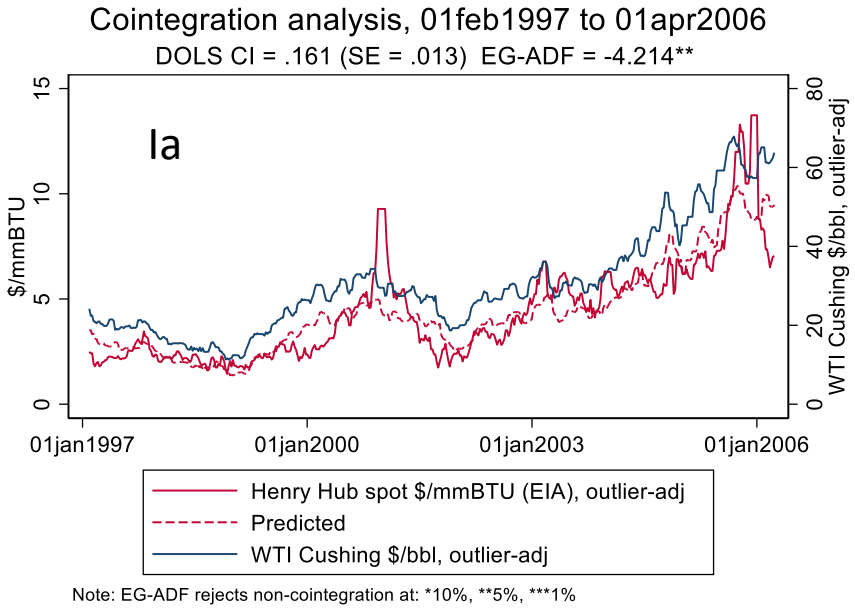
- Chenier Sabine Pass train 1 begins shipments
- Pipeline exports to Mexico ramped up in spring 2015

Cointegration: EU



Note: EG-ADF rejects non-cointegration at: *10%, **5%, ***1%

Cointegration results by institutional regime



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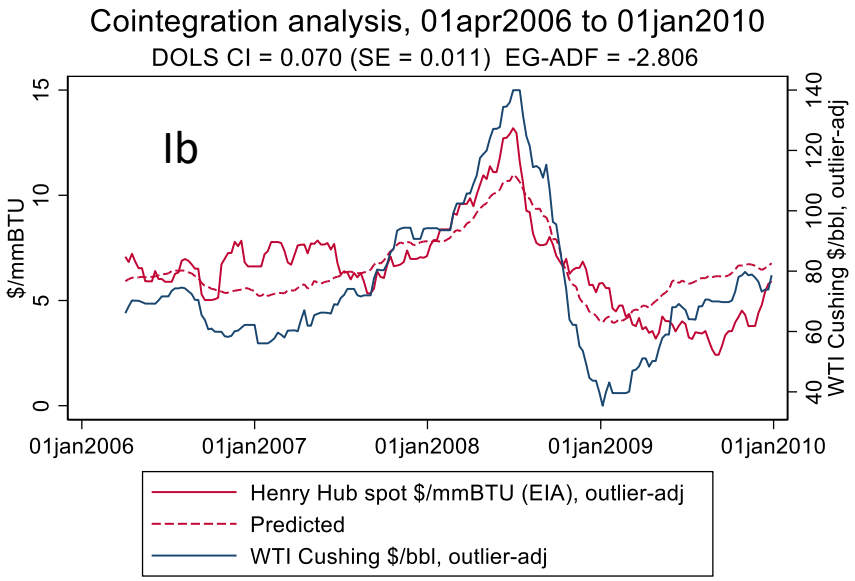

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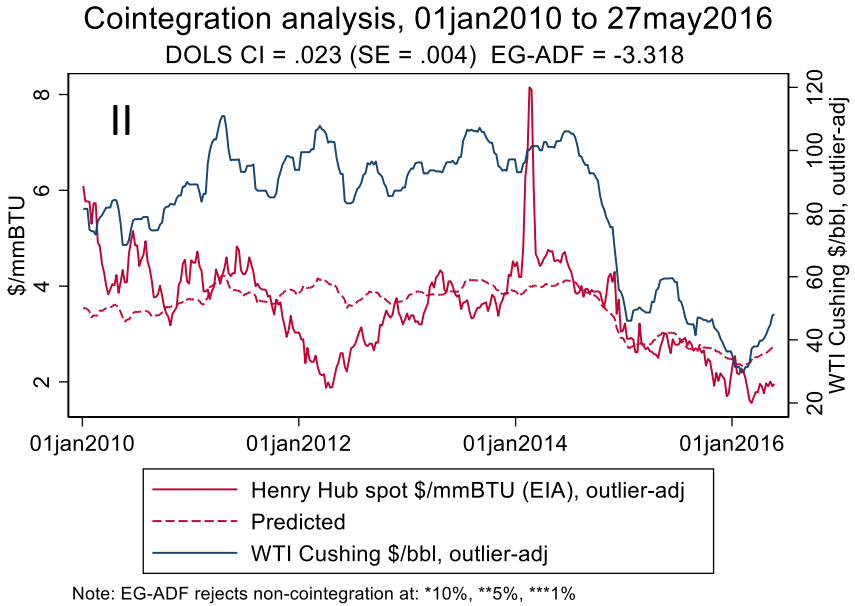

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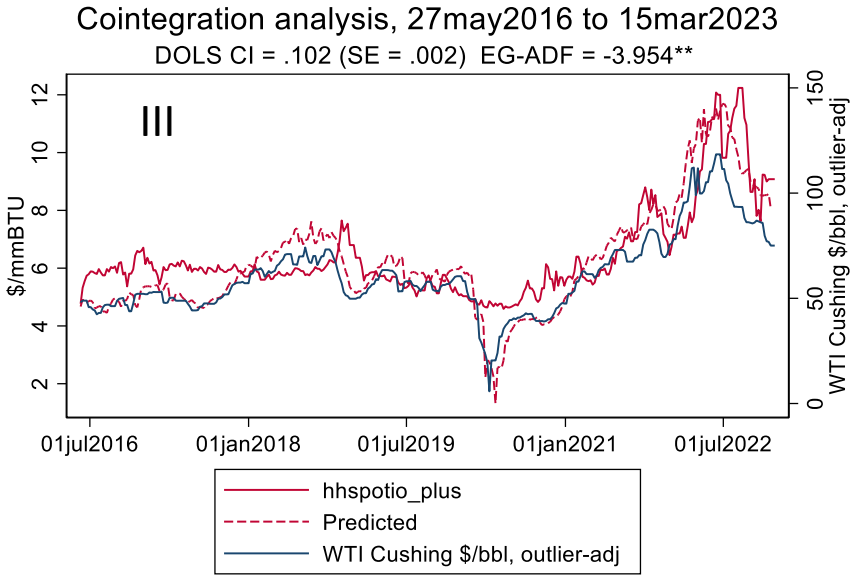
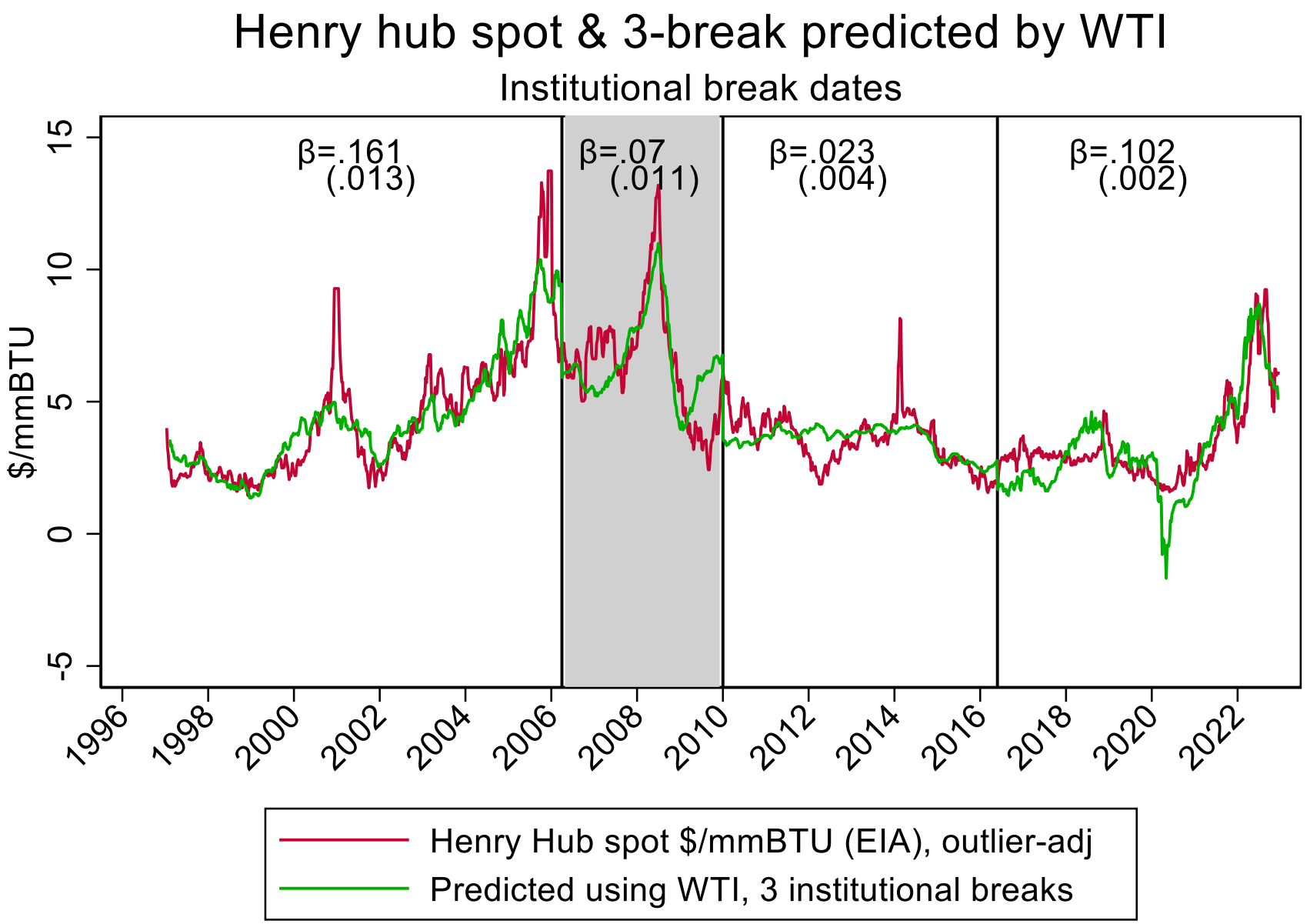
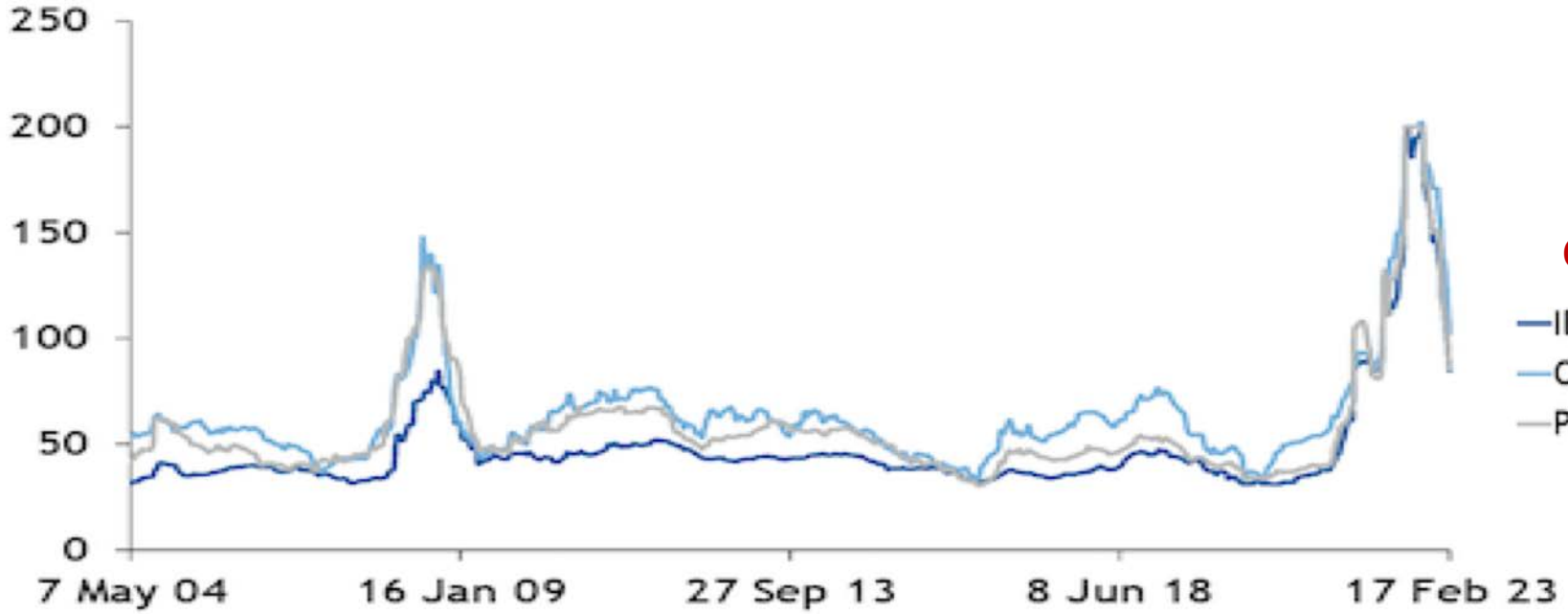


Note: EG-ADF rejects non-cointegration at: *10%, **5%, ***1%

Cointegration: Predicted oil price, with 3 institutional break dates



Coal prices



Central & Eastern U.S. Coal

- Illinois basin 11,500 Btu/lb 5lb SO2/mmBtu
- Central Appalachia CSX 12,500 Btu/lb
- Pittsburgh Seam 13,000 Btu/lb 4.5lb SO2/mmBtu

Henry Hub (monthly)

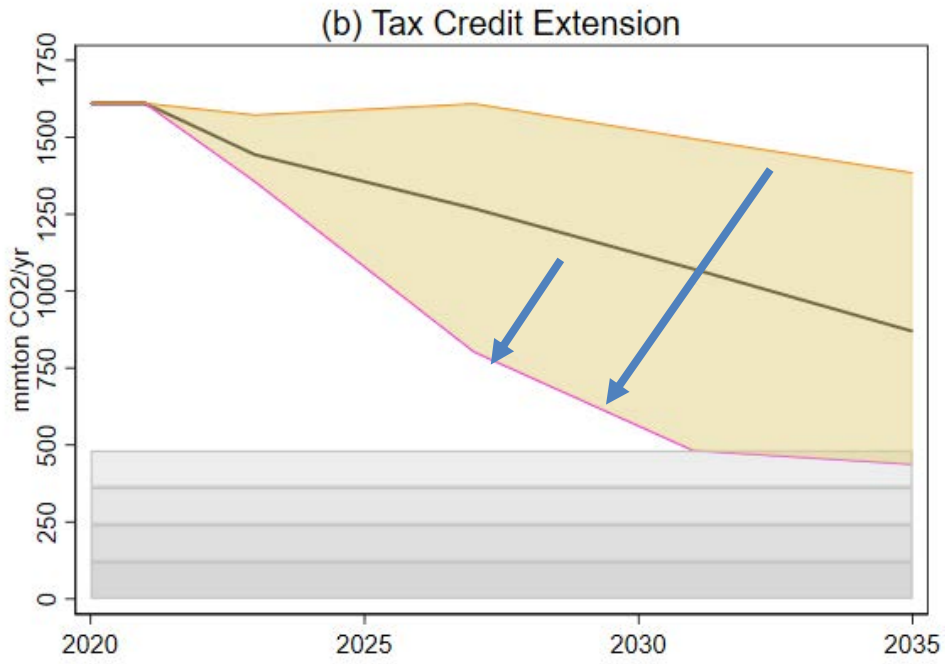
Source: Argus, EIA

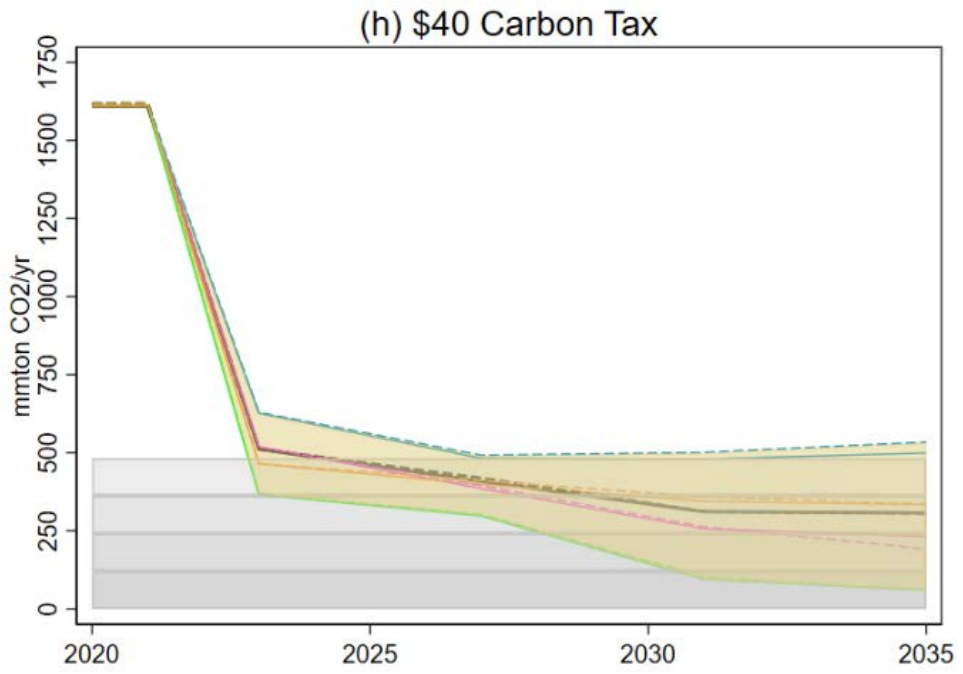
Implications for U.S. energy transition

Back-of-envelope estimates of U.S. power sector emissions in 2030, relative to 2007 peak, for various natural gas prices

Scenario	HH price (2022 $/mmBtu)	2030 emissions relative to 2007 peak	Delta rel to BAU (pp)
BAU	$3.10	46%	-
IRA only	$3.10	62%	-15 pp
LNG only	$5.10	57%	-11 pp
IRA + LNG	$5.10	72%	-26 pp
IRA + LNG	$7.10	76%	-30 pp

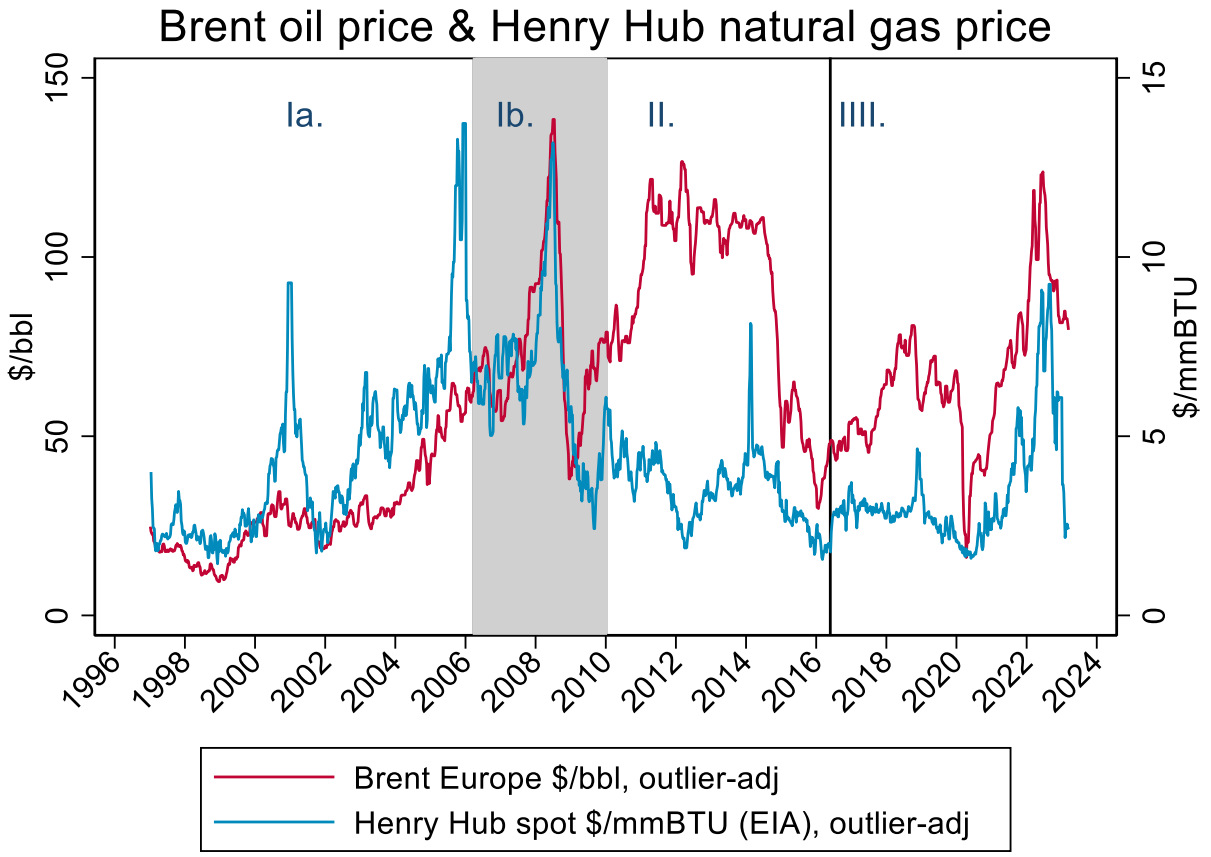
Power sector emissions projections under:
(a) IRA
(b) $40 carbon tax
(Stuart & Stock 2021)





(Some) International implications

- Higher US gas prices & lower world gas prices as U.S. ramps up exports
  - Effect on U.S. energy transition? On EU? Japan?
- What is the substitution margin of the 2030s? Green hydrogen v. gas + DAC?
- Implications for volatility?
  - While these energy sources are substitutes, collectively the short-run demand for energy services is likely to remain inelastic



Additional Slides

Destinations for U.S. LNG exports

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FOR CLIMATE AND SUSTAINABILITY
at Harvard University

Monthly U.S. LNG export volumes by destination, 2016-present (U.S. DOE)