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Energy Market Futures

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Technological change in fossil energy: Unconventional oil and gas

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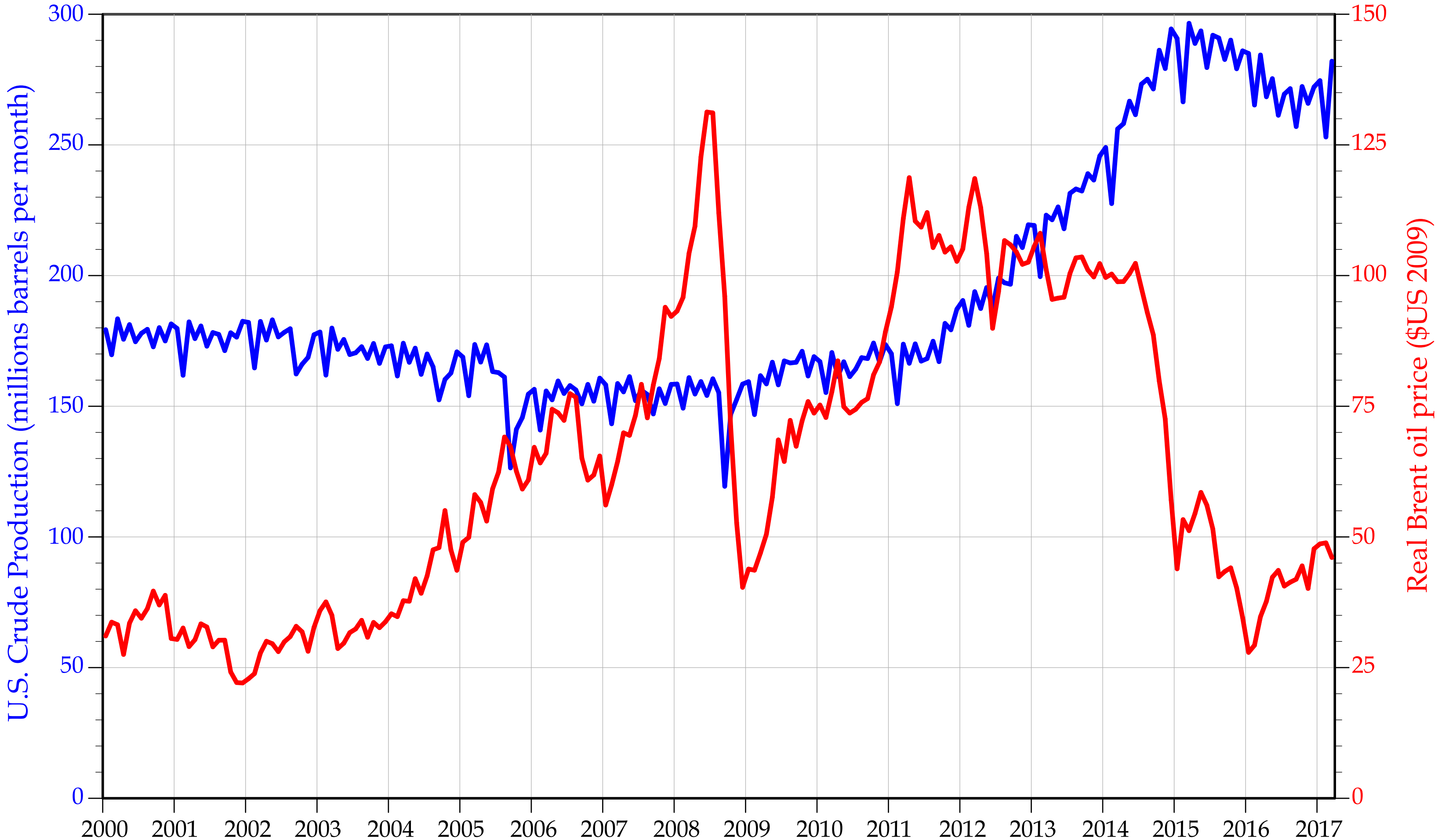
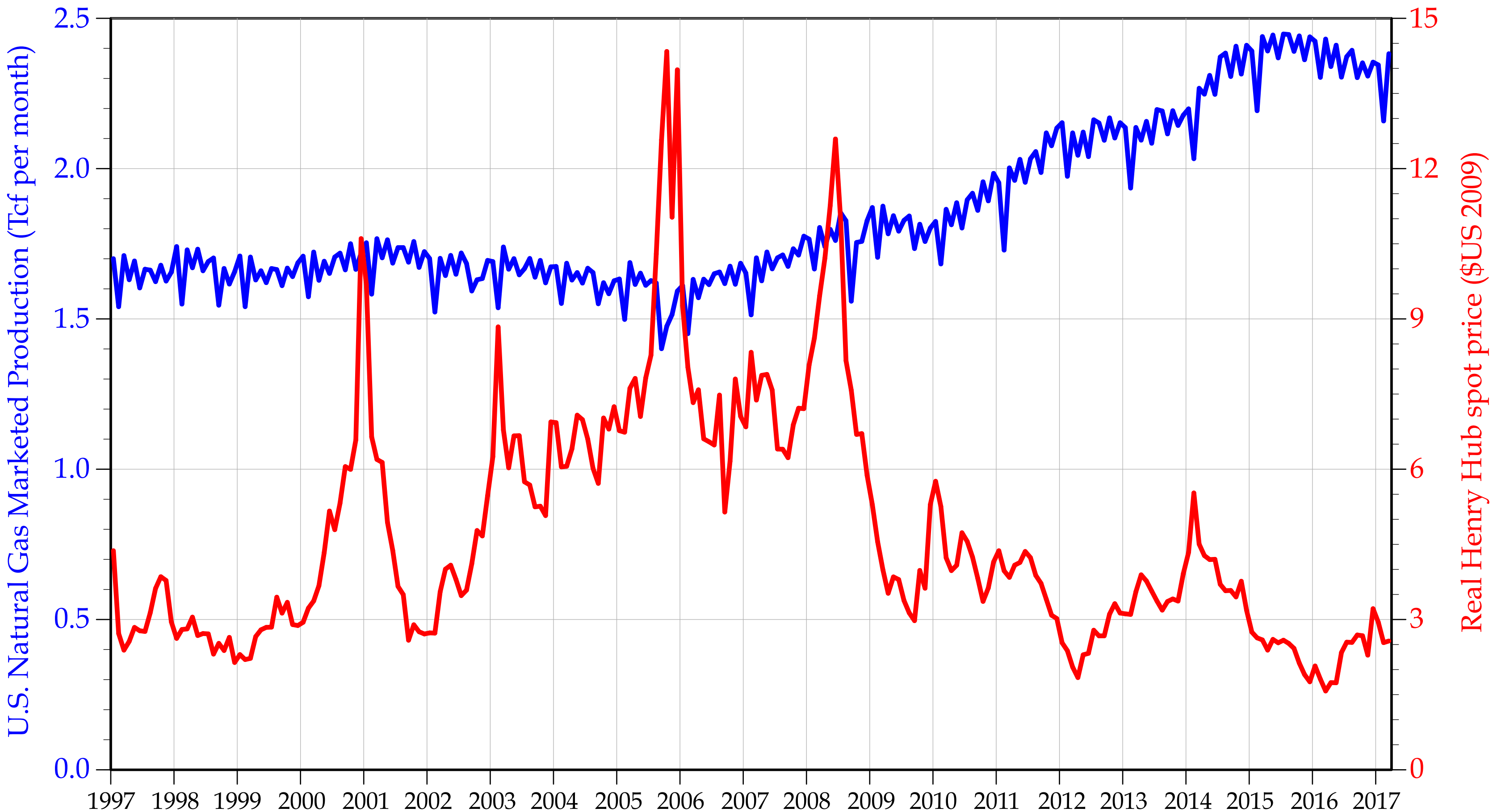
U.S. oil production and the real oil price



Source: EIA

U.S. natural gas production and real gas price



Source: EIA

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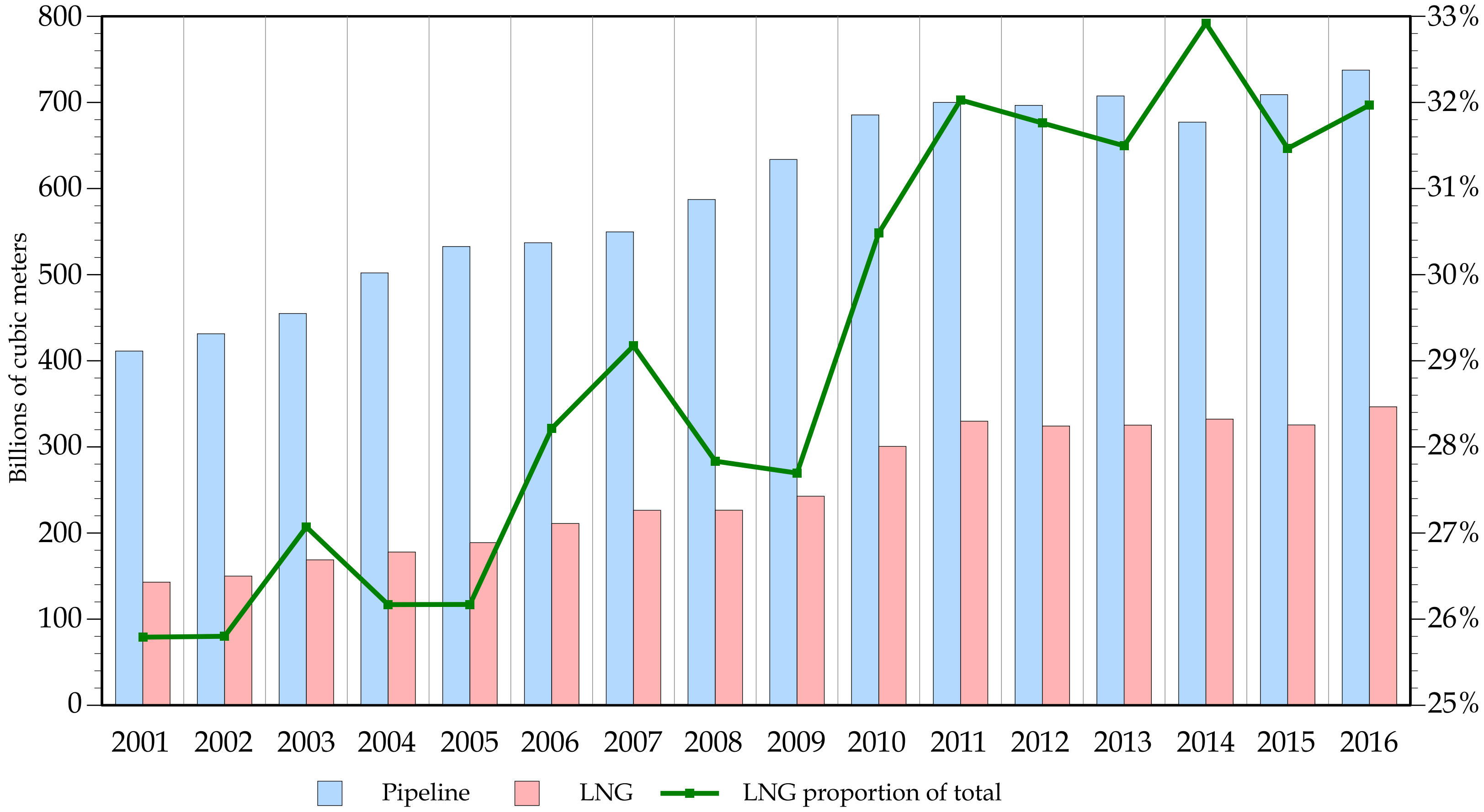
LNG and gas market developments: Spreading the benefits of natural gas?

World natural gas trade



Source: BP Energy Statistics

Growth in LNG demand

- Average annual growth of LNG since 2000 of 6.1% despite weak market in 2011–2016
  - Contrast with average annual growth of global TPE and TPE from natural gas of around 2.5%
- Some reasons for growth in LNG relative to natural gas as a whole:
  - Lower costs of LNG shipping and especially FSRU regasification
  - Strategic value of LNG relative to pipeline gas
- Natural gas has several advantages especially relative to coal
  - Less polluting
  - CCGT in particular is more energy efficient
  - OCGT are very flexible and useful for backing up renewables
- But natural gas is more expensive in most locations and requires more expensive infrastructure
  - Average annual growth of TPE from coal worldwide of around 3.8% from 2000-15

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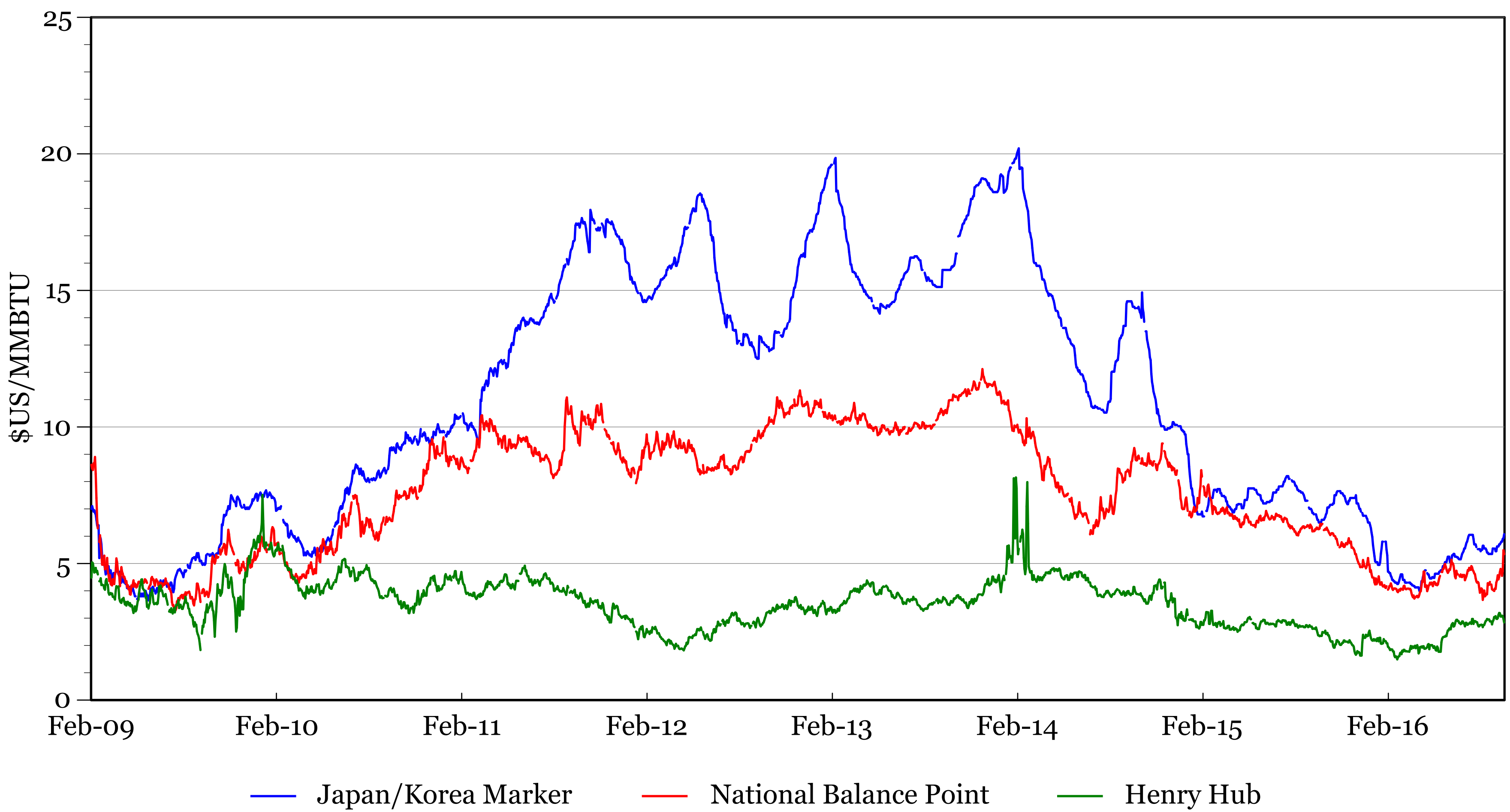
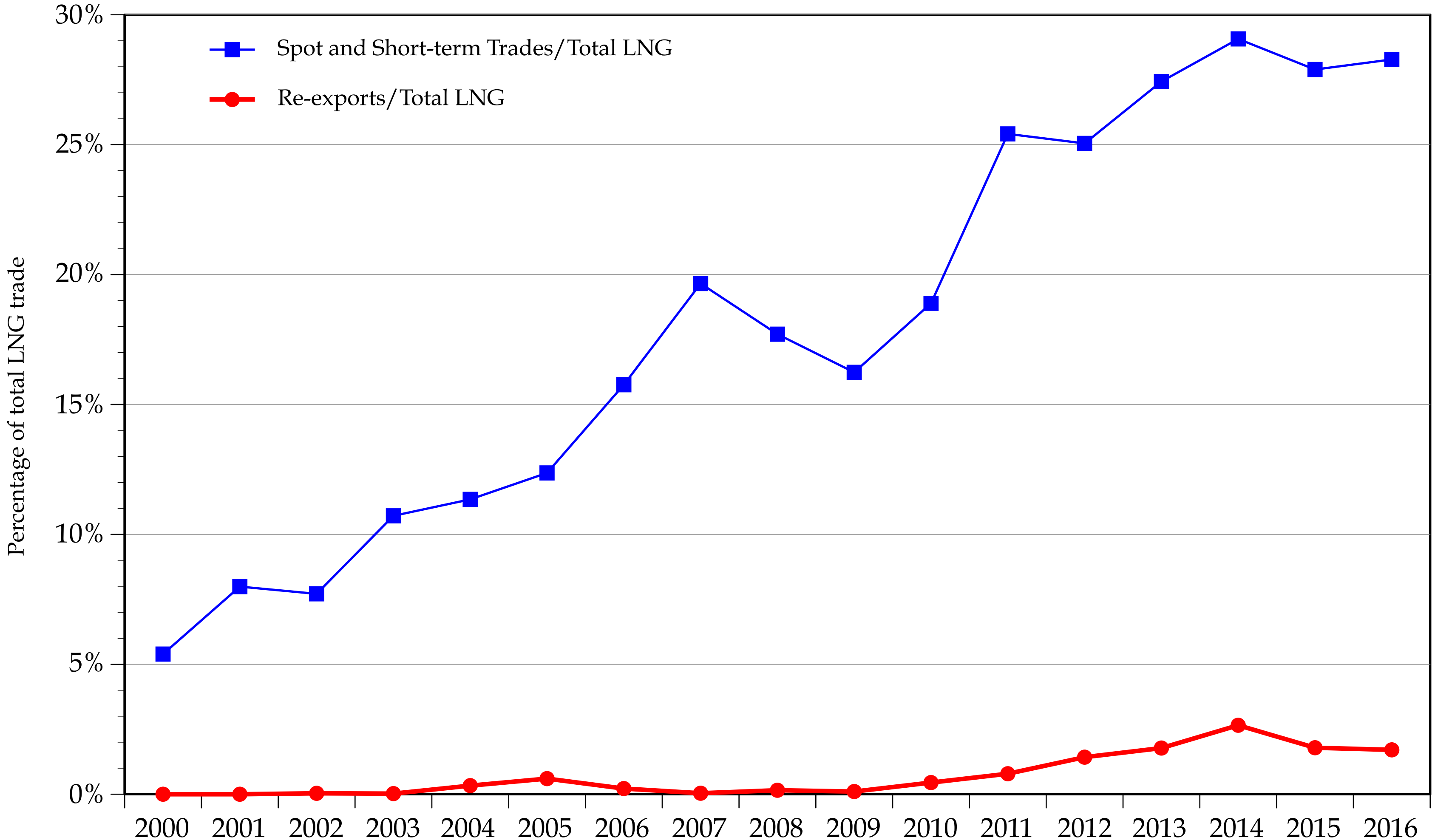
Recent evolution of spot natural gas prices



Source: Platts

Increasing spot and short-term LNG trade



Source: GIIGNL

Effects of US exports on LNG trade

- US plants require less investment than traditional liquefaction projects
- US exports should support continued growth of spot trade and price arbitrage
  - Exports are under a tolling arrangement with the feed gas price tied to Henry Hub
  - Several buyers will add the LNG to their global portfolio
  - Future co-location of regasification and liquefaction facilities in the US with pipeline connections to a deep market will facilitate short-term arbitrage
- Nevertheless, US exports will limit LNG price increases, which in turn will limit the number of US terminals ultimately built
- Future greenfield developments are likely to require higher prices and long-term contracts for majority of their output to support financing of large capex

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Approved/Proposed US LNG export terminals

Terminal status and location	Capacity as % 2016 LNG exports
Operational	
Sabine Pass (trains 1–4), LA	3.98
Under construction	
Sabine Pass (train 5), LA	1.99
Hackberry, LA	5.97
Freeport, TX	6.08
Cove Point, MD	2.33
Corpus Christi, TX	6.08
Elba Island, GA	0.99
Sub-total operational or under construction	**27.42**
Approved, not under construction	
Sabine Pass (train 6), LA	1.99
Hackberry, LA (expansion)	4.01
Lake Charles, LA (Southern Union)	6.25
Lake Charles, LA (Magnolia)	3.07
Golden Pass, TX	6.28
Total	**49.02**
6 terminals pending applications	27.91
7 terminals in pre-filing	38.0

Note: At average annual growth of LNG market since 2000 of 6.1%, it would take 11.7 years for the market to double in size

Typical LNG shipping costs ($US/MMBTU), 2015

Origin	Japan/ Korea	S China/ Taiwan	West India	SW Europe	NW Europe	NE USA	Argentina	Brazil
Sakhalin	0.15	0.22	0.57	1.20	1.26	1.60	0.96	1.33
Australia	0.32	0.29	0.36	0.98	1.08	1.11	0.74	0.88
Mid-East	0.58	0.50	0.15	0.71	0.80	1.08	0.74	0.85
Peru	0.81	0.92	1.03	0.82	0.85	0.93	0.34	0.51
Nigeria	1.26	1.11	0.82	0.43	0.47	0.65	0.52	0.43
Algeria	1.40	1.30	0.87	0.10	0.22	0.46	0.65	0.56
Spain	1.45	1.30	0.92		0.18	0.37	0.65	0.52
Belgium	1.59	1.44	1.01	0.18		0.42	0.73	0.65
Norway	1.79	1.59	1.19	0.30	0.18	0.46	0.86	0.82
Trinidad	1.84	1.74	1.29	0.43	0.43	0.28	0.52	0.35
US Gulf via no canals	1.86	1.70	1.49	0.56	0.56		0.78	0.61
US Gulf via Panama canal	1.29	1.53						
US Gulf via Suez canal	2.00	1.79	1.39					

Source: Platts

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Developing countries want cheap electricity

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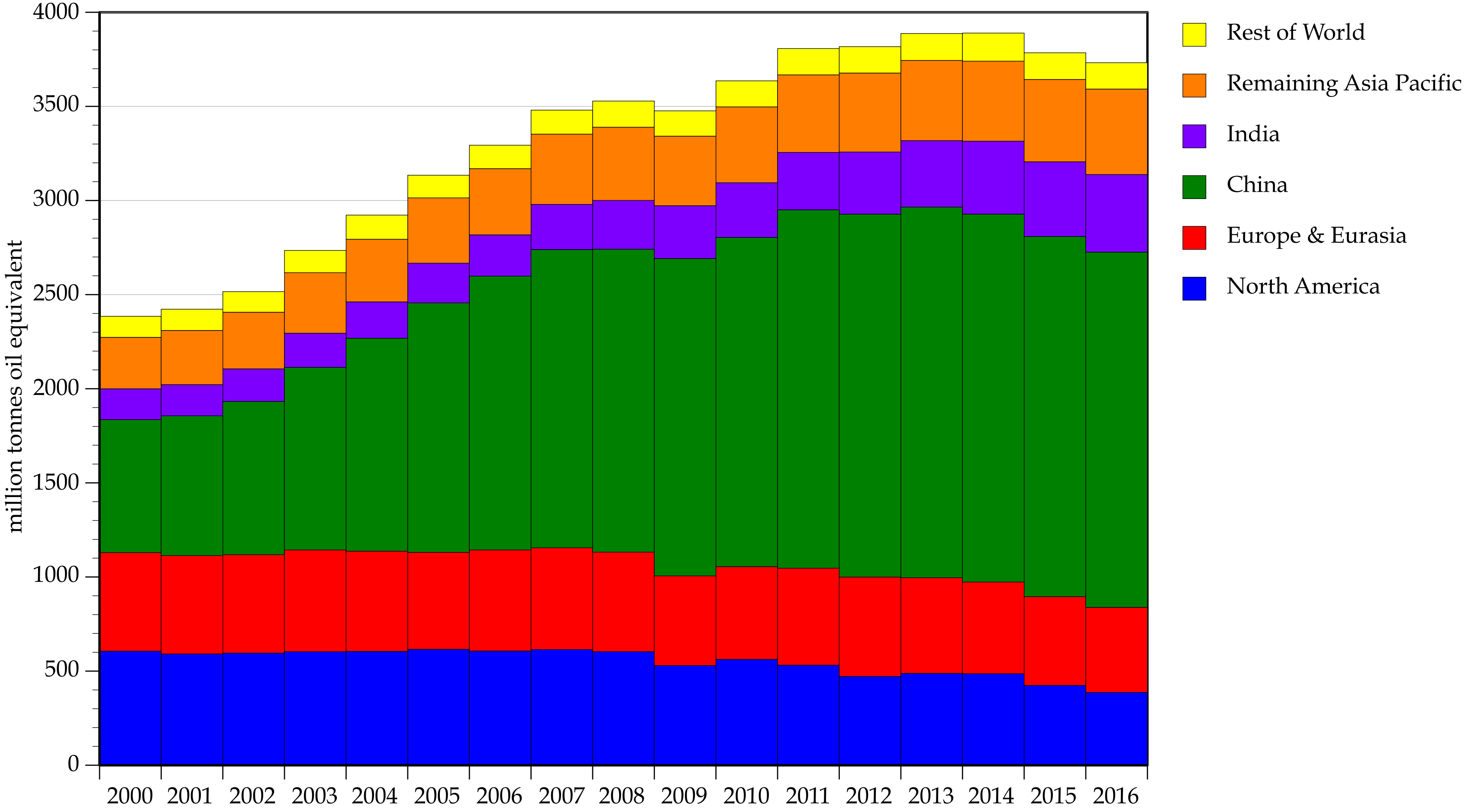
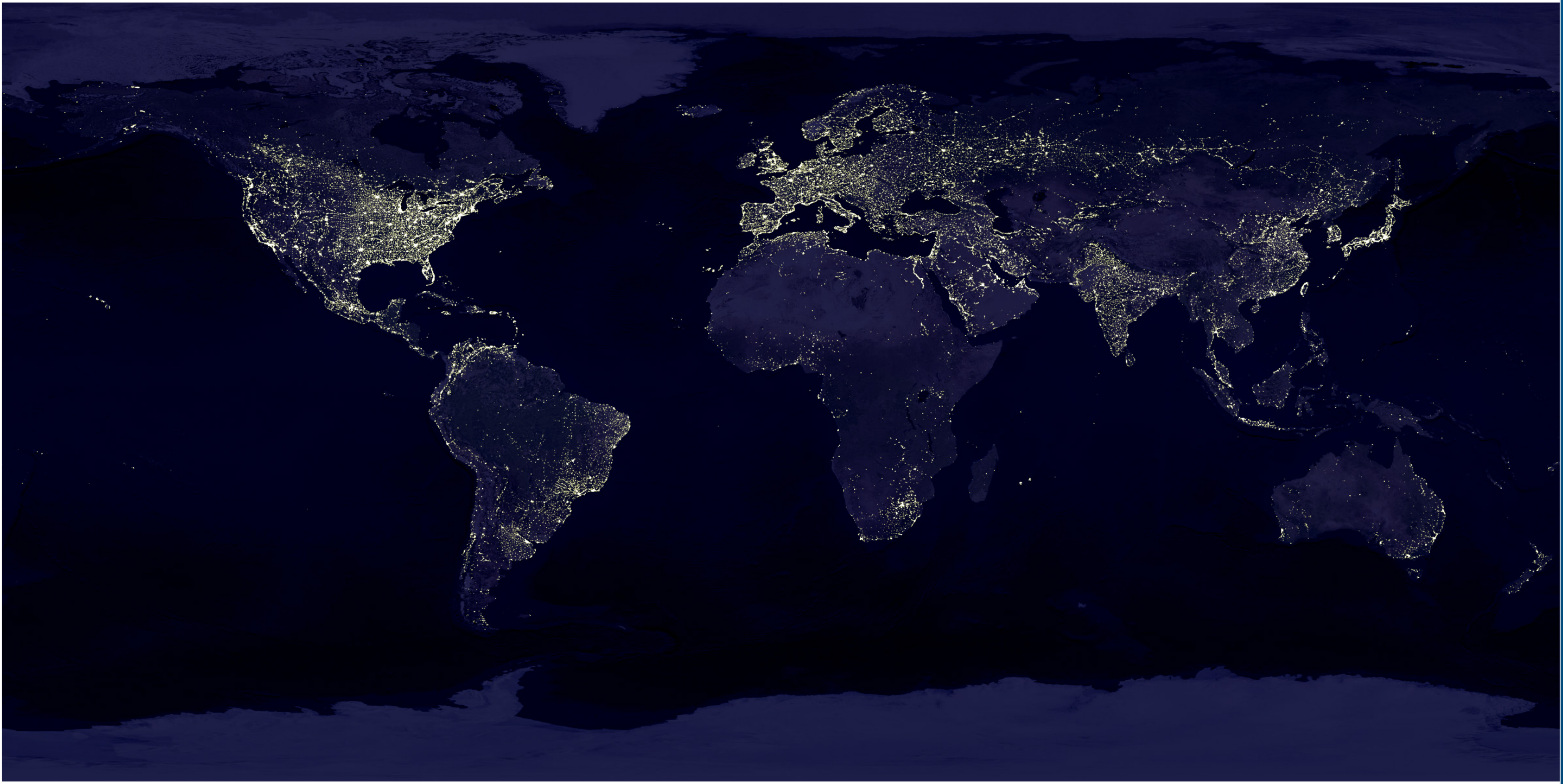
World Coal Consumption



Sources: BP Energy Statistics

Lights at night



Source: NASA

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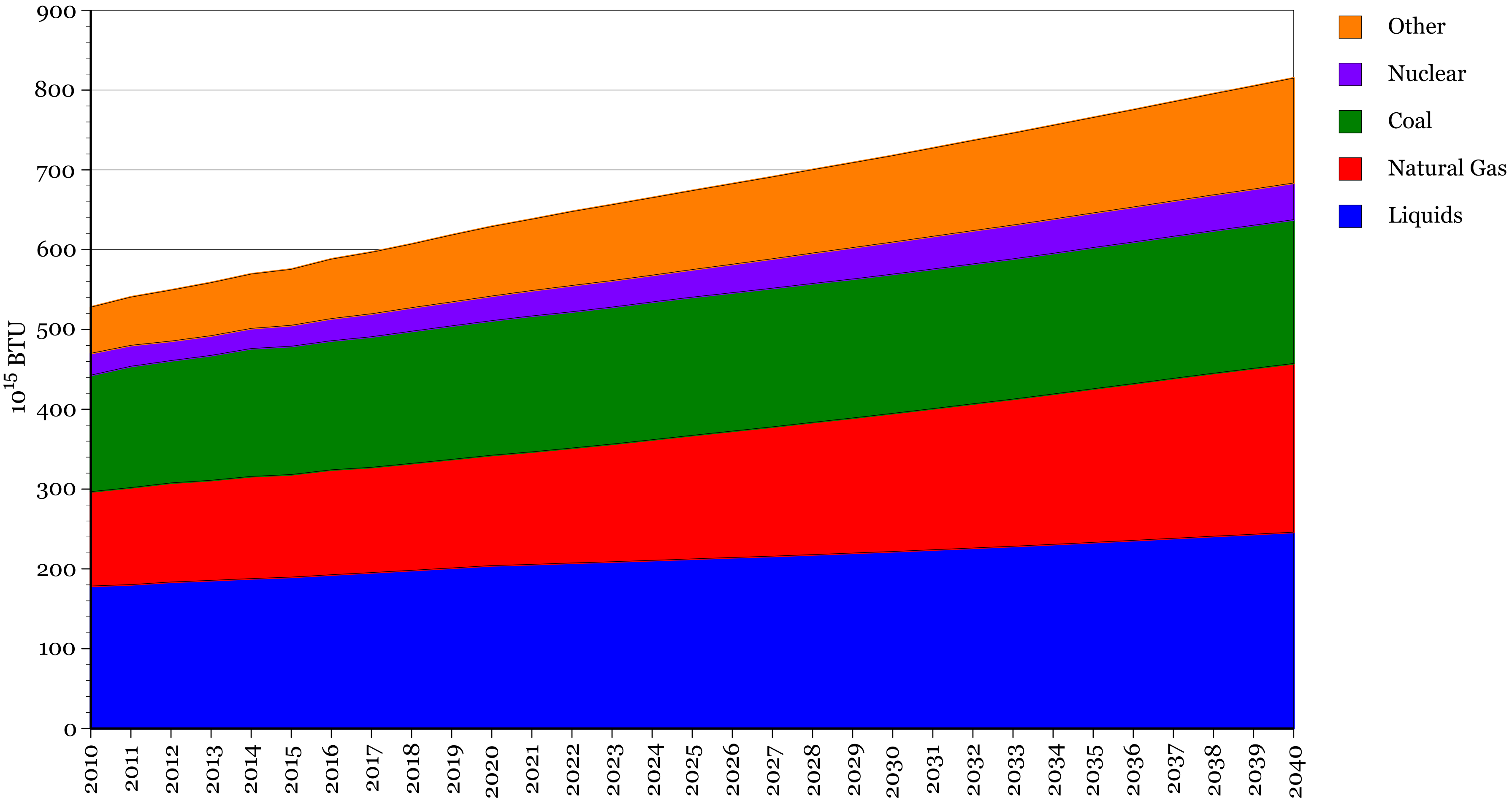
EIA Energy demand forecast



Source: EIA

Replacing fossil fuels in the long run

EIA: Electricity generating and storage costs (real WACC = 7.5%)

Parameter	GT	CC	Wind	Nuclear	Battery storage	Pumped storage
capital cost ($b/GW)	0.678	1.104	1.877	5.945	4.985	5.288
size (MW)	237	429	100	2234	50	250
fixed O&M ($b/GW)	0.0068	0.01	0.0397	0.10028	0.1	0.018
variable O&M ($'000/GWh)	10.7	2.0	0	2.3	0	0
fuel ($'000/GWh)	28.35	18.22	0	1.53	0	0
plant life	30	30	25	60	15	50
indicative load factor	0.05	0.50	0.355	0.9008	0.12	0.12
fixed/output (¢/kWh)	14.66	2.36	6.69	7.00	63.24	40.48
variable (¢/kWh)	3.90	2.02	0	0.38	0	0
total LCOE (¢/kWh)	18.56	4.38	6.69	7.38	63.24	40.48

Source: EIA and author calculations

Benefits/costs of wind generation

- Wind is currently the most cost competitive renewable energy source and has grown rapidly in response to renewable energy subsidies and mandates
- Rapid growth has in turn helped further reduced costs
- Cost-effective electricity storage could solve several problems with wind:
  - Output fluctuates substantially over short intervals
  - Wind generation cannot be dispatched when needed
  - Peak wind output tends to be at night when electricity demand is low
- Other issues: Wind generators on average have comparatively low load factors
  - GWEC statistics for 2015 imply average US load factors of 30.9% and 26.5% in the EU
  - In the analysis below, we use the higher Texas level of 35.5% as in above table
- Wind resources are often remote from load centers and new transmission lines also are used at low load factors

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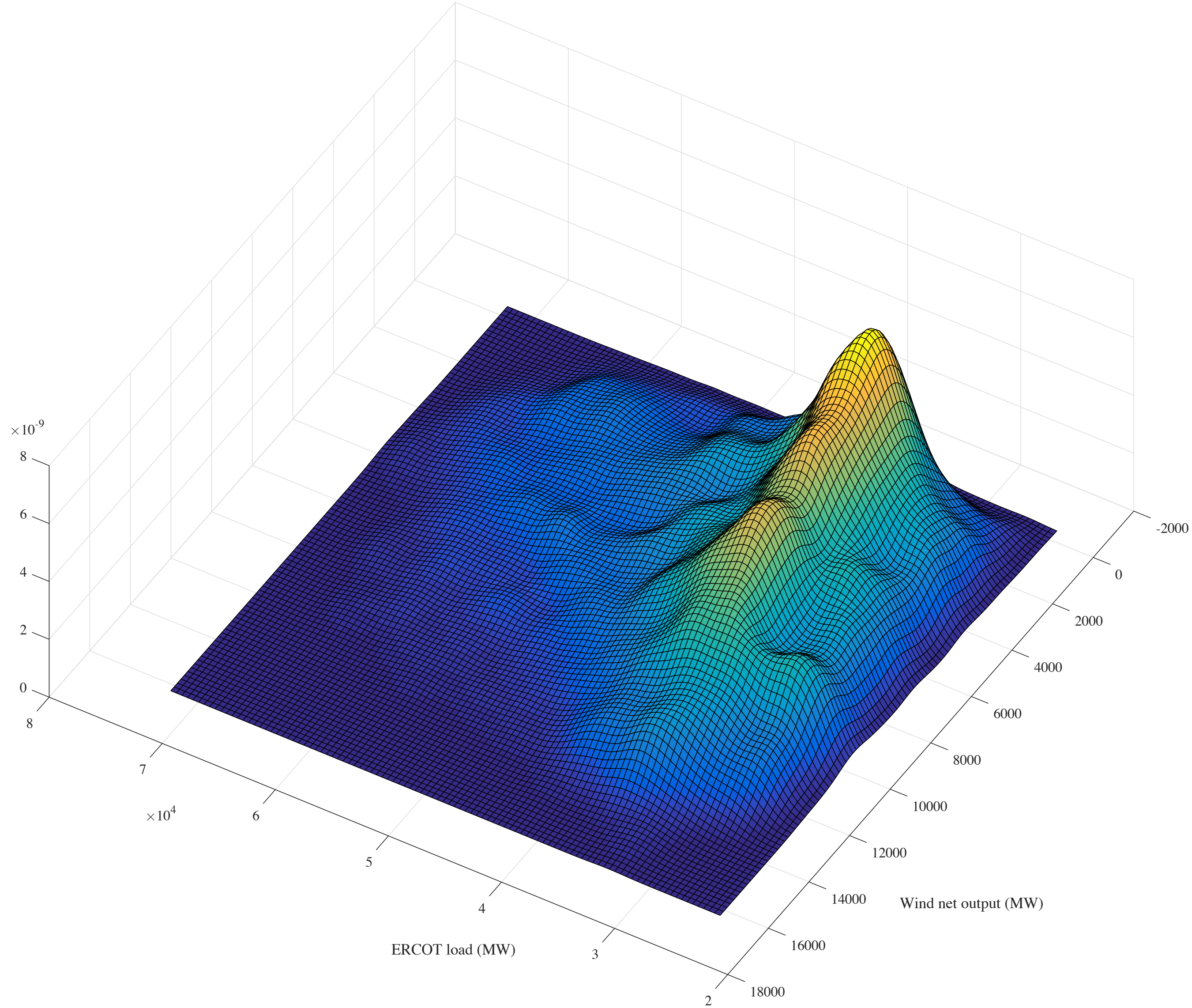
Wind capacity factor and ERCOT load, 2016



Source: ERCOT

Solutions for costs in long-run systems with storage

	WACC		
	0.05	**0.075**	**0.10**
Nuclear and storage			
Annual cost ($b)	29.875	39.798	50.286
Average cost (¢/kWh)	11.46	15.27	19.293
Wind and storage			
Annual cost ($b)	39.438	50.789	63.00
Average cost (¢/kWh)	15.13	19.49	24.171

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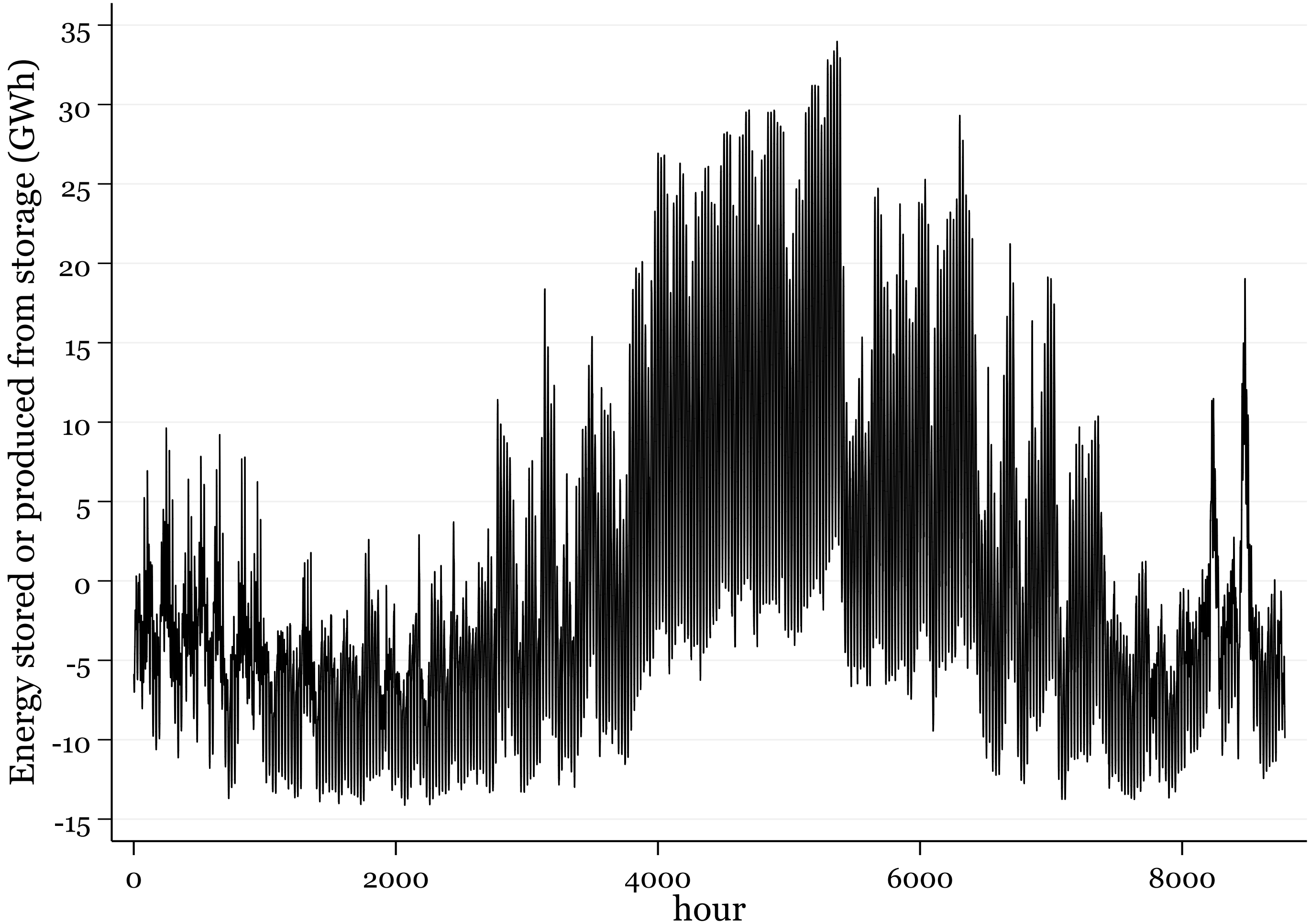
Storage with nuclear



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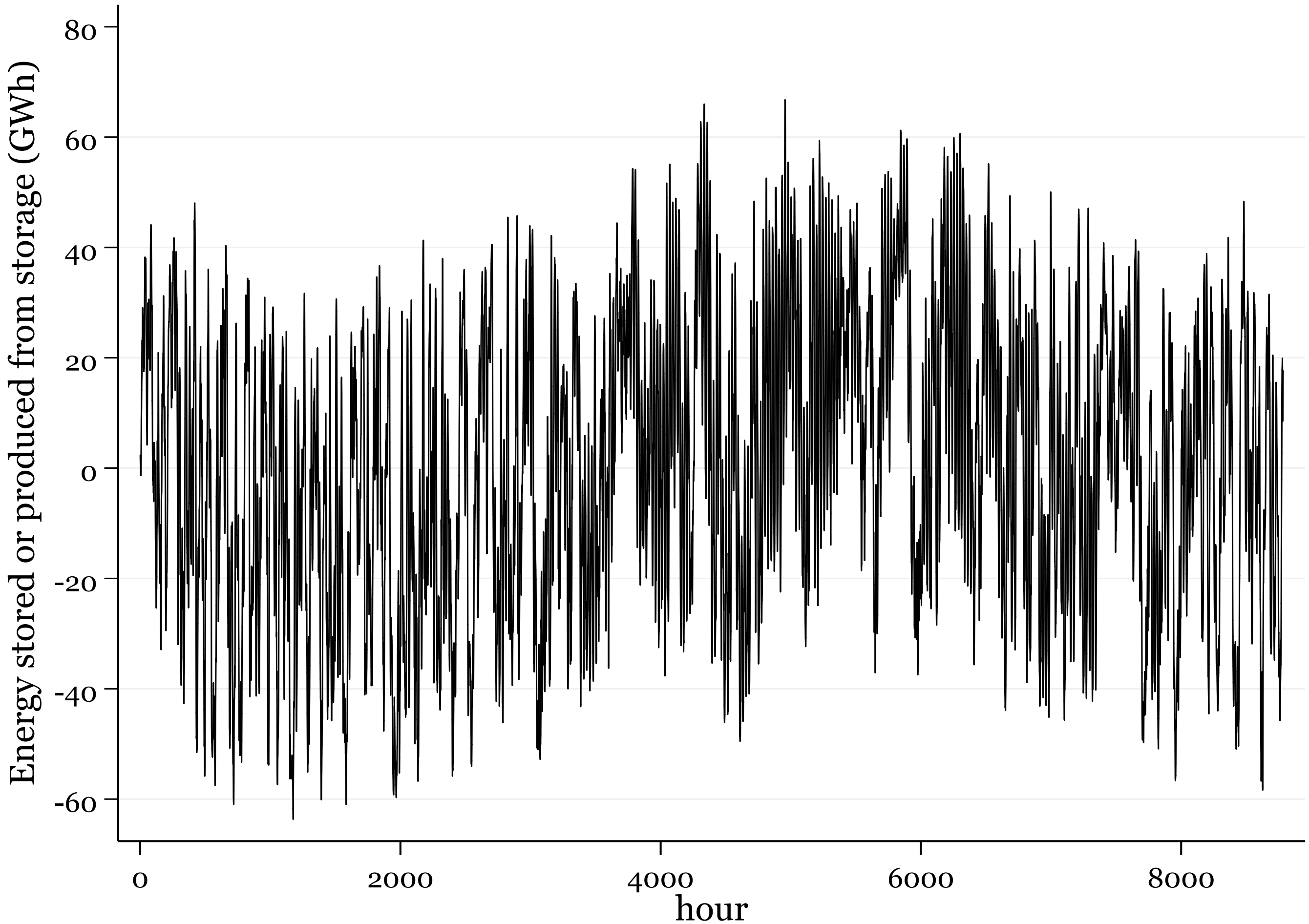
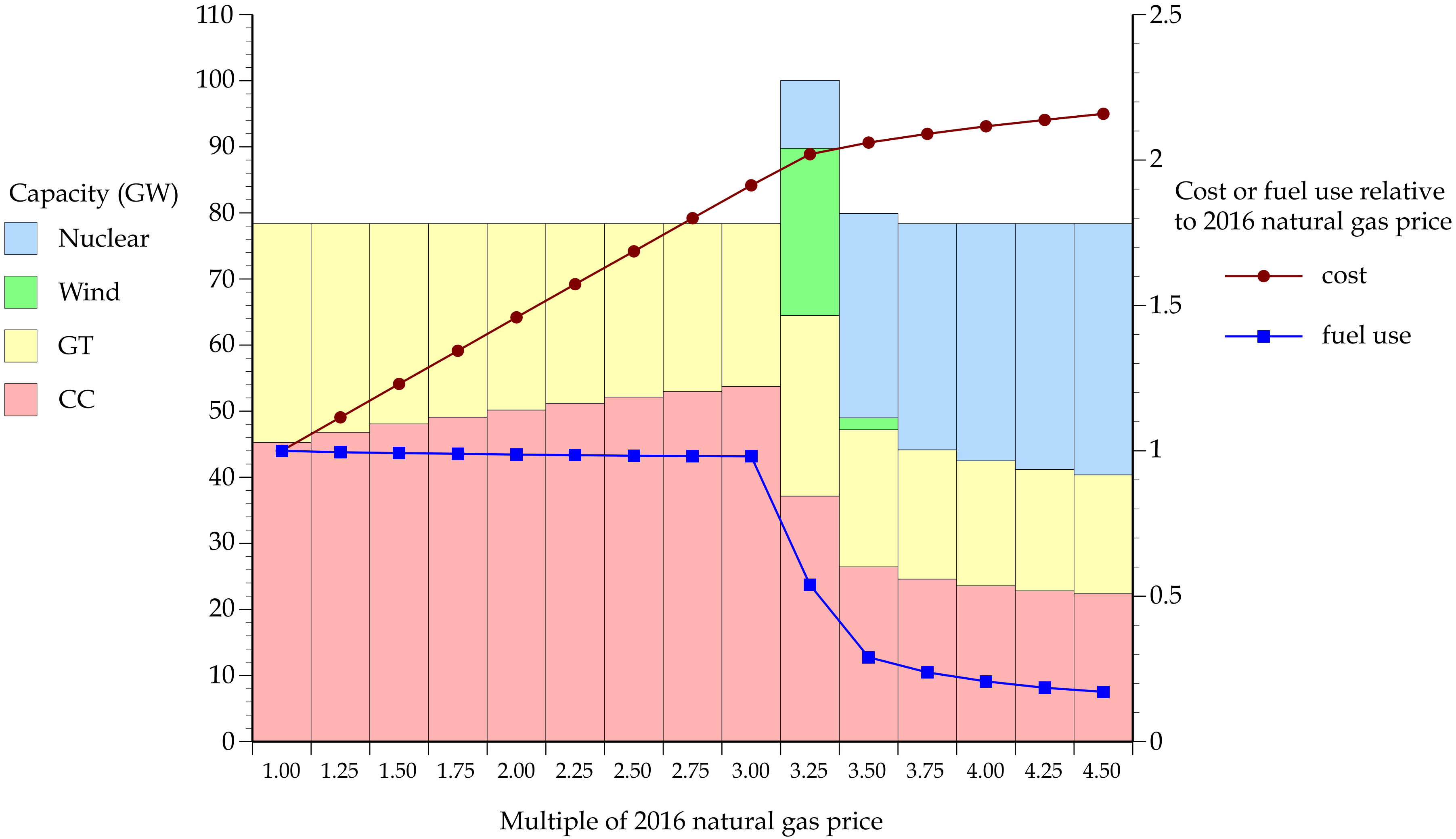
Storage with wind



Transition with WACC = 7.5%



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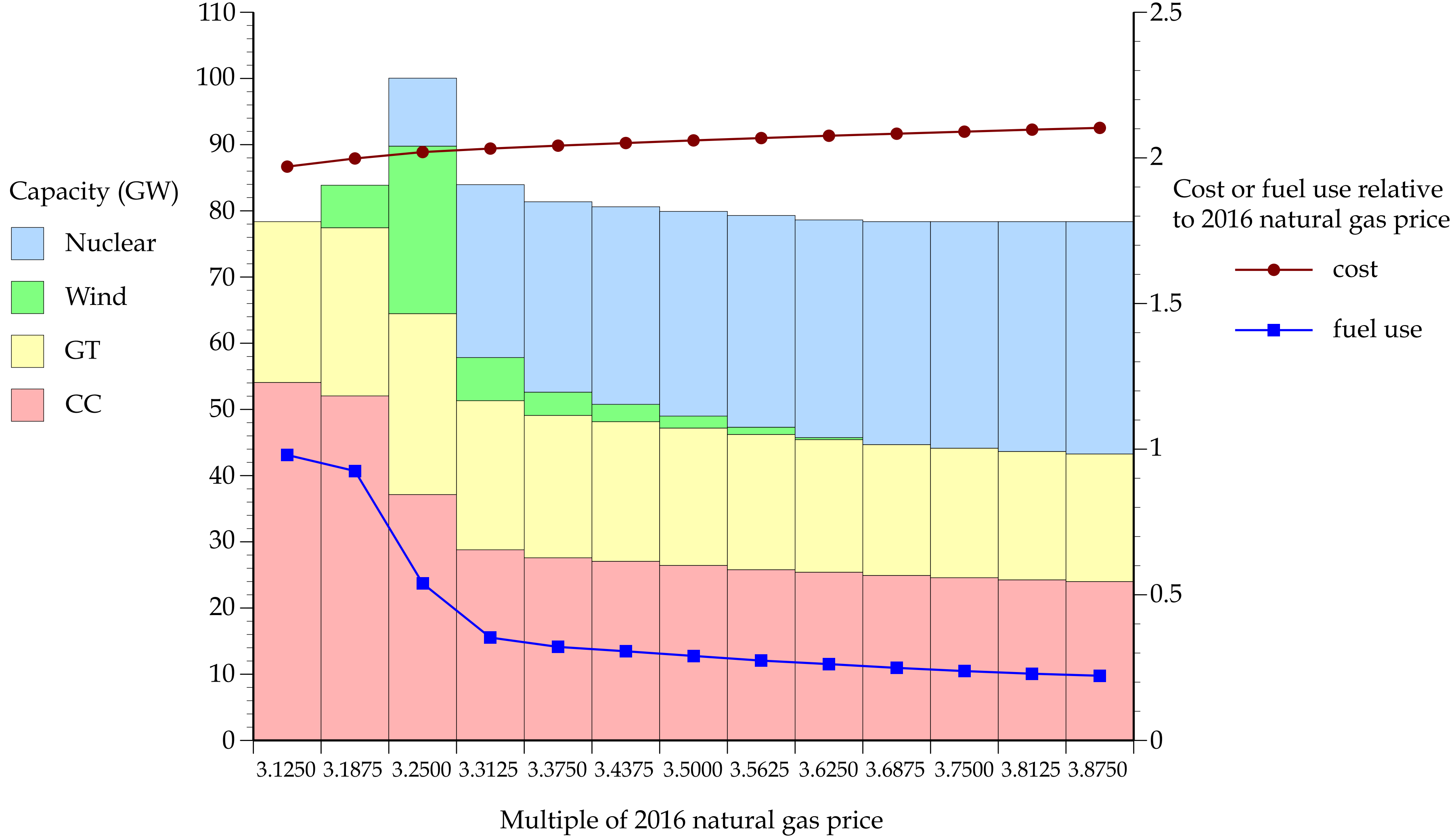
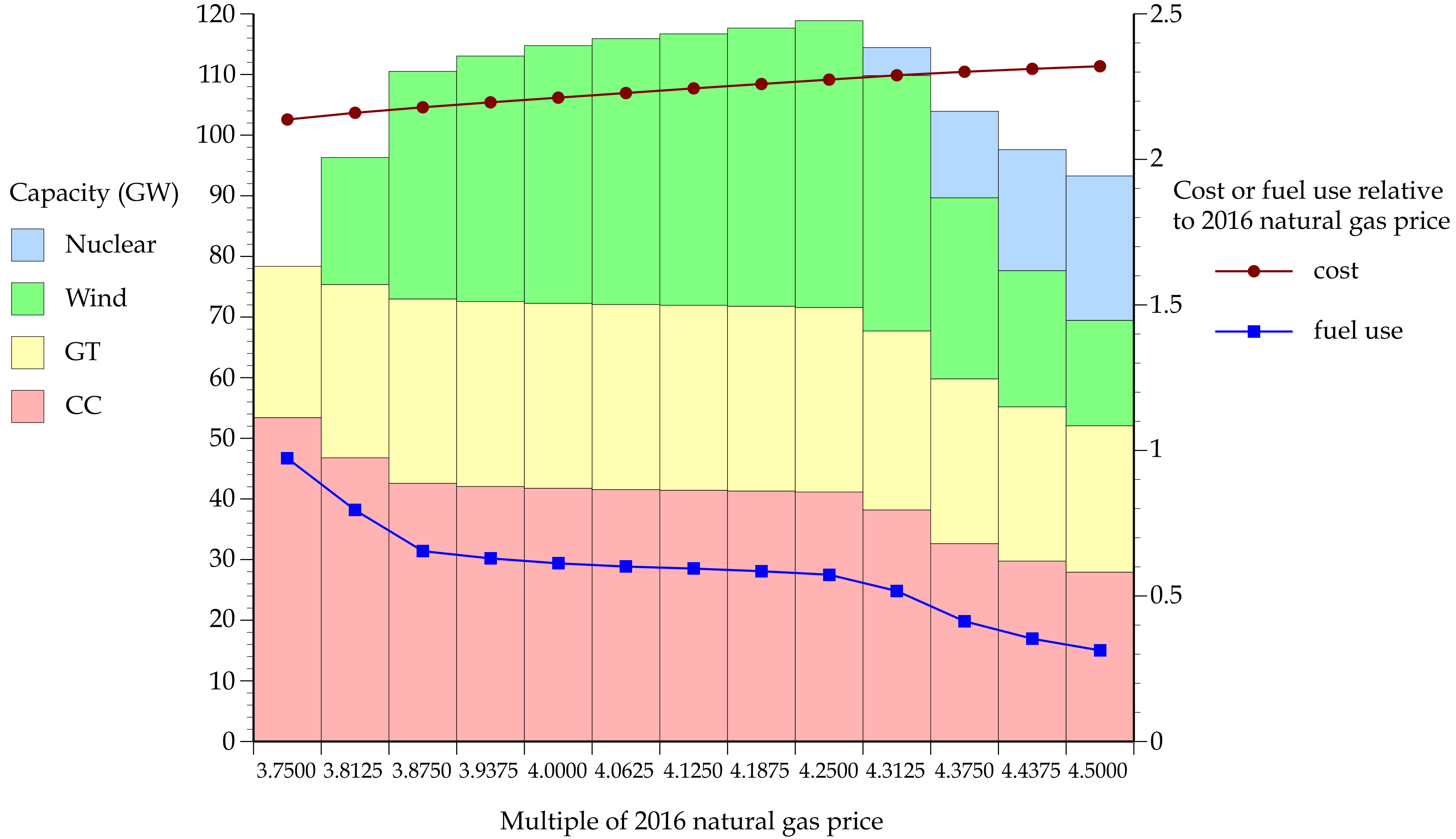
Transition with WACC = 7.5%



Transition with WACC = 10%



Constraining wind capacity to zero, WACC=7.5%

	$p_{NG} = \mathbf{9.22}$		$p_{NG} = \mathbf{9.40}$		$p_{NG} = \mathbf{10.12}$	
	ω free	**ω = 0**	**ω free**	**ω = 0**	**ω free**	**ω = 0**
Annual cost ($b)	28.505	28.507	28.824	28.863	29.385	29.386
Average cost (¢/kWh)	8.11	8.11	8.20	8.21	8.36	8.36
CC capacity (GW)	52.040	54.188	37.144	28.732	26.436	26.202
GT capacity (GW)	25.405	24.179	27.325	21.171	20.750	20.371
Wind capacity (GW)	6.428	0	25.308	0	1.806	0
Nuclear capacity (GW)	0	0	10.265	28.465	30.922	31.794
Pumped storage capacity (GW)	0	0	0	0	0	0
CC load factor (%)	71.24	72.65	56.73	47.85	41.82	41.64
GT load factor (%)	2.59	2.64	2.63	2.92	2.74	2.80
Nuclear load factor (%)			90.05	90.08	89.72	89.72
Fuel used (10^{15}BTU)	2.108	2.234	1.228	0.814	0.661	0.653

Constraining wind capacity to zero, WACC=10%

	p_{NG} = 11.21		p_{NG} = 11.57		p_{NG} = 12.29	
r = .10	ω free	ω = 0	ω free	ω = 0	ω free	ω = 0
Annual cost ($b)	34.440	34.580	34.964	35.389	35.950	36.301
Average cost (¢/kWh)	9.80	9.84	9.95	10.07	10.23	10.33
CC capacity (GW)	42.583	53.660	41.770	54.001	41.139	27.147
GT capacity (GW)	30.394	24.707	30.495	24.366	30.437	20.919
Wind capacity (GW)	37.543	0	42.499	0	47.298	0
Nuclear capacity (GW)	0	0	0	0	0	30.301
Pumped storage capacity (GW)	0	0	0	0	0	0
CC load factor (%)	60.74	73.26	57.85	72.87	54.93	44.70
GT load factor (%)	2.74	2.83	2.65	2.71	2.55	2.92
Nuclear load factor (%)						89.97
Fuel used (10^{15}BTU)	1.503	2.236	1.407	2.234	1.317	0.724

Summary comments

- Technological change in producing and using fossil fuels keeps them competitive
- Natural gas is preferred to coal for electricity generation on environmental grounds and in the US it is also currently less costly
  - Developments in LNG should help make natural gas more competitive globally
- But natural gas is also an expensive fuel with high infrastructure needs
- Developing countries still have a tremendous demand for energy and will prefer the cheapest available
- In the long-run, energy density favors nuclear (of some sort) as a replacement for fossil fuels
- Storage is thought to be the answer for renewables, but it helps stable base load power more by allowing larger capacity to run 24/7 and supply all the load
  - Intermittent and non-dispatchable sources like wind require much more storage to supply the same power output, greatly raising their overall costs