Outlook and Benefits of An Efficient U.S. Coal Fleet

Final Report

January 2019

Outlook of US HELE Plants

Objectives of this study

(1) Benchmark the installed capacity of US HELE plants against other jurisdictions

- Benchmarking of the US installed capacity of HELE plants
- Lessons learned from other jurisdictions on what it takes to foster the development of HELE plants
- Realistic scenarios for the pace of development of HELE plants in the US, in light of the experience of countries ahead of the curve

(2) Estimate the positive impact of HELE plants not monetized by private investors

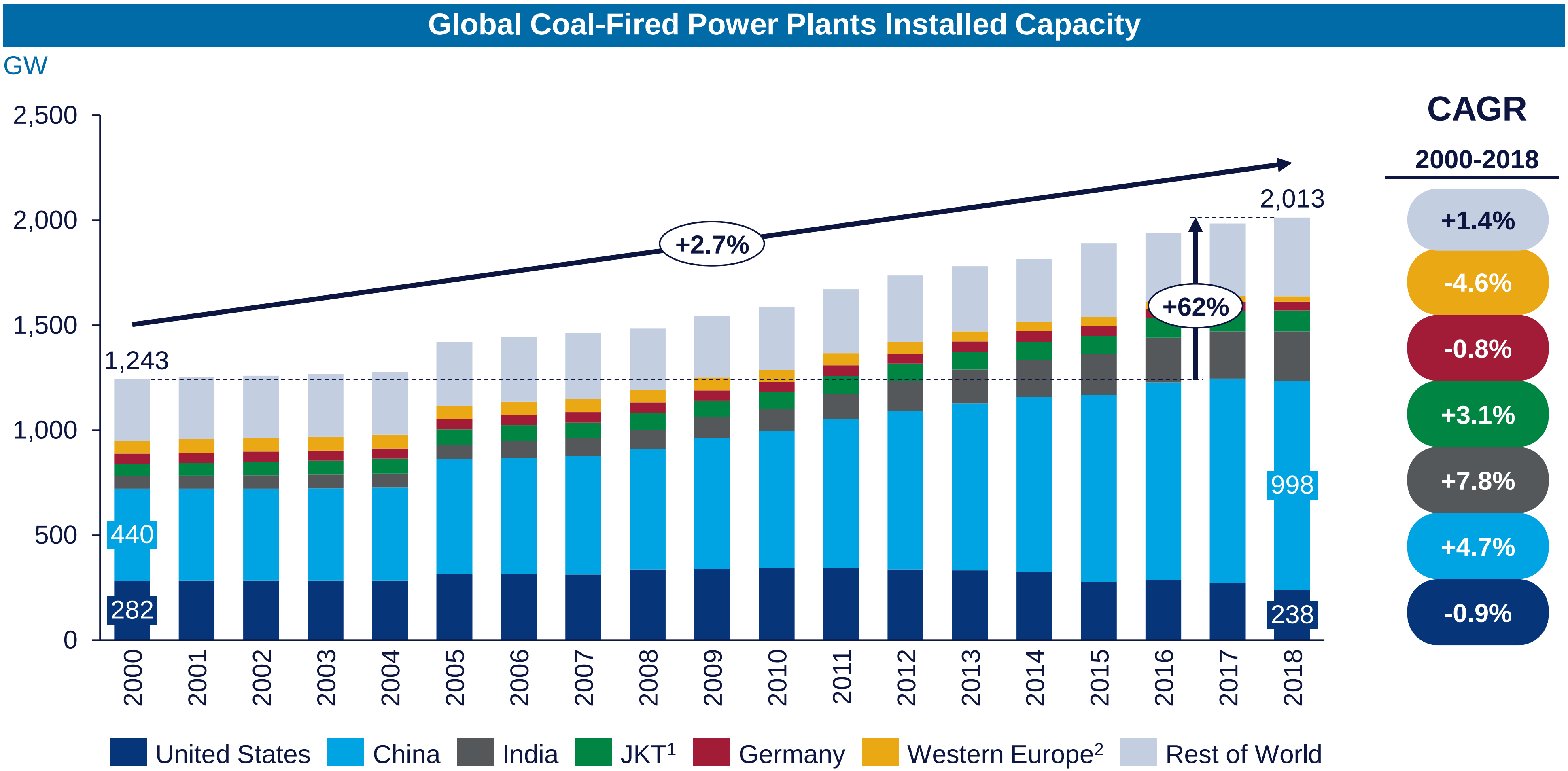
- Estimate other benefits not monetized, not properly captured by private investors
- Social valuation of HELE plants, encompassing benefits currently not monetized by investors

(3) Drive implications for policies and regulations

- Findings to foster the development of HELE plants in the US
- Potential implications for coal policies and regulations

Coal-fired power plants capacity has grown 62% globally since 2000, exceeding 2,000 GW in 2018

Coal still is and will continue to be a predominant fuel in the global energy matrix



Note: 1. JKT refers to Japan, South Korea and Taiwan. 2. Western Europe includes Spain, UK, Netherlands, France, Denmark and Belgium
Source: Wood Mackenzie Energy Market Service, Coal Market Service

Growth in coal plant capacity has been led by HELE power plants commissioned in the past decade

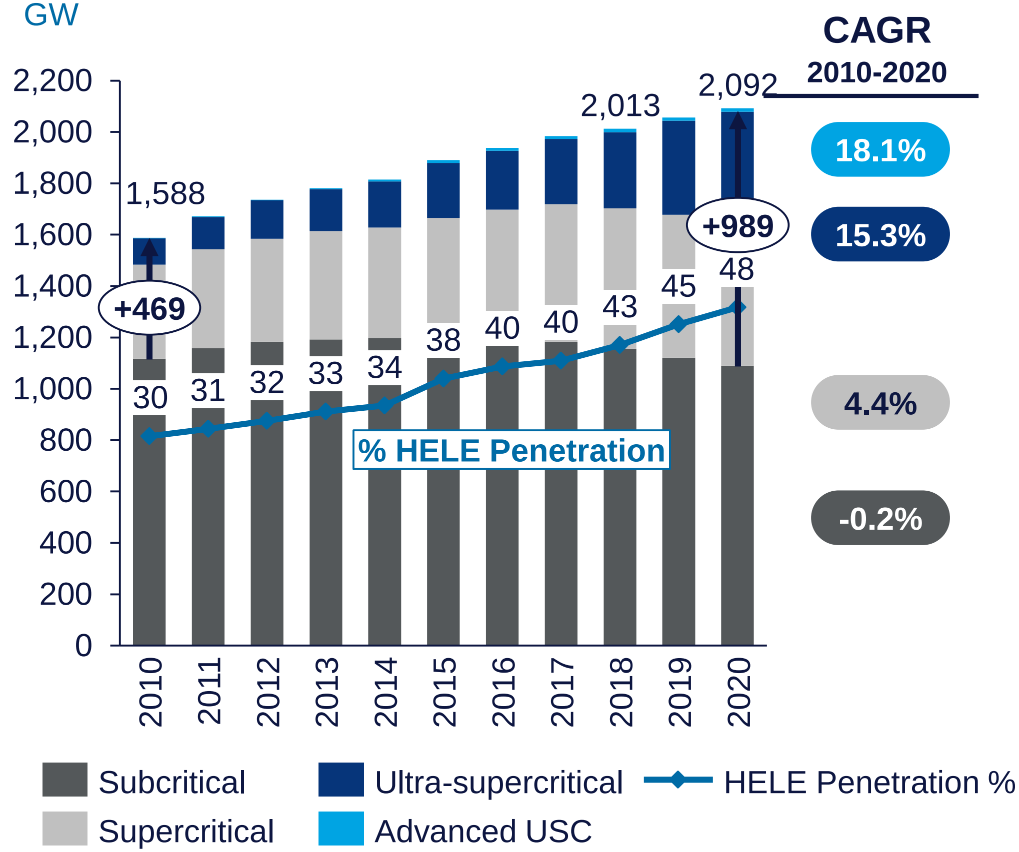
HELE plant share of total coal-fired power capacity increased from 30% to over 40%, and is expected to continue rising as new HELE plants replace subcritical plants

HELE Power Plant Definition

Category	Efficiency Rate	CO_2 Intensity	Coal Consumption	Steam Temperature
Advanced ultra-supercritical	More than 45%	670-740 g CO_2/ kWh	290-320 g/kWh	700ºC+
Ultra-supercritical	Up to 45%	740-800 g CO_2/ kWh	320-340 g/kWh	600ºC+
Supercritical	Up to 42%	800-880 g CO_2/ kWh	340-380 g/kWh	Approx. 550ºC-600ºC
Subcritical	Up to 38%	≥880 g CO_2/ kWh	≥380 g/kWh	<550ºC

HELE Plants

Global Coal-Fired Power Plants Installed Capacity[1]

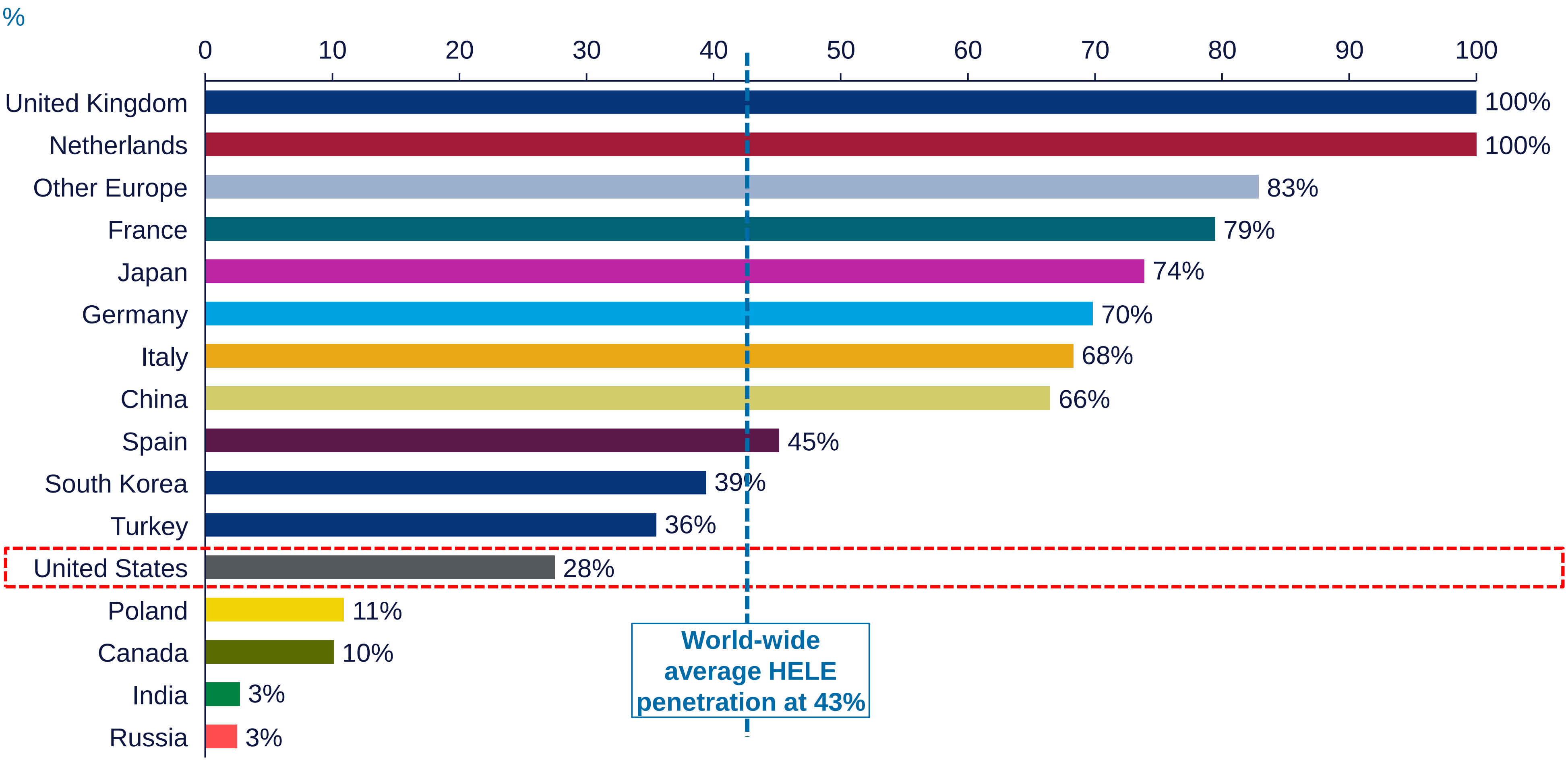


Note: 1. Coal-fired power plant capacity forecast is based on the under construction and announced power plant projects and planned retirements
Source: Wood Mackenzie, World Coal Association, EIA

HELE plants represent 43% of worldwide total coal-fired capacity

Among the major economies, Japan, Germany and China lead the world in coal plant efficiency

HELE Share of Total Coal-Fired Installed Capacity

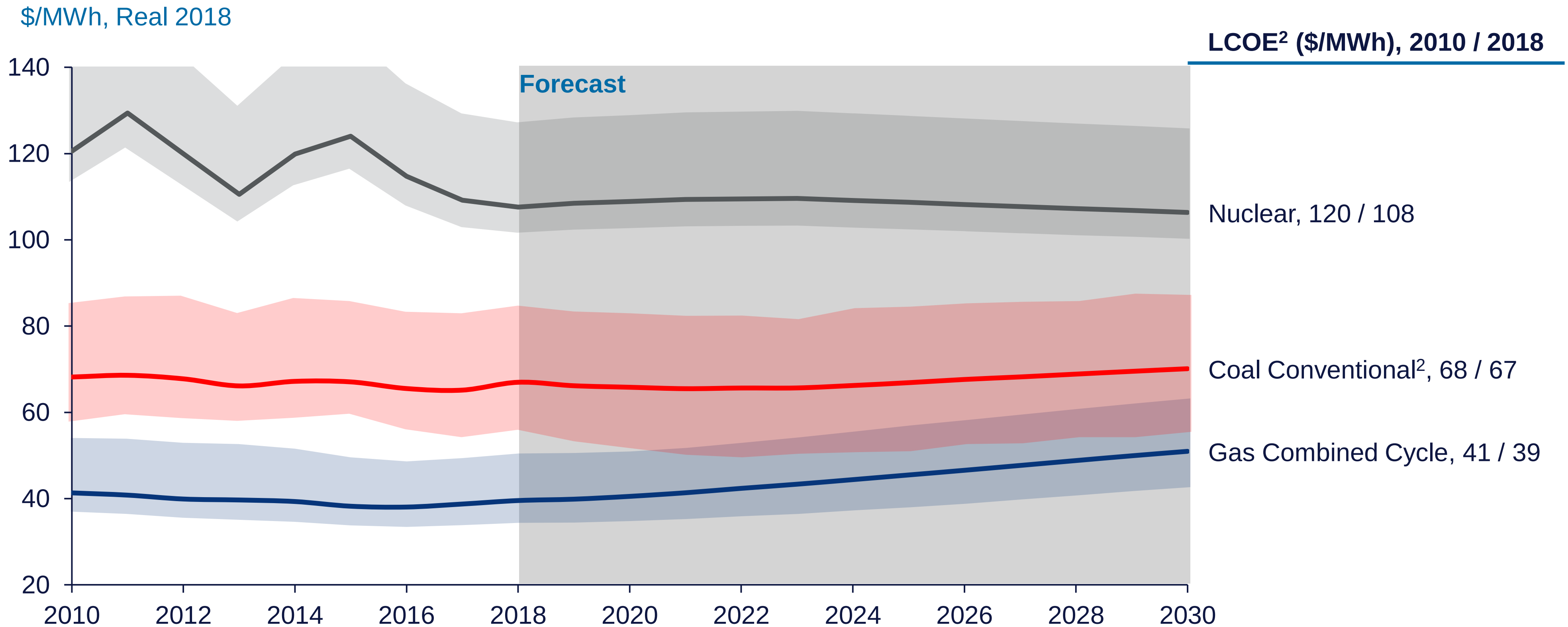


Source: Wood Mackenzie, EIA

Baseload dispatchable power plant economics

Fuel prices and capital costs hold challenges and offer opportunities

US Historical and Forecasted Levelized Cost by Technology[1]



Prior to the 2009 crash in natural gas prices, coal-fueled power plants long offered the lowest LCOE in the US

Note: 1. The lines represent the averages of all US states. The range present the maximum and minimum states 2. The conventional coal plant is assumed as Non-CCS (Carbon Capture and Storage).
Source: Wood Mackenzie North America Power and Renewable Service

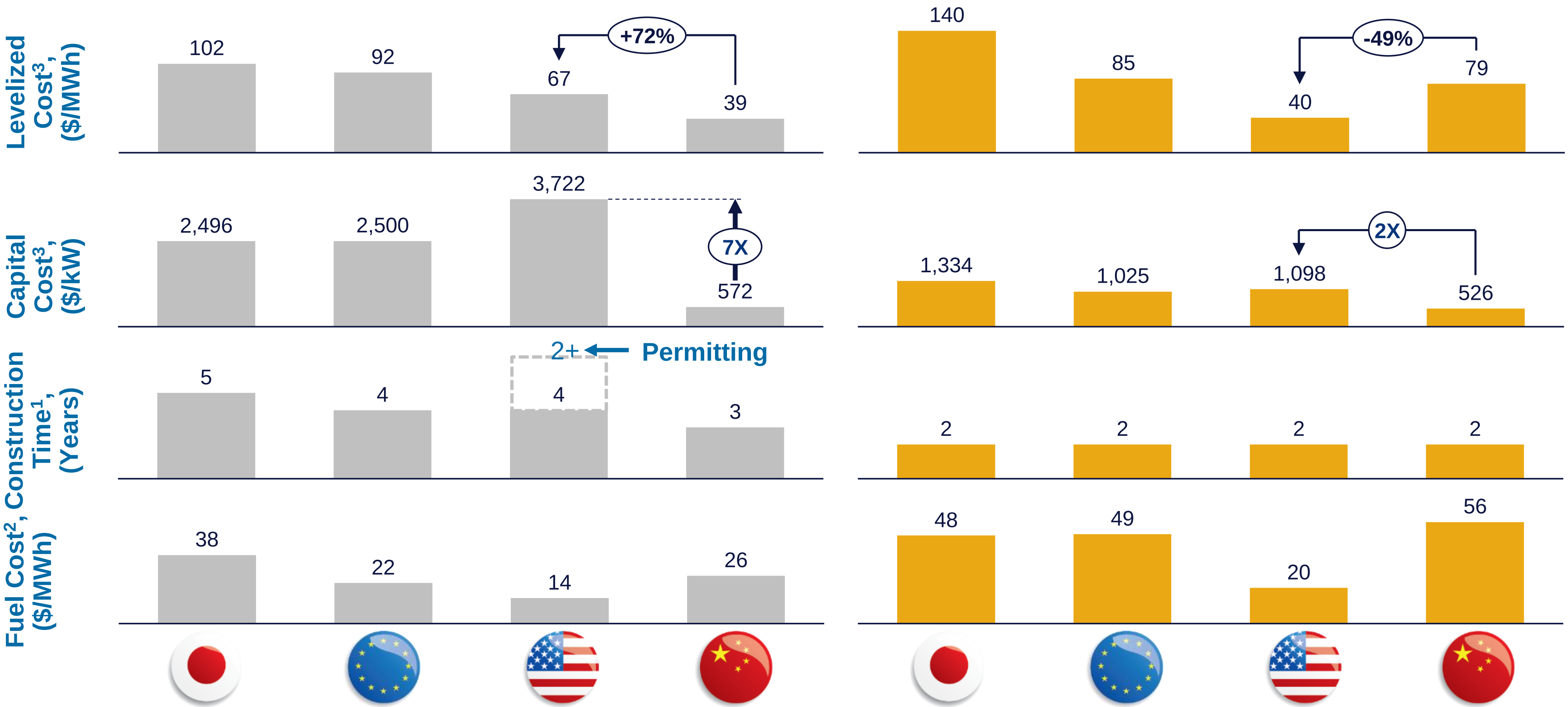
Reducing US HELE plant CAPEX is key for their competitiveness

US HELE plants exhibit a 72% higher levelized cost than Chinese plants due to a CAPEX difference of seven times

Comparison of combined cycle natural gas CAPEX in US and China shows opportunity for reduction of US HELE CAPEX

HELE Coal Plant Economics

Combined-Cycle Gas Plant Economics



Note: 1. Europe is the modelling assumption. US construction time is the average of several recent HELE power plants, including John Turk Jr Plant, Prairie State Generating Station, Trimble County Generating Station 2, and Longview Power. Japan construction time is the average of several currently under construction power plants, including Takehara power station new unit 1, Noshiro power station unit 3, Matsuura Kyushu power station unit 2, Sumitomo Metals Kashima power station Unit 2, Taketoyo power station Unit 5 and Hitachinaka Kyodo power station Unit 1
2. Assume imported LNG for China. 3. Costs are all in Real 2018 US$

Source: Wood Mackenzie, World Coal Association, Danish Energy Agency, IEA, NEA

However, HELE plants have other benefits that are not usually monetized using conventional power plant economics

Other Benefits not Currently Monetized by HELE Plants	
Infrastructure	Do not require significant network upgrades Do not require backstop generation or energy storage (e.g. batteries)
Market	Provide greater reliability, strengthen energy security and improve US competitiveness (key trading partners are using HELE technology and it enhances their competitive position) Provide ancillary services (spinning reserve, voltage regulation, resiliency) Do not require a new market paradigm
Impacts on Economy	Expand payrolls, tax base and increases revenues for local contractors, suppliers, service providers and ancillary businesses Increase construction jobs Stimulate US manufacturing industry

Source: Wood Mackenzie

HELE power plants help reduce uncertainty in the power markets, a benefit not recognized by the industry and the public

Additionally, some market opportunities for HELE plants are not being properly considered

Higher natural gas prices[1]

Uncertainty

- **Gas supply**: a) Reduced supply due to increased fracking regulation, e.g. New York fracking ban and Colorado Proposition 112; b) limitation on available shale drilling locations and c) worse than expected well performance.
- **Domestic gas demand**: Increased gas demand from the petrochemical industry.
- **Gas exports**: Rising LNG exports due to higher global gas demand and increasing US to Mexico piped exports.
- **Infrastructure requirements:** Investments required for interstate and intrastate gas pipeline projects in the US. Several large pipeline projects have drawn opposition by local communities and environmental groups.

Renewables integration into the grid[1]

Uncertainty

- **Feasibility:** Challenges to integrate renewables into the current grid system, which is designed by the dispatch model.
- **High cost:** Renewables integration would require market redesign and additional investments in the grid.
- **Resilience and reliability:** Grid reliability issues as renewables (mostly solar and wind) are intermittent resources.
- **Dependency on energy storage**: Renewables depend on utility-scale battery technologies to mature.

HELE plant construction

Opportunity

- **Lower capital cost:** Leading HELE technology in the US, streamlined EPC process and domestically manufactured plant equipment.
- **Faster development time:** More time-efficient plant construction, shortened HELE power plant permitting process and regulation requirement.

Higher electricity demand

Opportunity

- **Stronger economy and faster population growth:** Higher GDP growth rate (seen in recent years) could drive up electricity demand across all sectors.
- **Electric vehicle and household electrification:** Residential and transportation power demand could increase as a result.
- **Digitization, automation and big data:** Increase in industrial power demand.

Note: 1. See appendix for details
Source: Wood Mackenzie

Under scenario 5, installed HELE plants capacity could increase by 155 GW and coal consumption for power by 67%

Scenario definitions (2018-2035)

1 Business as usual

- Base case Henry Hub forecast
- Base case solar LCOE
- US level HELE plant CAPEX

2 High gas price

- 2X Henry Hub forecast
- Base case solar LCOE
- US level HELE plant CAPEX

3 Scenario 2 + level solar cost[2]

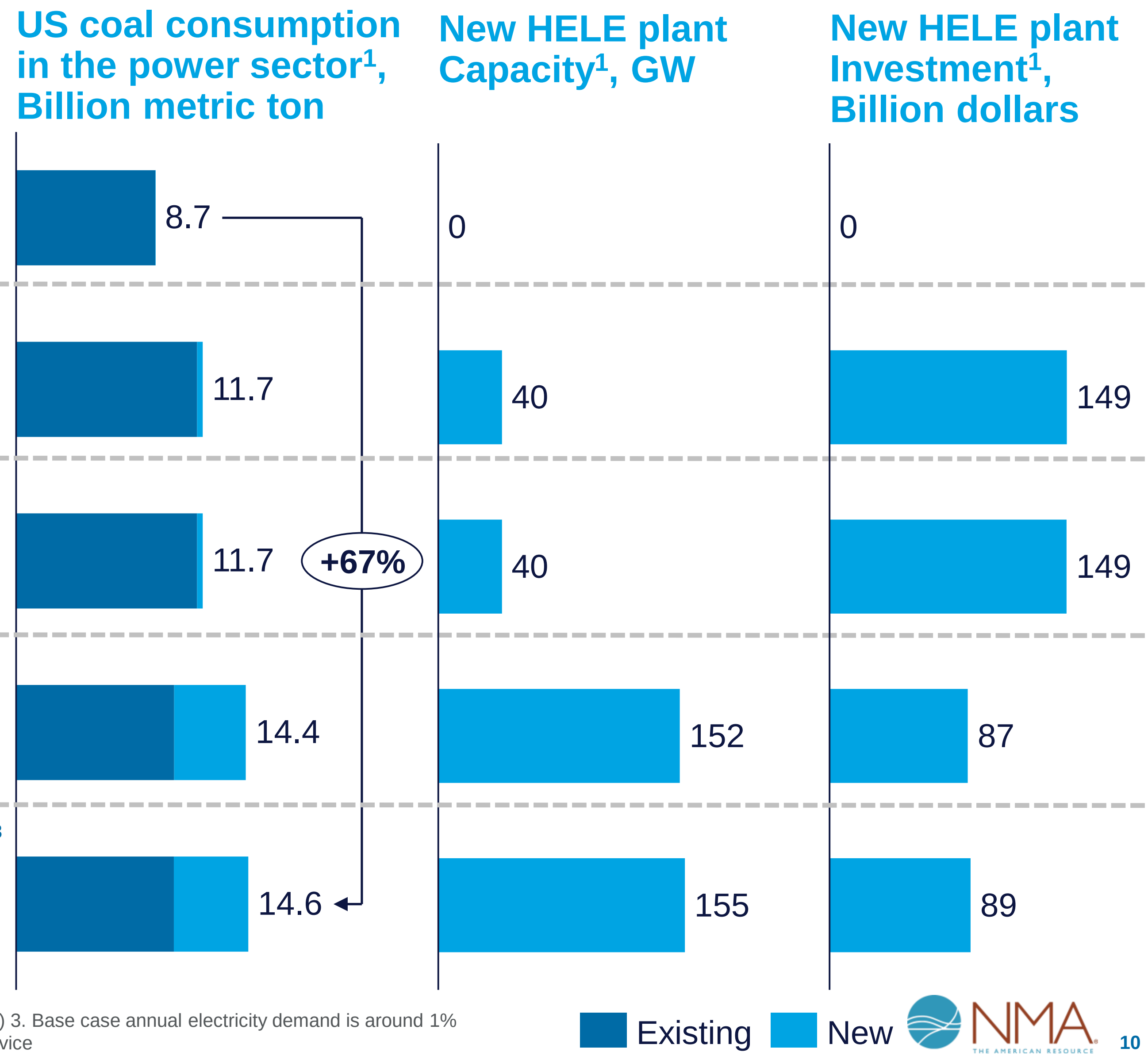
- 2X Henry Hub forecast
- Flat solar LCOE forecast
- US level HELE plant CAPEX

4 Scenario 3 + low HELE plant cost

- 2X Henry Hub forecast
- Flat solar LCOE forecast
- Chinese level HELE plant CAPEX

5 Scenario 4 + higher electricity demand[3]

- 2X Henry Hub forecast
- Flat solar LCOE forecast
- Chinese level HELE plant CAPEX
- 2% electricity demand growth



Note: 1. Including 2018-2035. 2. Without ITC (Investment Tax Credit) 3. Base case annual electricity demand is around 1%
Source: Wood Mackenzie North America Power and Renewable Service

Suggested ideas to foster HELE power plant deployment in the US

We envision the HELE development in the US to require policy support from a regulatory, economic and technological standpoint in addition to potential market opportunities

Regulations

- Support the Administration in the pulling back / streamlining of regulatory requirements

Financing

- Support financial institutions that finance HELE projects
- Provide insurance for HELE projects
- Lift restrictions on global lending for coal power plants

Level the Playing Field

- Provide ITC/PTC for coal or eliminate them for other generation technologies
- Develop a methodology to calculate the "true cost" to capture infrastructure savings and reward resiliency, fuel diversity and social benefits

Coal Plant Technology

- Encourage US EPC firms to participate in HELE development overseas
- Support cogeneration technologies to increase the power plant efficiency

Opportunities

- Natural gas prices begin to rise due to regulation and limitations on fracking and higher gas demand
- Limitations to the integration of renewables
- Form global alliances with countries planning to continue to use coal and promote the use of efficient coal technologies
- Higher electricity demand in the US

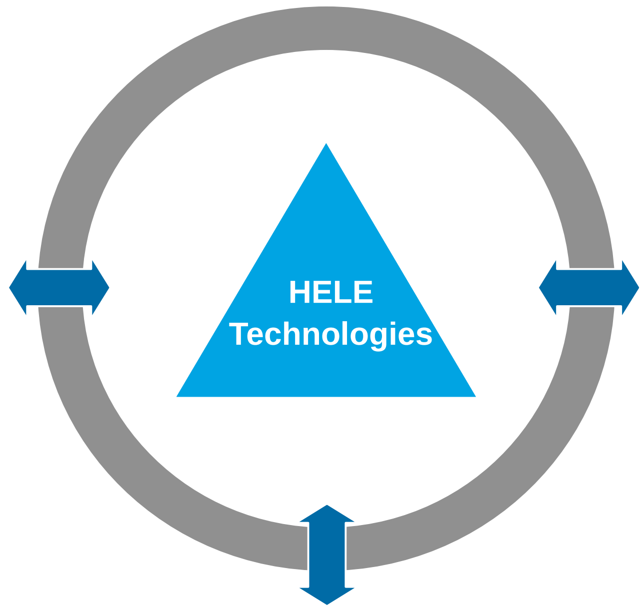
Agenda

What are the advanced coal technologies?

The technologies applied to achieve higher efficiency and low emission from coal-fired power plants include

Supercritical & Ultra-supercritical

- Based on a pulverised coal combustion system
- These technologies operate at pressures and temperatures where liquid water and gaseous water are stable while coexisting. At this point there is no difference between both states
- The process results in lower heat rates, hence higher efficiency



Fluidised Bed Combustion

- This technology allows a greater flexibility in the use of fuels like coal, waste and biomass
- The process consists of a mixture of solid particles suspended in an ascending gas flow, that together have fluid properties
- The combustion takes place in the bed with high calorific transfer to the unit, but low combustion temperatures

Integrated Gasification Combined Cycle (IGCC)

- It combines cycle technology that employs gas and steam turbines. This integrated gasification results in high temperatures with an efficiency of up to 55%
- This technology uses a gasifier to convert coal (or other carbon-based materials) to syngas which powers the combined cycle turbine

Source: Wood Mackenzie, World Coal Association, KPMG, Universidad del Callao: Mechanical Engineering Faculty

What are the parameters for different HELE plant categories?

Global HELE Power Plant Definition – Excluding US

Category	Efficiency Rate	CO_2 Intensity	Coal Consumption	Steam Temperature
Advanced ultra-supercritical	More than 45%	670-740 g CO_2/ kWh	290-320 g/kWh	700ºC+
Ultra-supercritical	Up to 45%	740-800 g CO_2/ kWh	320-340 g/kWh	600ºC+
Supercritical	Up to 42%	800-880 g CO_2/ kWh	340-380 g/kWh	Approx. 550ºC-600ºC
Subcritical	Up to 38%	≥880 g CO_2/ kWh	≥380 g/kWh	<550ºC

US HELE Power Plant Definition (EIA)

Due to the difference in efficiency measurements, WM used EIA supercritical and ultra-supercritical definitions[1] for US coal power plants and combined with Wood Mackenzie data to conduct this analysis

Advanced ultra-supercritical Power Plants

(None)

Ultra-supercritical Power Plants

John W Turk Jr 1	Arkansas	614 MW	Start-up in 2012

Supercritical Power Plants (Examples)

Longview Power LLC 1	West Virginia	700 MW	Start-up in 2011
Trimble County 2	Kentucky	747 MW	Start-up in 2011
Iatan 2	Missouri	850 MW	Start-up in 2010
Sandy Creek Energy	Texas	927 MW	Start-up in 2013
Prairie State Station 1	Illinois	800 MW	Start-up in 2012

Subcritical Power Plants (Examples)

Crystal River 2	Florida	494 MW	Start-up in 1969
Seminole (FL) 2	Florida	660 MW	Start-up in 1985
Cope ST1	South Carolina	420 MW	Start-up in 1996
Trenton Channel 9	Michigan	518 MW	Start-up in 1968
Cross 3	South Carolina	551 MW	Start-up in 2007

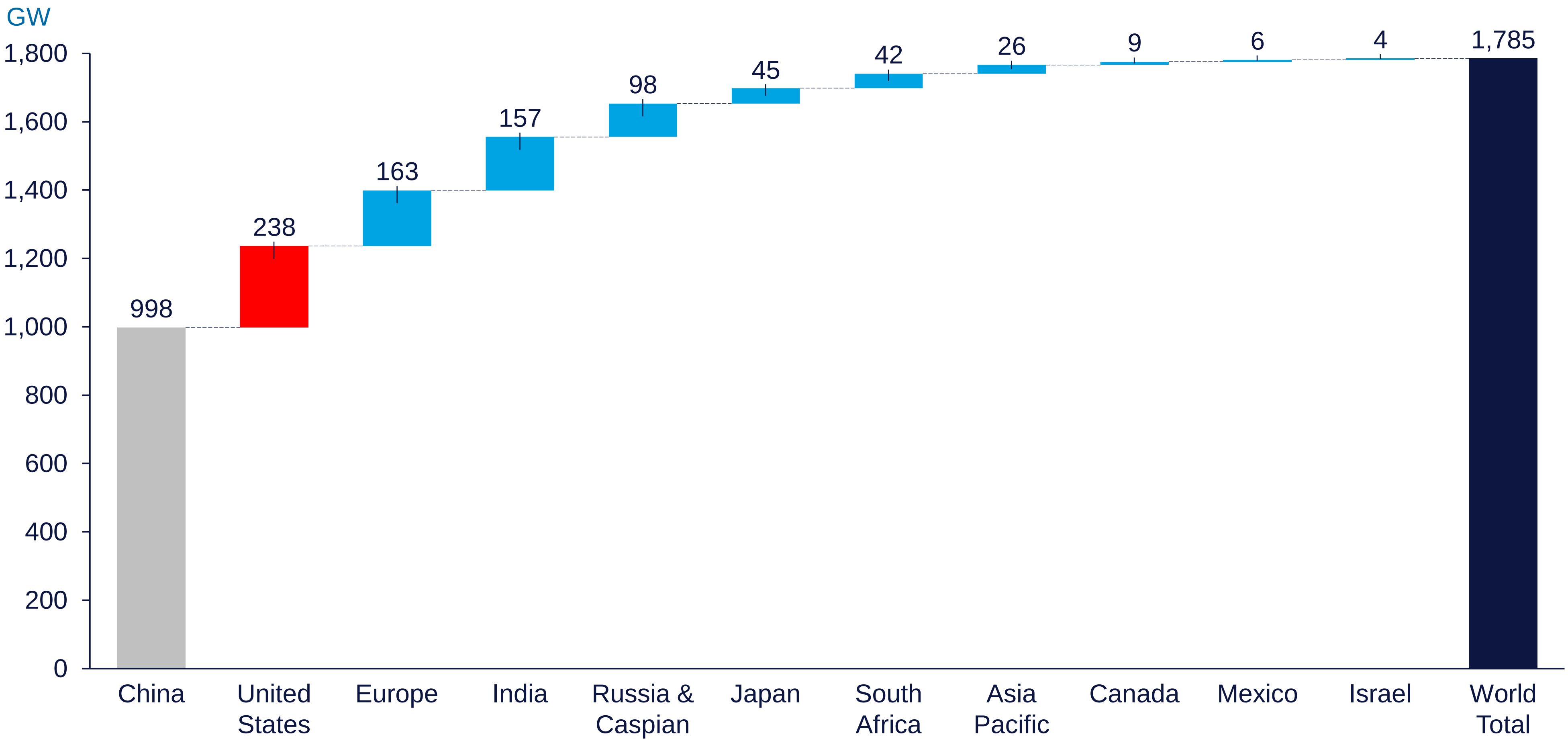
Note: (1) https://www.eia.gov/electricity/data/eia860/
Source: Wood Mackenzie, World Coal Association, EIA

Agenda

Global: Coal-fired power installed capacity

China currently has the highest coal-fired installed power capacity in the world followed by the US and Europe

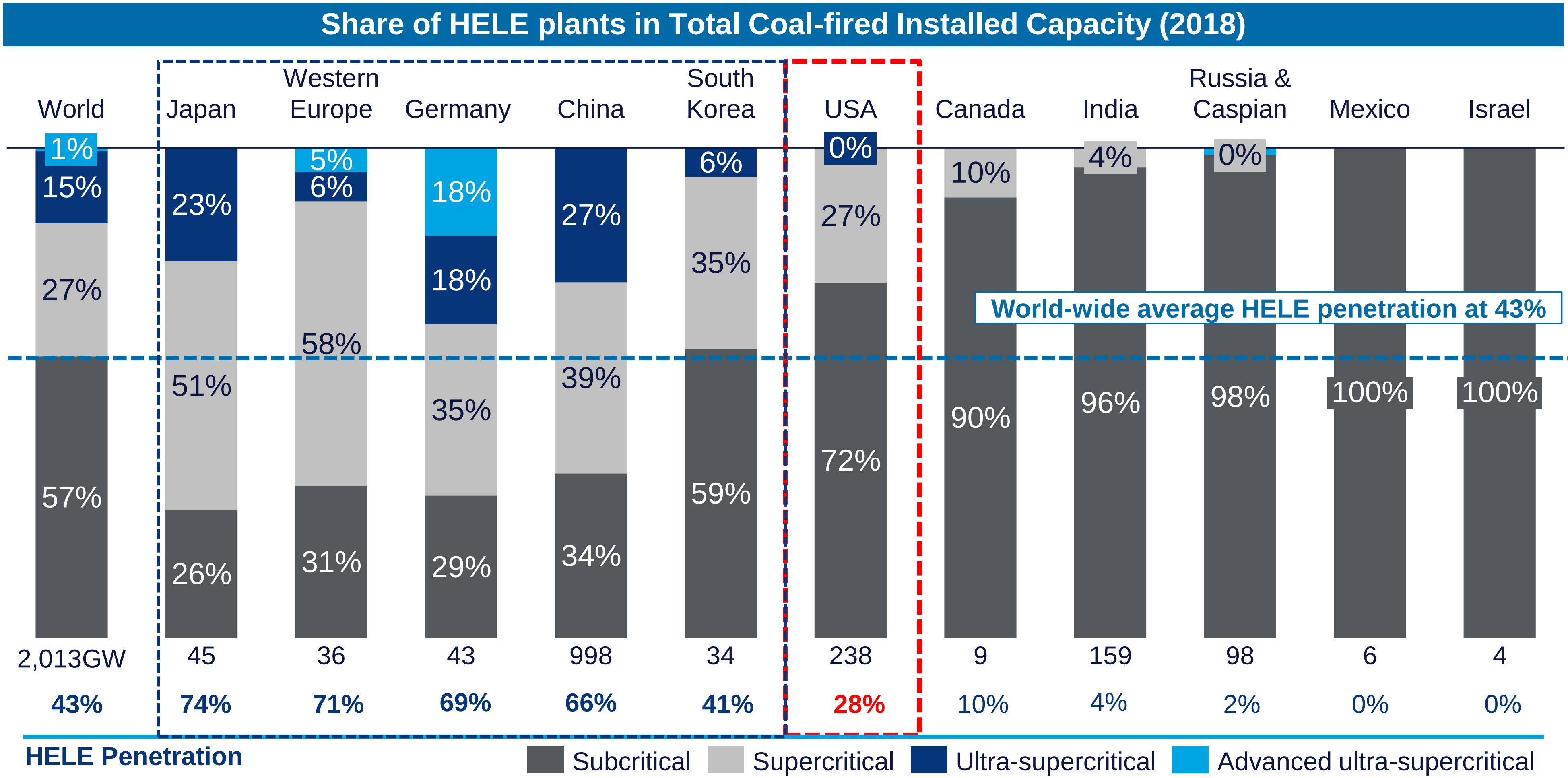
Coal-fired Power Plant Installed Capacity US vs. World in 2018



Source: Wood Mackenzie

woodmac.com

Today, HELE plants represent 43% of global coal-fired power plants capacity, including 16% ultra-supercritical or further advanced



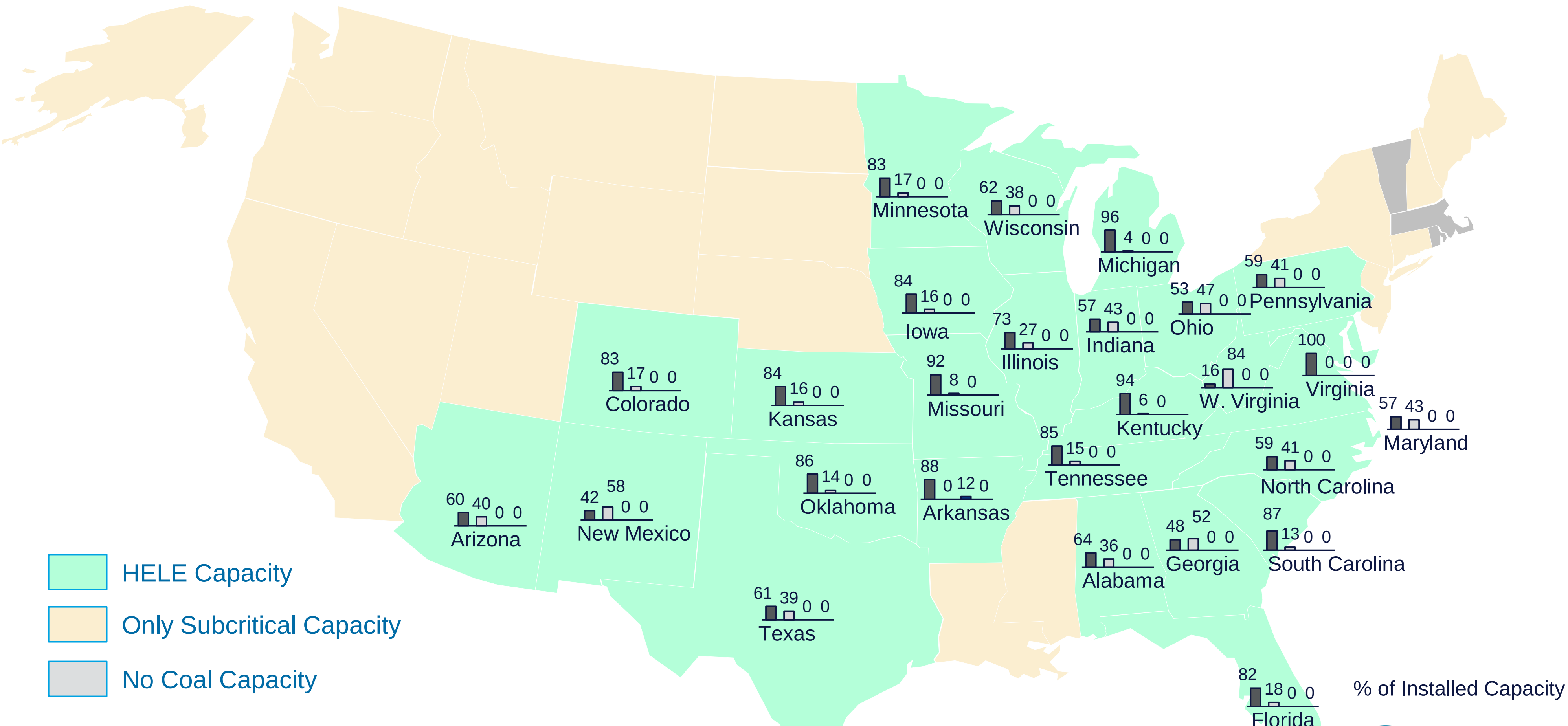
Note: 1. John W Turk Jr plant is the only Ultra-supercritical coal plant in the US, with 614 MW capacity. 2.West Europe includes UK, France, Belgium, Netherlands, Spain
Source: Wood Mackenzie, EIA

NMA

US: Coal-fired power plant share by technology by state

Subcritical coal-fired power plants represent 72% of the total coal capacity; most states face a significant gap to achieving an efficient coal-fired power plant fleet

Coal-fired Power Plant Technology Share by State (2018)



Note: (1) Supercritical and ultra-supercritical definitions are based on EIA categorization
Source: Wood Mackenzie, EIA

US: Top operating coal-fired power plants by efficiency

John W. Turk, Jr coal power plant is the only ultra-supercritical plant in the US, but the Longview Power plant is the most efficient plant

Top US HELE Coal-fired Power Plants by Efficiency

Power Plant and Unit	Status	State	EIA HELE Category	Capacity MW	WM Estimated Heat Rate Btu/kWh	WM Estimated Efficiency %	Start Year	Expected Retirement Year
John W. Turk, Jr 1	Operating	Arkansas	Ultra-supercritical	614	9,000	38%	2012	2069
Longview Power LLC 1	Operating	West Virginia	Supercritical	700	8,600	40%	2011	2068
Trimble County 2	Operating	Kentucky	Supercritical	747	8,615	40%	2011	2068
Iatan 2	Operating	Missouri	Supercritical	850	8,845	39%	2010	2067
Sandy Creek Energy Station S01	Operating	Texas	Supercritical	927	8,850	39%	2013	2070
Prairie State Generating Stati PC1	Operating	Illinois	Supercritical	800	9,000	38%	2012	2069
Cliffside 6	Operating	North Carolina	Supercritical	800	9,000	38%	2012	2069
Prairie State Generating Stati PC2	Operating	Illinois	Supercritical	800	9,000	38%	2012	2069
Elm Road Generating Station 2	Operating	Wisconsin	Supercritical	634	9,027	38%	2011	2068
J K Spruce 2	Operating	Texas	Supercritical	780	9,060	38%	2010	2067
Marshall (NC-Catawba) 4	Operating	North Carolina	Supercritical	670	9,073	38%	1970	2027
Weston (WI) 4	Operating	Wisconsin	Supercritical	535	9,094	38%	2008	2065
Bull Run (TN) 1	Operating	Tennessee	Supercritical	888	9,095	38%	1967	2027
Morgantown Generating Plant ST2	Operating	Maryland	Supercritical	620	9,107	37%	1971	2028
Oak Grove (TX) OG1	Operating	Texas	Supercritical	817	9,130	37%	2009	2066
Oak Grove (TX) OG2	Operating	Texas	Supercritical	827	9,130	37%	2010	2067
Belews Creek 2	Operating	North Carolina	Supercritical	1,147	9,149	37%	1975	2032
Walter Scott Jr Energy Center 4	Operating	Iowa	Supercritical	816	9,229	37%	2007	2064
Rockport (IN) 1	Operating	Indiana	Supercritical	1,319	9,243	37%	1984	2026
Belews Creek 1	Operating	North Carolina	Supercritical	1,147	9,255	37%	1974	2031

HELE Coal-fired power plants built in the last decade

Source: Wood Mackenzie, EIA

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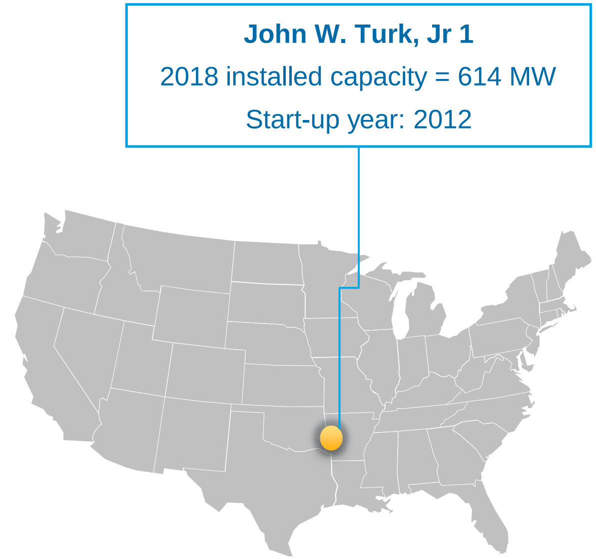
Appendix

John W. Turk, Jr power plant is the only Ultra-supercritical plant in the US

United States: John W. Turk, Jr

Fuel Type	Subbituminous Coal
Prime Mover	Steam Turbine
Status	Operating
Efficiency Type	Ultra-supercritical
WM Estimated Heat Rate	9,000 Btu/kWh
Efficiency Rate	37.9%

Fulton, Arkansas



Plant overview

- American Electric Power operates the plant through its subsidiary Southwestern Electric Power Co. (SWEPCO) with an ownership of 73%. Other holders include Arkansas Electric Cooperative Corp 12%; East Texas Electric Cooperative 8% and Oklahoma Municipal Power Authority 7%. Commissioning of the plant culminated almost seven years of legal, regulatory, and construction work to bring the $1.8 billion project to completion.
- The plant started operations in December 2012 and is awarded for being one of the cleanest and most efficient coal-fired power plants in the United States. Such recognition is the result of applied air quality control systems that include a selective catalytic reduction (SCR) system and low nitrogen oxide (NOx) burners with close-coupled over-fire air for control of NOx; a dry flue gas desulfurization (FGD) system and pulsejet fabric filter (baghouse) for sulfur dioxide and particulate control; and activated carbon injection to reduce mercury emissions.
- The plant burns low-sulphur subbituminous coal in a spiral-wound universal pressure-type boiler, producing steam at 26.2 MPa (3789 psi) and 600º C.

Source: Wood Mackenzie, Southwestern Electric Power Company, WCA

Longview Power plant is regarded as one of the cleanest coal-fired power plants in the United States

United States: Longview Power LLC

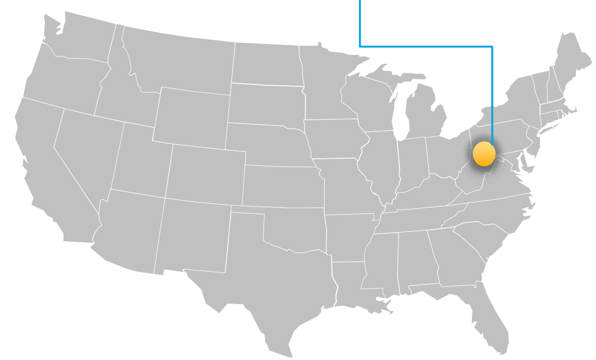
Fuel Type	Bituminous Coal
Prime Mover	Steam Turbine
Status	Operating
Efficiency Type	Supercritical
WM Estimated Heat Rate	8,600 Btu/kWh
Efficiency Rate	39.7%

Maidsville, West Virginia

Longview Power LLC

2018 installed capacity = 700 MW

Start-up year: 2011



Plant overview

- The construction of the plant began in January 2007, after approval of final permits for the project. In 2011, operations started and Longview became the first new power plant to initiate operation in West Virginia in 18 years.
- The plant cost approximately $2.2Bn, and its ownership is divided as follows: Bain Capital 35%, Kohlberg Kravis Roberts & Co (KKR) 30%, Centerbridge Partners 11%, American Securities 11%, Longview Power 10% and Affiliated Managers Group 3%.
- The plant uses best-in-class air pollution control systems that effectively maintain emissions well below its environmental permit limits, which are among the most stringent in the nation for coal plants. Furthermore, Longview's CO_2 output is 15%. It also was certified by the West Virginia Public Service Commission to have the lowest CO_2 emissions of any coal-fired plant in West Virginia.

Source: Wood Mackenzie, Longview Power LCC

Sichuan Baima Unit 2 (CFB) started operation in 2000 and was the first 600MW supercritical plant with the largest capacity of its class

China Energy Investment Corporation
国家能源投资集团

China: Sichuan Baima Unit 2

Start Year	2000
Status	Operating
Main Fuel Type	Hard Coal
Main Steam Temperature	571º C
Efficiency Type	Supercritical
Efficiency Rate	-

Neijiang, Sichuan, China

Sichuan Baima Unit 2
Current capacity = 600 MW

Plant overview

- The Baima 600M WCFB (Unit 2) demonstration power station boiler was independently developed and designed by Dongfang Boiler Group Co., Ltd. It is the world's first 600MW supercritical circulating fluidized bed boiler with the largest capacity of its class.
- It combines the advantages of CFB combustion technology and supercritical steam cycle. The design coal for the 600 MW SCCFB unit is a high-ash-content, high-sulfur and low-grade lean coal. The ash content is 43.82%, the sulphur content is 3.3% and the LHVaris 15173 kJ/kg. The desulfurization efficiency reached 97.12%, and the NOx emission concentration was 111.94 mg/Nm^3.

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Note: 1. The Sichuan Baima power station is a 900 MW complex constituted by two CFB demonstration units. The first is a 300 MW unit completed in 2006 and the second is a 600 MW unit that started operations in 2013.
Source: Wood Mackenzie, China Energy Investment Corporation

1,320MW Anhui Pingshan Phase II was commissioned in 2017 with the goal of achieving "energy savings and emissions reduction"

申能股份有限公司
SHENERGY COMPANY LIMITED

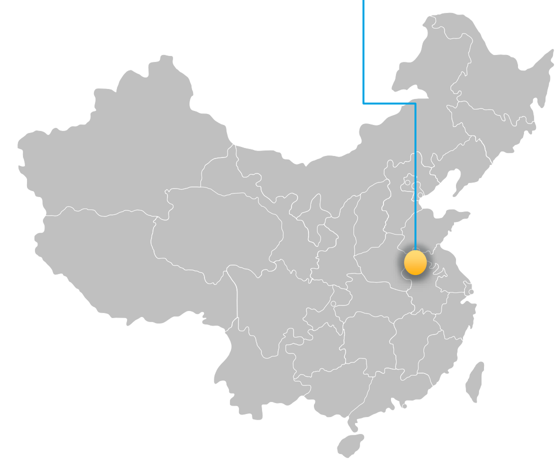
China: Anhui Pingshan Phase II

Start Year	2019
Status	Under construction
Main Fuel Type	Hard Coal
Main Steam Temperature	600º C
Efficiency Type	Ultra-supercritical
Efficiency Rate	48.9%

Huaibei, Anhui, China

Anhui Pingshan Phase II

Expected capacity = 1,350 MW



Plant overview

- Anhui Pingshan Phase II is a 1,350 MW expansion[1] approved in 2017 as a national demonstration project which will count with a conventional and elevated turbine layout. This unit is expected to become the most efficient and cleanest coal-fired power unit in the world.
- Its design will allow a power supply with a CO_2 gross emission of 251 g/kWh, which is about 15 grams lower than the current domestic most advanced secondary reheat design that reaches a CO_2 emission of 266.18 g/kWh. The total projected investment is approximately USD 780 million.
- This large scale power plant development was commissioned under the national energy policy "energy savings & emissions reduction", which is considered one of the world's leading coal-fired HELE technologies policy for production of clean energy.

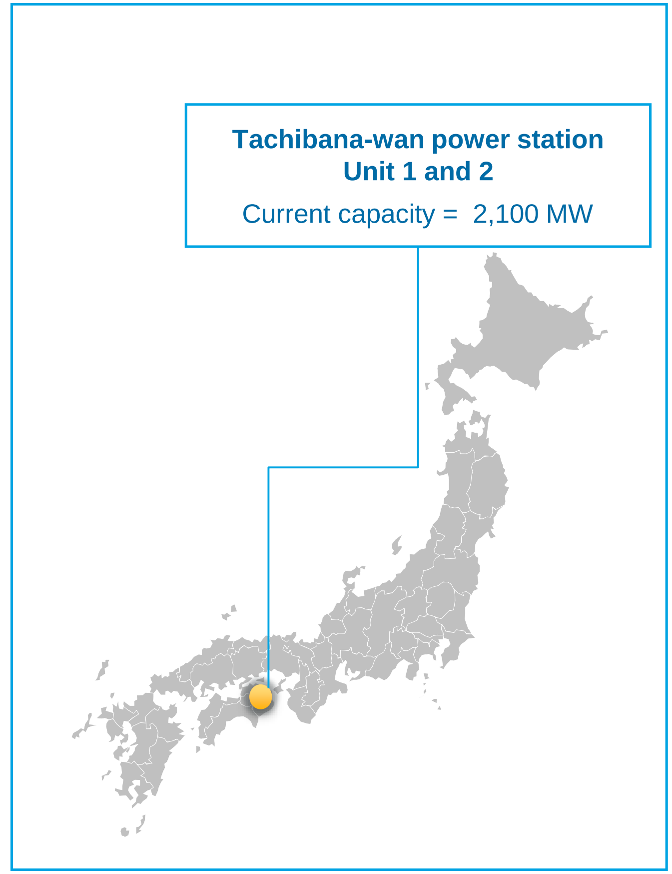
Note: 1. The expansion is located at the Huaibei Pingshan power station, that is a 2 units coal-fired power plant with a capacity of 1,320 MW. Unit 1 and unit 2 were commissioned in 2015 and 2016 respectively, both with a 660 MW capacity
Source: Wood Mackenzie, Shenergy Company Limited

2,100 MW Tachibana-Wan power plant has 2 ultra-supercritical units, with the largest single-unit output in Japan of 1,050 MW

Japan: Tachibana-wan Power Station Unit 1 and 2

Start Year	2000
End Year	Operating
Main Fuel Type	Bituminous Coal
Processing Type	610º C
Efficiency Type	Ultra-supercritical
Efficiency	45.0%

Anan, Tokushima Prefecture, Japan



Plant overview

- It is a coal-fired power station that comprises two 1,050 MW units that have been in operation since 2000.
- The power station's technology supports a temperature of 600º C for main steam, 610º C for reheat steam and a pressure of up to 25.0 Mpa.
- The single-unit output of 1,050 MW is the largest in the country and the electricity generated is sent not only to Shikoku but also to the Kansai, China and Kyushu districts.
- The applied technologies include large-capacity MPS-300 pulverisers, large-capacity low-NOx Hitachi NR2-burners, spirally wound water-wall of multi-ribbed tubes, high-strength austenitic steel tubes, high-strength ferritic steel piping, multi-stage super-heater spray systems, large capacity steam-water separators.

Source: Wood Mackenzie, J Power

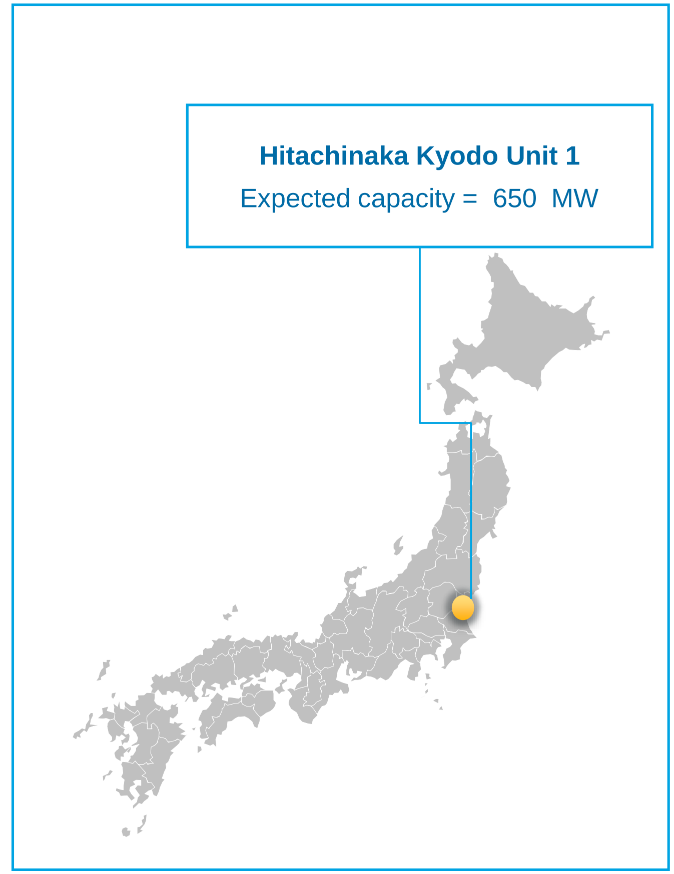
Hitachinaka Kyodo plant was one of several new proposed HELE plants due to nuclear retirements after the Fukushima earthquake

CHUBU Electric Power

Japan: Hitachinaka Kyodo Power Station Unit 1

Start Year	2020-2021
Status	Under construction
Main Fuel Type	Hard Coal
Main Steam Temperature	600º C
Efficiency Type	Ultra-supercritical
Efficiency Rate	43.0 %

Okai-mura, Naka-gun, Ibaraki, Japan



Plant overview

- It is a proposed USC 650 MW coal-fired power plant with a projected commissioning date of 2020-2021 and is currently under construction at TEPCO's 2,000 MW Hitachinaka Thermal Power Station.
- The project will be operated by Hitachinaka Generation Co., Inc. which its ownership is divided between Chubu Electric Power (96.55%) and Tokyo Electric Power Co. TEPCO (3.45%).
- Japan's Ministry of Economy, Trade and Industry (METI) and Ministry of Environment (MoE) published in April 2013 the "Best Available Technology (BAT)". This guideline is based on best practice for thermal power plants to control GHG emission and no new installation or plan can be approved unless power producers meet these standards.
- The project assessment speeding process and posterior endorsement of the unit by Japan's environment minister Tamayo Marukawa in 2016, came as result of the USC technology that the station will apply, which meet BAT requirements.

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Source: Wood Mackenzie, Chubu Electric Power, Bloomberg, Sourcewatch

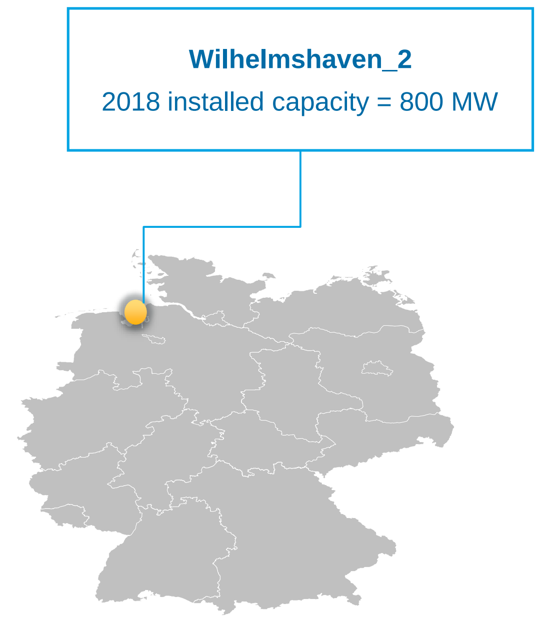
Wilhelmshaven power plant is one of the most modern coal-fired plants in Germany

BKW

Germany: Wilhelmshaven Power Plant

Start Year	2014
End Year	2037
Fuel Type	Hard Coal
Processing Type	PCC
Efficiency Type	Advanced ultra-supercritical
Efficiency	46%

Wilhelmshaven, Germany



Plant overview

- BKW has a 33% holding in a coal-fired power plant currently operated by Engie (previously known as GDF Suez) in north Germany. This plant has a gross installed capacity of 800 MW. With a projected thermal efficiency of over 46% Wilhelmshaven power plant is one of the most technologically advanced facilities in Europe. It produces electricity with significantly lower CO_2 emissions than existing coal-fired power plants that achieve an efficiency of almost 40%.
- The plant can be used very flexibly and is located right on the north German coast, a fact which has two distinct advantages: first, the plant can easily be supplied by sea with coal from all over the world; second, it can be cooled by sea water, thus helping to protect local freshwater resources. Operating figures and data for the plant are as much as 50% below Germany's strict environmental limits.

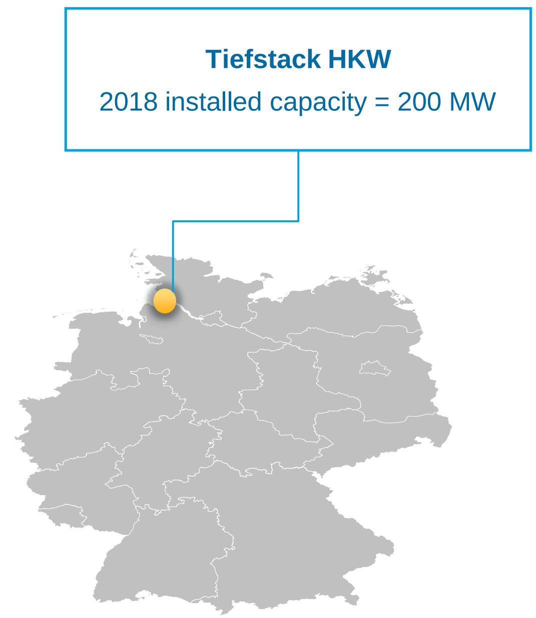
Source: Wood Mackenzie, BKW Energie AG

Tiefstack HKW power plant is a cogeneration power plant that achieves advanced ultra-supercritical efficiency

Germany: Tiefstack HKW Power Plant

Start Year	2009
End Year	2038
Main Fuel Type	Hard Coal
Processing Type	CHP
Efficiency Type	Advanced ultra-supercritical
Efficiency	55%

Hamburg, Germany



Plant overview

- The Tiefstack cogeneration plant covers almost half of Hamburg's total district heating needs. The power plant is located on a historical site at the point where Hamburgische Electricitäts-Werke AG opened its first major power plant in 1917. The current power plant was put into operation in 1993. In 2009 Tiefstack's electricity and heat capacity was expanded by a natural gas-fired combined cycle power plant.
- Cogeneration: The baseload unit uses hard coal as fuel, whereas two heating boilers for peak-load demand use natural gas and oil.
- The power plant is equipped for both base load and peak load production. The power plants are equipped with state-of-the-art flue gas cleaning systems. These ensure that the flue gases emitted from the 120-meter-high chimney fall well below the permissible limit values.

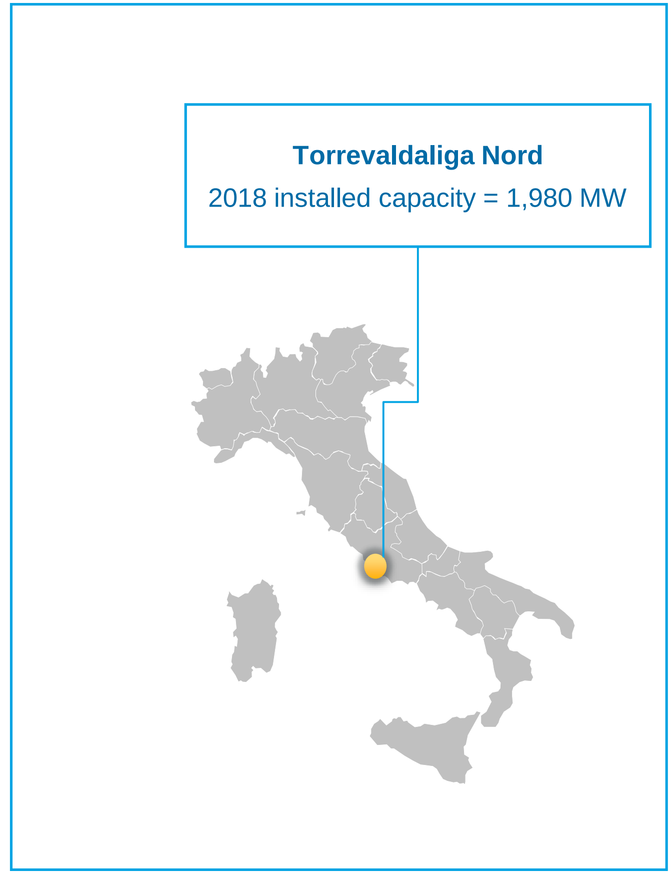
Source: Wood Mackenzie, Vattenfall

Torrevaldaliga Nord power plant replaced its oil-fired power units for coal-fired in 2008

Italy: Torrevaldaliga Nord Power Plant

Start Year	2008
End Year	2037
Main Fuel Type	Hard Coal
Processing Type	PCC
Efficiency Type	Advanced ultra-supercritical
Efficiency	57%

Civitavecchia, Rome Province, Italy



Plant overview

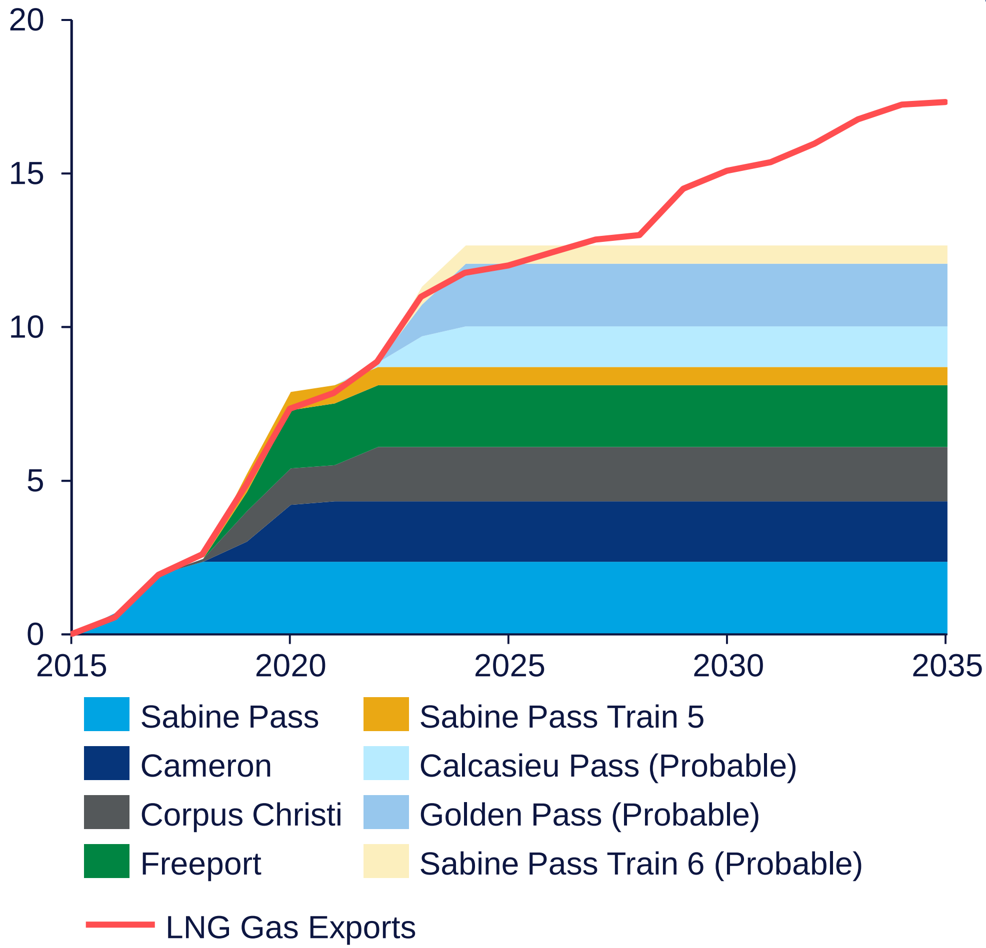
- The plant is owned by Enel Produzione SpA, and first consisted of four oil-fired 660 MW units. The units were replaced with three 660 MW coal-fired units, for a total installed capacity of 1,980 MW.
- The replacement project (from fuel-oil plants) encountered stiff opposition in 2006 arguing that the company lacked full authorization for the coal loading jetty. In May of the same year the issues were solved and the project was clear to go. The 3 units were completed in 2008.
- On May 21st, 2018 Torrevaldaliga Nord became the first power plant in the world to use Convexum and Percepto systems. These systems are aimed at providing an environmental and security monitoring service, able to perform autonomous flights, assisted by video analysis algorithms and three-dimensional routes definitions via software.

Source: Wood Mackenzie, ENEL

Agenda

Sanctioned LNG projects in the Gulf Coast would reach ~8.5 bcfd by 2022, and could further increase to almost 13 bcfd by 2025

U.S. Gulf Coast LNG Capacity by Terminal



Gulf Coast LNG Projects Status

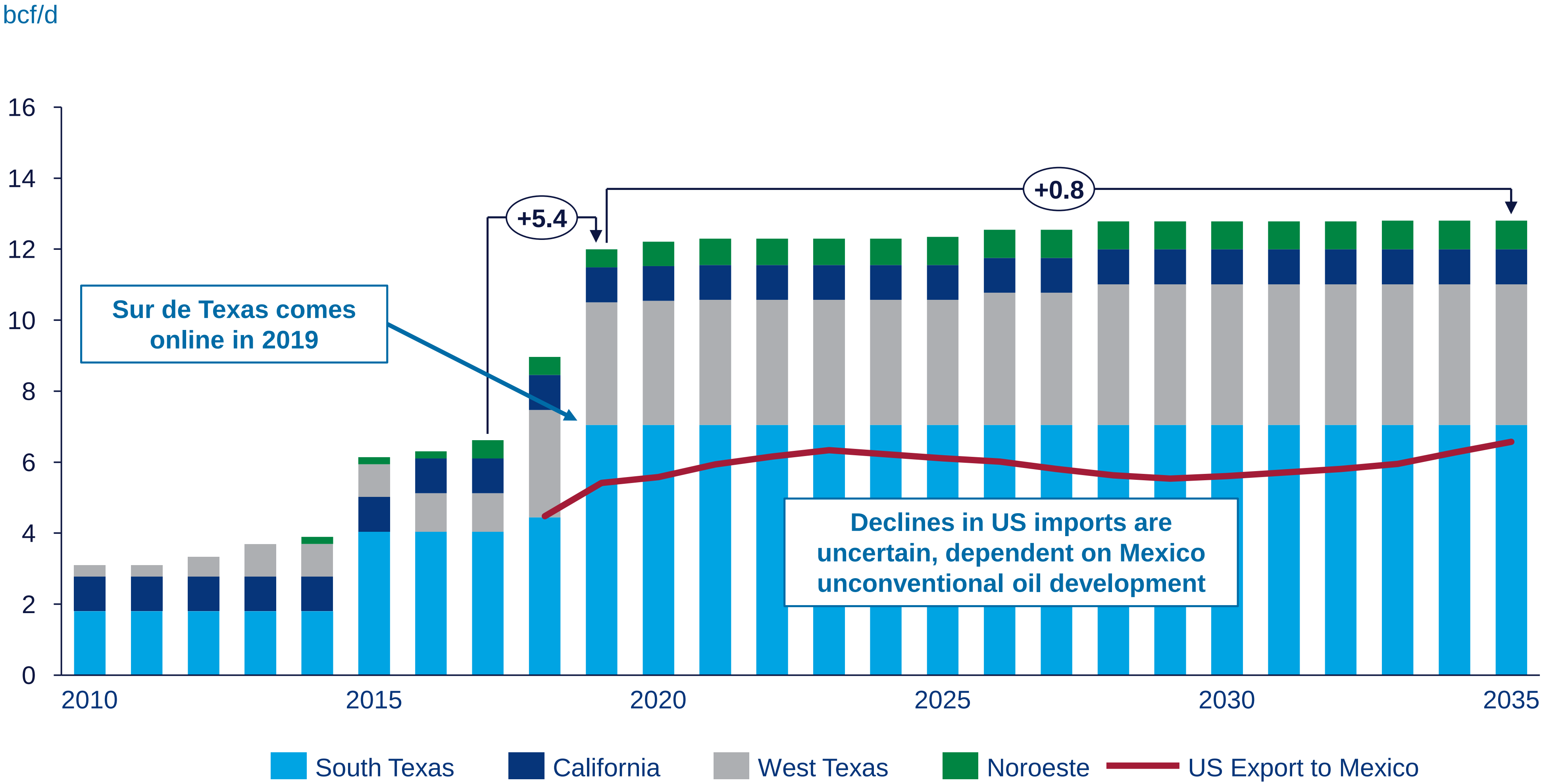
An extensive backlog of possible LNG projects are currently in the FERC queue and going through environmental impact review, and could add additional LNG demand

LNG Project	Developer	Draft Env. Impact Statement	Final Env. Impact Statement	Federal Auth. Deadline	Final Order
Calcasieu Pass	Venture Global		26-Oct-18	24-Jan-19	22-Jan-19
Freeport Train 4[1]	Freeport	n/a	2-Nov-18	31-Jan-19	
Driftwood	Tellurian	Sep 2018	18-Jan-19	18-Apr-19	
Port Arthur	Sempra	Sep 2018	31-Jan-19	1-May-19	
Corpus Christi Ph.3[1]	Cheniere	n/a	8-Feb-19	9-May-19	
Texas LNG	Texas LNG	Oct 2018	15-Mar-19	13-Jun-19	
Gulf LNG	Kinder Morgan	Nov 2018	17-Apr-19	16-Jul-19	16-Jul-19
Annova	Exelon	Dec 2018	19-Apr-19	18-Jun-19	
Rio Grande	NextDecade	Oct 2018	26-Apr-19	25-Jul-19	
Plaquemines	Venture Global	Nov 2018	3-May-19	1-Aug-19	

Note: Freeport Train 4 and Corpus Christi Phase 3 require an Environmental Assessment (EA) rather than Environmental Impact Statement (EIS)
Source: Wood Mackenzie North America Gas Tool

New projects are set to anticipate the expanding U.S. gas volumes, adding ~3 bcfd of cross-border pipeline capacity in 2019

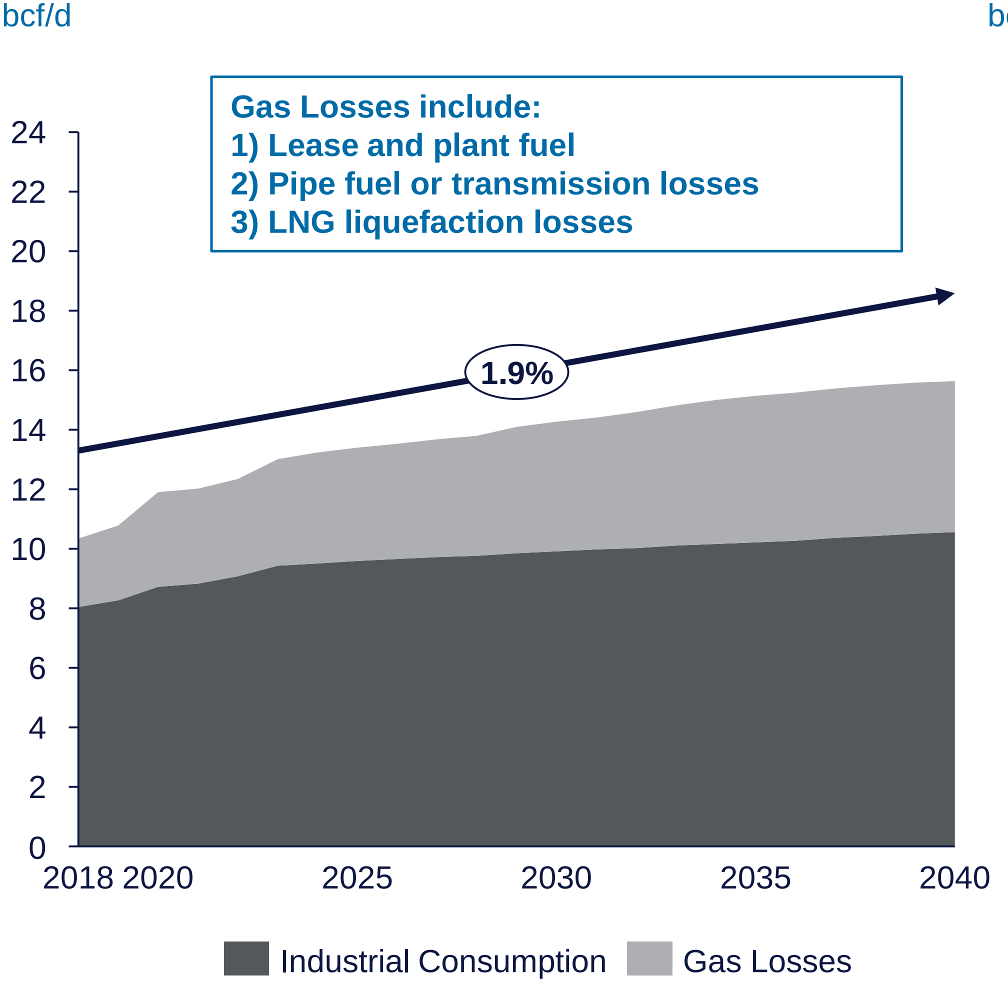
Mexico-US Gas Pipeline Capacity and Exports



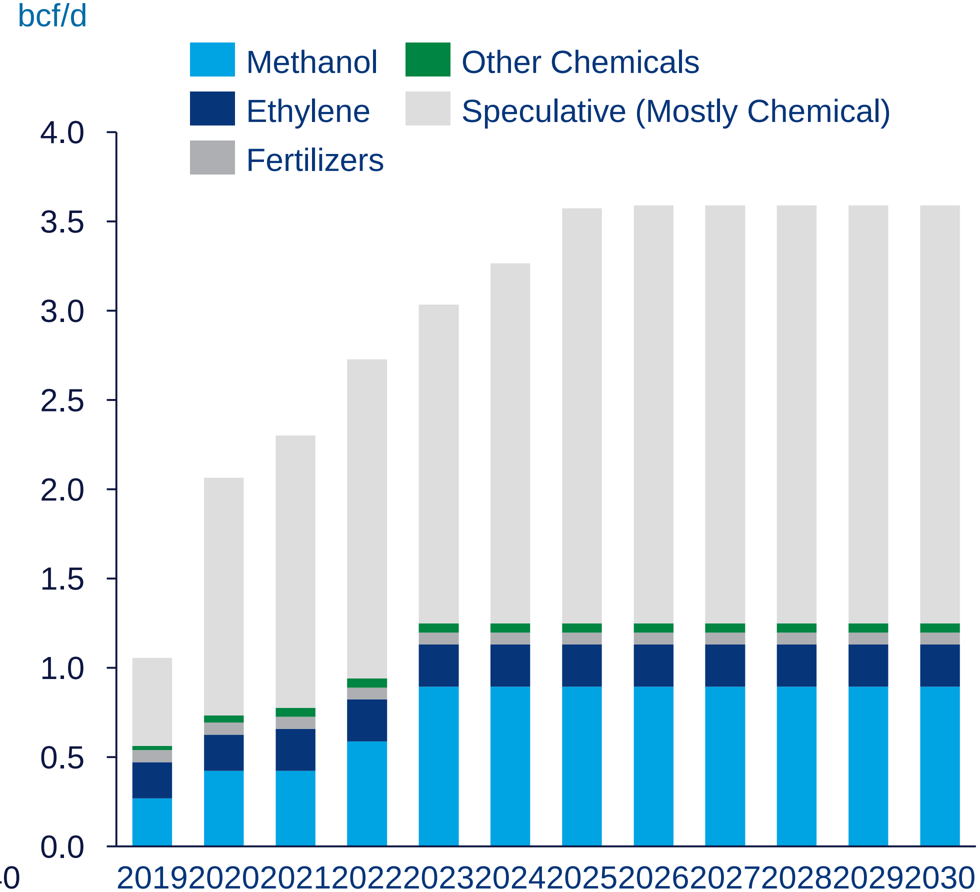
Source: Wood Mackenzie North America Gas Tool

The fuel consumption from a massive buildout of industrial plants, pipelines and LNGs drives the US Gulf Coast gas demand

Texas/Louisiana Industrial Related Demand Forecast



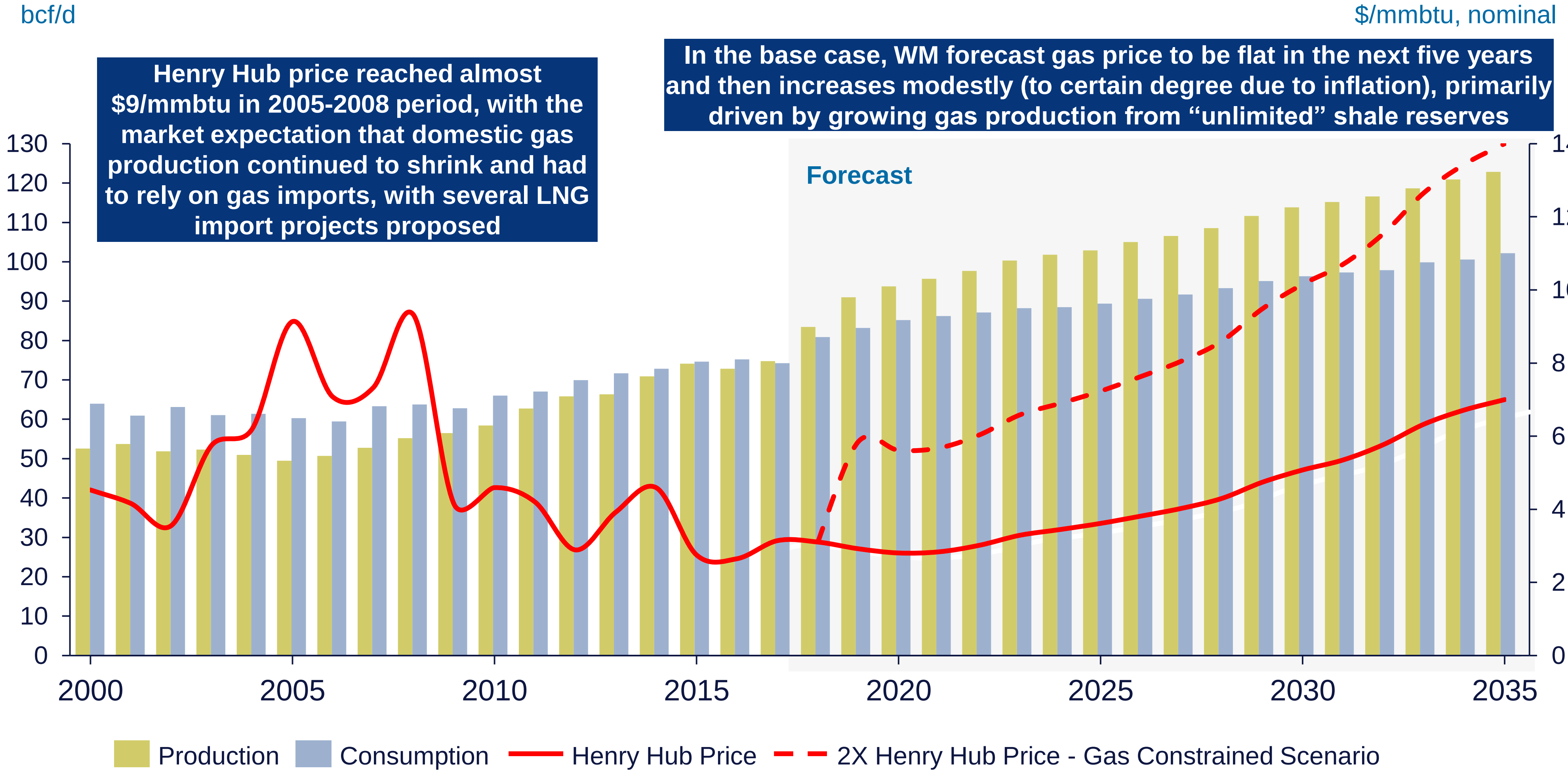
Gulf Coast Industrial Project Capacity Additions[1]



Source: Wood Mackenzie North America Gas Tool

In the alternative scenario, Henry Hub price forecast is doubled as a result of potential gas supply restrictions and demand upside

US Natural Gas Production and Consumption vs Henry Hub Price – Historical and Forecasts

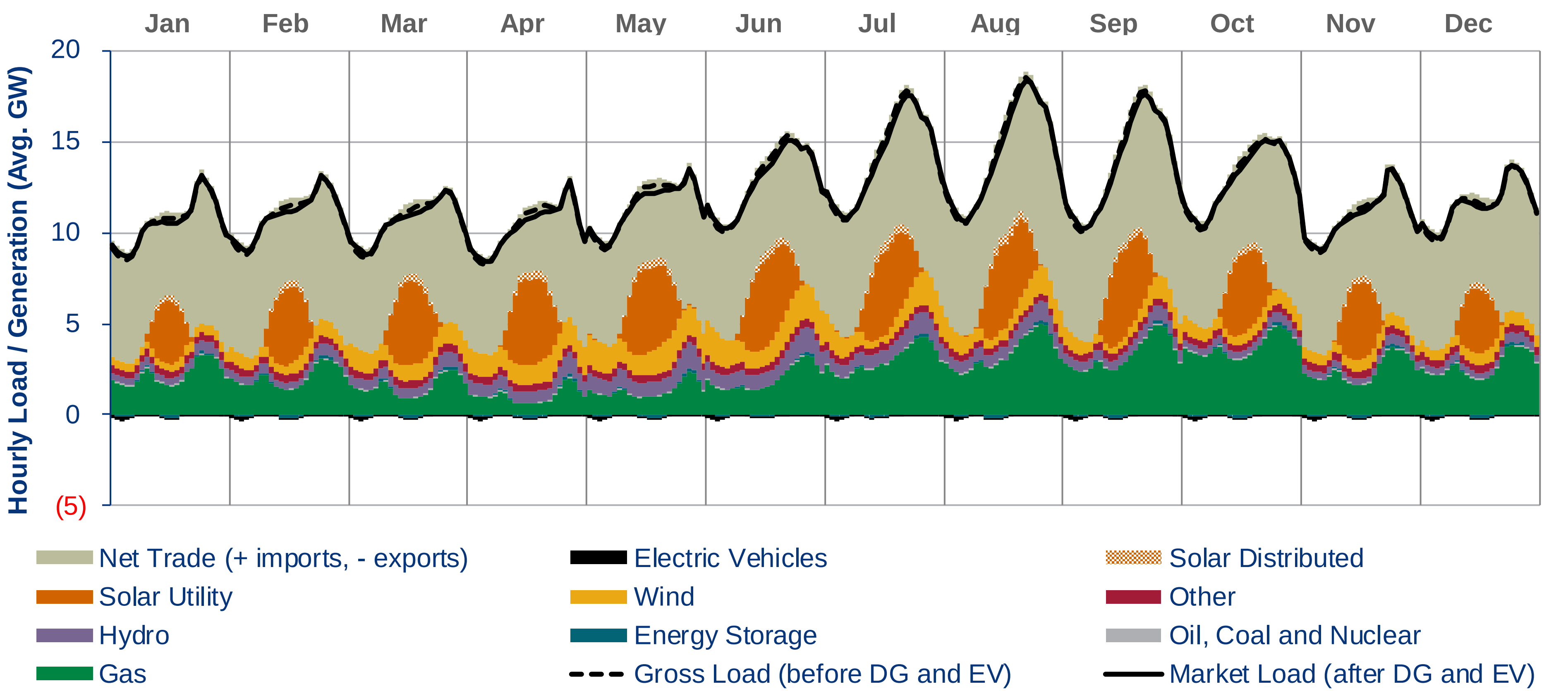


However, domestic gas supply is subject to uncertainty, e.g. well performance, government regulations and global gas demand… and these could result in gas shortfall and increase of henry hub price back to the 2005-2008 level

Source: EIA, Wood Mackenzie

In California, the aggressive adoption of renewables has already turned the load profile to one with drastic "duck curve"

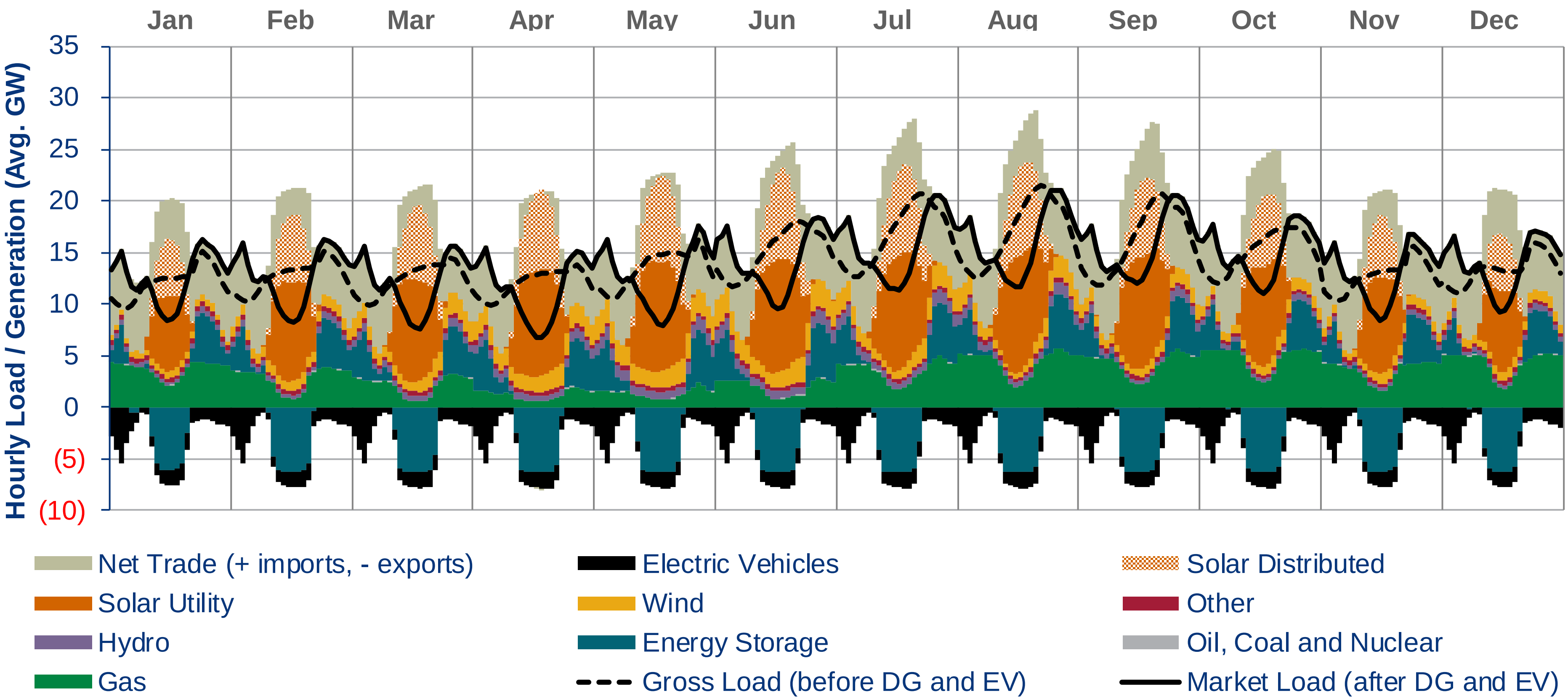
CAISO SP15 Monthly "Average Day" Hourly Energy Balance – 2018



Source: Wood Mackenzie

Renewables expansion puts pressure on the grid; the transformation depends on successful integration and energy storage technology

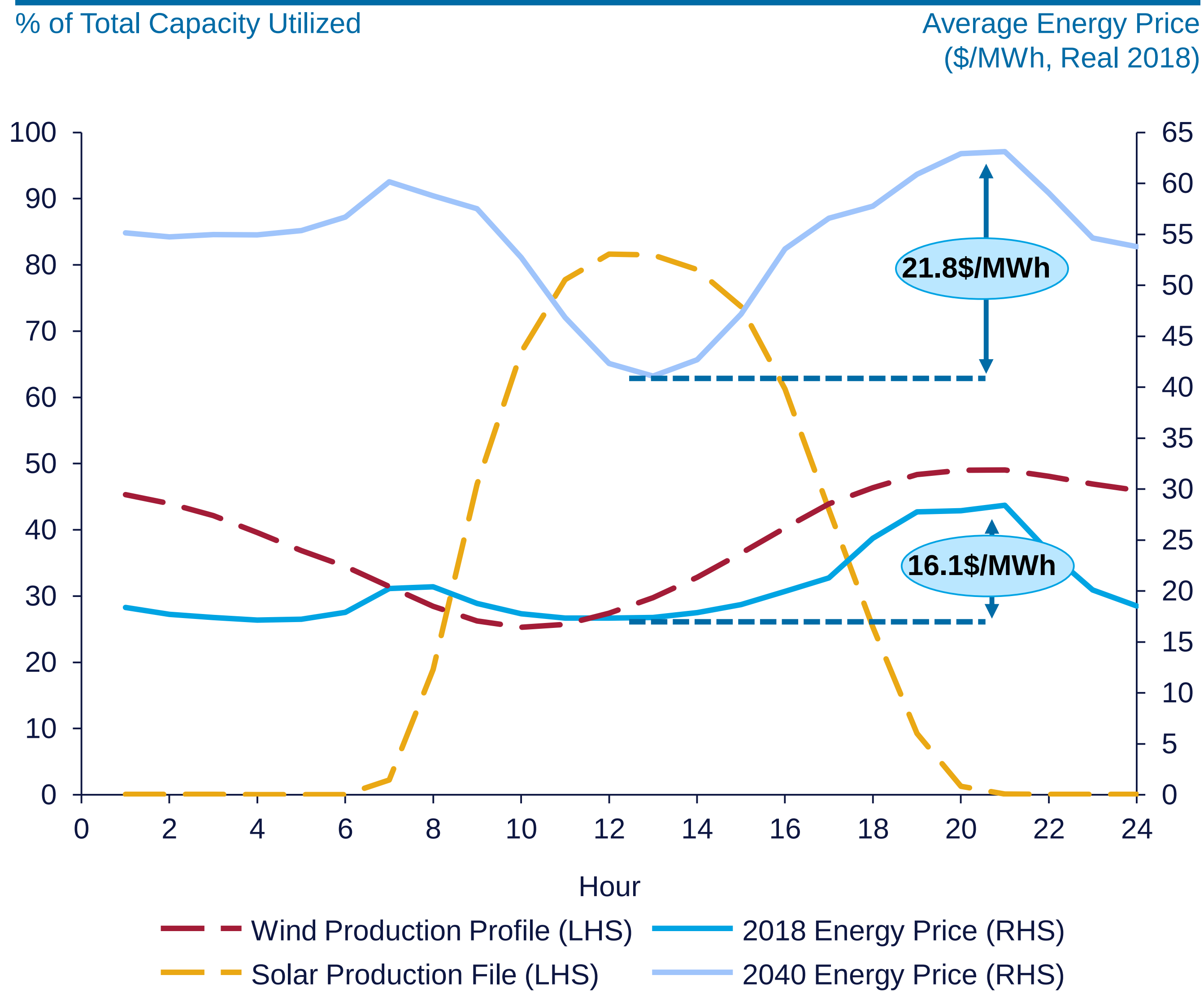
CAISO SP15 Monthly "Average Day" Hourly Energy Balance – 2040



Source: Wood Mackenzie

This not only poses questions on grid reliability, but also creates significant fluctuation of energy price throughout the day

CAISO SP15 "Average Day" Wind/Solar Production Profile vs Energy Price



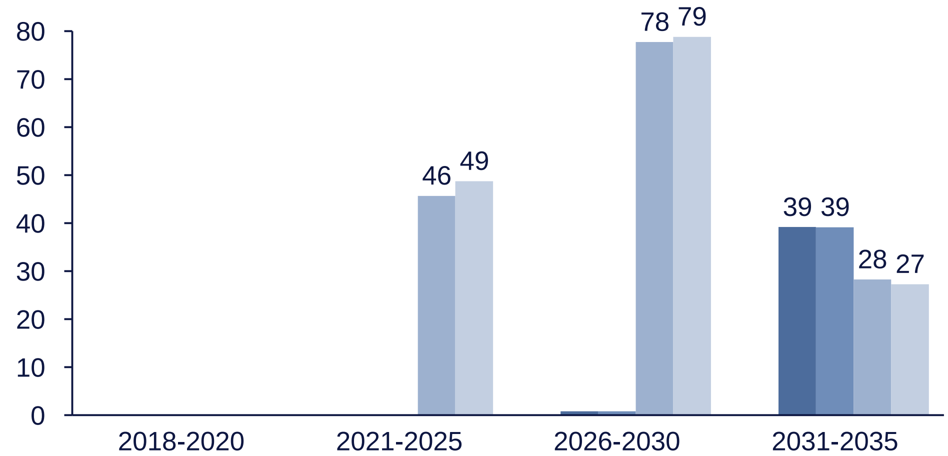
- Wind production is assumed to be 30%~50% of the facility's name plate capacity
- Wind peak production is reached when the energy price is the highest, at 8-9pm
- Significant addition of utility scale solar capacity is expected to further diverge the low and peak energy pricing

Source: Wood Mackenzie, CAISO

In the alternative scenarios, competitive coal power plant economics stimulate new HELE capacity and higher coal consumption in the US

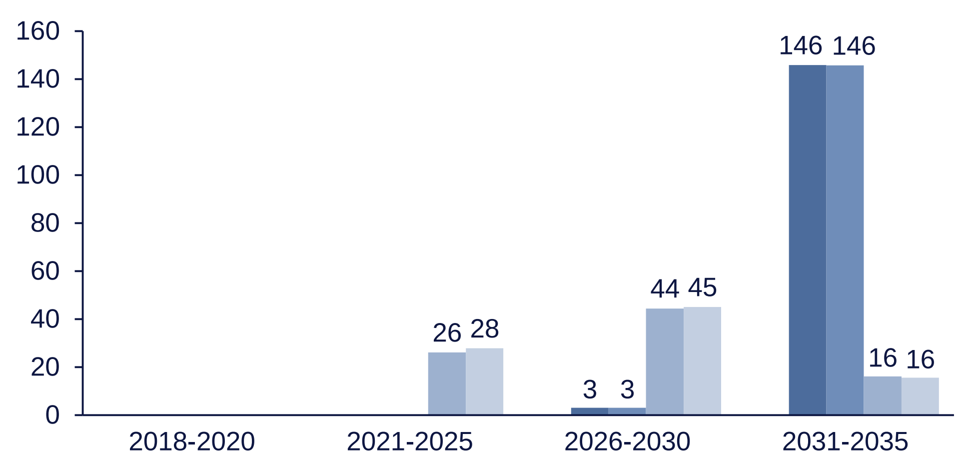
New HELE Capacity Addition in the US

GW



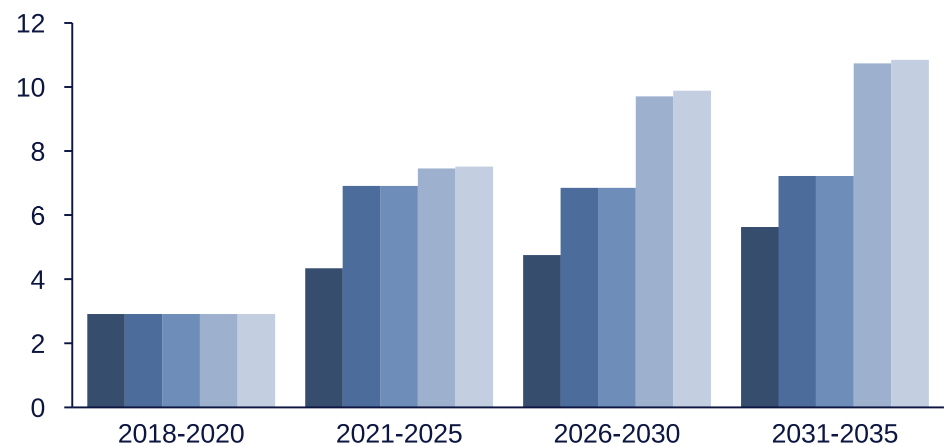
Capital Investment for HELE Power Plant

$Billion, Real 2018



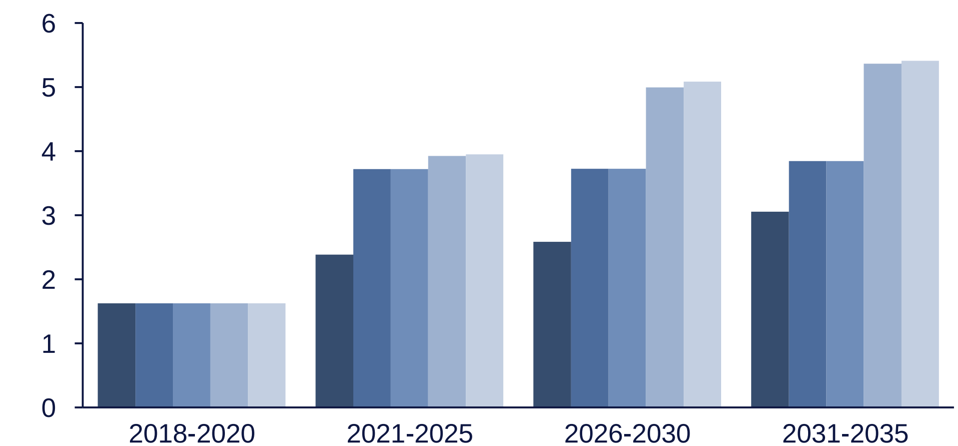
Total US Power Generation from Coal Plants

PWh



Coal Consumption in the US Power Sector

Billion metric ton



Scenario 1 Scenario 2 Scenario 3 Scenario 4 Scenario 5

Source: Wood Mackenzie

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