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Gas: Interim Bridge or Long-Term Solution?

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Agenda

- **Executive Summary**
- Long-term industrial and generation gas demands
- Comparative economics of gas vs. coal or renewables
- Core continuing end uses for gas
- Gas technology pathways for lower GHG emissions
- Conclusions

Executive Summary

- Presentation of highlights from Industrial/Power Gas Markets Study by IGU Utilization Committee, and recent work for AGA on emerging gas end-use technologies
- Industrial and power generation demands for gas hold up well through 2040, even under COP 21 compliance. Significant coal-to-gas fuel switching, especially in Asia. Renewable gas increases penetration by 2030s and especially after 2040.
- Increased renewables penetration will drive up the demand for gas-fired generation capacity (as a backup), but will erode CCCT capacity factors and gas consumption.
- Modeling of a Minimum Gas case with accelerated renewables development and decarbonization efforts, substantially beyond COP 21 compliance trajectories, indicates modest reductions in power generation gas demands in Europe and North America. These will be largely offset by increased demands in other regions due to lower LNG prices.
- Natural gas is destined to play a major role in the global energy sector for decades to come, especially in the industrial and power generation segments where gas is an essential fuel.

Thank you to my Enovation Partners colleagues and our friends from RBAC, Inc. for their assistance.

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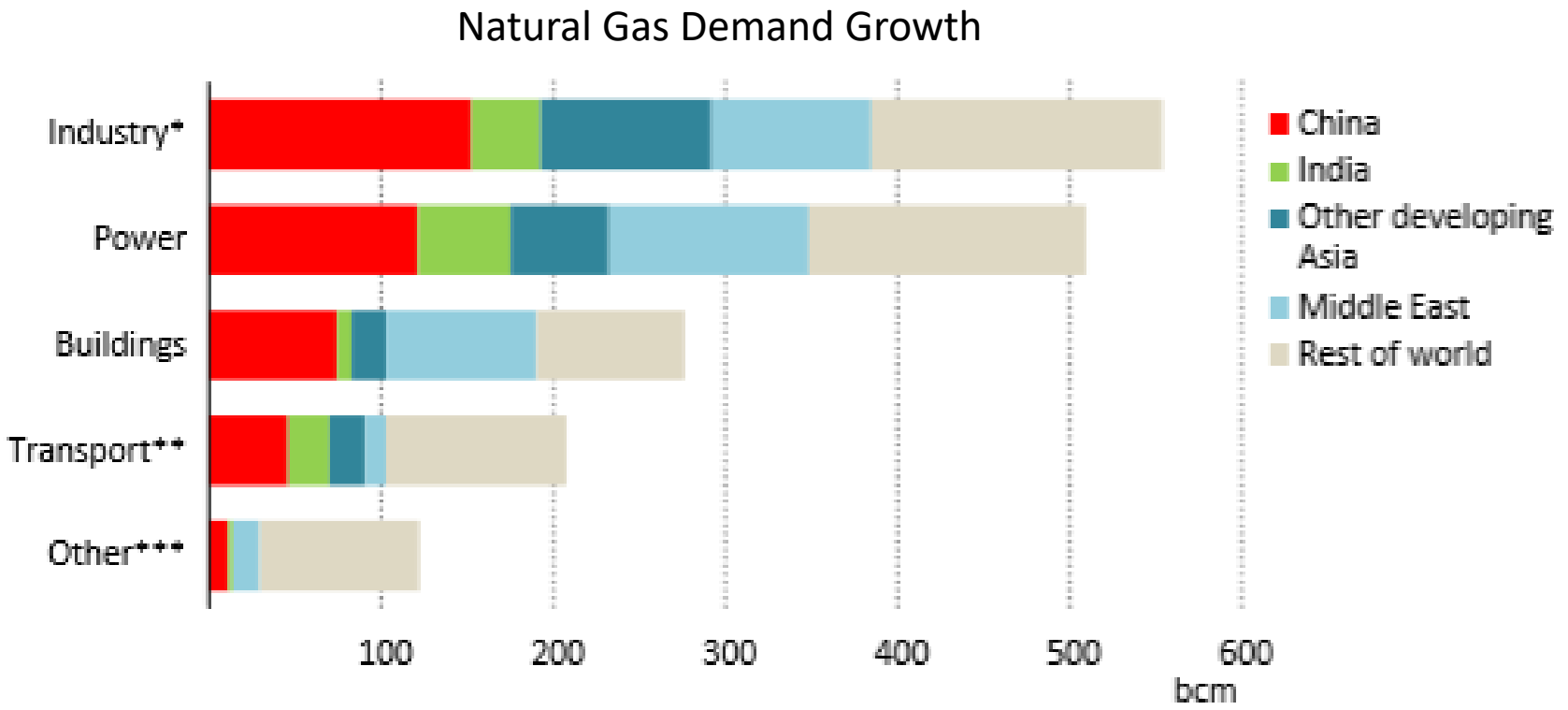
Gas demand growth to 2040 will be driven by industrial and power sectors

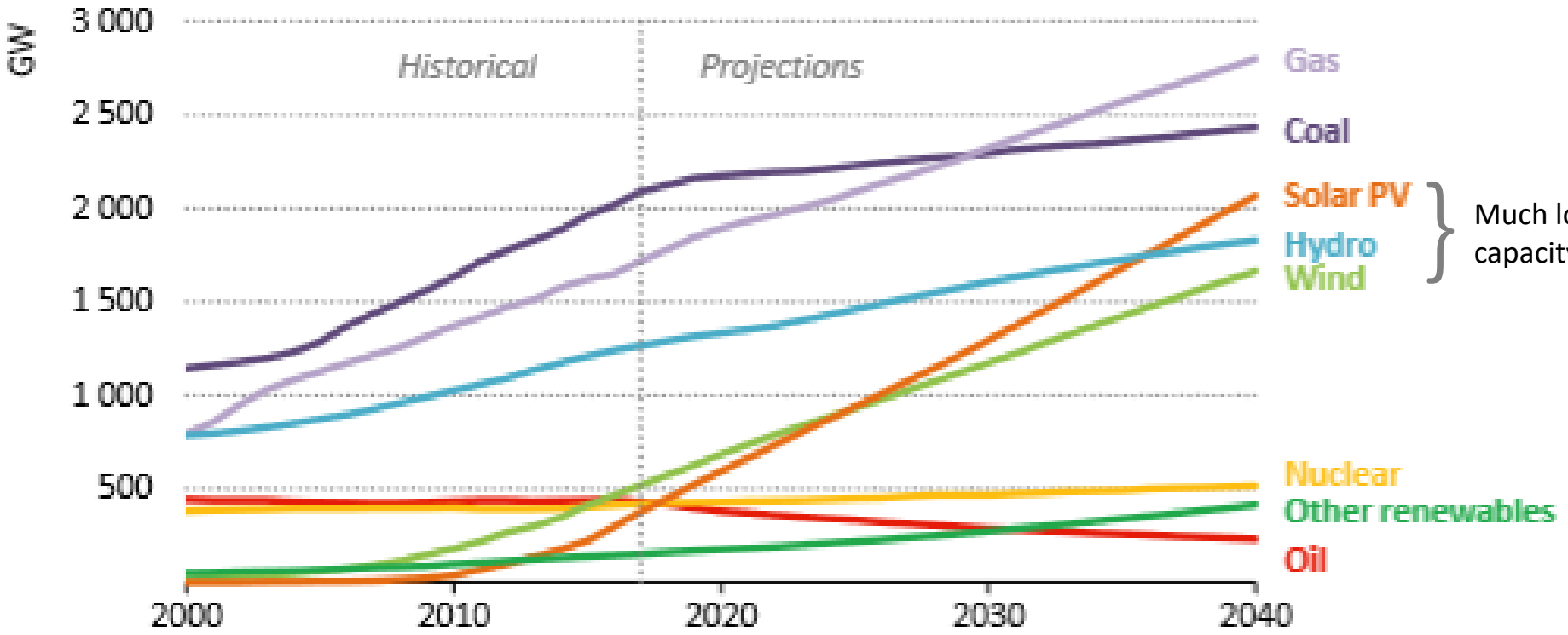


More than 80% of projected gas demand growth to 2040 is in developing economies across Asia, Middle East, Africa and Latin America

* Includes gas used as feedstocks and energy consumption in blast furnaces and gas-to-liquids process. ** Includes bunker demand. *** Includes agriculture and other non-energy use.

Source: IEA 2017 World Energy Outlook, New Policies scenario

Gas surpasses coal in global power generation capacity by 2030. Total renewables capacity about equals gas + coal capacity by 2040.



The New Policies Scenario reshuffles the leaders in power generation capacity; by 2030, gas surpasses coal while wind and solar PV gain ground

Energy share lower for renewables

Source: IEA 2017 World Energy Outlook, New Policies scenario

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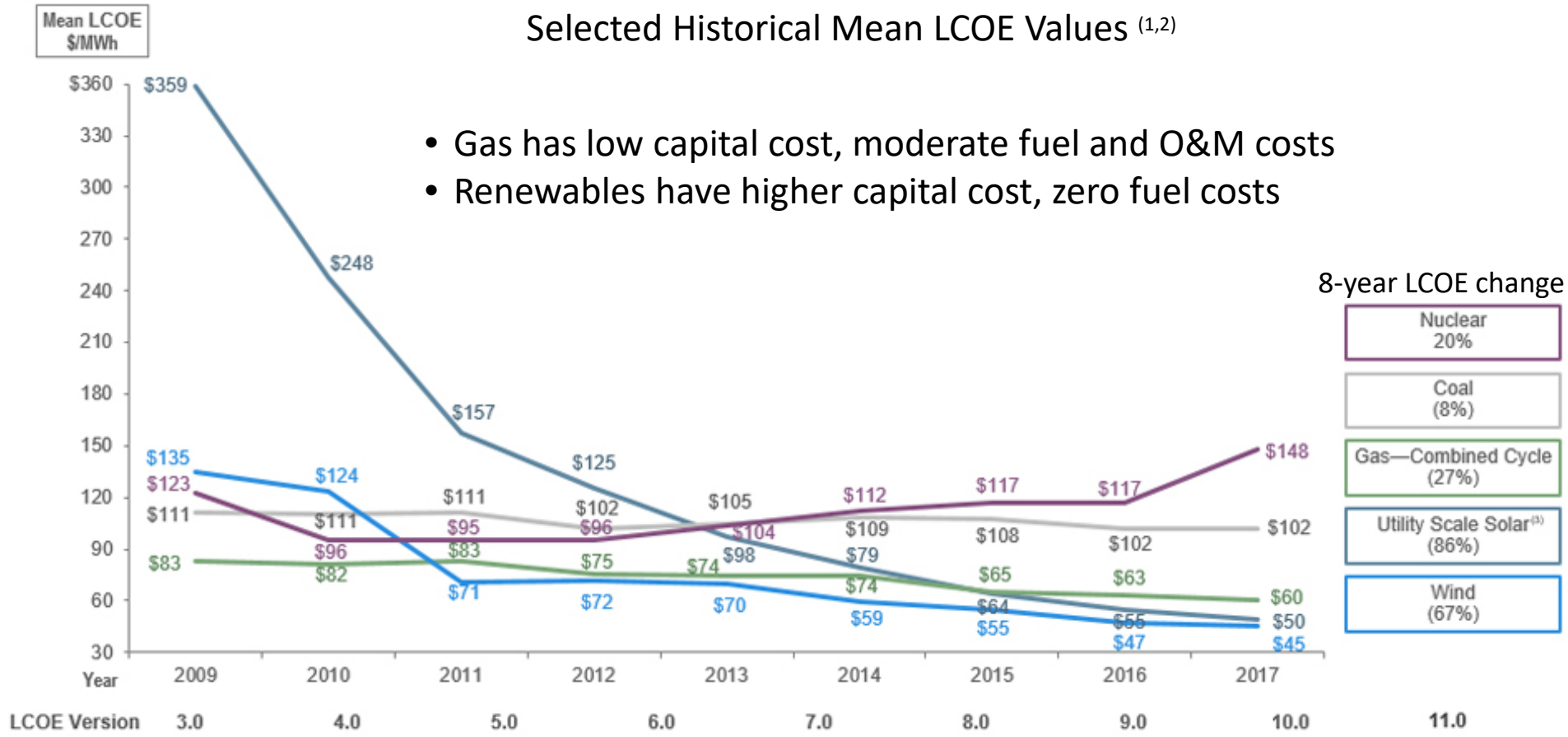
Renewables now have lower Levelized Cost of Energy than gas CCCTs – but are not dispatchable

Selected Historical Mean LCOE Values (1,2)



- Gas has low capital cost, moderate fuel and O&M costs
- Renewables have higher capital cost, zero fuel costs

Source: Lazard estimates.

Note: Reflects average of unsubsidized high and low LCOE range for given version of LCOE study.

(1) Primarily relates to North American alternative energy landscape, but reflects broader/global cost declines.

(2) Reflects total decrease in mean LCOE since the later of Lazard's LCOE—Version 3.0 or the first year Lazard has tracked the relevant technology.

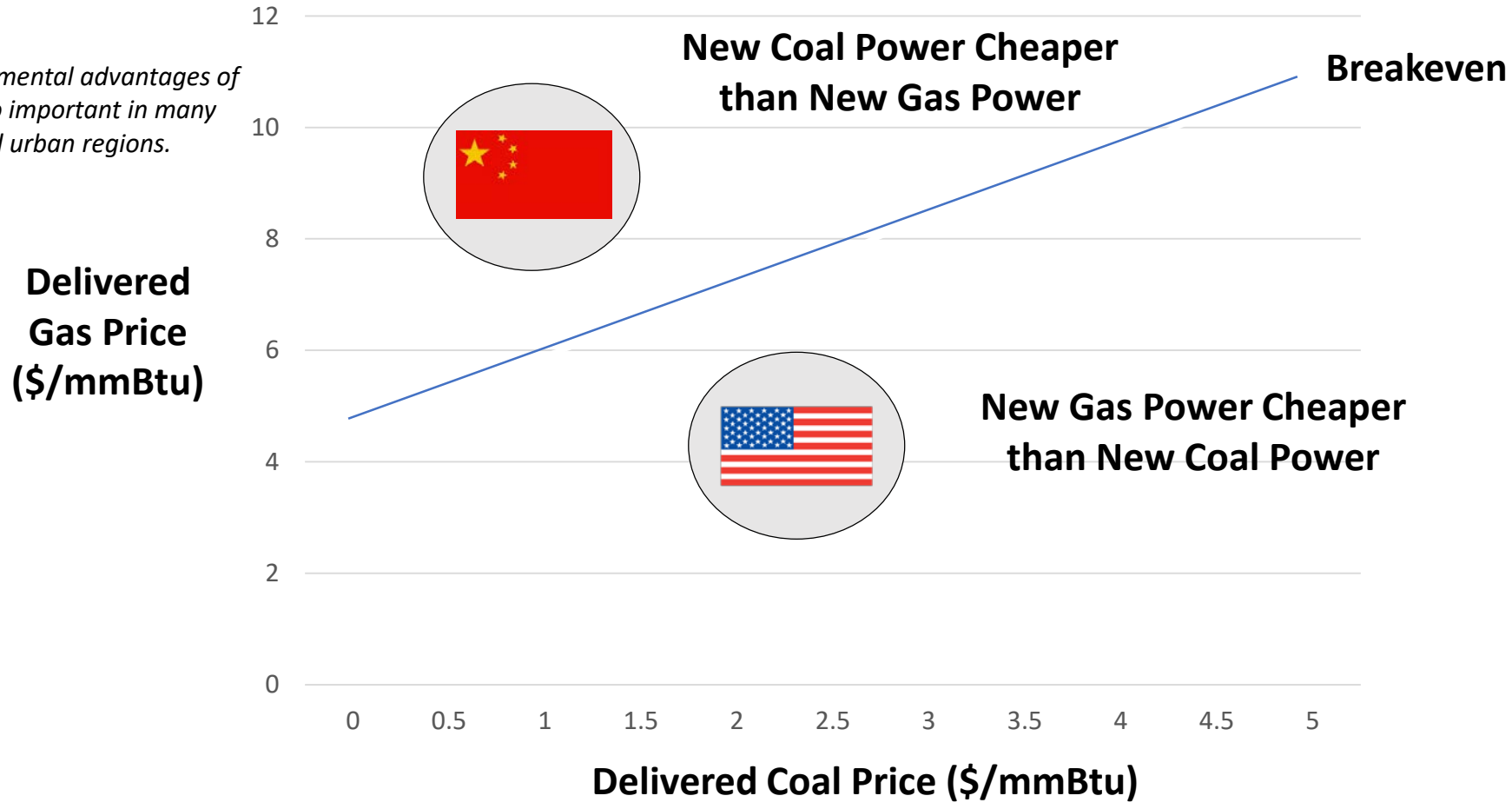
(3) Reflects mean of fixed-tilt (high end) and single-axis tracking (low end) crystalline PV installations.

More wind and solar will drive down gas generation capacity factor in high renewable regions

Source: Lazard Levelized Cost of Energy 11.0

Delivered fuel prices drive many gas vs. coal decisions

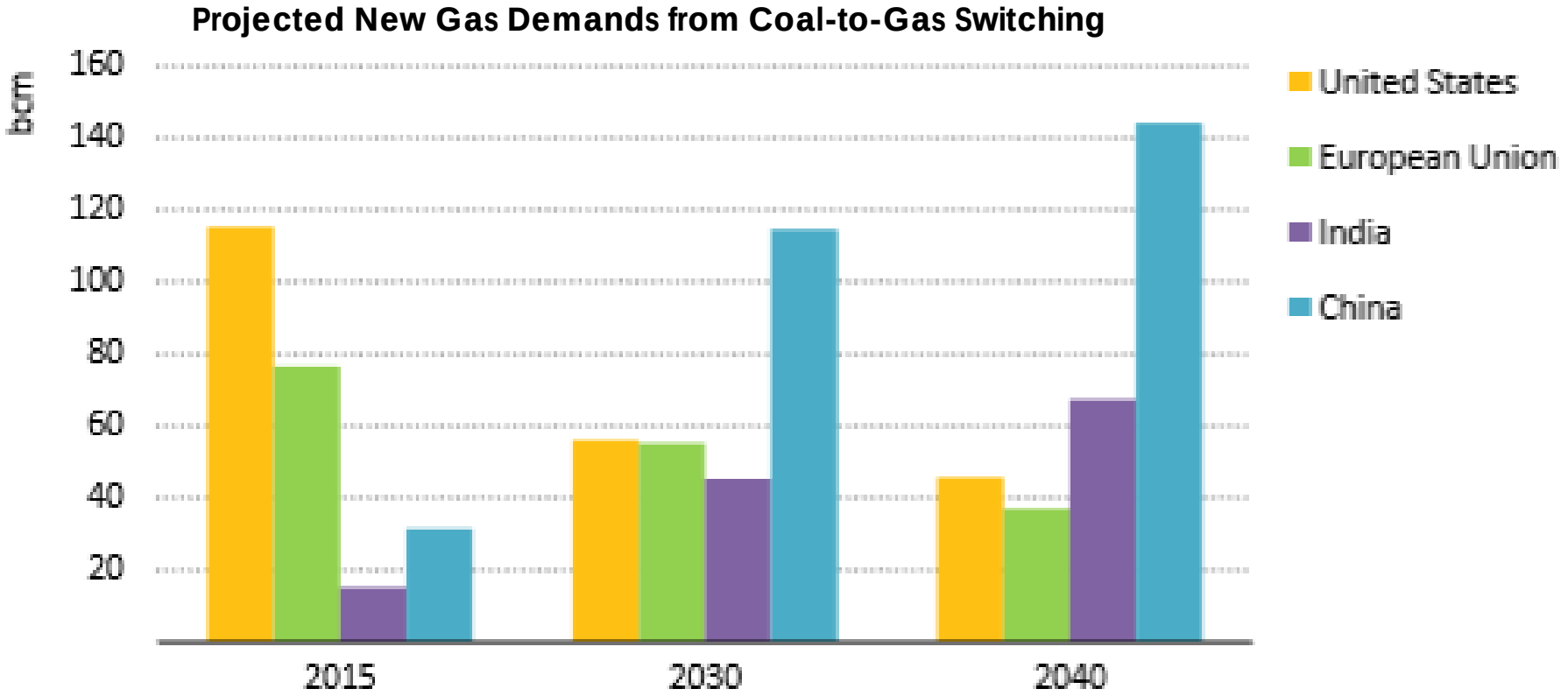
Environmental advantages of gas also important in many polluted urban regions.



Note: Utilizes high-end of range of cost estimates for gas CCGT and low-end of range of cost estimates of coal, assuming 70% capacity factor and 10% cost of capital. Excludes environmental extermality.costs

Source: Enovation Partners analysis (based on Lazard Levelized Cost of Energy study)

Annualized potential for further coal-to-gas switching in power generation growing in Asia, shrinking in Europe / U.S.



The ability to temporarily switch away from gas decreases in the US and the European Union as coal plants are closed, but increases in China as more gas plants are built

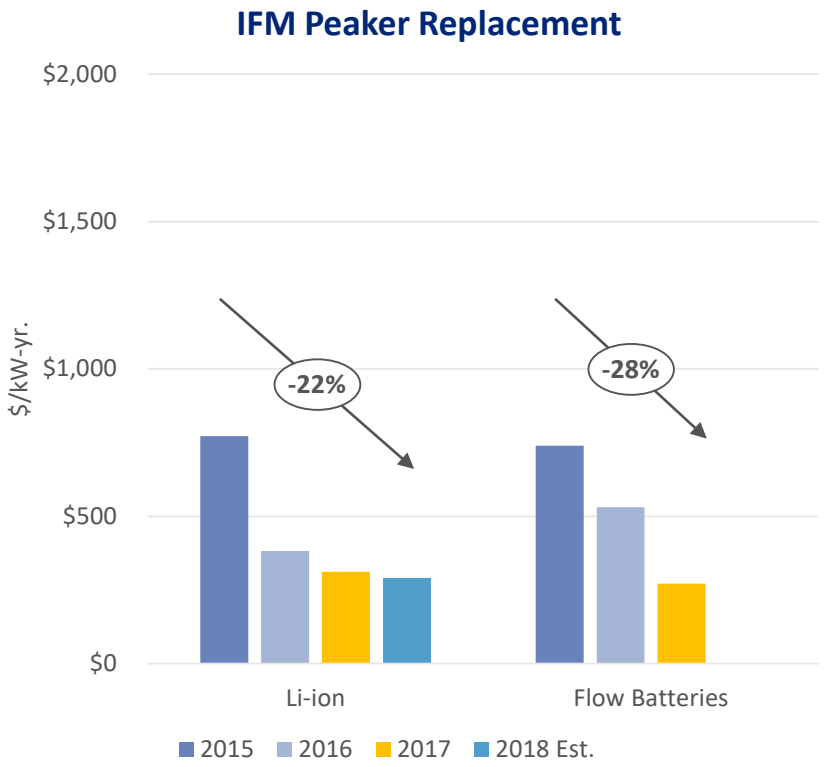
Considerable coal/oil to gas switching also in SE Asia and Africa

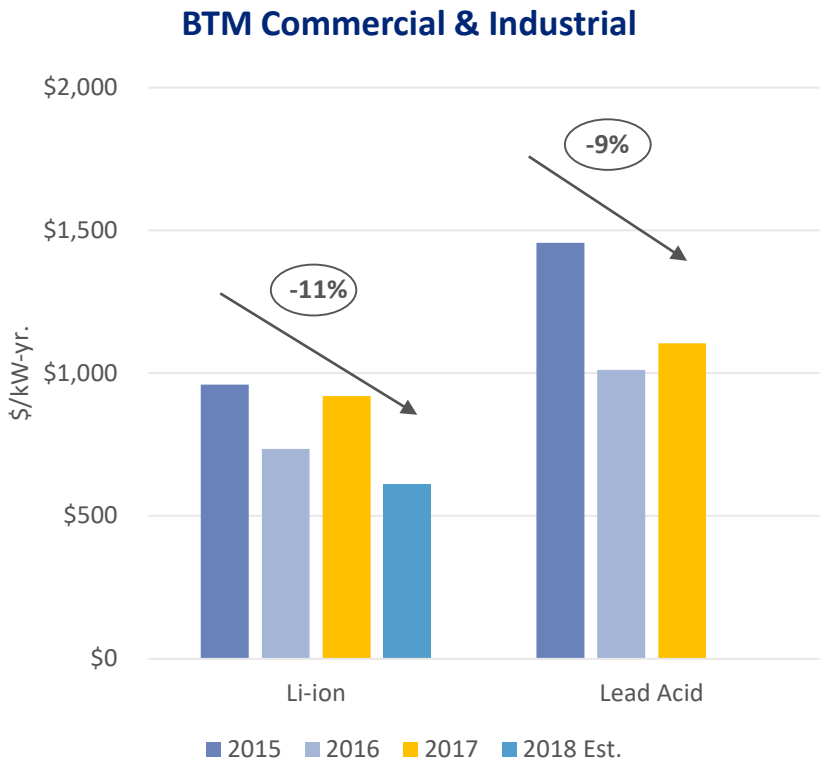
Source: IEA 2017 World Energy Outlook, New Policies scenario

Can renewables + storage displace gas? Energy storage costs have declined sharply over the past few years...

IFM = In Front of Meter
BTM = Behind the Meter

Historical Levelized Costs and Annualized Cost Decline for Storage Technologies[1]





1. 2017 and 2018 estimates include consideration of capitalized treatment of augmentation costs

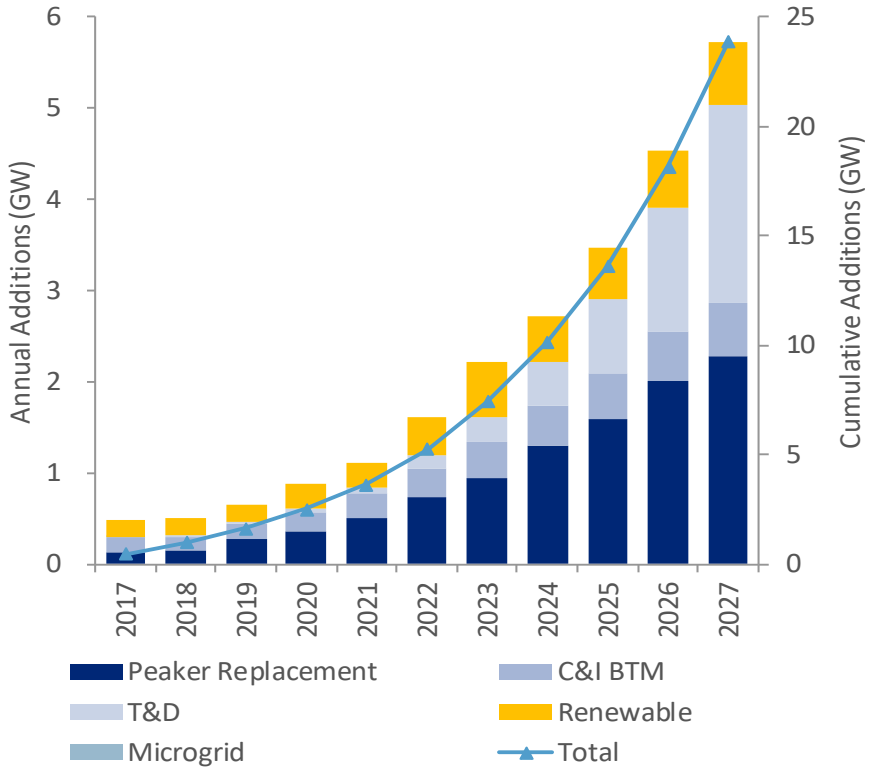
Sources: Lazard, Enovation Partners analysis

...But cost reduction curves are flattening as scale is achieved. IFM peaker replacement remains economically challenged.

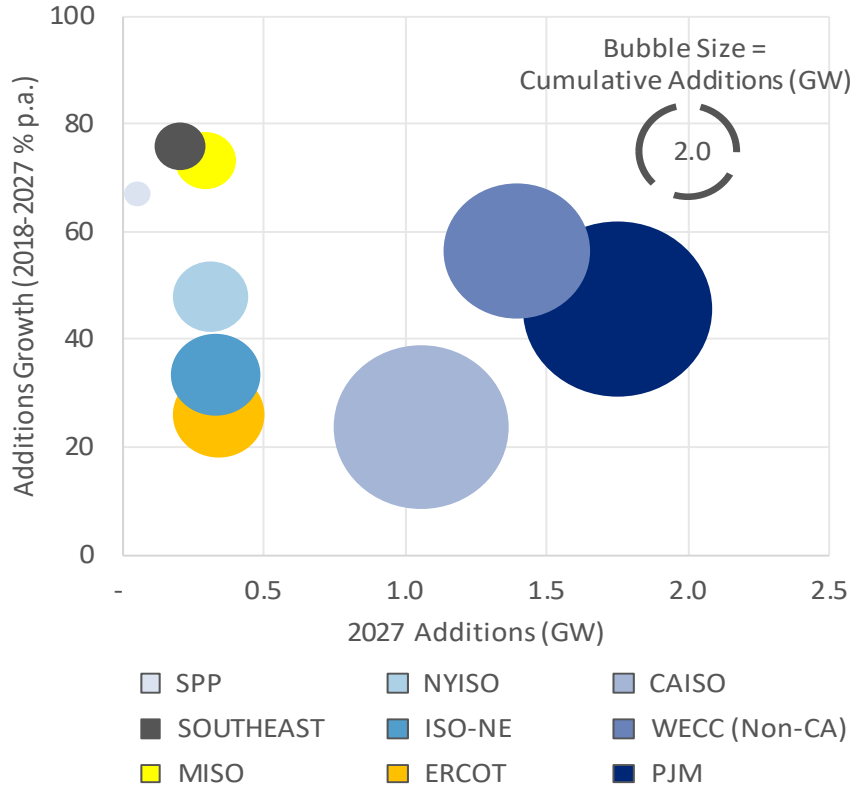
Utility scale storage deployments will rise rapidly through 2025, yet net displacement of coal/gas fuel use will be modest

North American Energy Storage Market Outlook (2018 – 2027)

Annual vs. Cumulative Additions



Cumulative Additions vs Growth

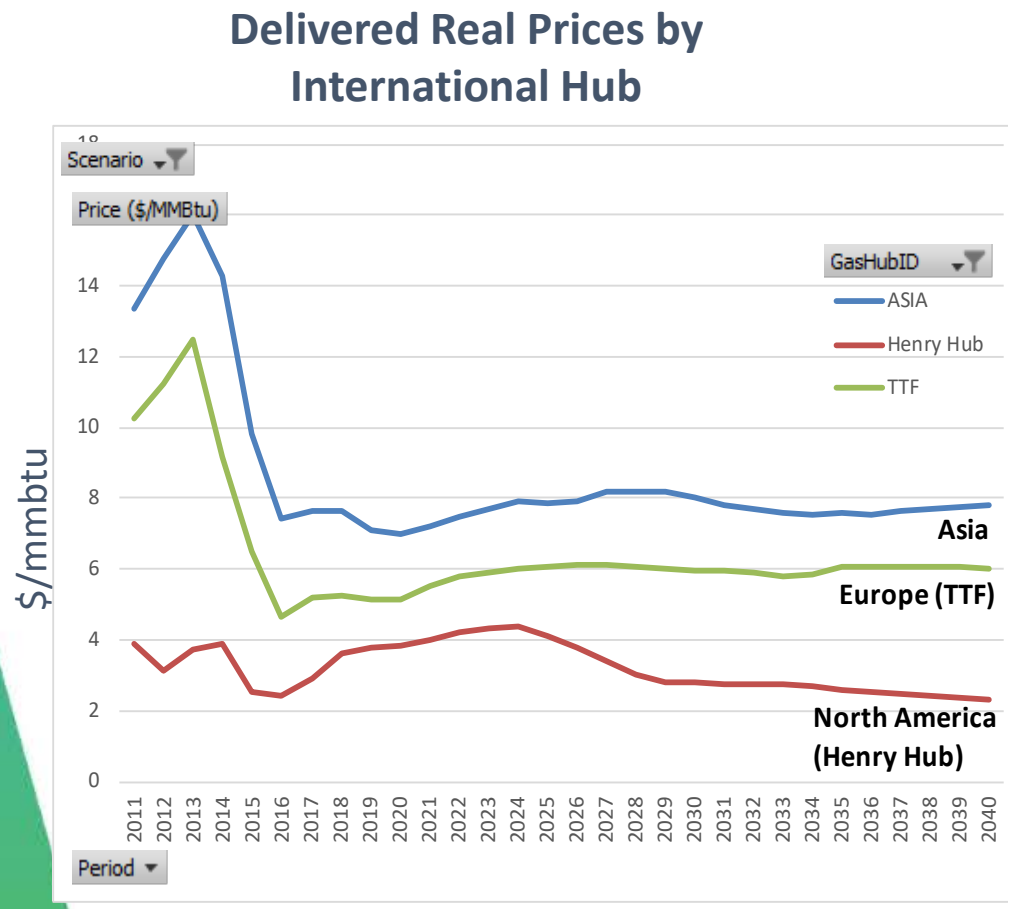


1. For all countries: expenditures include upfront capital & EPC costs of new projects; does not consider operating costs, warrantee, etc.

Source: Enovation Partners analysis

- Coal and renewables are main threat to power demands for gas.
- Storage will displace modest amounts of peaker generation.

How would accelerated renewables development in Europe and North America affect global gas markets?



- Constructed Minimum Gas scenario through 2040
- Assumed further decarbonization of electricity sector and accelerated decarbonization of transport sector, beyond IEA's Sustainable Policies case.
- These trends were assumed to affect Europe and North America first, then middle-income countries (notably China, India and Brazil) on roughly a five-year lag.
- Modeled impact with **RBAC's G2M2® Global Gas Market Modelling System**. Detailed supply, transport and cost logic by major production region.
- Results:
  - Gas demand drops in Europe and North America. Lower LNG prices encourage higher demand growth in developing countries.
  - Moving back down the supply curve, North American LNG pushes out much production from other mid-cost production regions. U.S. becomes largest LNG exporter.
  - Global natural gas demands decline modestly.

Source: RBAC, Inc.; Enovation Partners analysis

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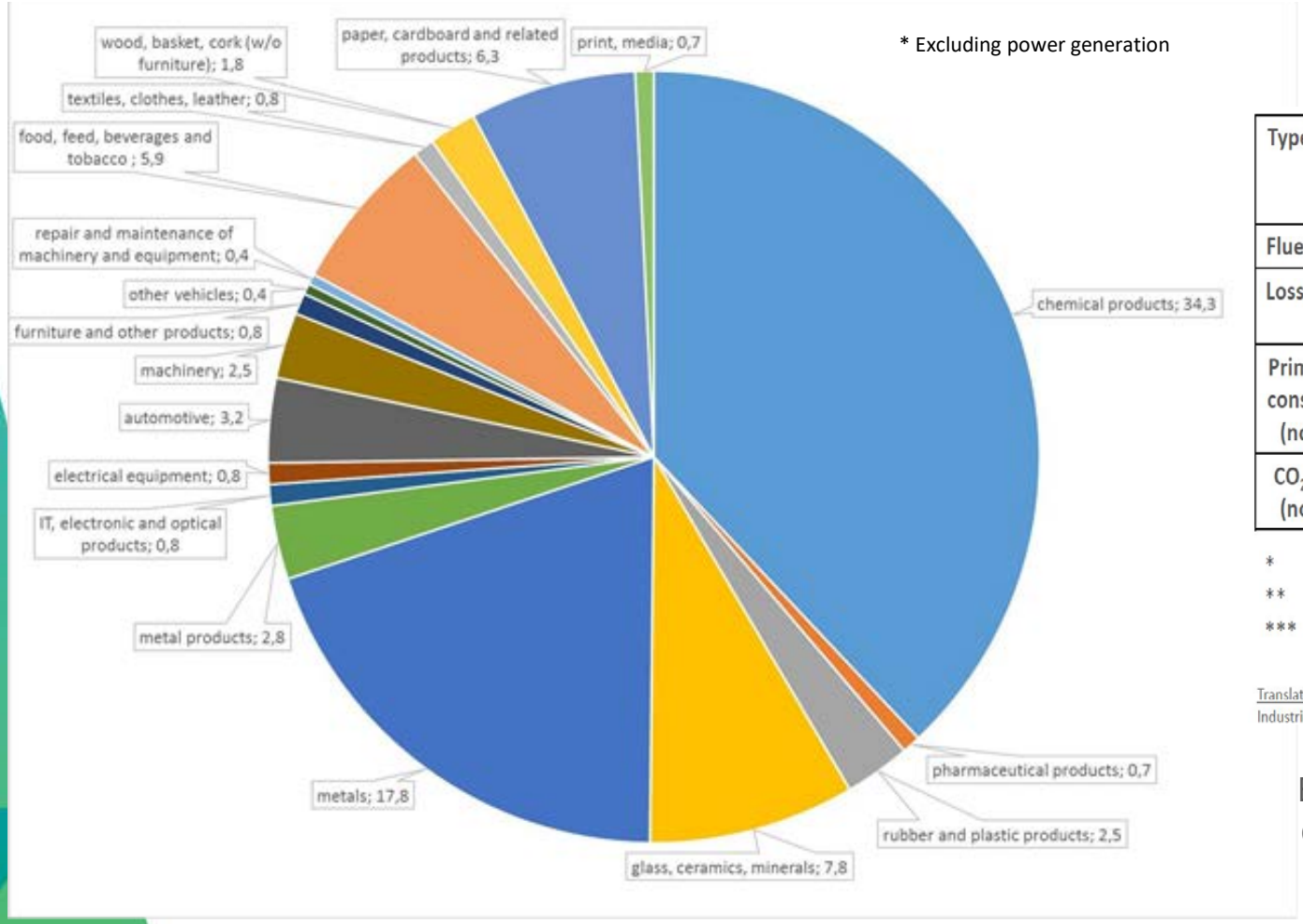
Most industrial end uses of gas are not well-suited to electrification

Share of Industrial Gas Consumption by Segment* - Germany 2012



* Excluding power generation

>75% of German industrial gas demand is in intense energy uses

Example: Metal Heat Treatment

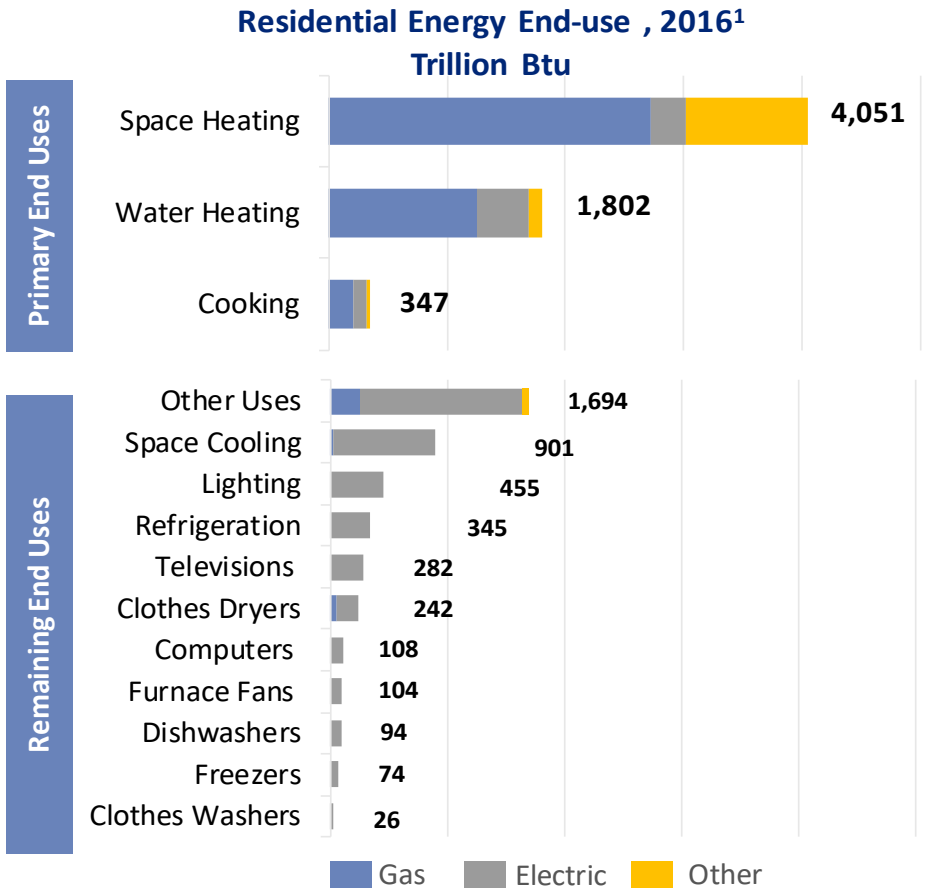
Type of heating system	Natural gas without air preheating	Natural gas with air preheating	Natural gas with optimized air preheating	Natural gas with oxy-fuel combustion***	electric heating
Flue gas losses*	50 %	30 %	15 %	15 %	-
Losses in power plant	-	-	-	7 %	58 %
Primary energy consumption** (normalized)	2	1.4	1.2	1.3	2.4
CO_2 emissions (normalized)	2	1.4	1.2	1.6	2.6

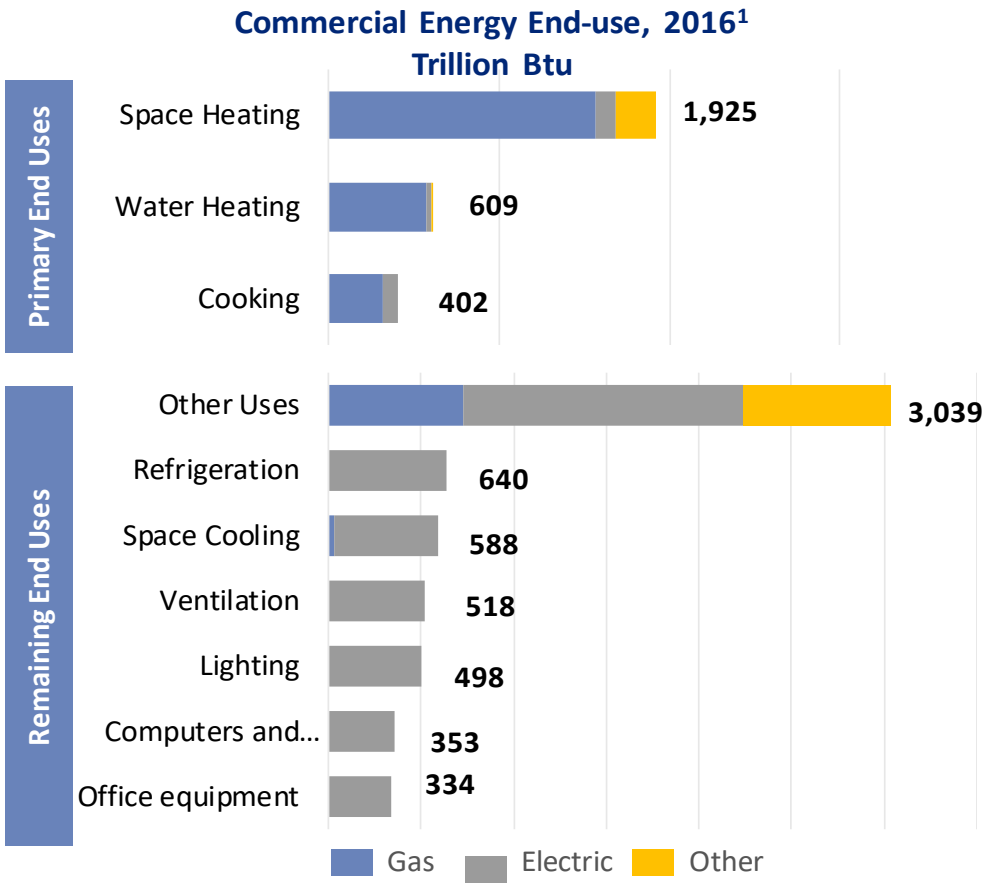
* @ 1,000 °C furnace temperature
** based on the energy mix in German power plants (BMWi)
*** based on 0.5 kWh_{el}/m^3 for O_2 production

Translated from: Wünning, J.: „Rekuperator- und Regeneratorbrenner", 7. Praxistagung „Effiziente Brennertechnik für Industrieöfen", Essen, Germany, 2016

Energy consumption, CO_2 emissions and capital costs are lower with gas

Space and water heating, cooking and drying account for great bulk of Commercial and Residential gas demand





Source: EIA, AEO 2018

Electrifying space, water, and process heating would be very expensive pathway for reducing GHG emissions. (See recent AGA reports.)

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Emerging gas end-use technologies can make substantial and cost-effective contributions to GHG reduction goals

>100

Innovative Gas Technologies for Residential / Small Commercial identified from around the world

25-40%

GHG reduction potential on a customer basis by integration of these technologies and other efficiency practices

60-80%+

GHG reduction – sufficient to meet COP 21 goals – with inclusion of future CHP technologies and Renewable Gas

- Gas technologies can enhance energy system reliability (system-wide and as a local backup) and efficiency, while reducing the need for new electric generation and T&D infrastructure and preserving the future value of gas infrastructure.
- Electric technologies will also improve, and are supported by incentives, but their GHG impacts depend on the generation fuel mix. In some regions electrification will increase GHG emissions through the 2030s.

Combining emerging gas end-use technologies in the residential sector creates multiple pathways for customers to reduce GHG emissions

Building Efficiency, 10-45%

- IoT based thermostat
- Building envelope

Space Cooling, up to 45%
Space Heating, up to 40%

- Gas heat pump

Water heating, up to 55%

- Absorption heat pump

Cooking, minimal change

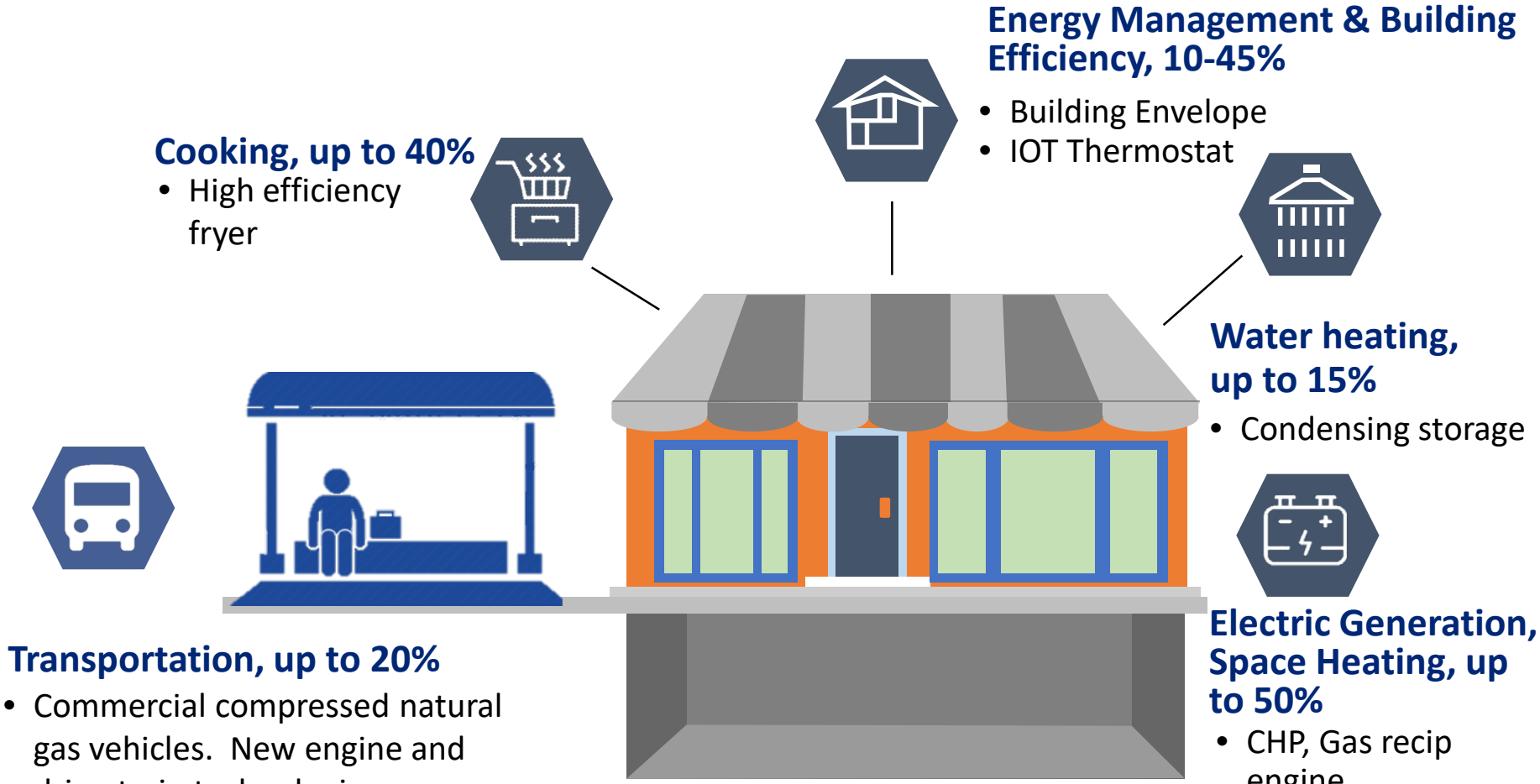
- Gas stove
- Gas oven

Laundry, 55%

- Gas dryer
- Ozone washing

Notes: GHG reduction potential is estimated based on efficiency improvements over stock average gas equipment efficiency and building envelope in 2016
Source: AGA Gas Technology Pathways study

Combining emerging gas end-use technologies in the commercial sector creates multiple pathways for customers to reduce GHG emissions



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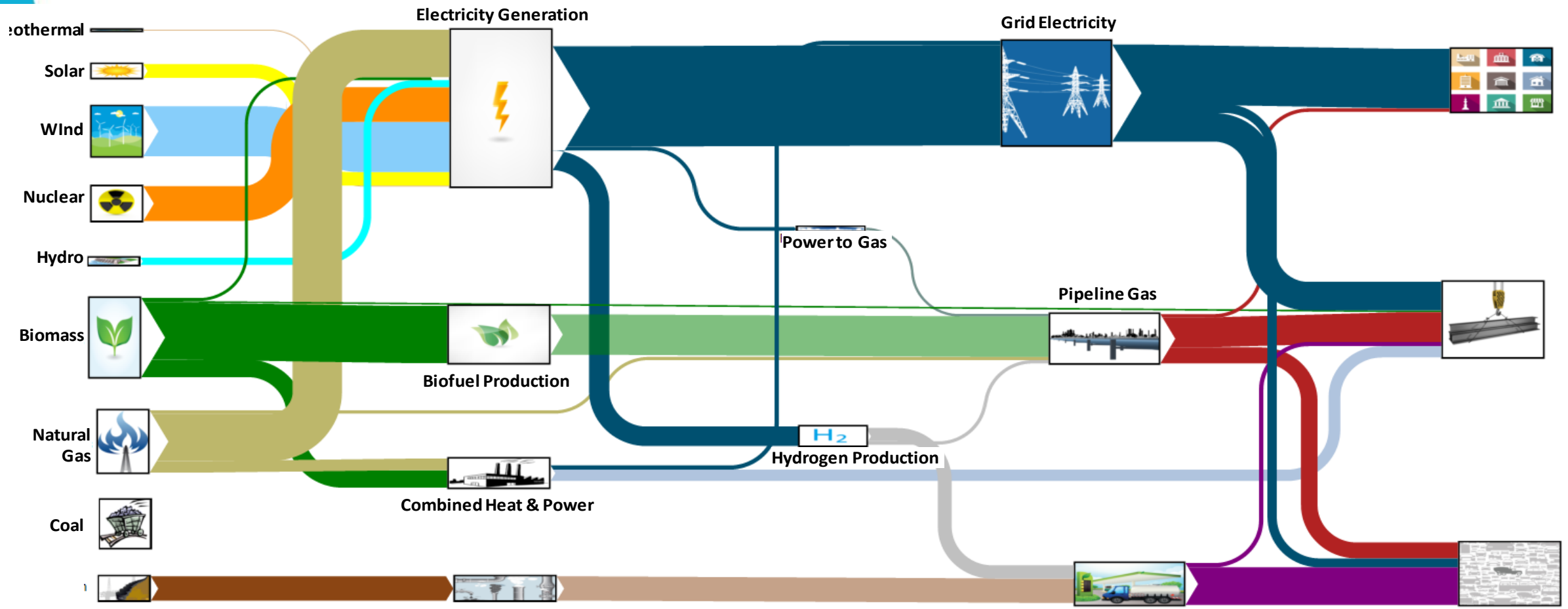
Gas should play an important and cost-effective role in meeting Paris commitments to 80% GHG reduction

Sankey diagram for U.S. energy system in 2050 – Mixed Case



Various source/process/end use scenarios can achieve 2050 GHG emission goals. Mixed case generally less costly. Renewable gas in end game.

Source: Deep Decarbonization Pathways Project, 2015

What is the role of gas in a decarbonizing future?

- Gas-fired generation capacity will continue to grow around the world, albeit with lower capacity factors in renewables-rich areas.
- Intense, longer duration end uses for gas (e.g., heating, industrial processes) are generally not well suited to electrification – higher costs, often lower productivity, increased GHG emissions through medium term.
- Innovative gas technologies are available to improve end-use efficiency and reduce GHG emissions at low cost, and deserve policy support.
- Renewable gas and micro-CHPs can achieve long-term COP21 targets and preserve the value of gas T&D infrastructure.
- Policy goals for sustainable energy can be achieved at significantly lower cost through integrating innovative gas solutions into the long-term energy mix, while offering customers more choice and improved affordability, reliability and comfort.

Gas is not merely a bridge to the future, but a core part of the most cost-effective and sustainable energy mix.

Thank you for your attention

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