An Overview of the Natural Gas Industry and Technology Trends for the coming decade

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GTI

Outline

- Part 1:
  - Natural Gas Industry Structure Overview
  - Natural Gas Properties
  - Pipeline Overview
  - Distribution Overview
- Part 2:
  - Technology Trends
  - 3-5 Year Outlook (views expressed purely my own)

GTI Technology Expertise

Unconventional Gas
- Shale Reservoir Analysis
- Water Management

Energy Conversion
- Gas to Liquids
- Gas Processing and clean-up

LNG
- Small scale liquefaction
- Modeling
- Interchangeability

Gasification
- Coal to Gas
- Biomass and gas blends

Energy Efficiency
- Industrial equipment
- Commercial & Residential appliance

Natural Gas Vehicles
- Engine development & testing
- Demonstration & training

Transportation
- Fueling systems
- Advanced Storage
- LNG for marine and rail

Power Generation
- Combined heat & power
- Low NOx equipment

Infrastructure
- Pipeline Inspection
- Operator tools

Pipeline Integrity
- Models
- Testing/analysis
- Materials research

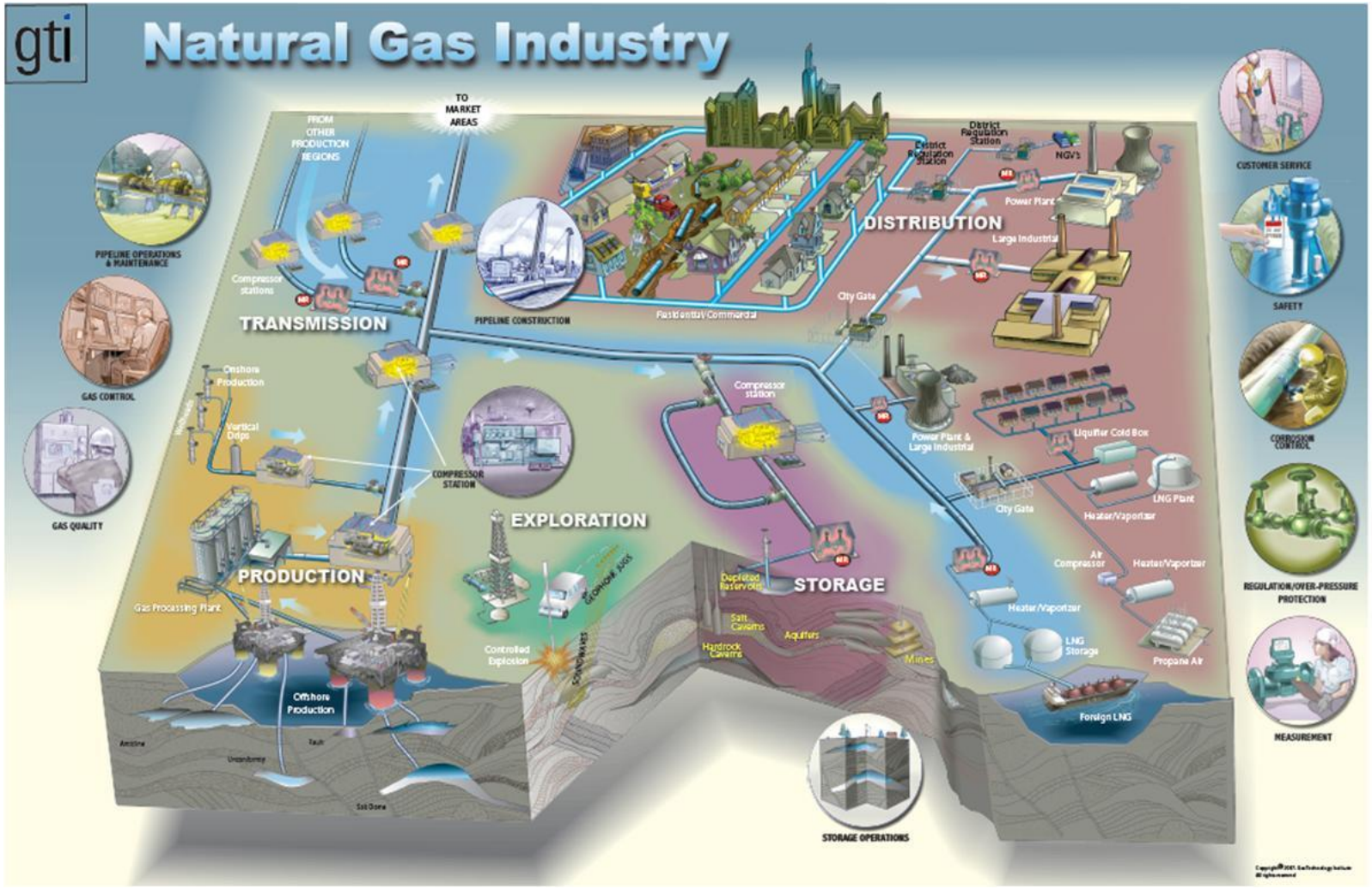
Biology
- Methanotrophic microbes
- Renewables

Hydrogen
- Generation and dispensing
- Fuel cells

Structure of the Gas Industry

Source: Florida Gas Transmission Co.,

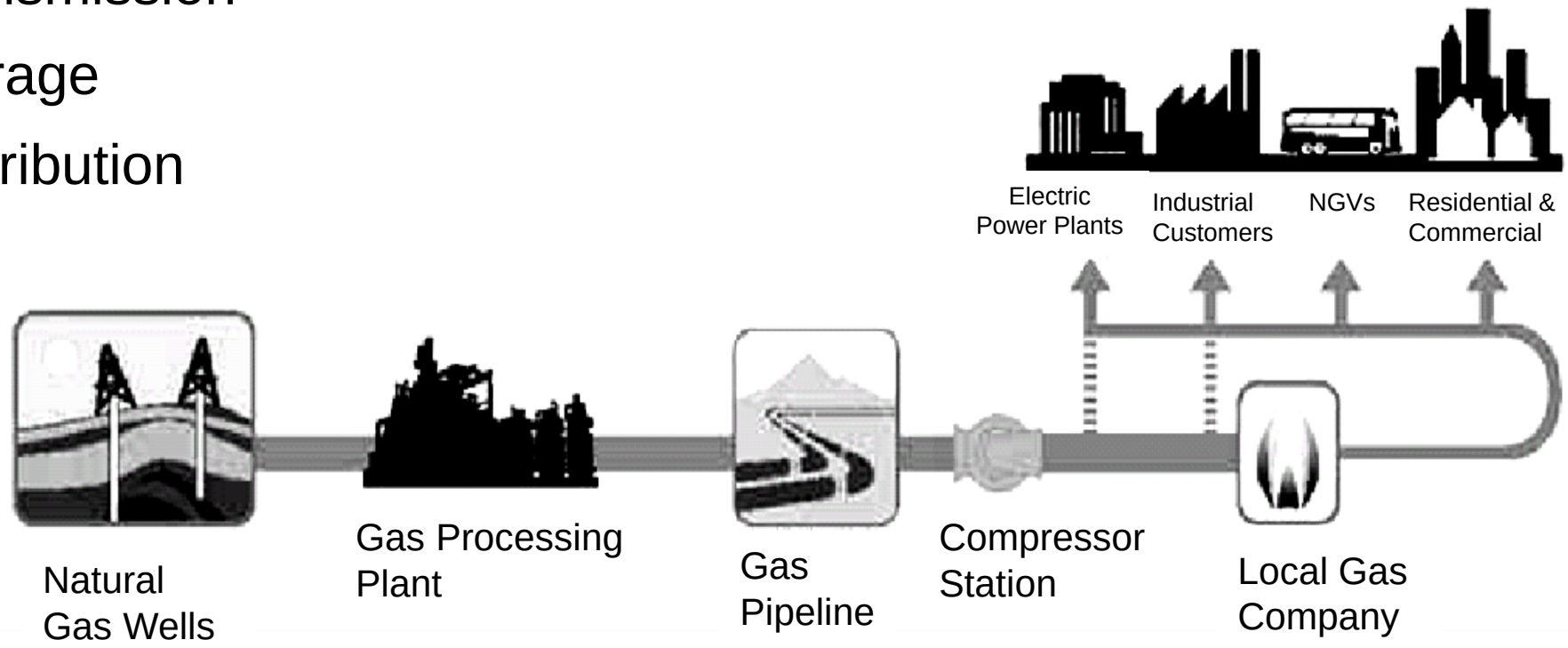
Natural Gas Industry Map



Picture Courtesy of GTI

Structure of the Industry

- Exploration and Production
- Transmission
- Storage
- Distribution

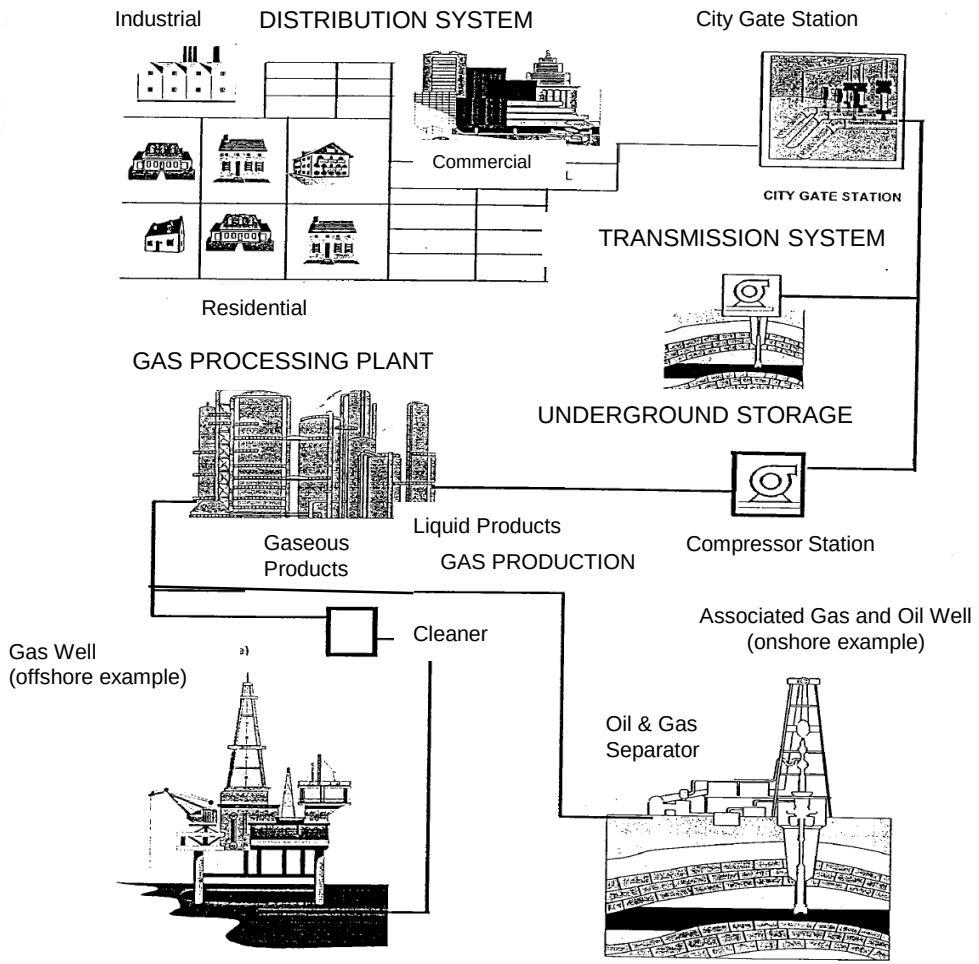


Picture Courtesy of GTI

Pipeline Definitions

- *Gathering line* means a pipeline that transports gas from a production facility to a transmission line
- *Transmission line* means a pipeline that transports gas from a gathering line or storage facility to a distribution center, storage, or large volume customer
- *Distribution line* is typically lower pressure and receives gas from transmission and redelivers gas to end use customers.
- Different O&M requirements for transmission and distribution pipelines

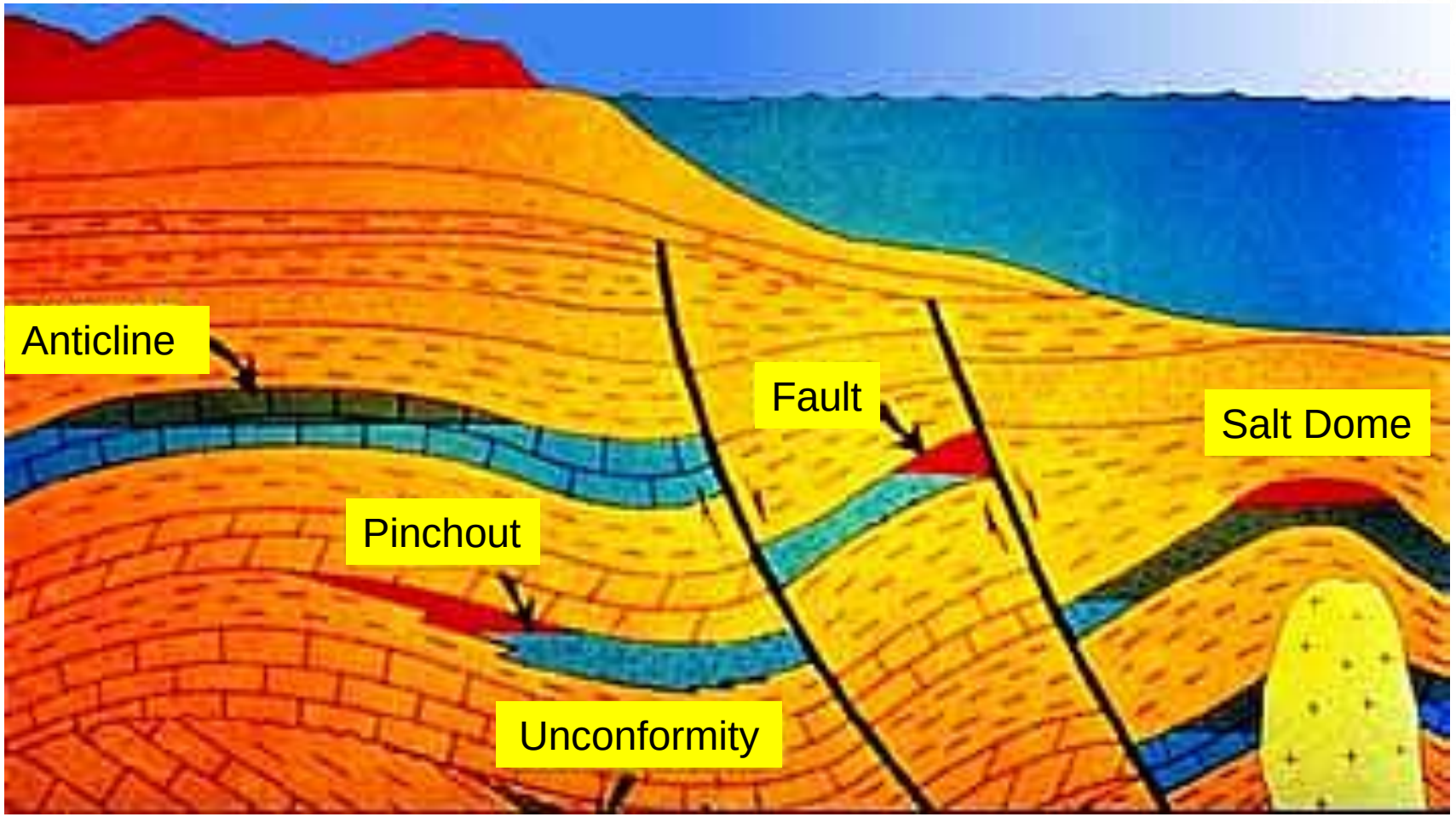
Overview – What Physically Happens to the Gas?



- Production well
- Separation and Processing
- Transported by pipeline
- Distribution to end users

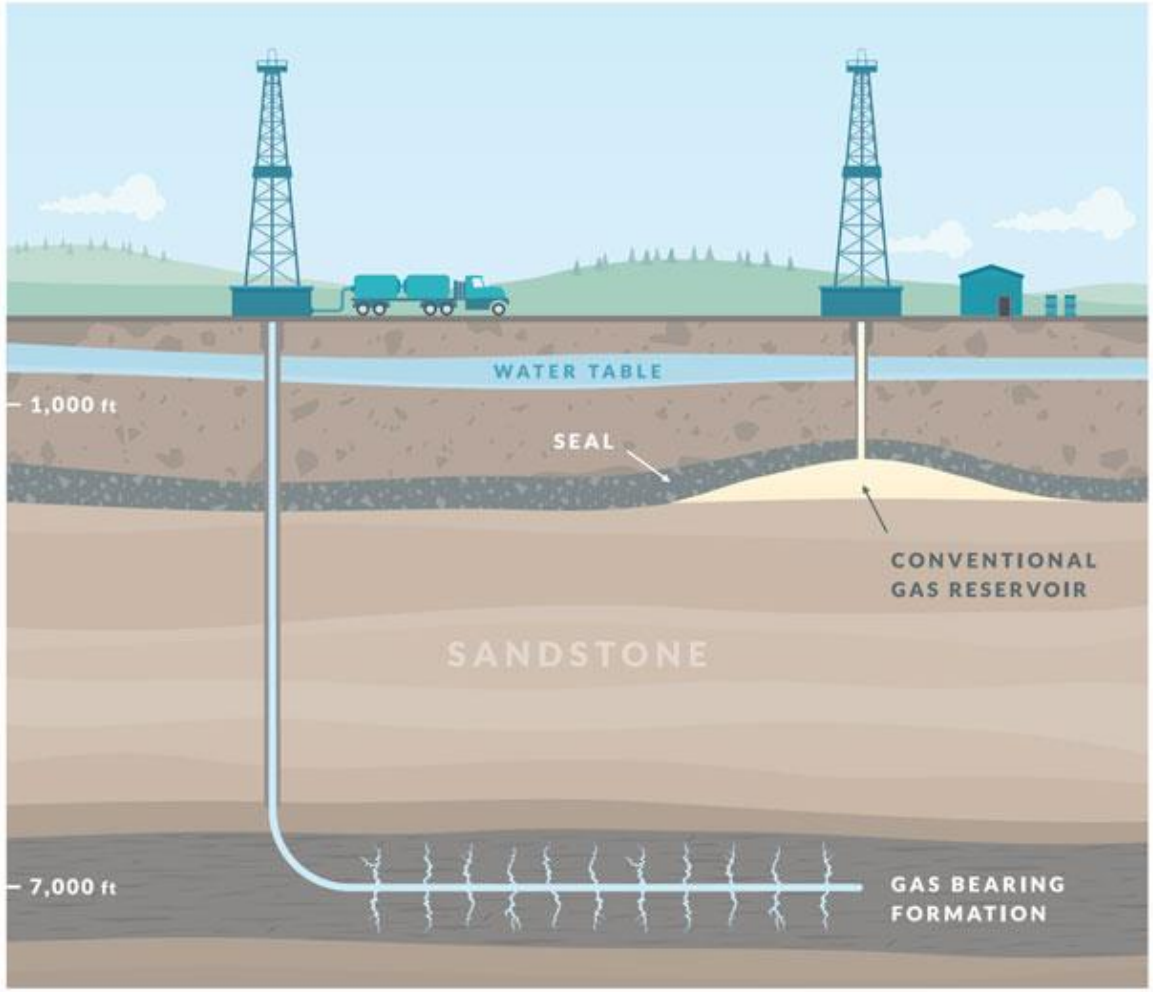
Picture Courtesy of GTI

Conventional Resources



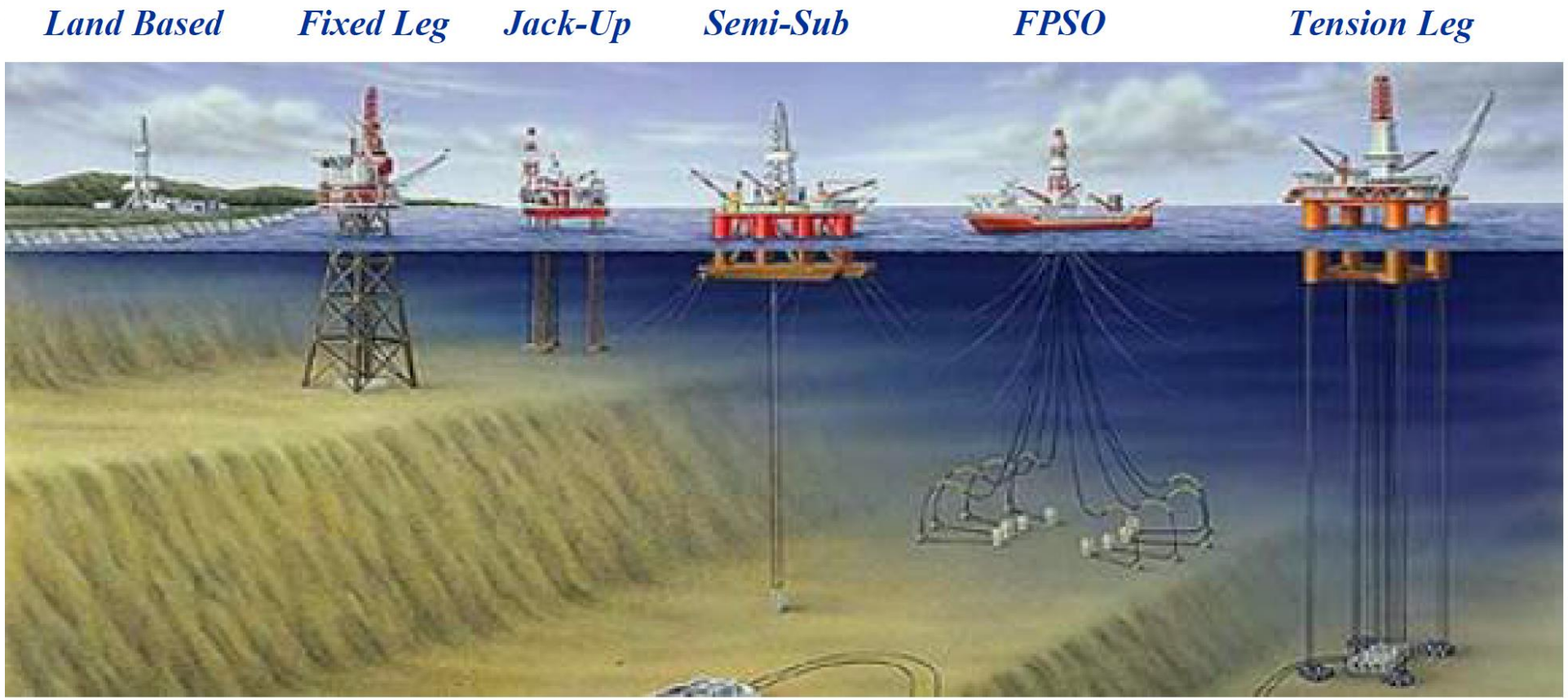
Picture Courtesy of GTI

Natural Gas: Hydraulic Fracturing and Conventional



Data Source: Energy Information Agency, Energy In Brief, Dec. 5, 2012

Production



Picture Courtesy of SWRI

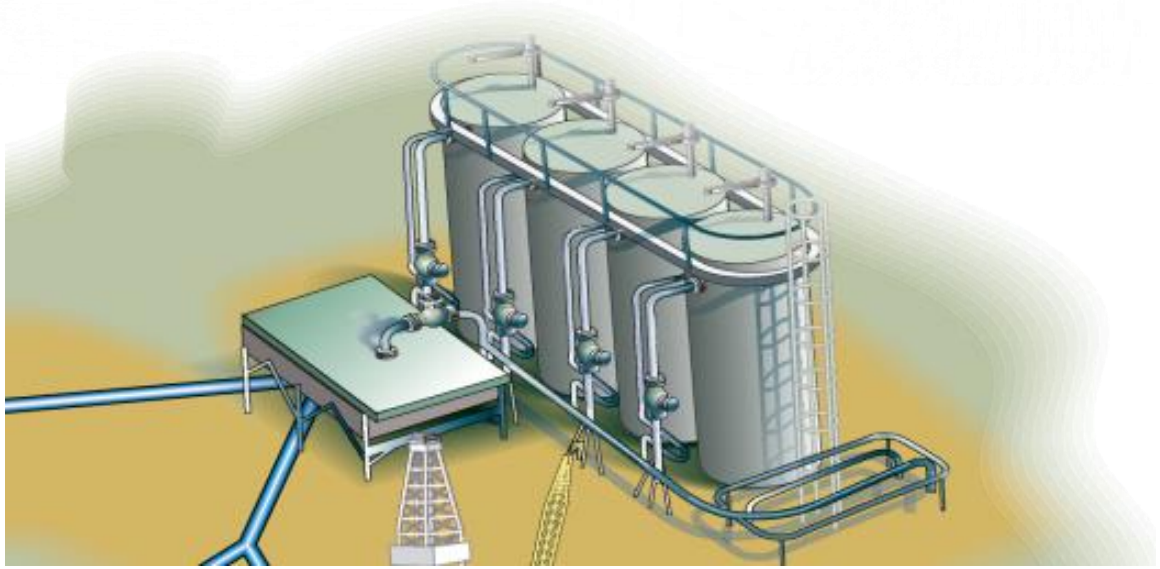
Shale Gas Basins in the US

Source: U.S. Energy Information Administration based on data from various published studies. Canada and Mexico plays from ARI.
Updated: May 9, 2011

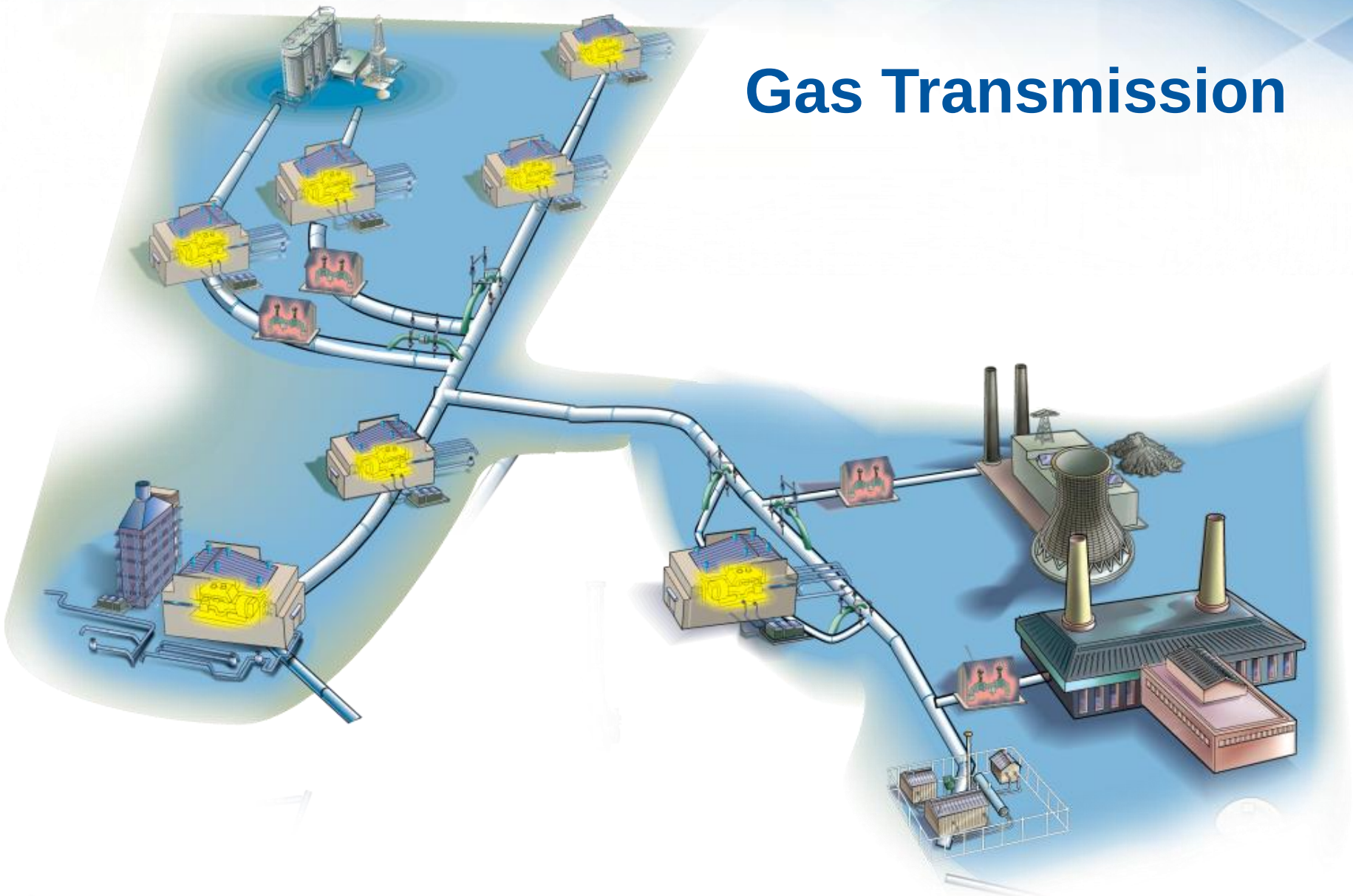
Gas Separation, Dehydration, and Processing

Removal of

- Water
  - Avoid Hydrate Formation
  - Avoid Corrosion
- Dirt and Contaminants
- Propane and Butane
  - Sellable By-Product
  - More Valuable than Bulk Gas
- Nitrogen and Carbon Dioxide
  - Non-Combustibles that Lower Heating Value
- Sulfur Compounds
  - Turning Sour Gas “Sweet”



Gas Transmission



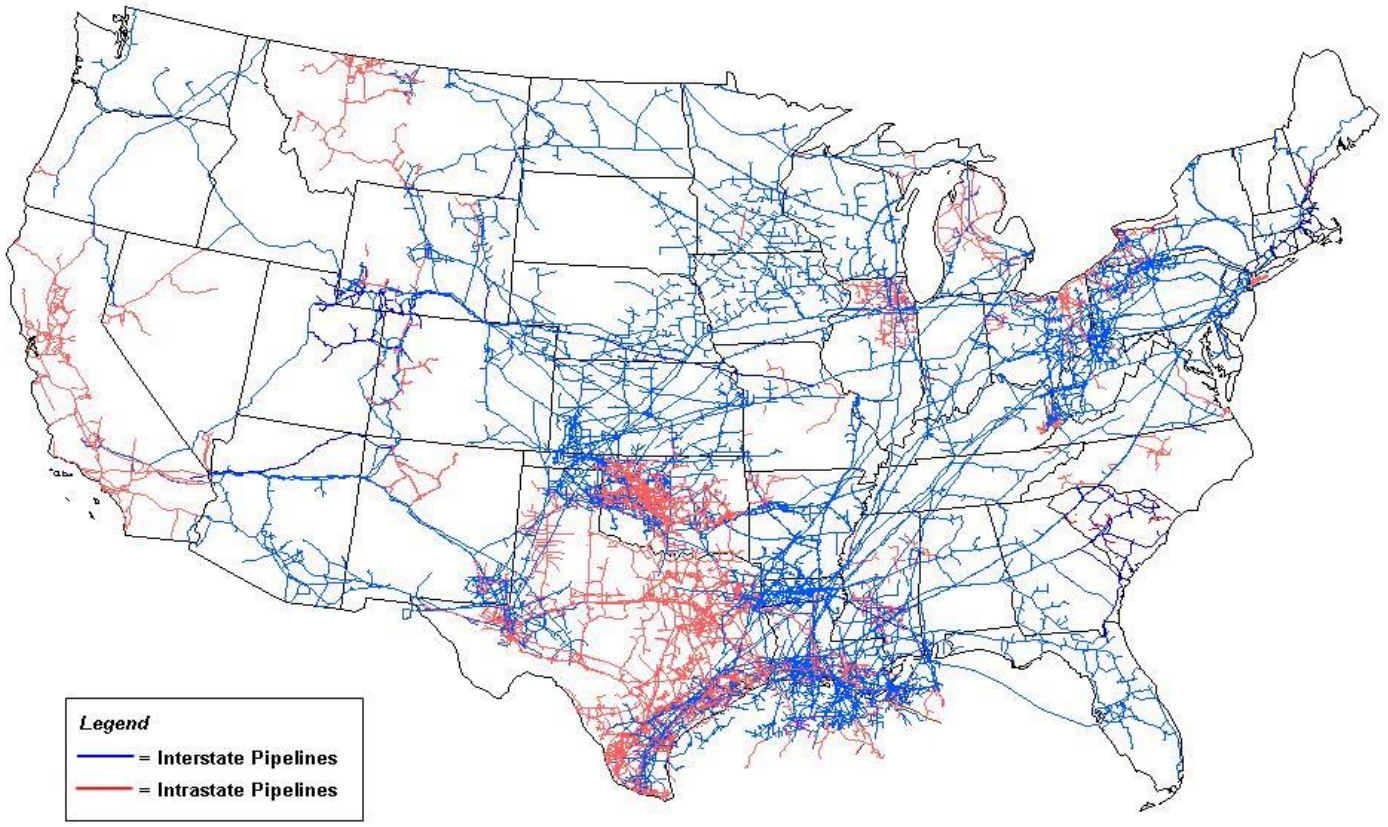
Picture Courtesy of GTI

How Transmission Works

Picture Courtesy of Reniregroup.com and Natural Gas Now

Picture Courtesy of GTI

U.S. Natural Gas Pipelines



Source: Energy Information Administration, Office of Oil & Gas, Natural Gas Division, Gas Transportation Information System

Picture Courtesy of GTI

Transmission Characteristics

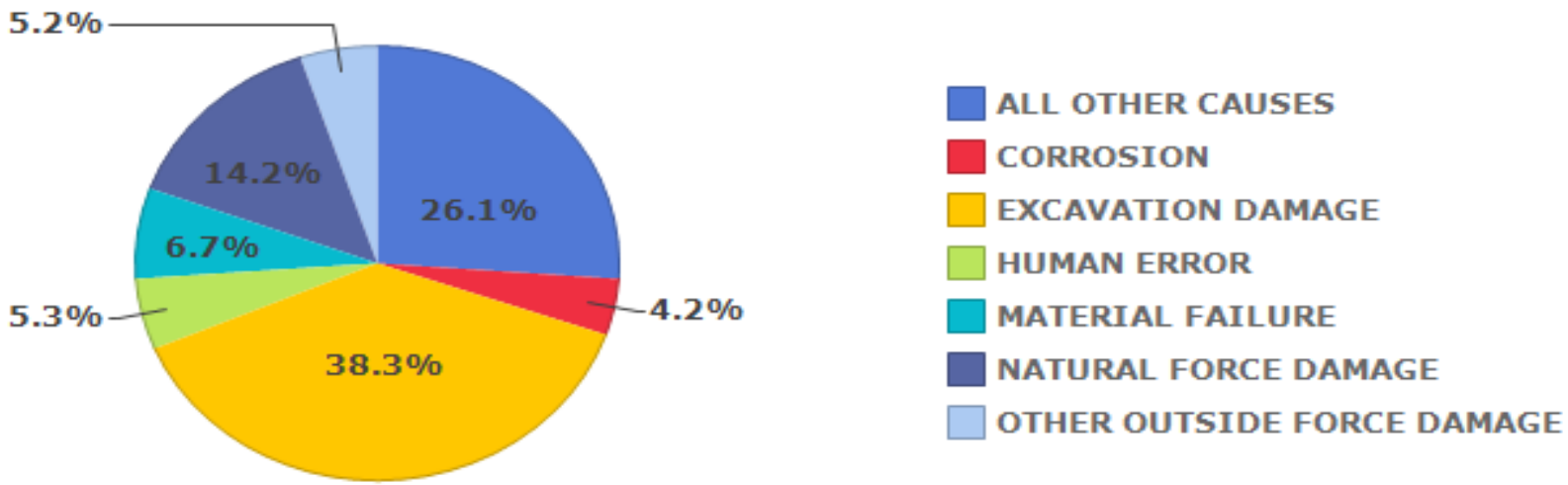
- Long-haul, large volume
- Crosses state boundaries
- High pressure / large diameter
- High-grade steel material
- Compressor stations positioned approximately every 100 miles
- Regulated by PHMSA (safety), and FERC (rates and tariff provisions)

How Do You Maintain Safety and Integrity of the Pipeline?

- What are the top 4-5 causes of pipeline incidents?

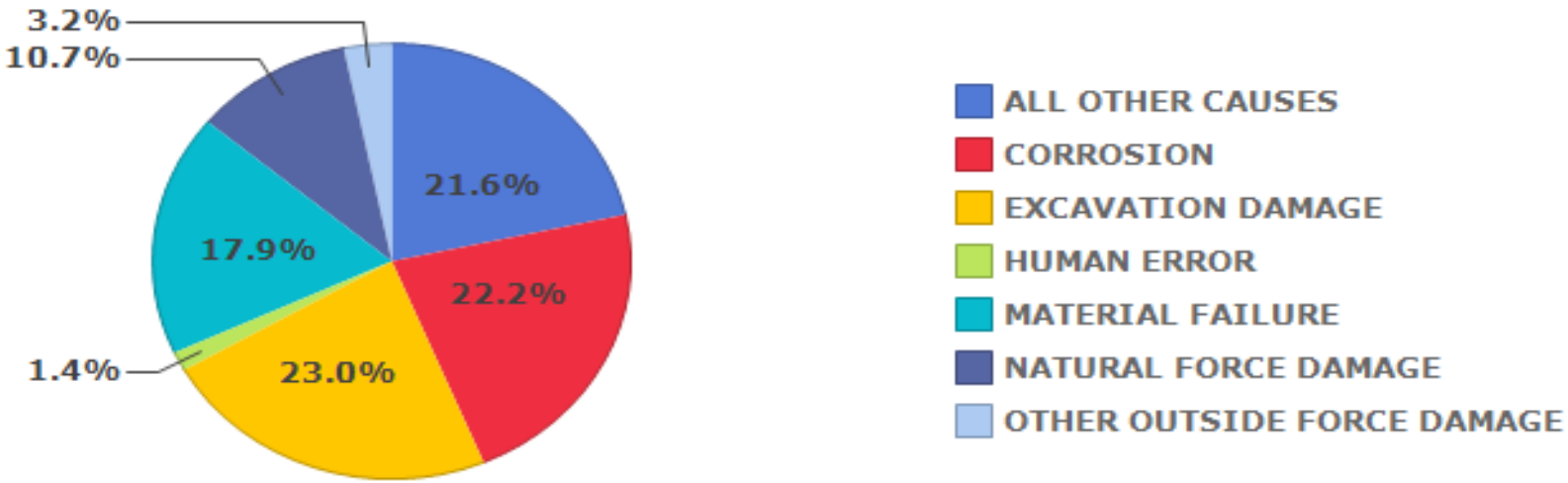
Failure Cause Breakdown

National Gas Distribution Failure Causes 1987-2006



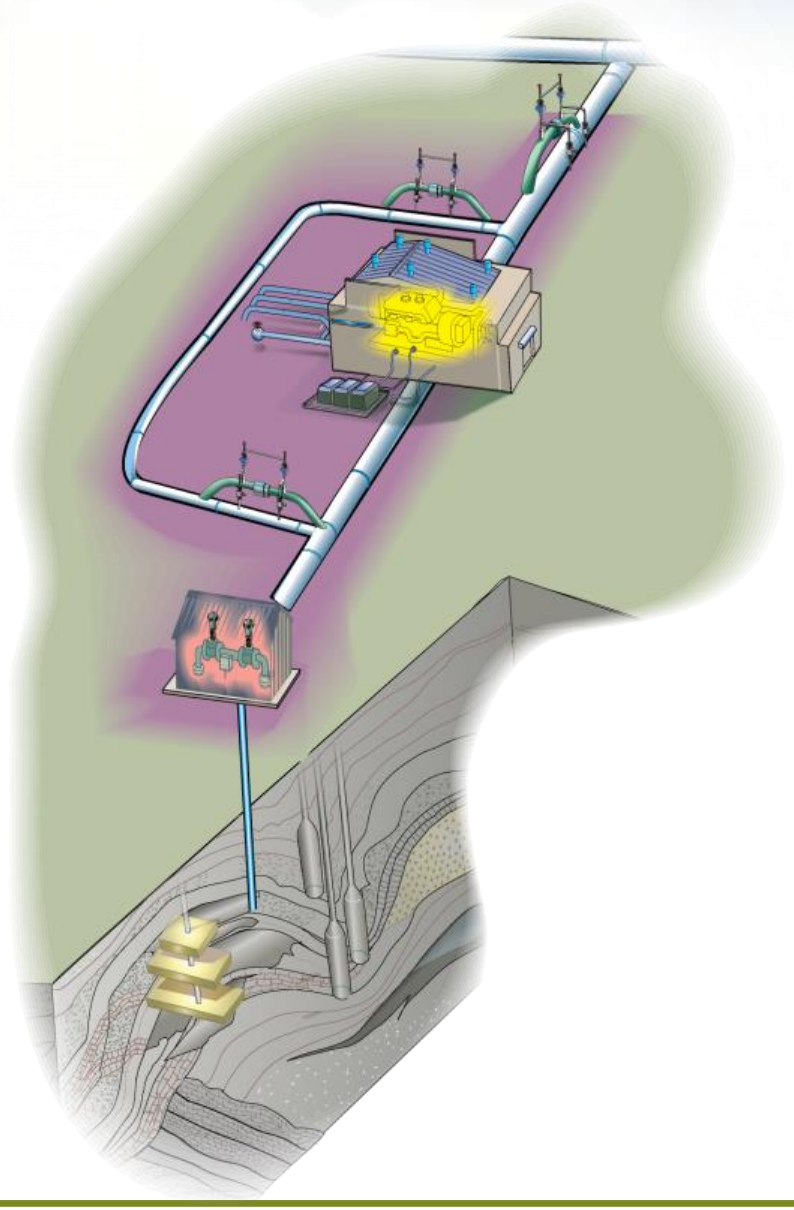
Failure Cause Breakdown

National Gas Transmission Failure Causes 1987-2006



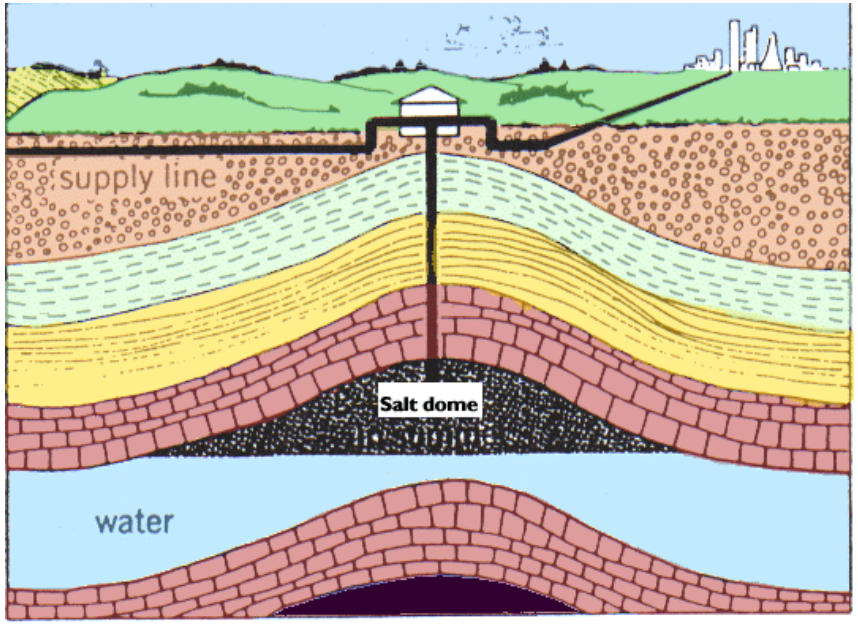
Picture Courtesy of PHMSA Significant Incident Files 2007

Storage



Picture Courtesy of GTI

Storage

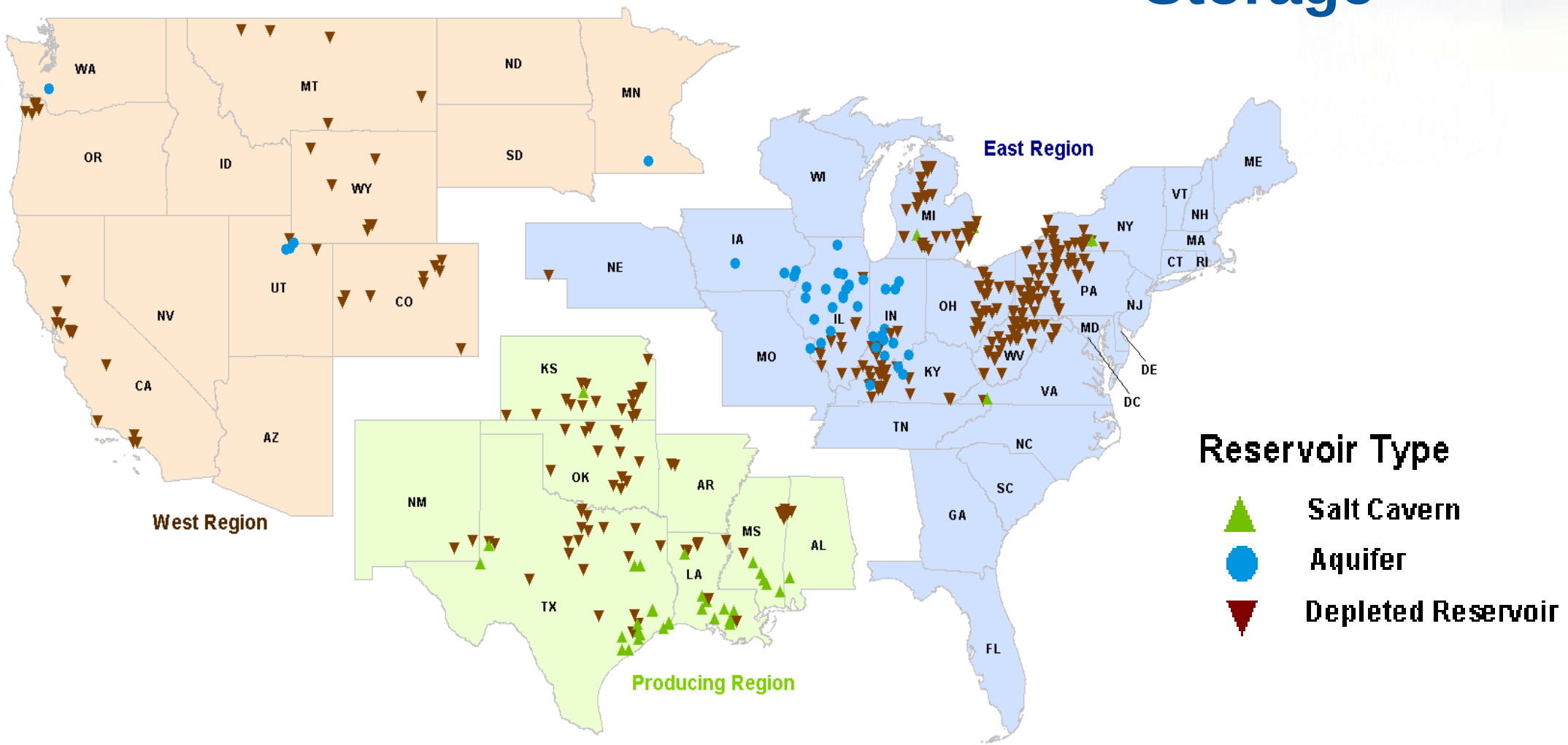


TYPICAL AQUIFER STORAGE FIELD

- Usage of gas is seasonal – high in the winter, lower in the summer
- System is improved by storing summer gas for winter use

Picture Courtesy of GTI

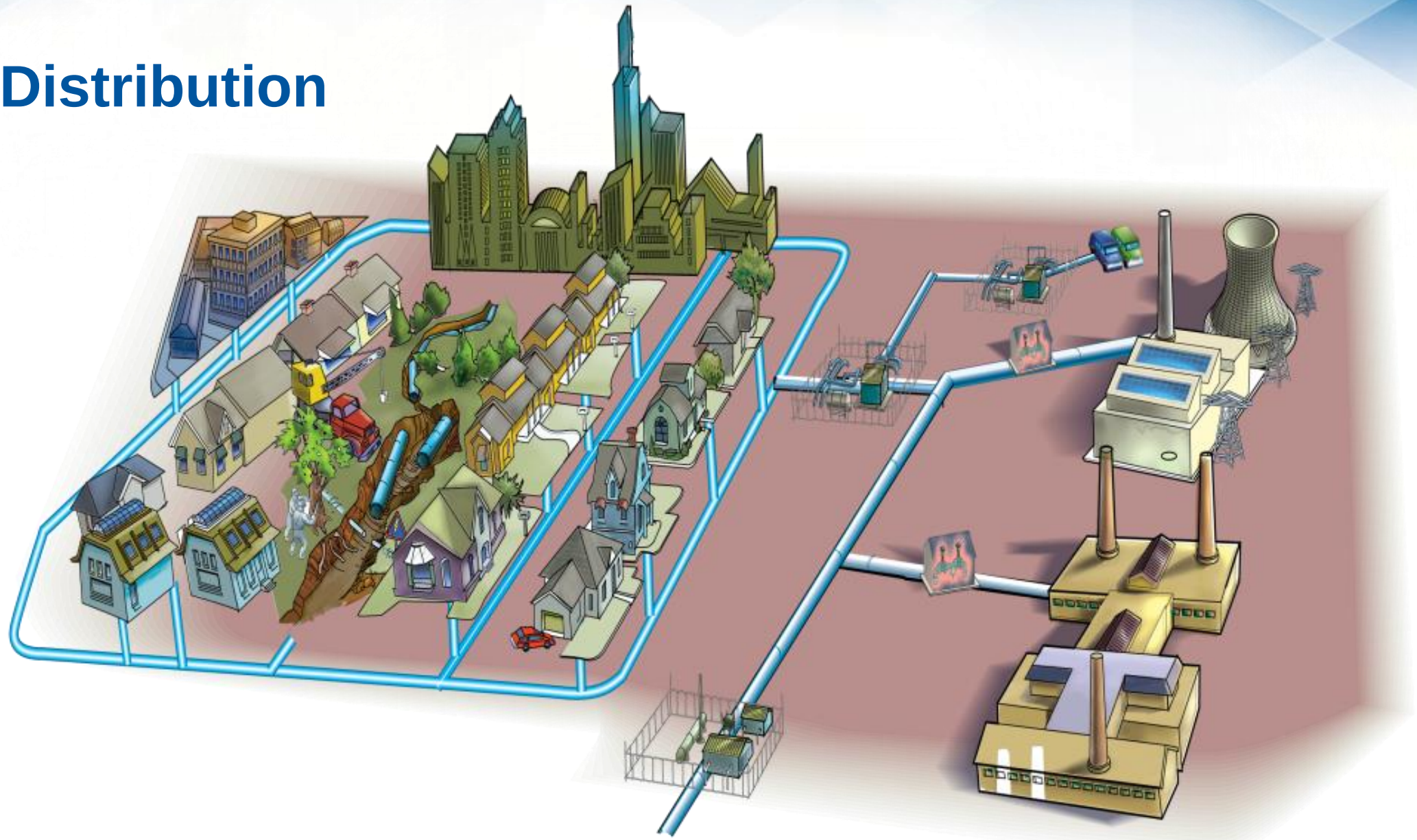
Storage



Note: Locations of storage facilities presented in the map are approximate. Some symbols representing storage facilities may overlap.
Source: U.S. Energy Information Administration, Form EIA-191A, "Annual Underground Gas Storage Report"

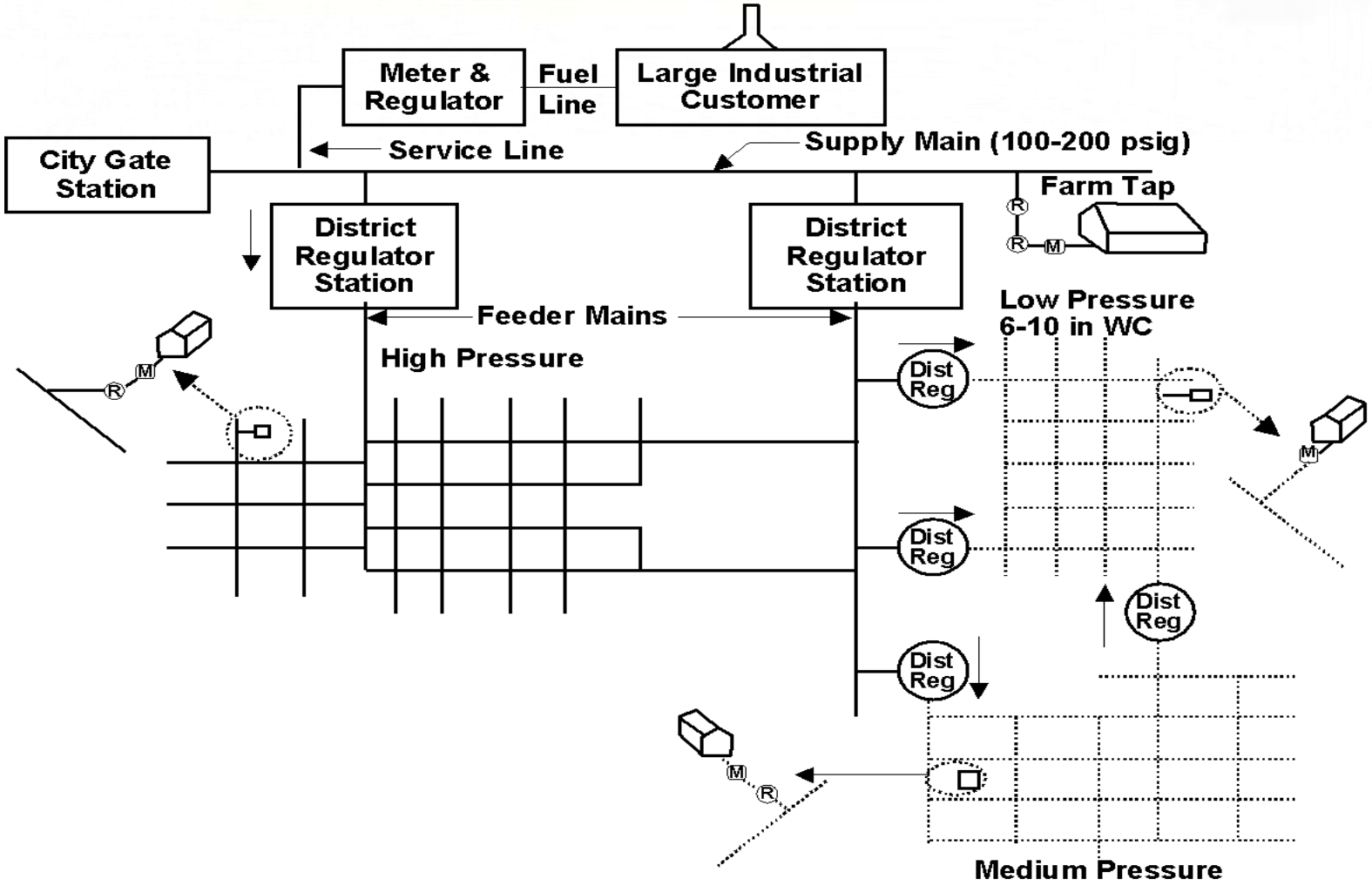
Picture Courtesy of EIA

Distribution



Picture Courtesy of GTI

Distribution Overview



Picture Courtesy of GTI

Distribution

- What is distribution?
  - Defined as local distribution system property from the city gate to the customer’s meter
- Distribution Piping Materials

Plastic Pipe

Plastic Pipe Trailer

Coiled Plastic Pipe

Picture Courtesy of GTI

Track Hoes

Picture Courtesy of GTI

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Trenchers

Chain trenchers

Wheel trencher

Picture Courtesy of GTI

Plow in – Plastic Pipe

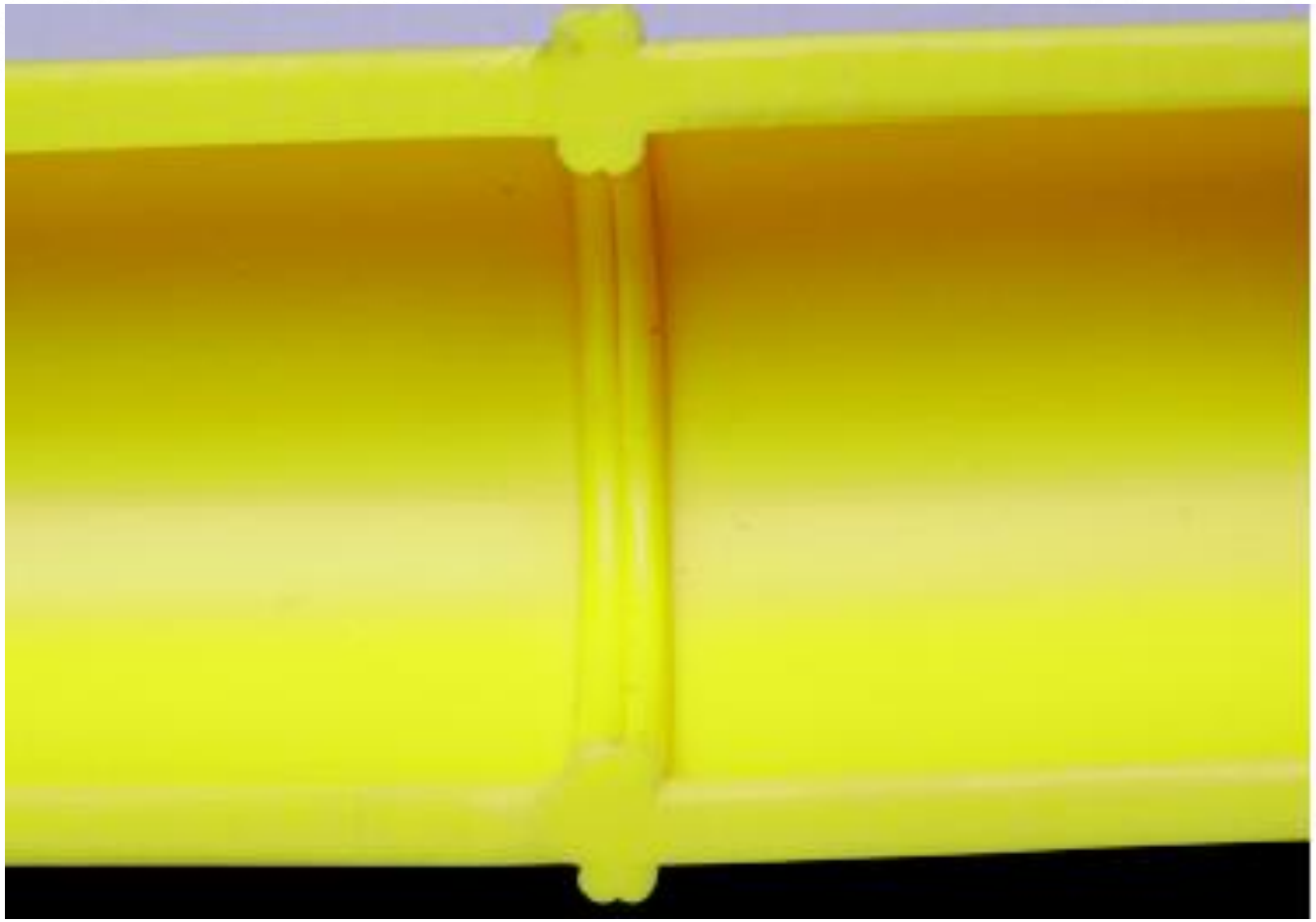
Picture Courtesy of GTI

Directional Drilling

- Pilot hole
- Reaming
- Drill mud
- Pull back
  - Weak link
  - Pipe ovality
- Safe pull force

Picture Courtesy of GTI

Plastic Pipe and Butt Joint

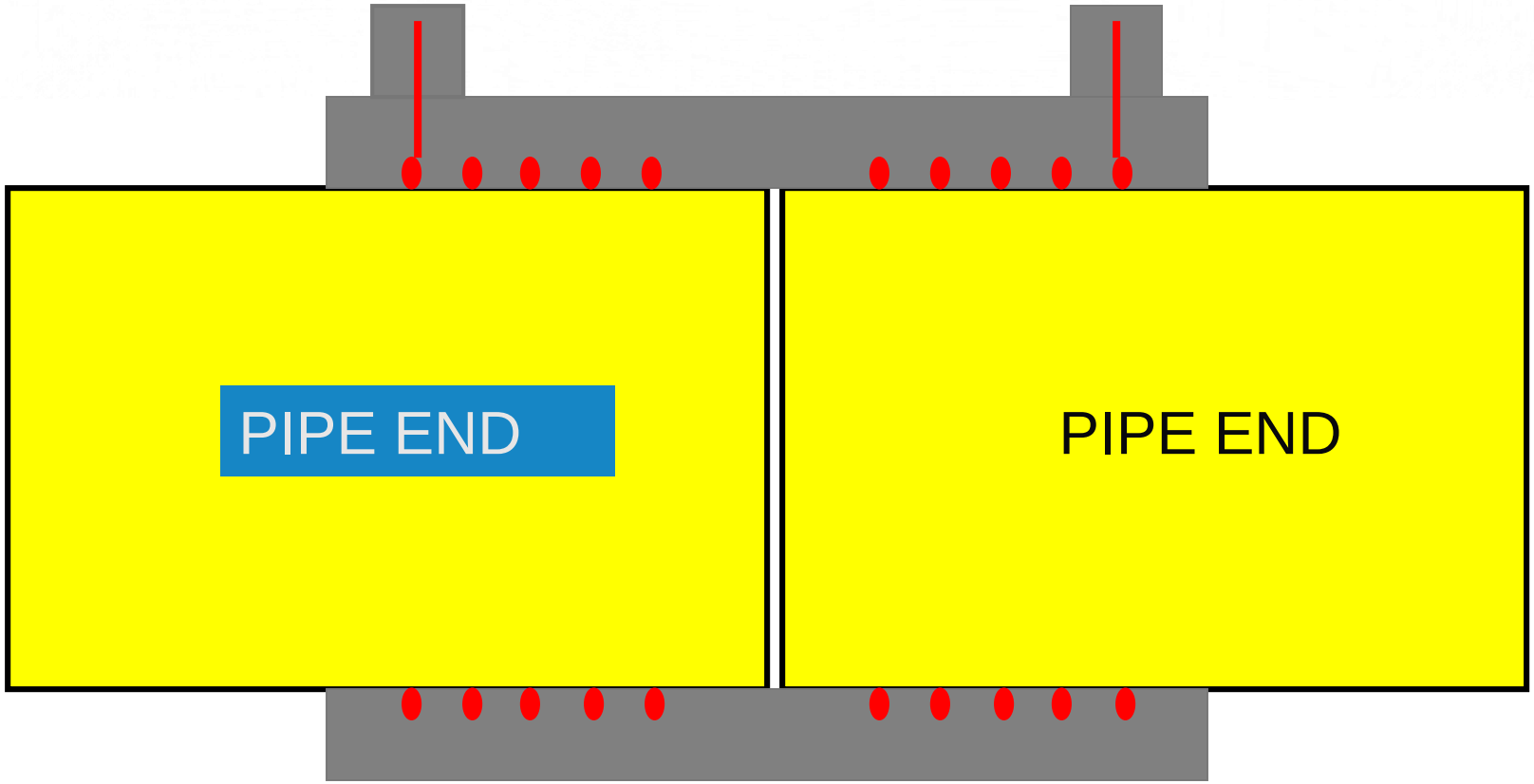


Picture Courtesy of GTI

Plastic Service and Main

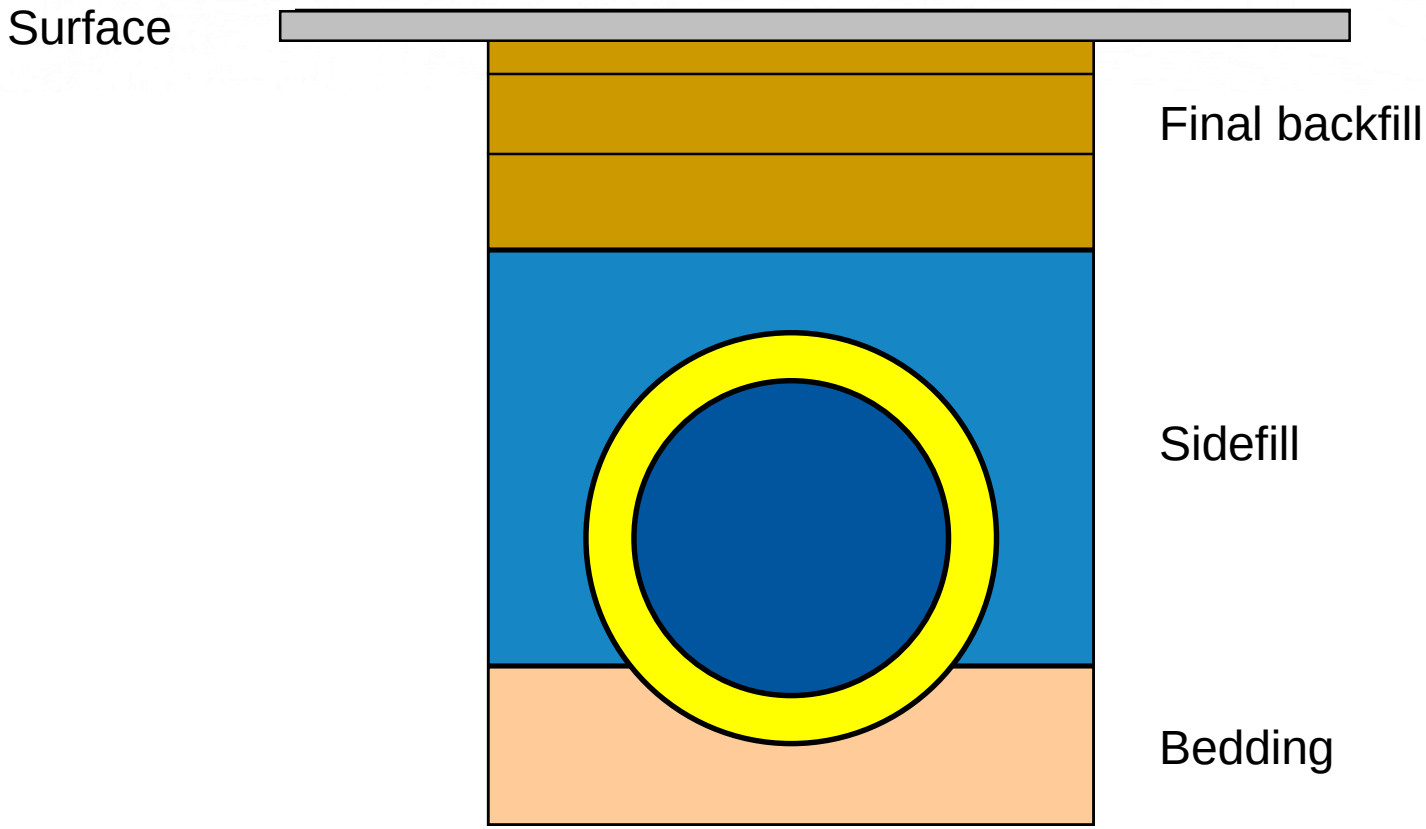
Picture Courtesy of GTI

Electro Fusion Process



Picture Courtesy of GTI

Proper Installation

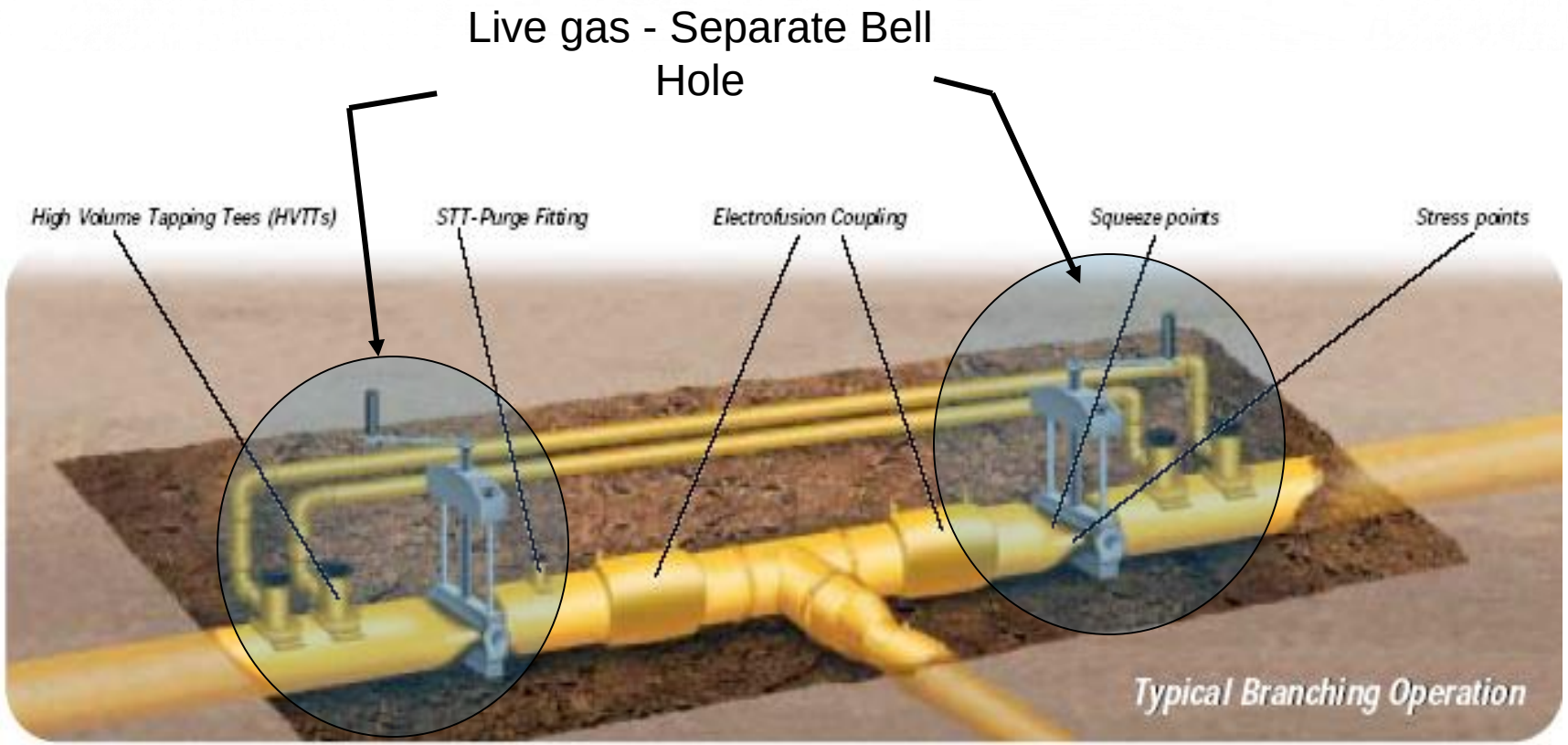


Picture Courtesy of GTI

Locate Wire & Warning Tape

Picture Courtesy of GTI

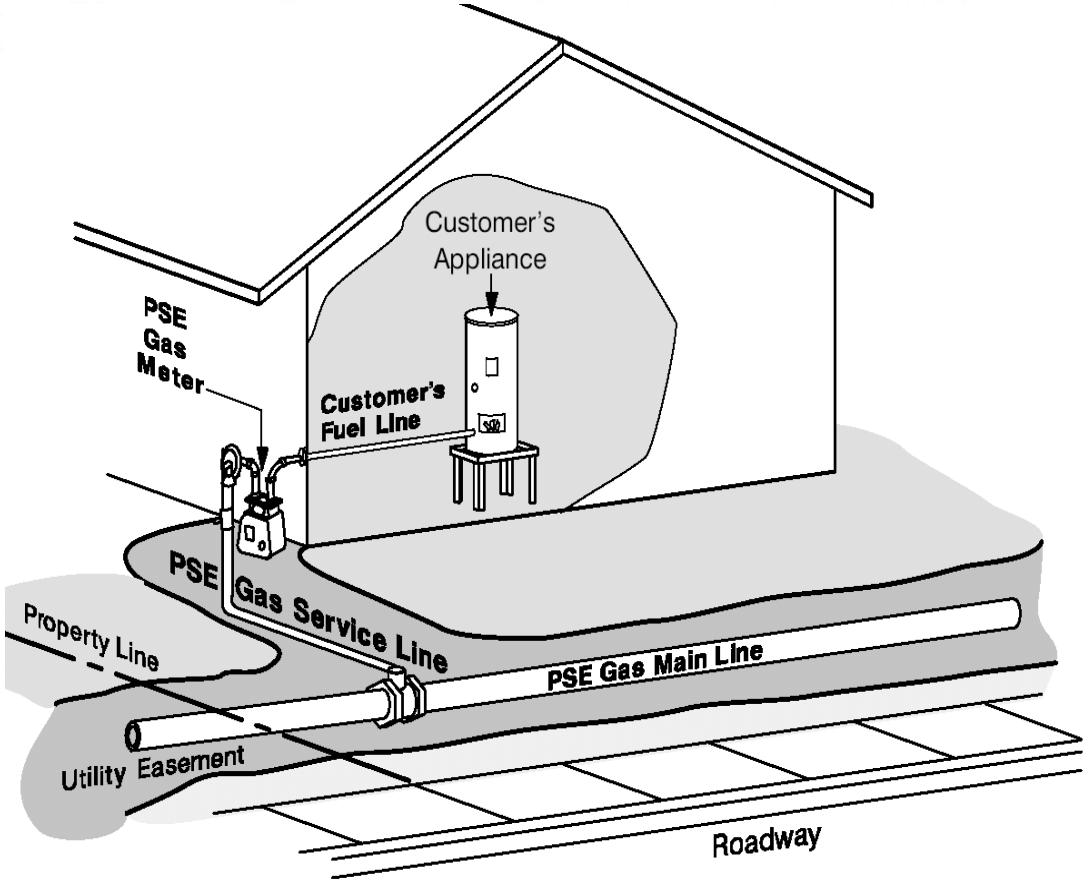
Typical Plastic Gas Stopping and Replacement



Picture Courtesy of GTI

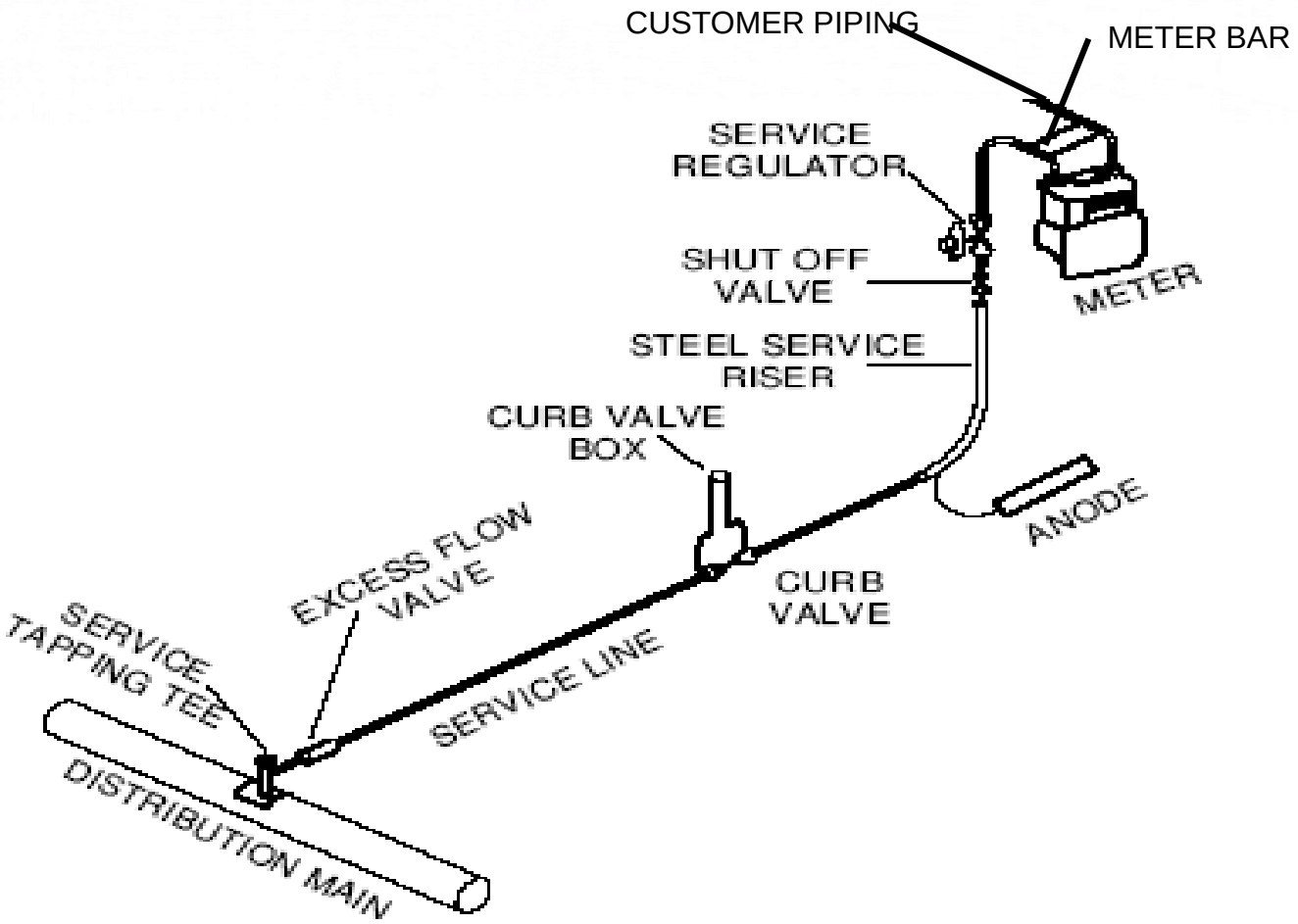
Main to Appliance

- Customer piping
  - Existing
  - New
- Service line
- Meter set, valve & riser



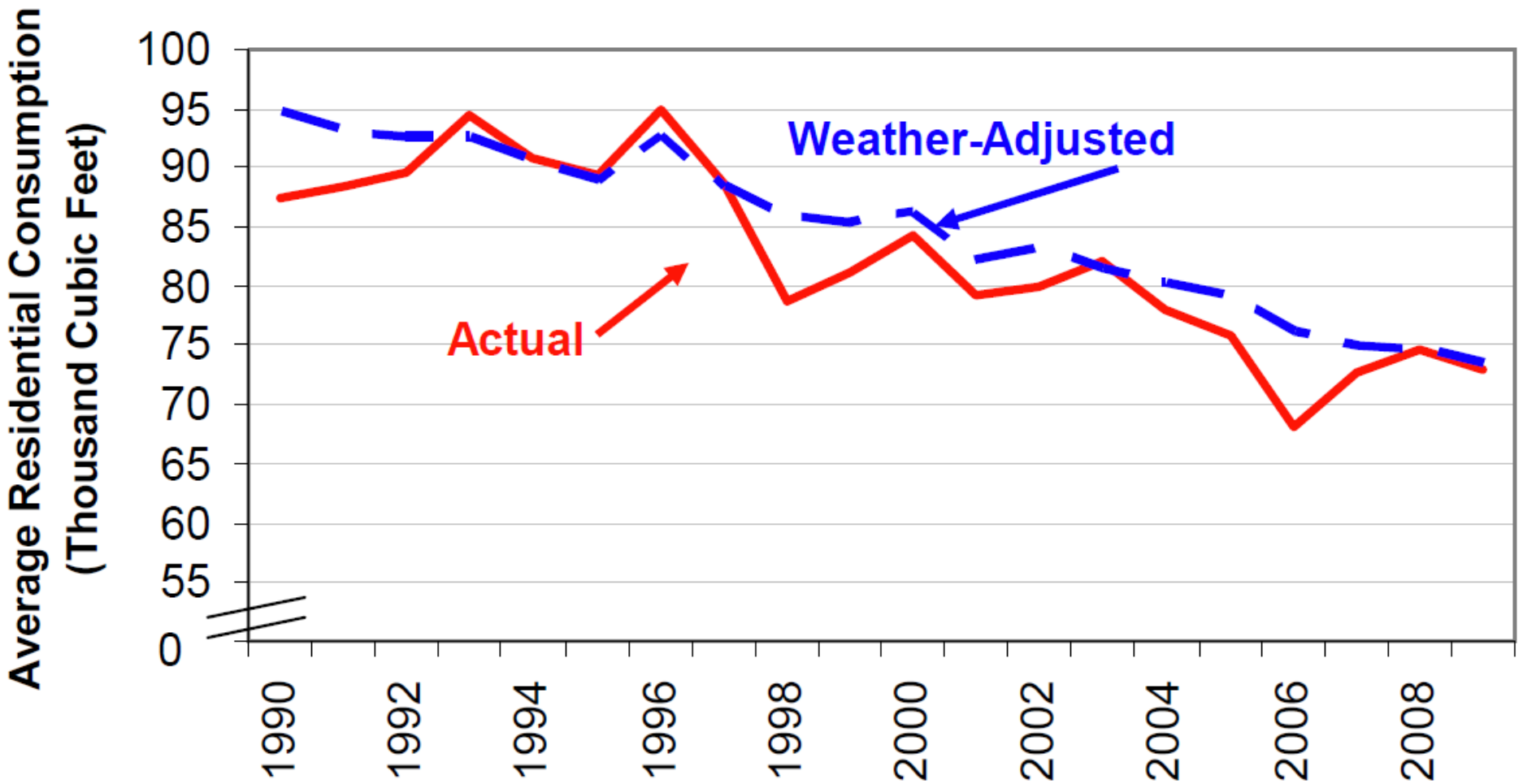
Picture Courtesy of PSE

Service Installations - Components



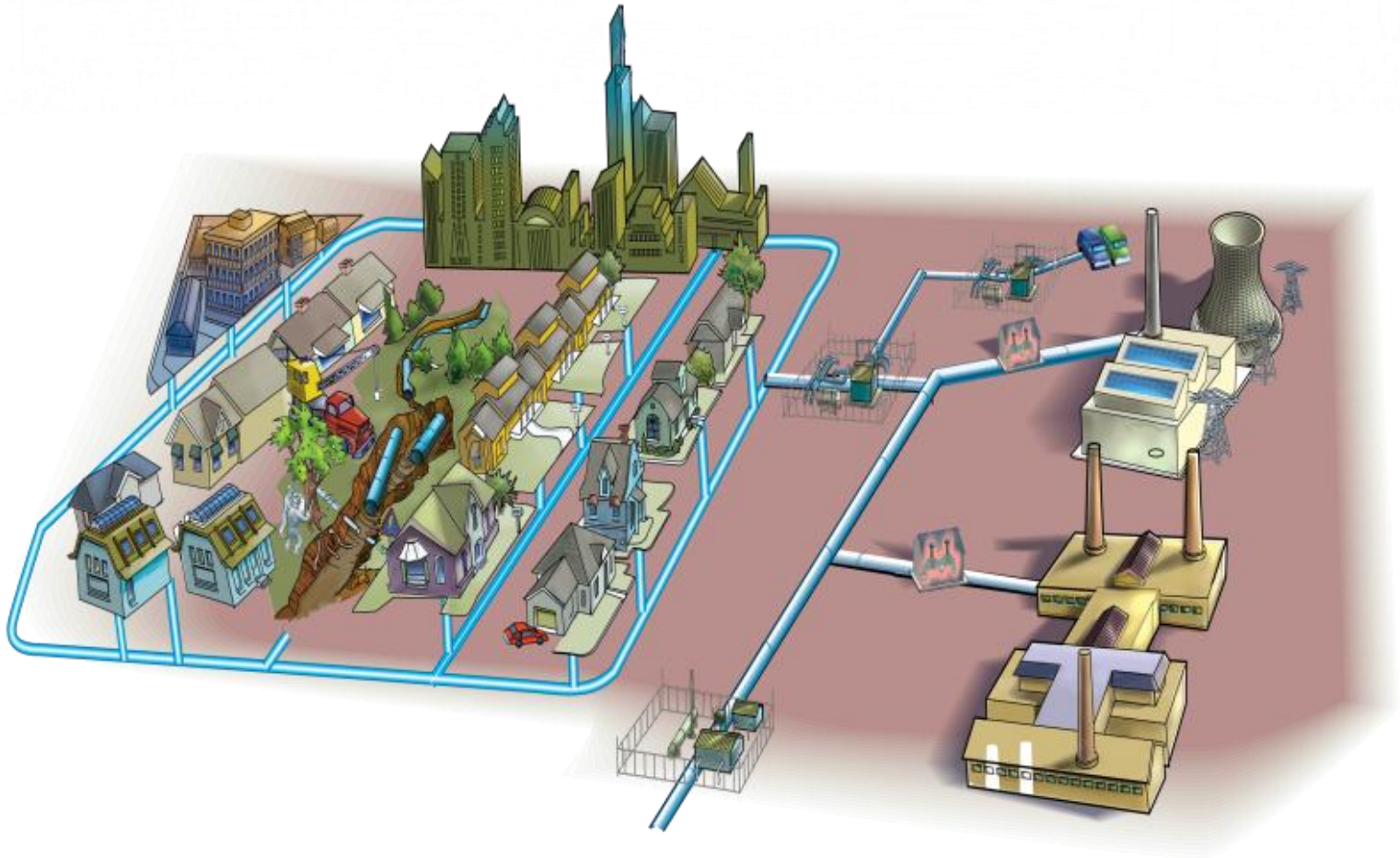
Picture Courtesy of PSE

Total Gas Used per Residential Meter



Data Courtesy Trends in U.S. Residential Natural Gas Consumption 2010

The Market for Gas?

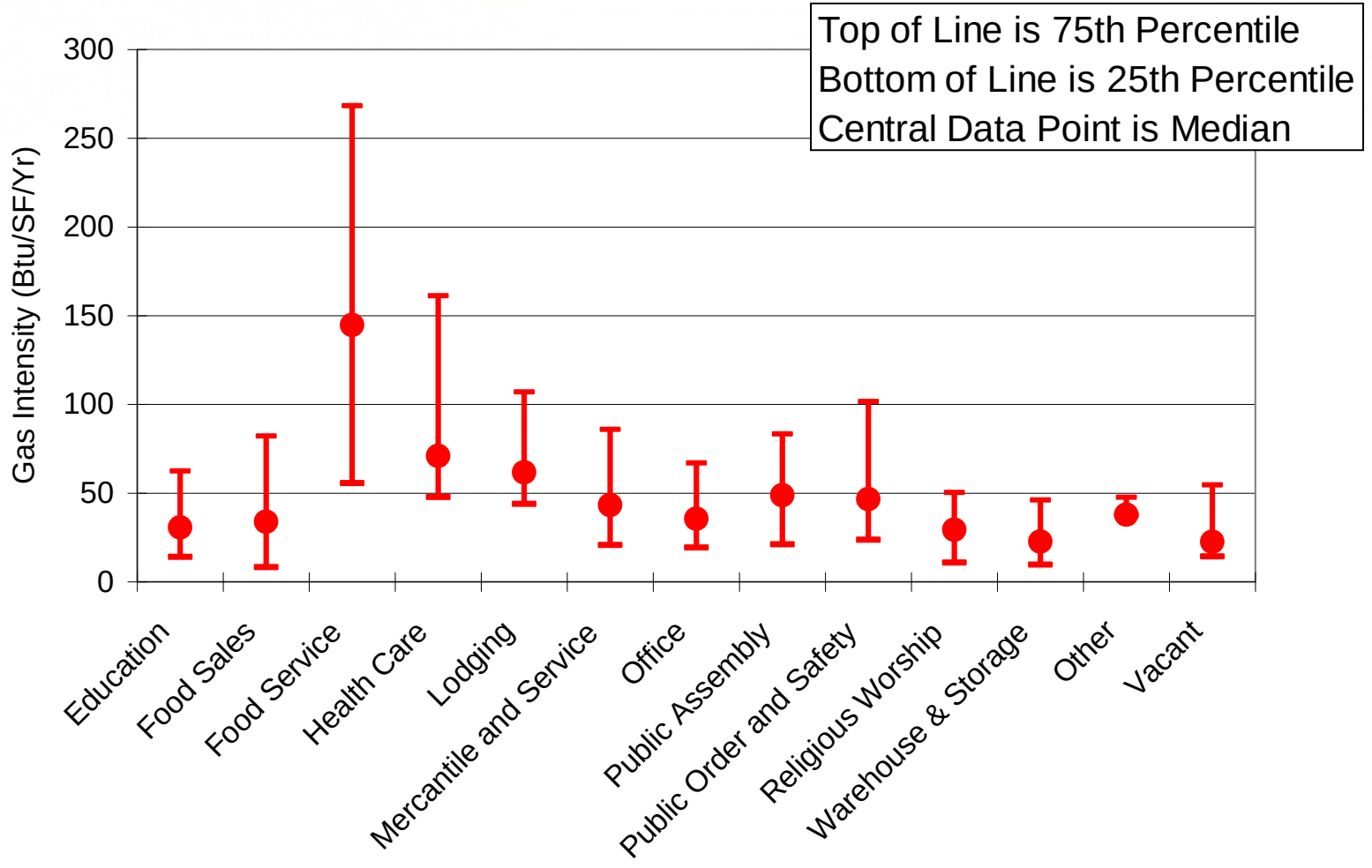


Picture Courtesy of GTI

How is Gas Used?

- Four major markets
  - Residential buildings
  - Commercial buildings
  - Industrial applications
  - Power generation
- Compare markets
- Examine commercial and industrial

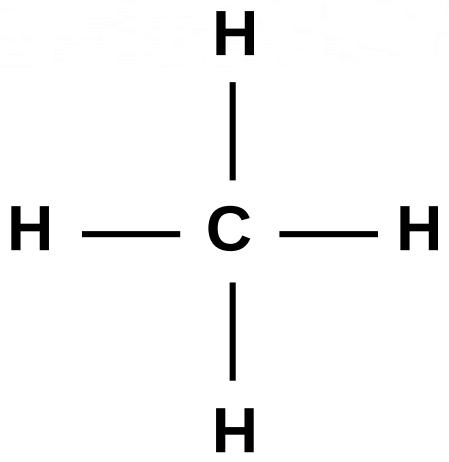
Who Uses the Most Gas?
Commercial Buildings, Use/Sq. Ft.



Natural Gas Properties

Chemical Composition

- Methane (CH_4) – 95-98%
- Ethane (C_2H_6) – 1-2%
- Propane (C_3H_8) – ½-1%
- Butane (C_4H_{10}) – ½-1%
- Nitrogen (N_2) - < 3%
- Carbon Dioxide (CO_2) - < 3%



What is Natural Gas?

- Not
  - Gasoline – liquid
  - Liquid Propane Gas – liquid (stored)
  - Manufactured gas
- Natural Gas
  - Methane mixture - gas
  - Compressed Natural Gas - gas
  - Liquefied Natural Gas – liquid (stored)

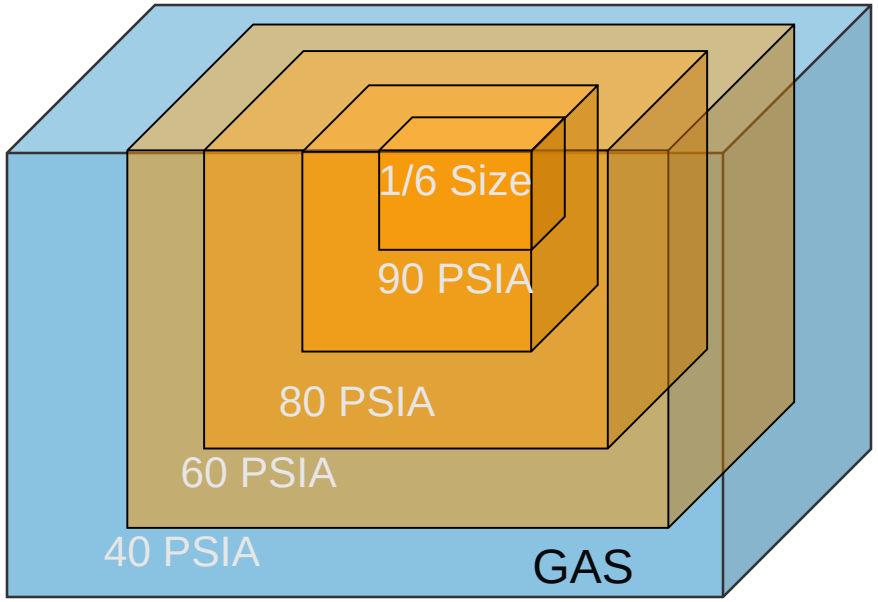
Properties

- Non-toxic
- Colorless, odorless, tasteless
- Specific gravity: 0.60 to 0.65
- Flammable range
- Ignition temperature:
  - 1100˚ to 1200˚ F
  - 593˚ to 649˚ C
- Energy content
  - ~1040 BTUs / scf
- Compressible

Compressible

GAS

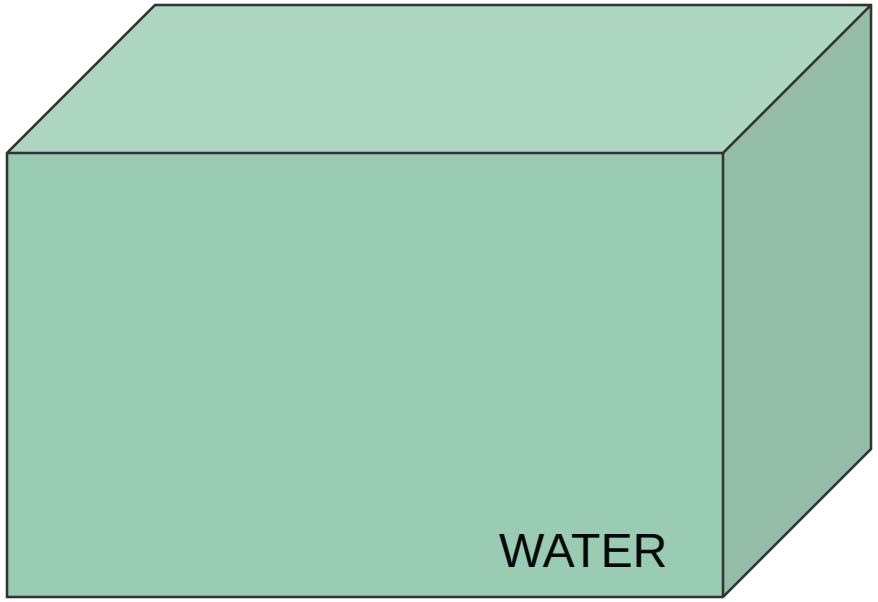
Increasing the pressure from 15 to 90 psia make the gas occupy less space



15 PSIA

WATER

Increasing the pressure from 15 to 90 psia, the volume stays the same

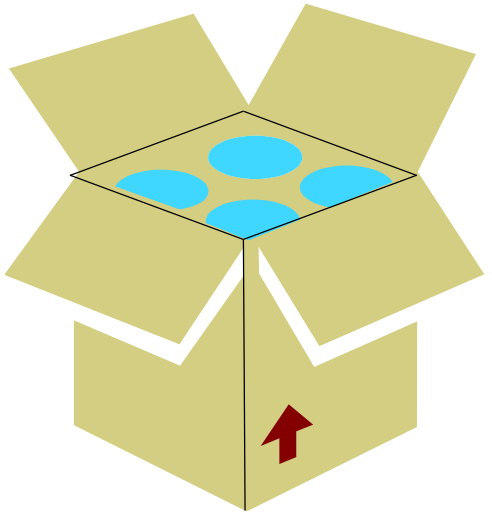


15 to 90 PSIA

Picture Courtesy of GTI

Units of Measurement - Volume

- Gas volume
  - Cubic Feet (ft^3)
    - CF – 1 ft^3
    - MCF – 1000 ft^3
    - MMCF – 1,000,000 ft^3
  - Cubic Meters (m^3)
- Energy content
  - Therm – 100,000 Btu
  - MMBtu – Million Btu



What's a BTU?

- British Thermal Unit
- Heat required to raise the temperature of 1 lb mass of water one degree

60.5°F

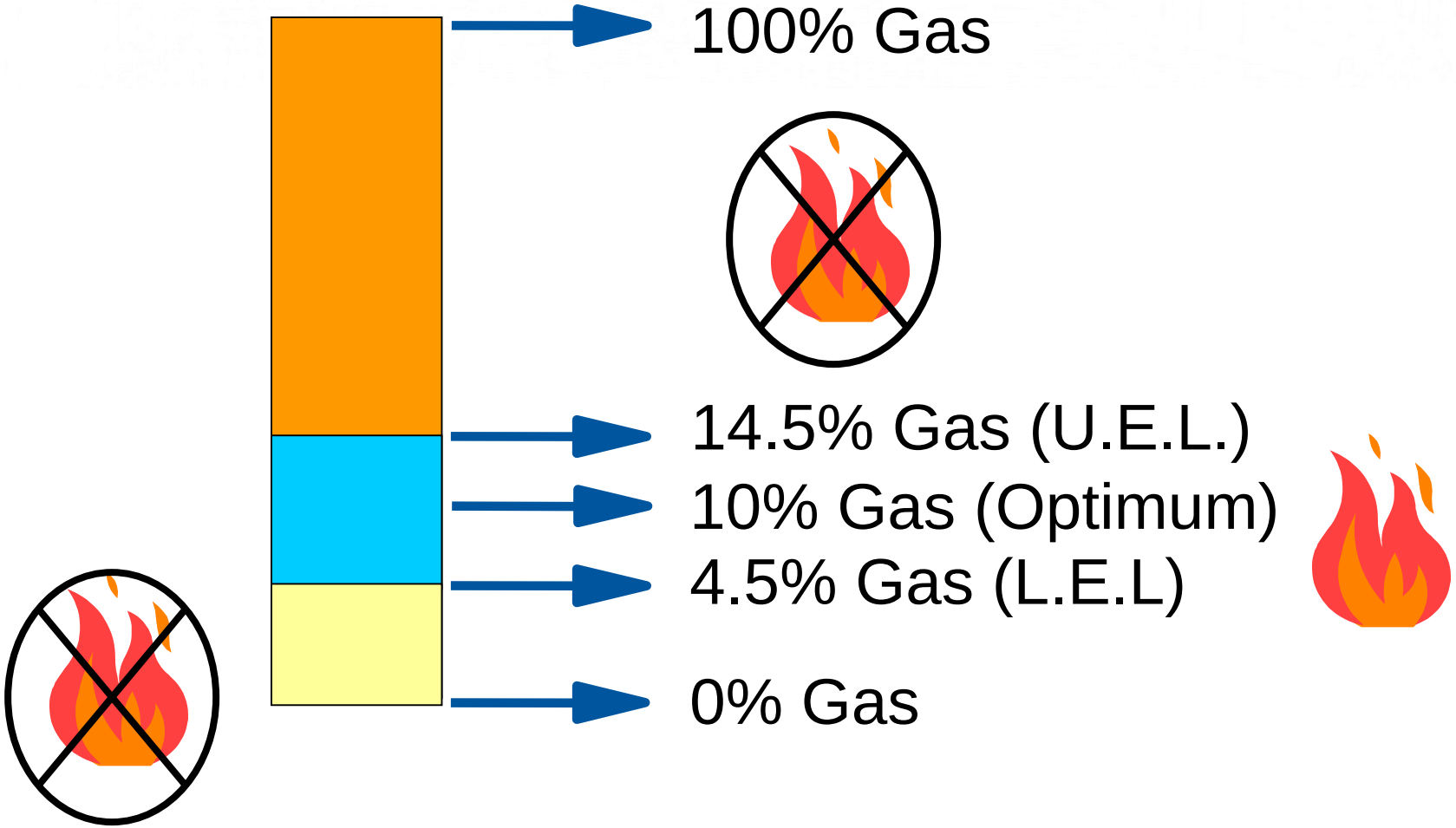
59.5°F

Typical Btu Content

- Methane
  - 1012 Btu/Standard Cubic Foot
  - 1070 k-joules/Standard Cubic Foot
- Natural Gas
  - Can be as High as
    - 1200 Btu/scf
    - 1266 k-joules/scf
  - Should stay above
    - 950 Btu/scf
    - 1002 k-joules/scf

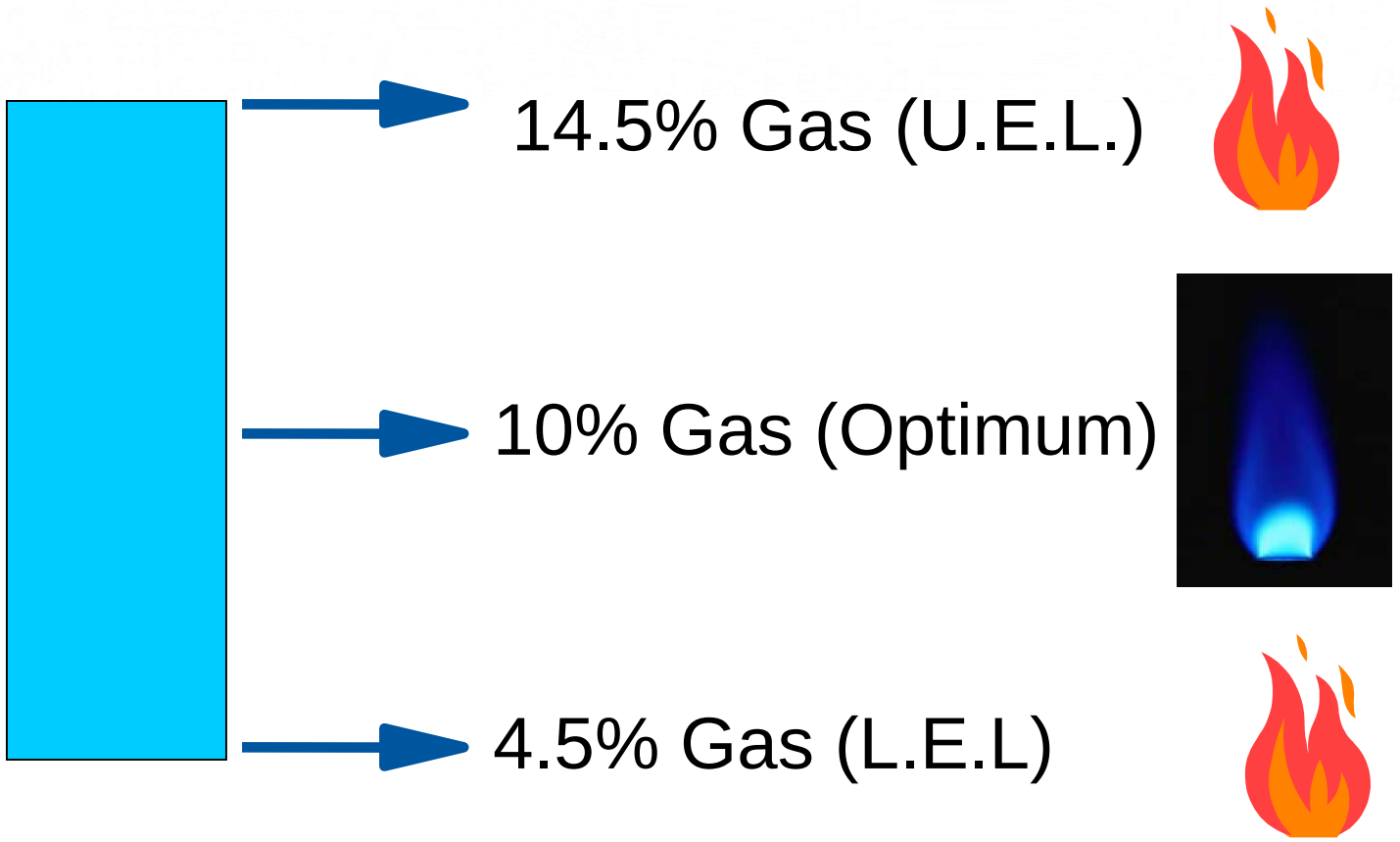
Component	BTU/CF
Methane	1012
Ethane	1770
Propane	2516
Butane	3255
Pentane	4004
N_2	0
CO_2	0

Flammable Range for Natural Gas



Picture Courtesy of GTI

Flammable Range for Natural Gas



Picture Courtesy of GTI

Ignition

- Gas must be heated to 1200°F (649°C) to be effectively ignited
- Must occur in a location where a combustible mixture of air and gas are present (4.5-14.5%)

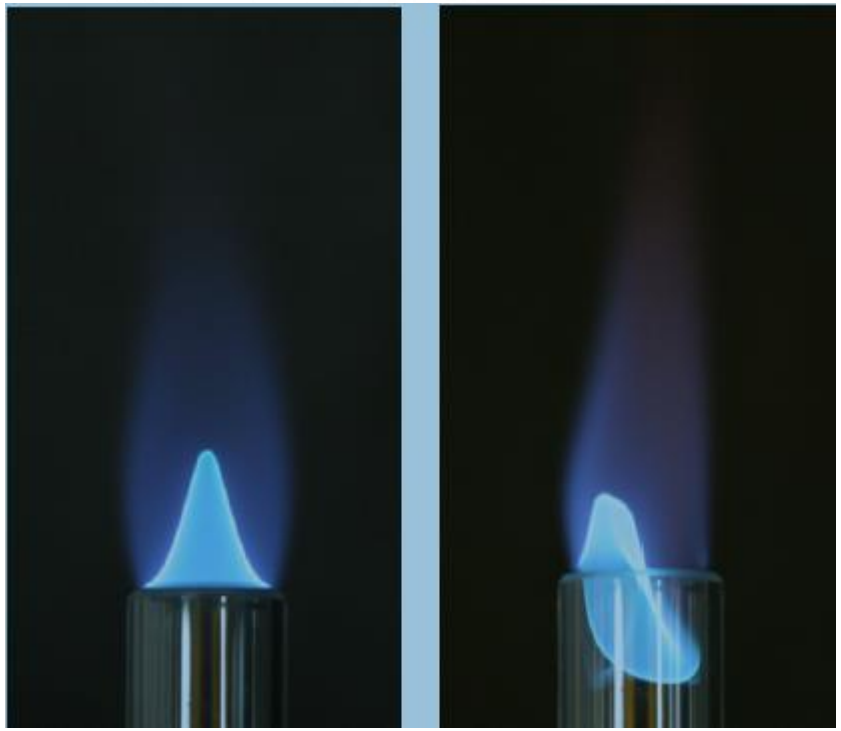
Combustion Process

- **$CH_4 + 2O_2 = CO_2 + 2\ H_2O$ + Heat**
- With insufficient oxygen, the reaction may complete as
  - $CH_4 + (1.5)O_2 = CO + 2\ H_2O$ + Less Heat
- If combustion happens at too high a temp
  - Air brings N_2 in as well
  - Nitrogen and oxygen in the air react to oxides of nitrogen - another pollutant

Carbon Monoxide

- Odorless
- Colorless and tasteless
- Product of incomplete combustion
- Deadly in small amounts

Normal gas flame / High H2/CO flame



H. Levinsky, KEMA, University of Groningen,
The Netherlands

Odorant

- Methane – odorless
- Odorant added
  - Detectable at 1% gas in air
  - Many different odorants

If You Smell Natural Gas:

- Leave the building and call the gas company from a nearby phone
- Use your cell phone OUTSIDE the building
- Do not start to open or close doors and windows
- Do not turn on or off any lights or appliances
- Do not use the telephone in your home
- Do not light any matches
- Put out any open flames
- Natural Gas Company employees NEVER ring the doorbell

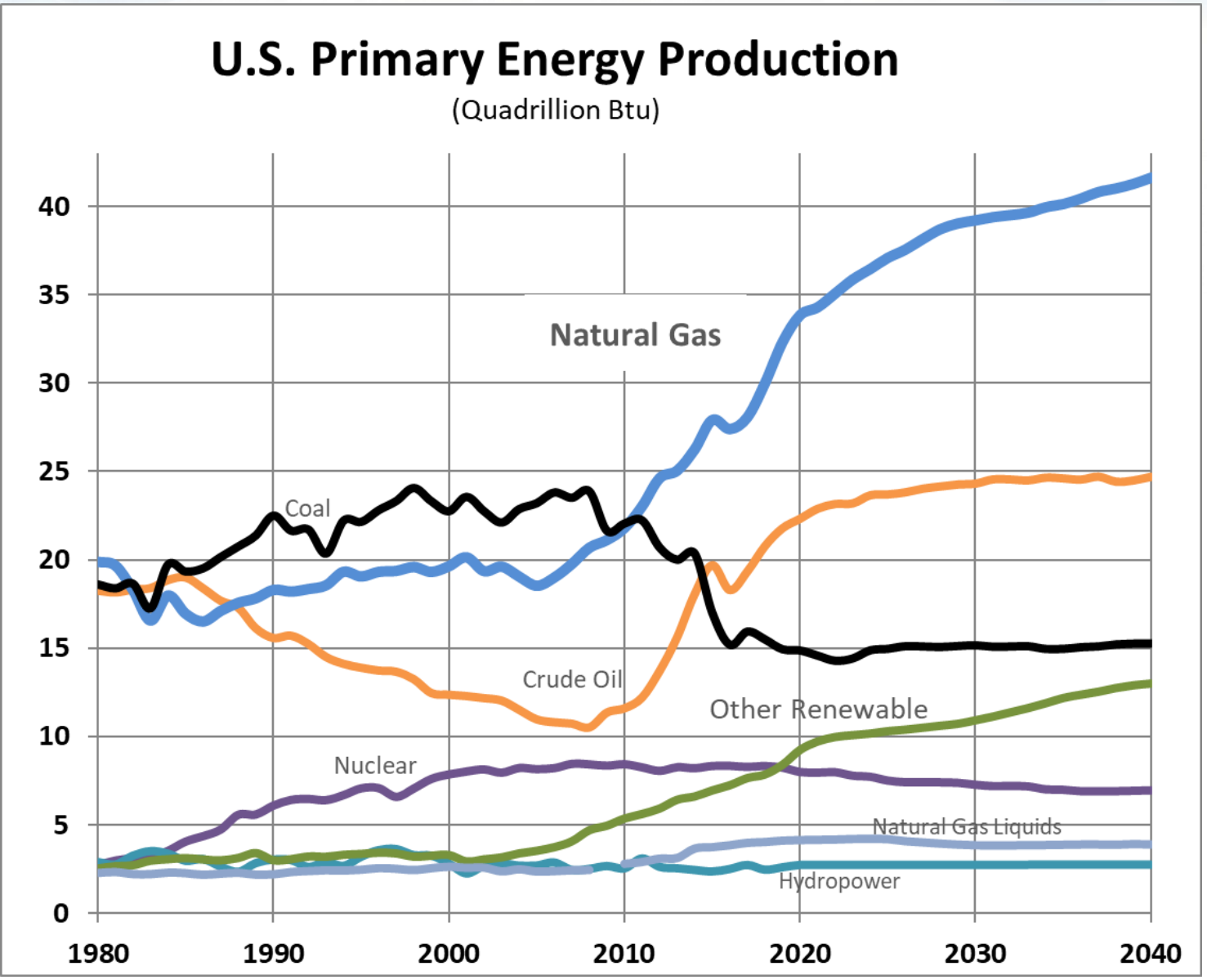
Overwhelmed yet?

Technology Trends

- Gas Supply / Demand
- Power Generation
- Water Management
- Infrastructure Update
- Mobility
- IT / Data Management
- Decarbonization
- 3-5 year Outlook

U.S natural gas is…

- ***The leading energy source produced in the country***
- ***The world's most extensive gaseous energy delivery network***
- ***Is saving consumers over $50 billion a year in energy costs***
- ***Adding to economic growth & job creation***

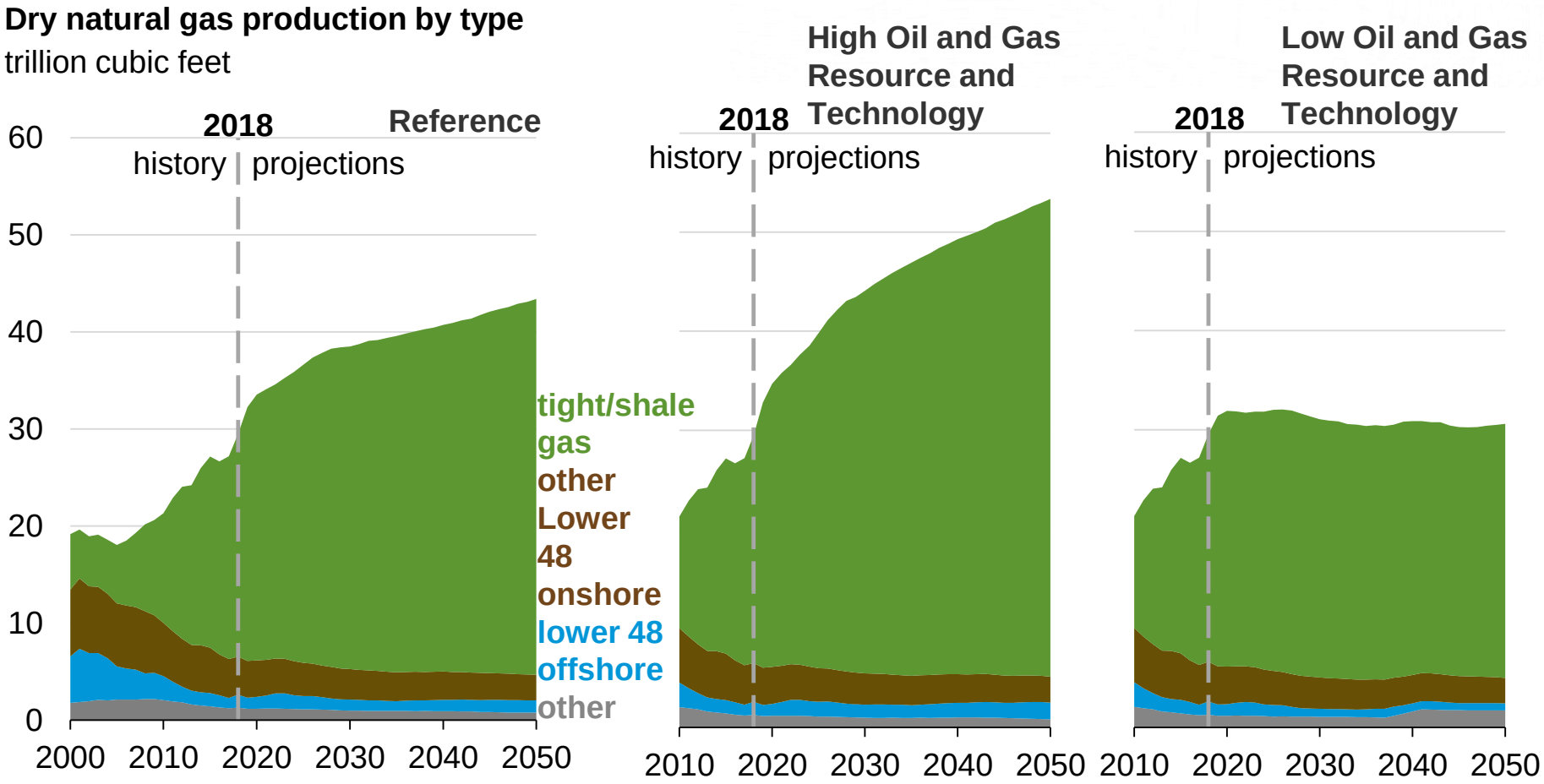


Natural Gas: Number One Energy Source Produced In The U.S and Transported In The World's Most Extensive Gaseous Energy Delivery Network

- Approximate Asset Value: $335 billion
- Natural Gas Transmission Pipelines: 300,650 miles
- Natural Gas Distribution Pipelines: 2,223,000 miles (mains and services)

Source: DOE EIA

U.S. dry natural gas production increases as a result of continued development of tight and shale resources—



Source: DOE EIA

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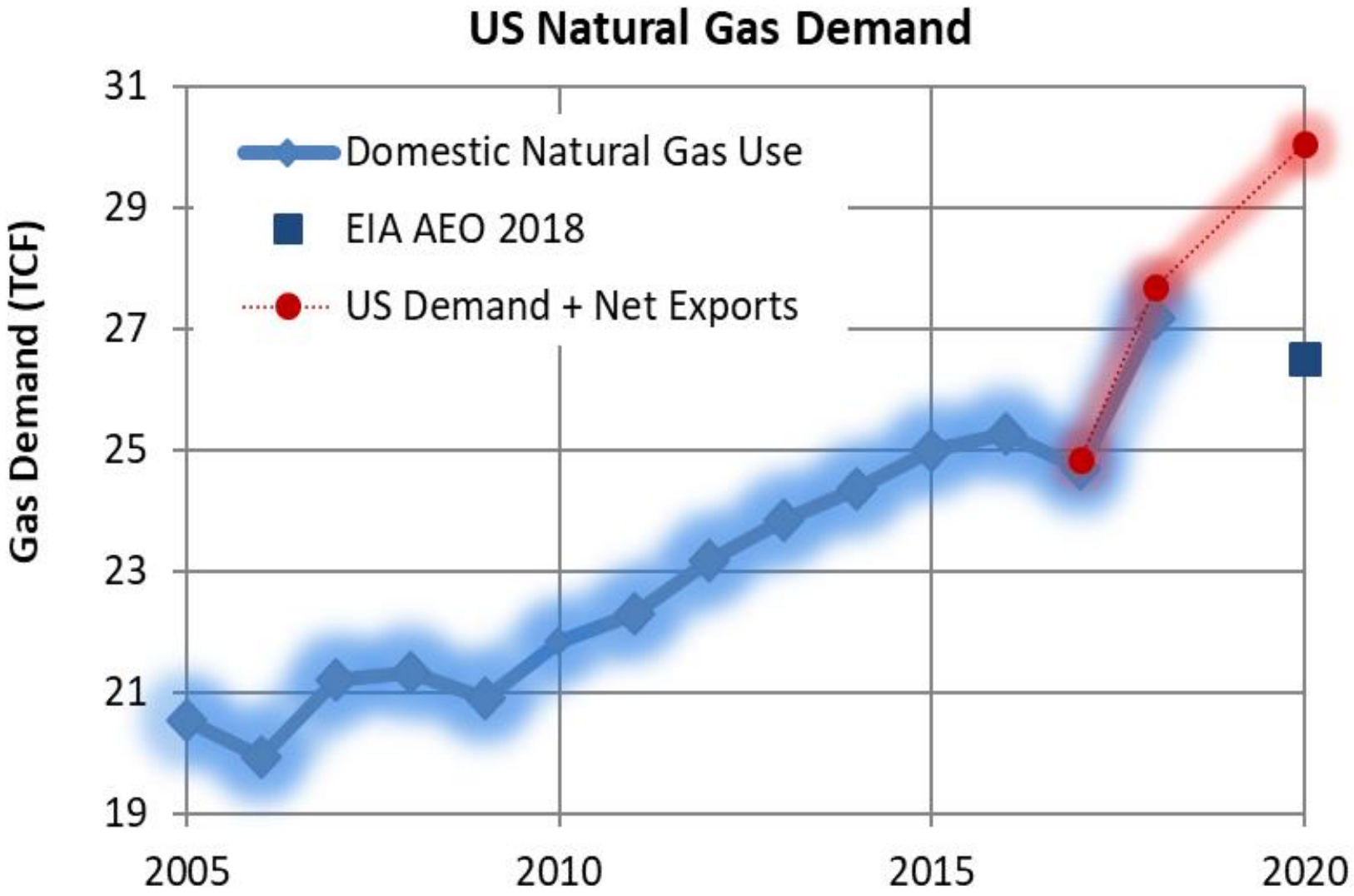


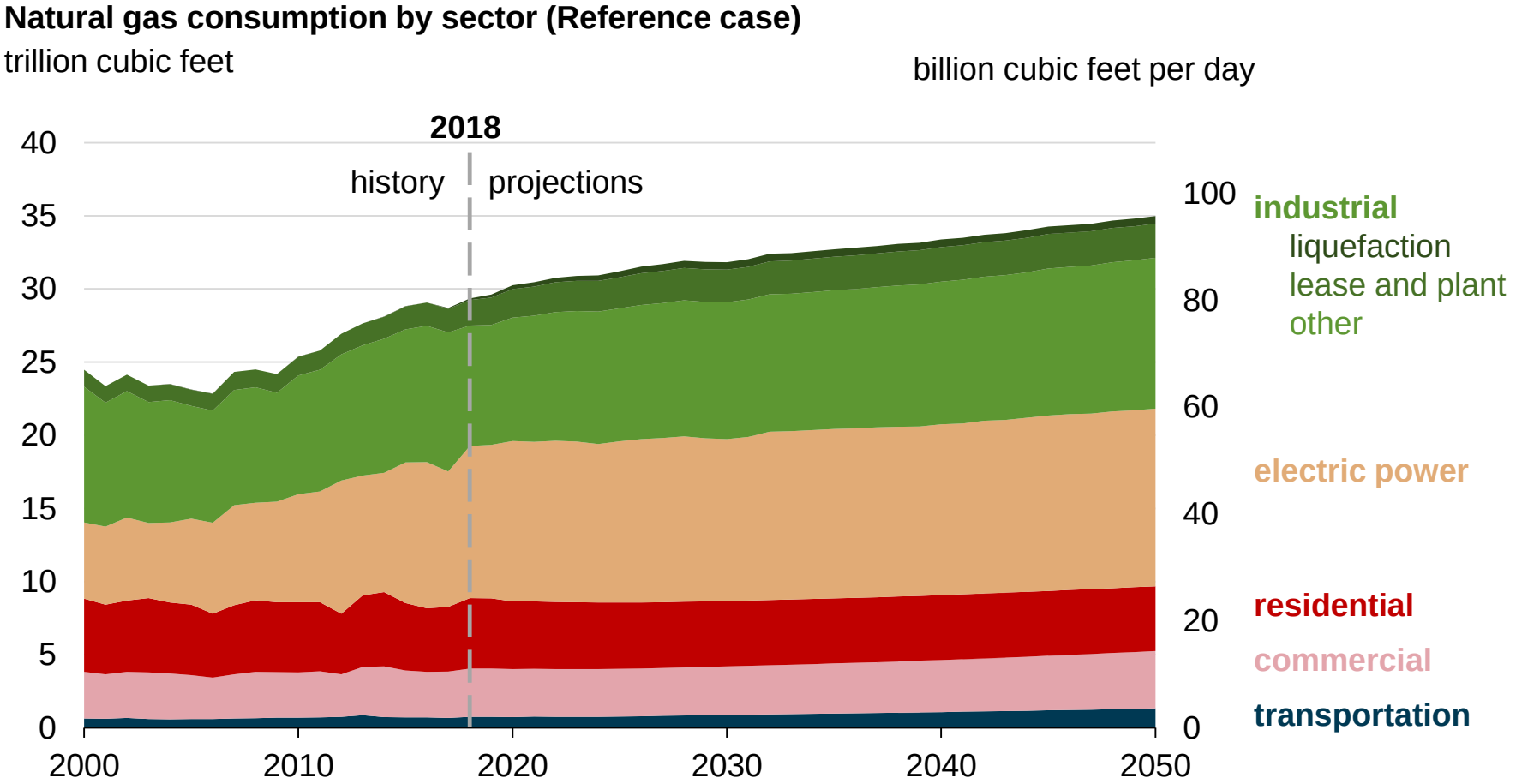
Source: DOE-EIA

Steady growth in total natural gas demand since 2005 – mainly driven by power and industrial sectors.

Future demand includes growing portion of natural gas exports, as U.S. ramps up domestic LNG production.

Industrial and electric power demand drives natural gas consumption growth—

Natural gas consumption by sector (Reference case)



Source: DOE EIA

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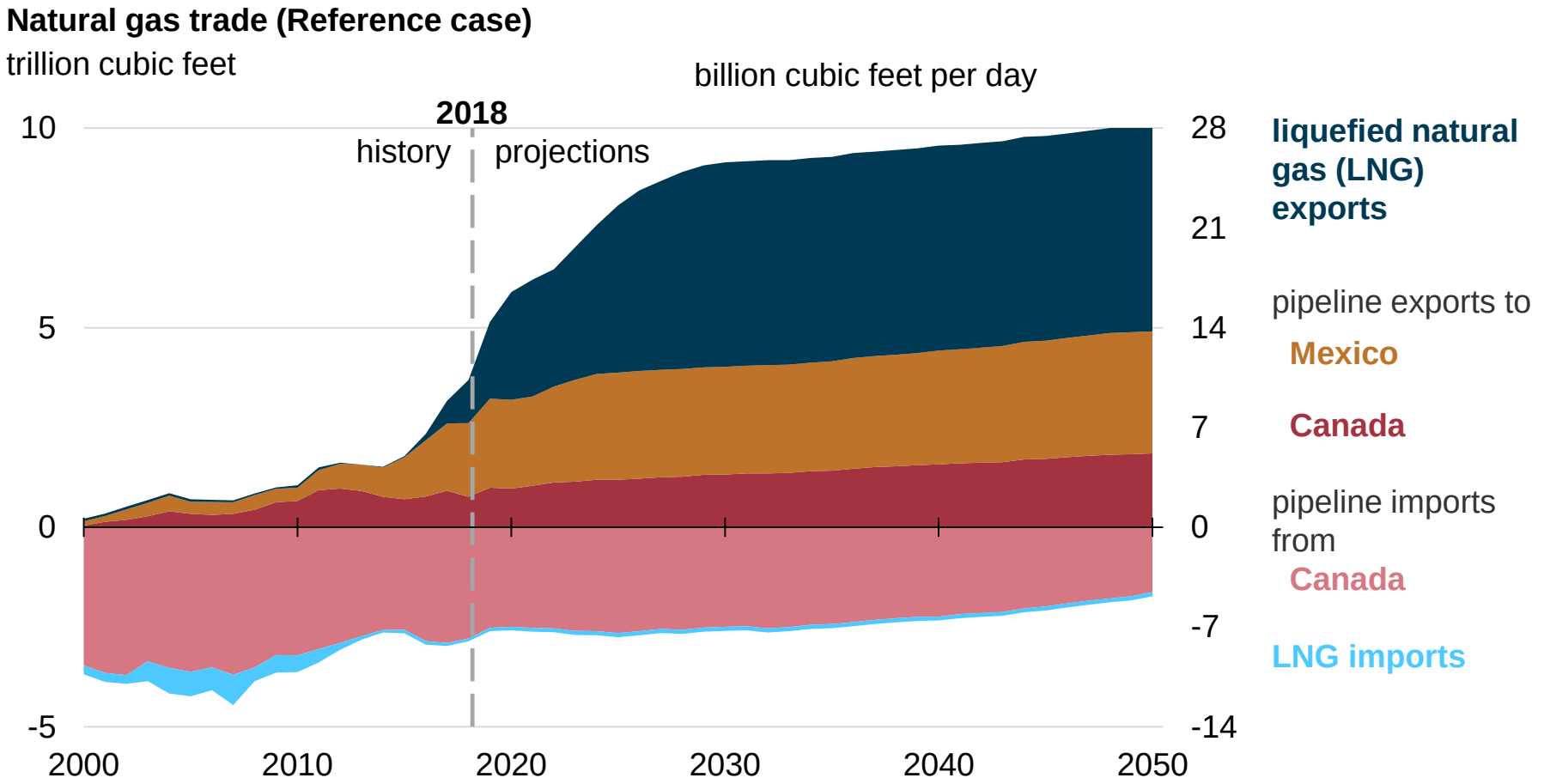
Net exports of natural gas from the United States continue to grow in the Reference case—



Source: DOE EIA

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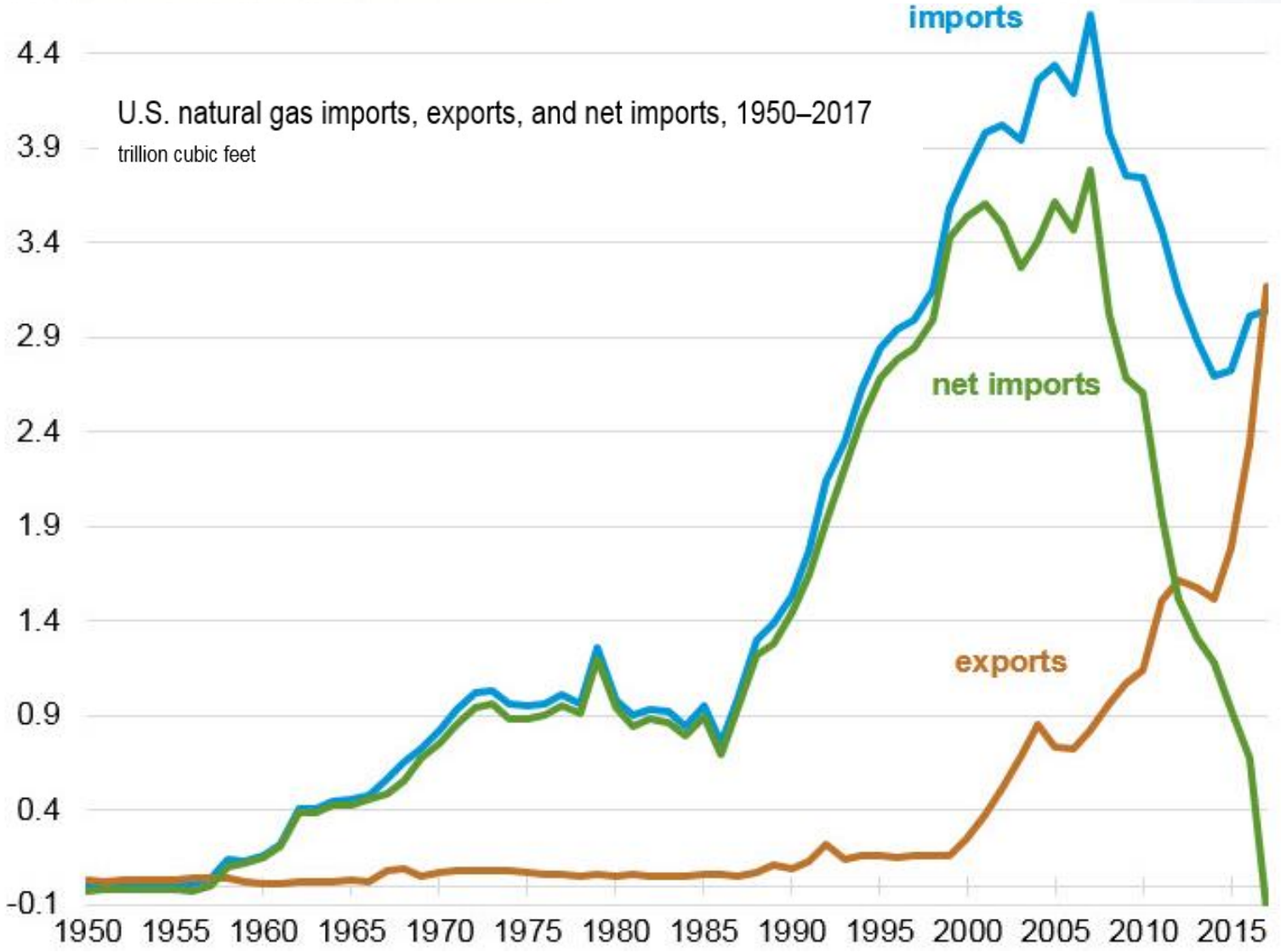
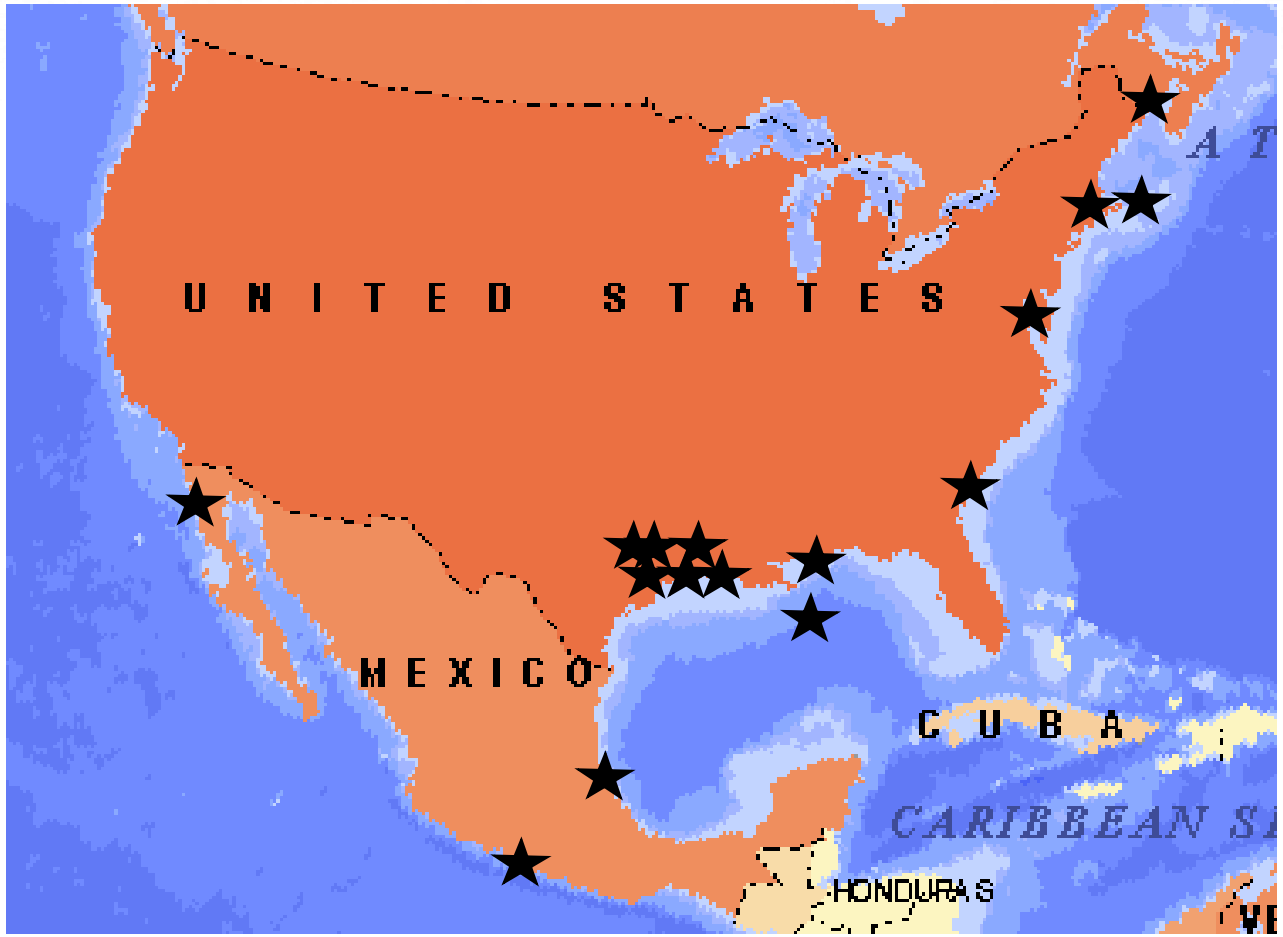
Imports/Exports



Picture Courtesy of EIA Monthly Energy Review 3.2018

LNG Import/Export Terminals in North America



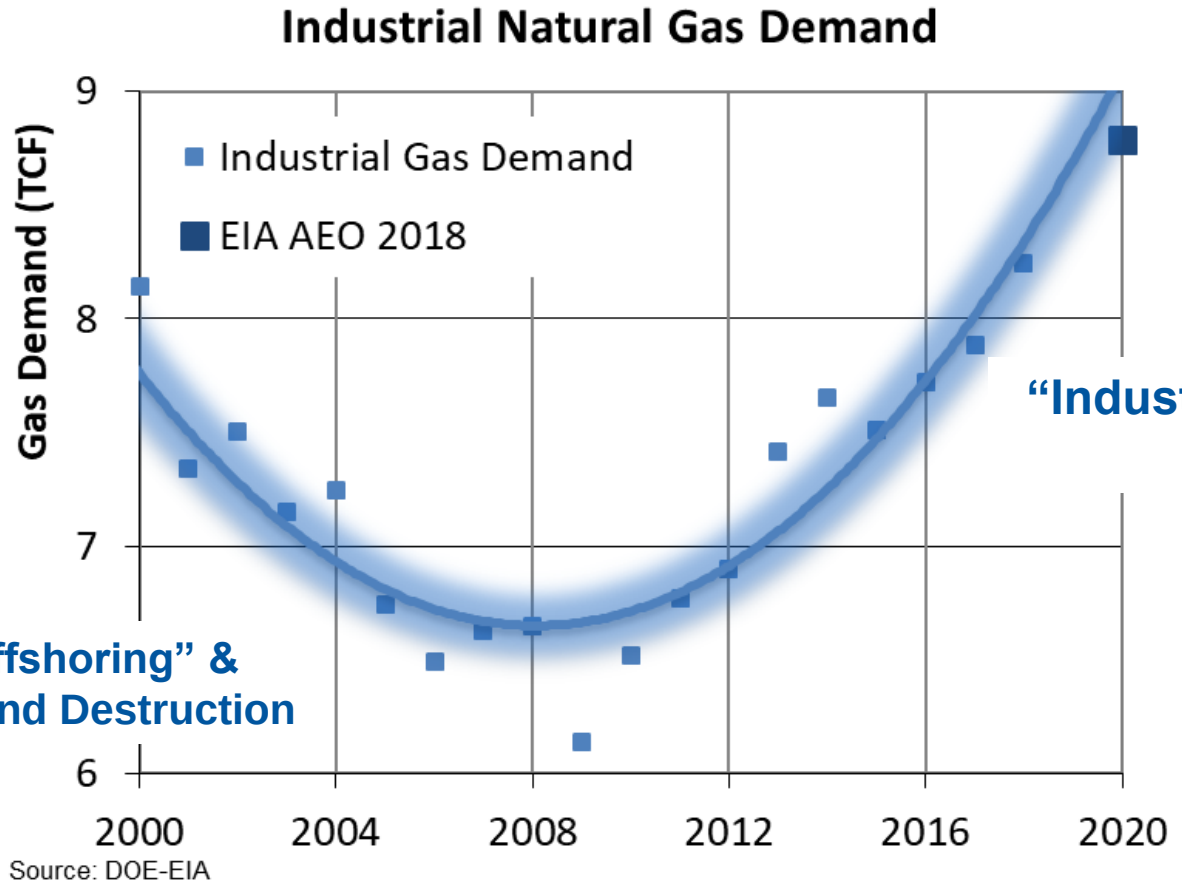
Picture Courtesy of GTI

How Gas is Shipped - LNG

Picture Courtesy of CLNG

U.S. Industrial Renaissance

Fueled By Natural Gas



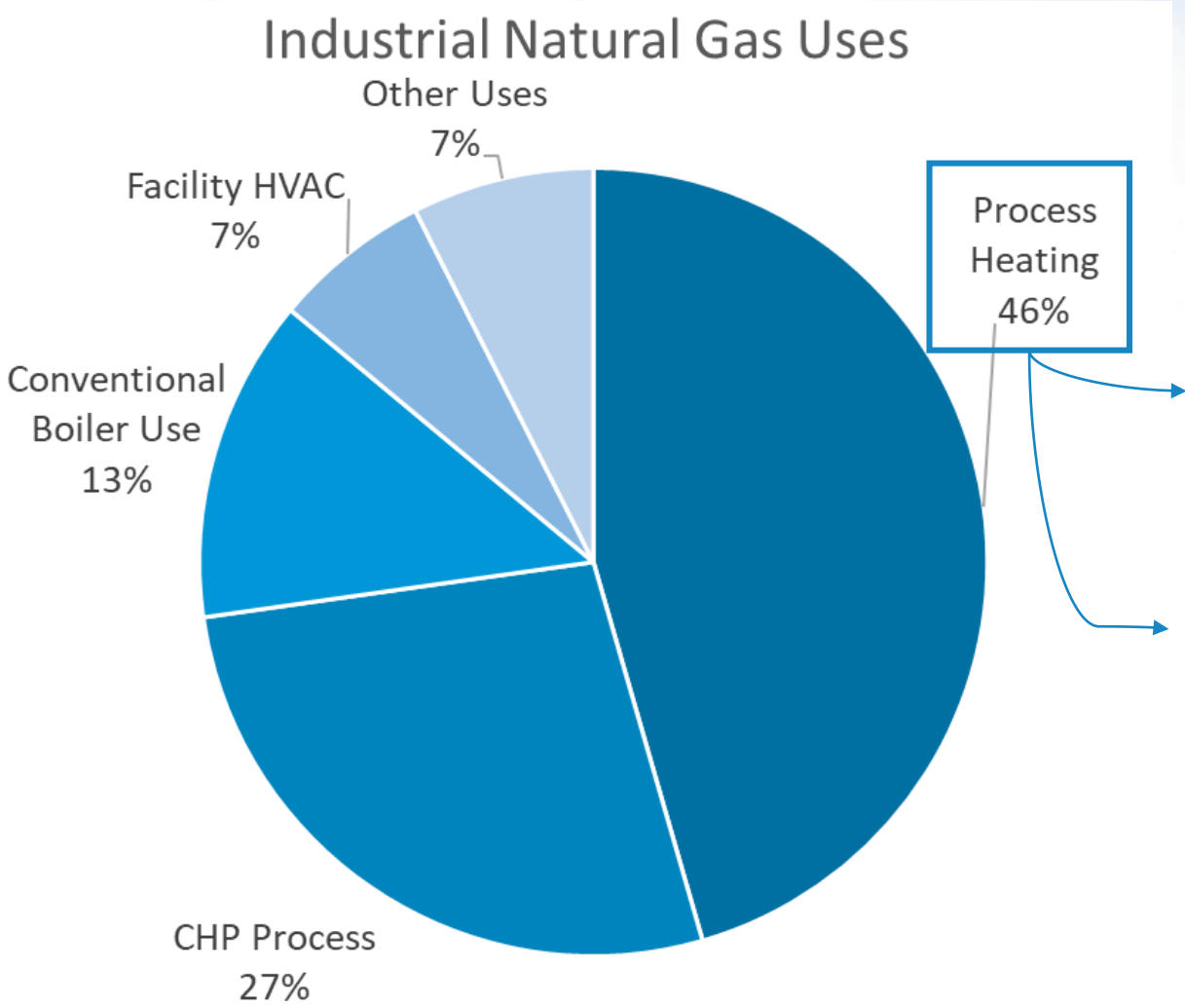
"Offshoring" & Demand Destruction

"Industrial Renaissance" & Growth

"Offshoring" ended a decade ago with shale gas.
Robust industrial rebound & manufacturing growth.

Boilers (e.g., steam, hot water

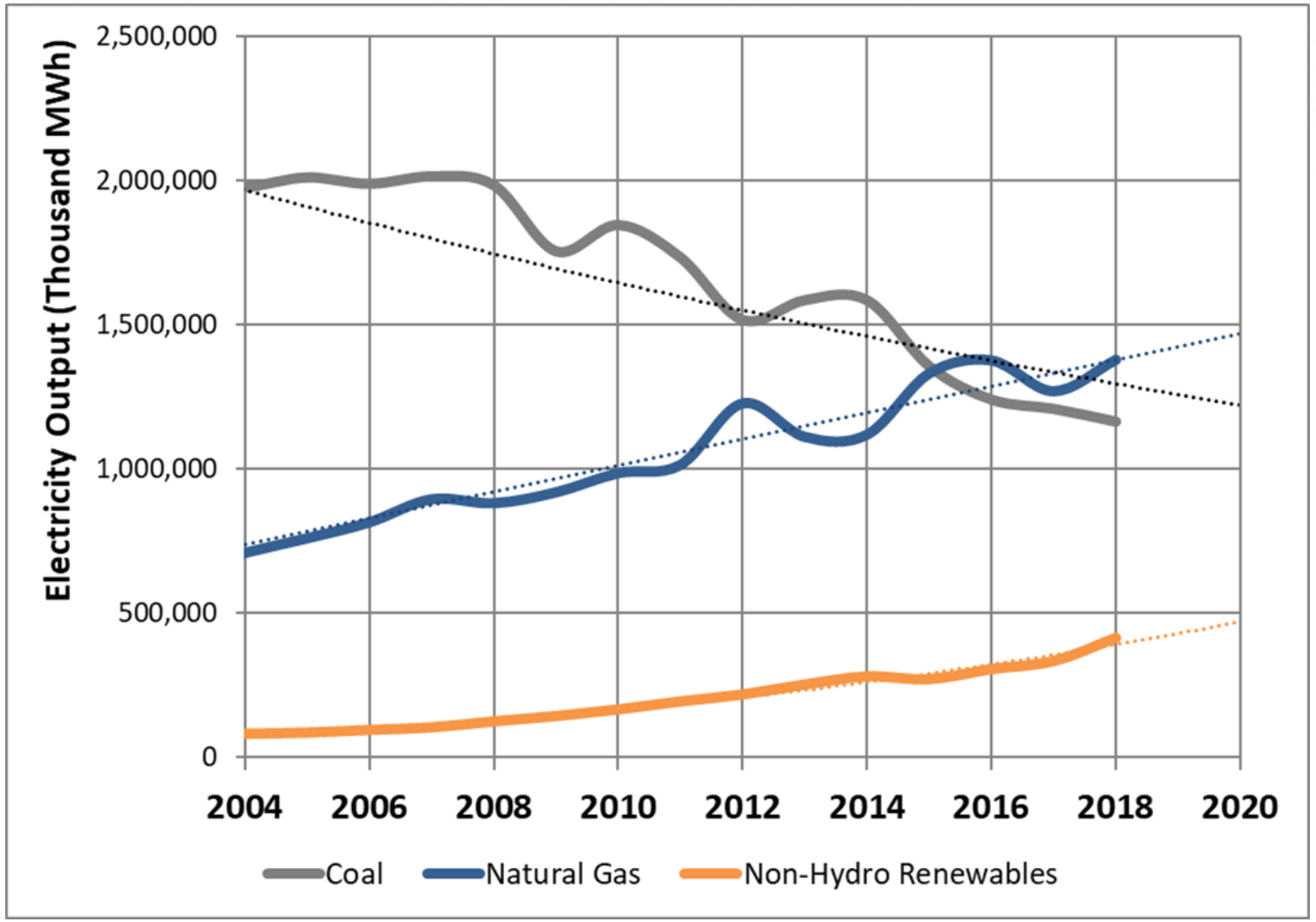
CHP



High Temp (e.g., metals, glass)

Low Temp (e.g., food, plastics, paint)

Power Generation – Major Trends

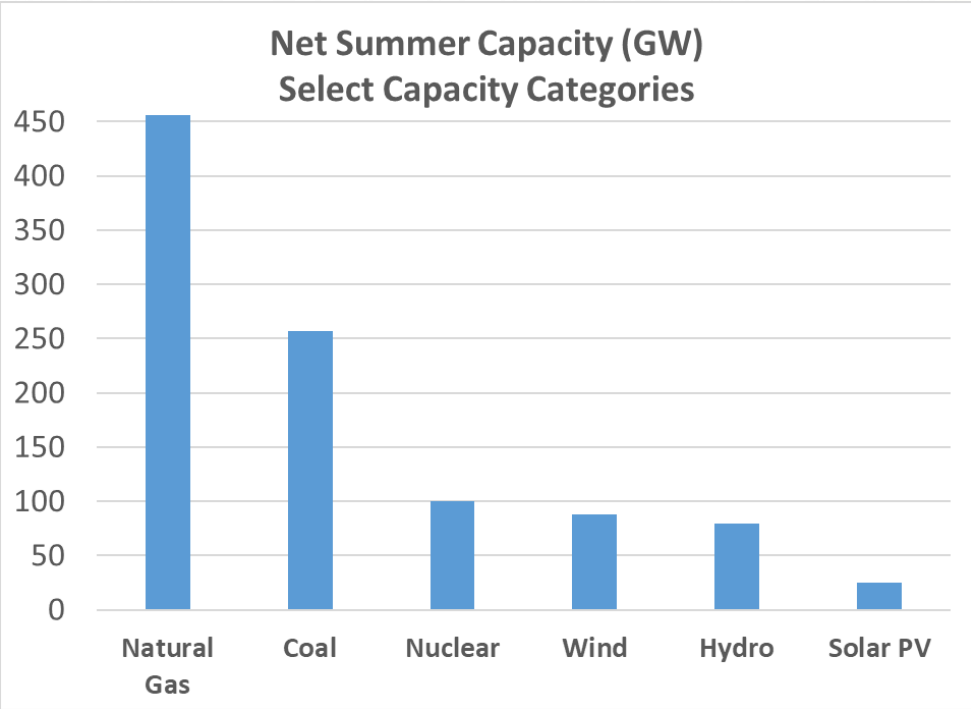


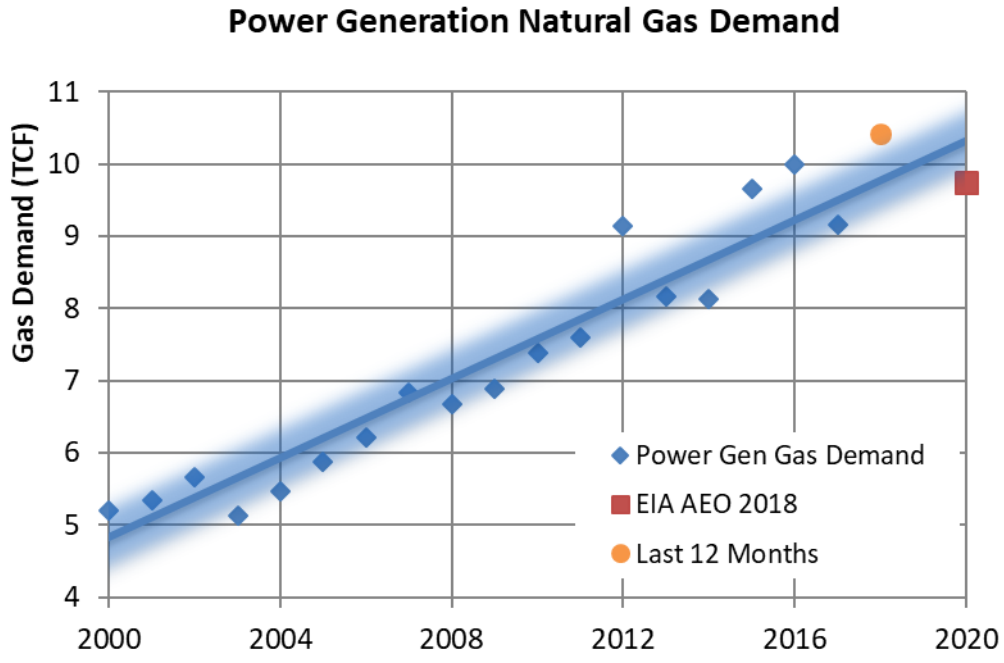
US coal power generation reached a peak in 2008 – steady decline since.

Natural gas and non-hydro renewables (e.g., wind and solar) contributing heavily to

US Power Generation

Natural Gas Use for Power Generation Growing

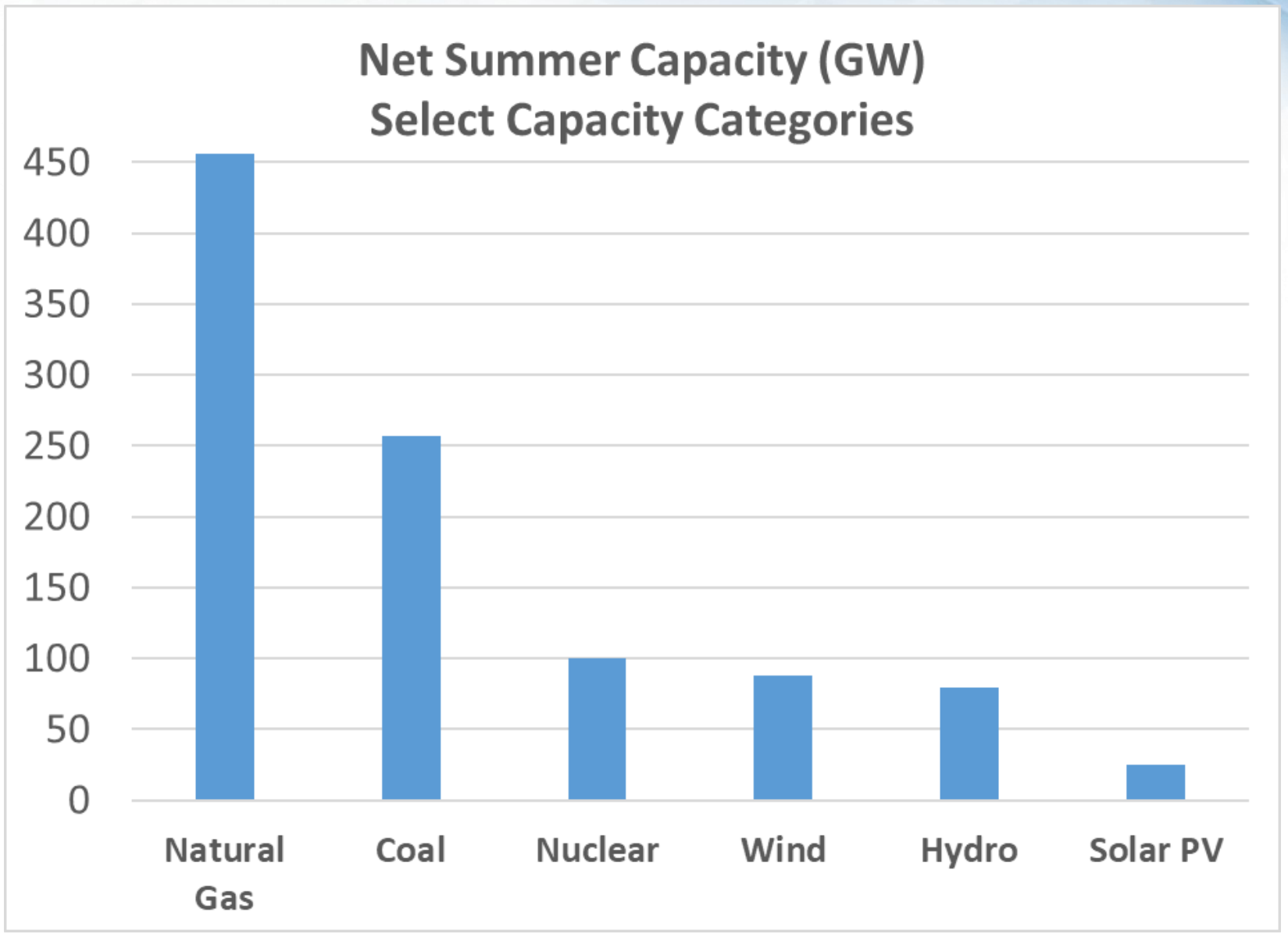




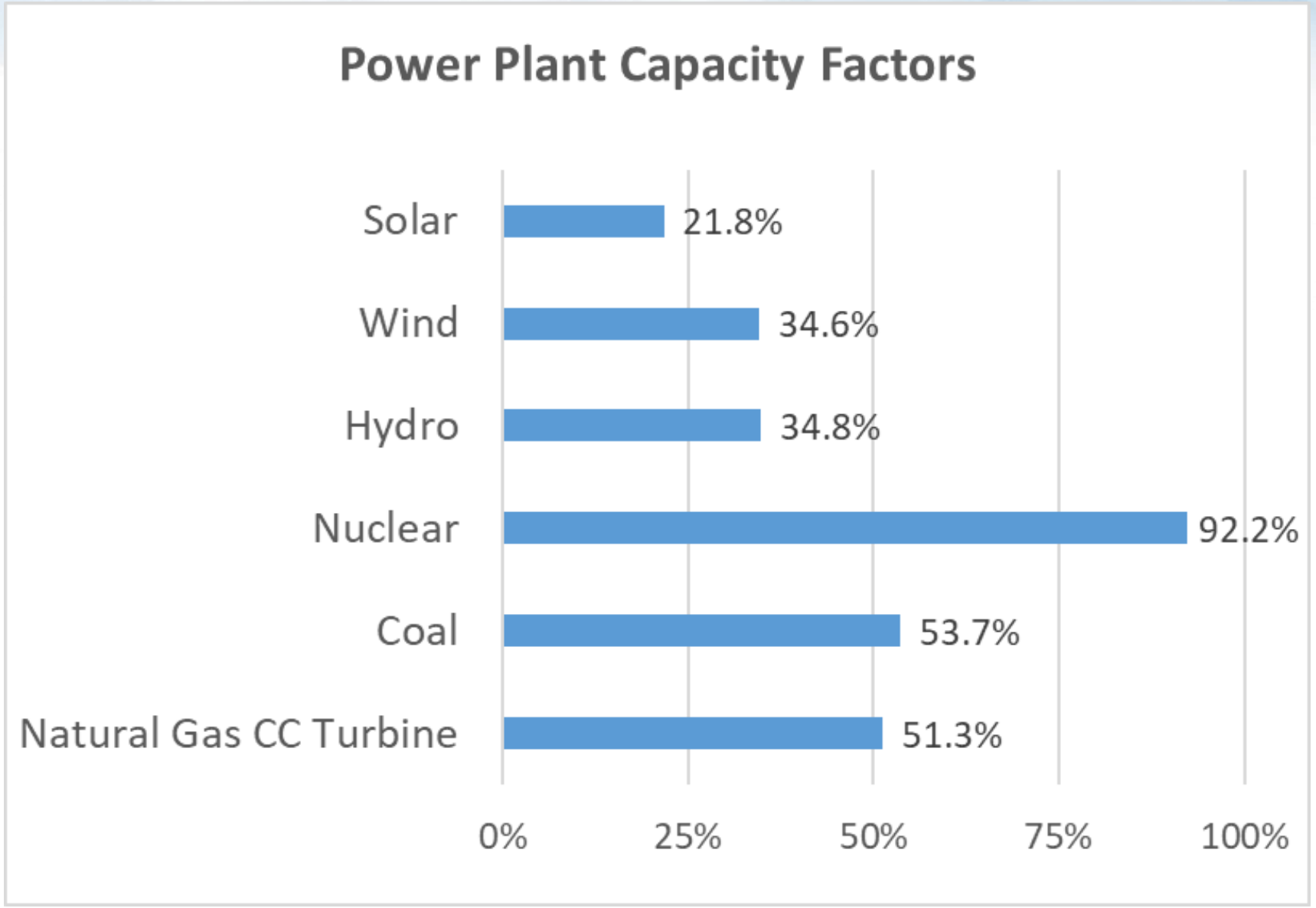
Source: DOE-EIA

Natural Gas Generation Capacity Substantially Larger Than Other Sources – Greater Than Coal, Nuclear, Wind

Natural Gas Use For Power Generation Has Doubled Since 2000. Ongoing Coal and Select Nuclear Power Retirements Likely Sustains



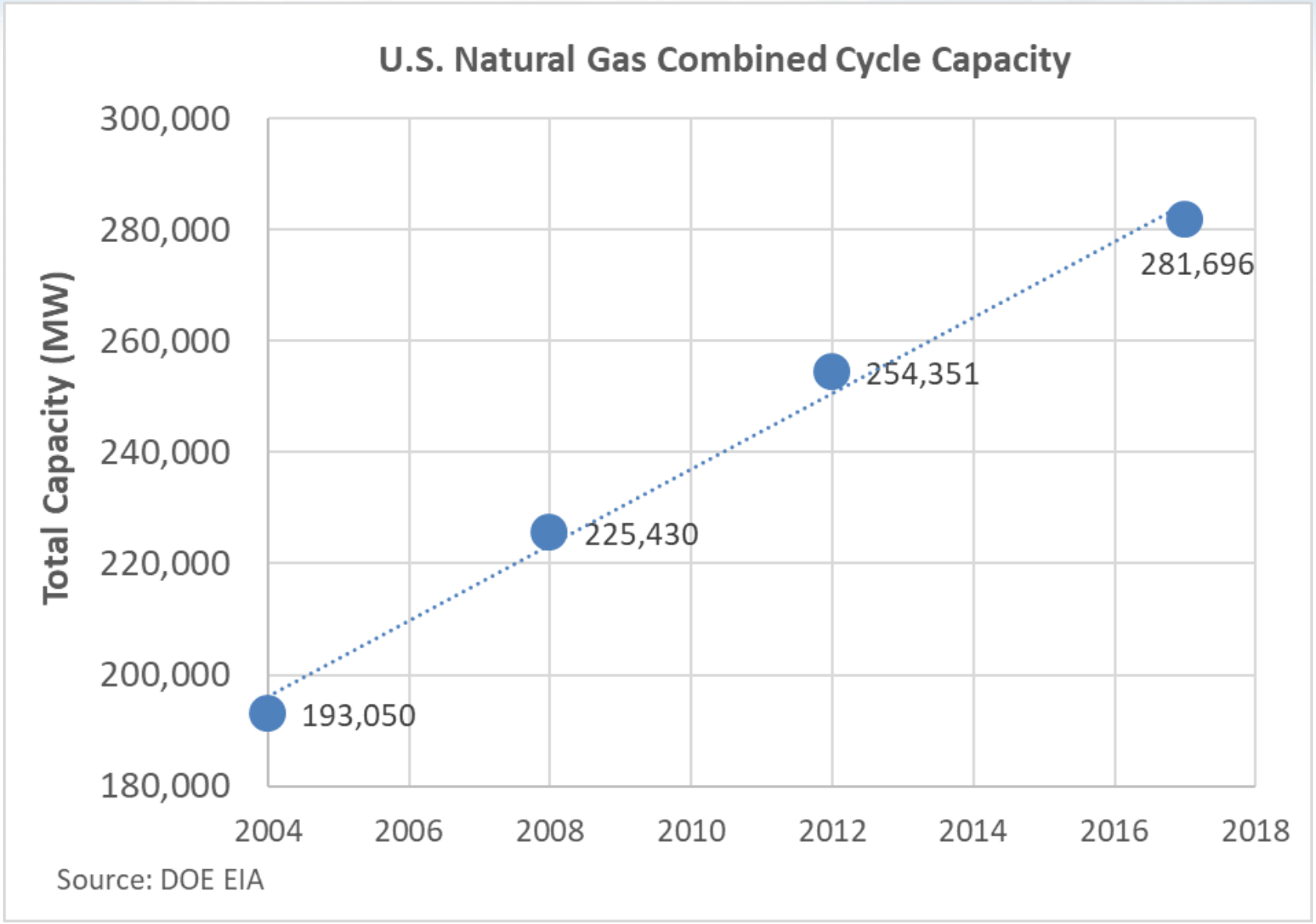
Source: DOE EIA



Coal and natural gas capacity factors typically constrained by demand and economics – not technical capability.

Wind and solar capacity factors typical illustrate technical potential.

Source: DOE EIA (2017 data)

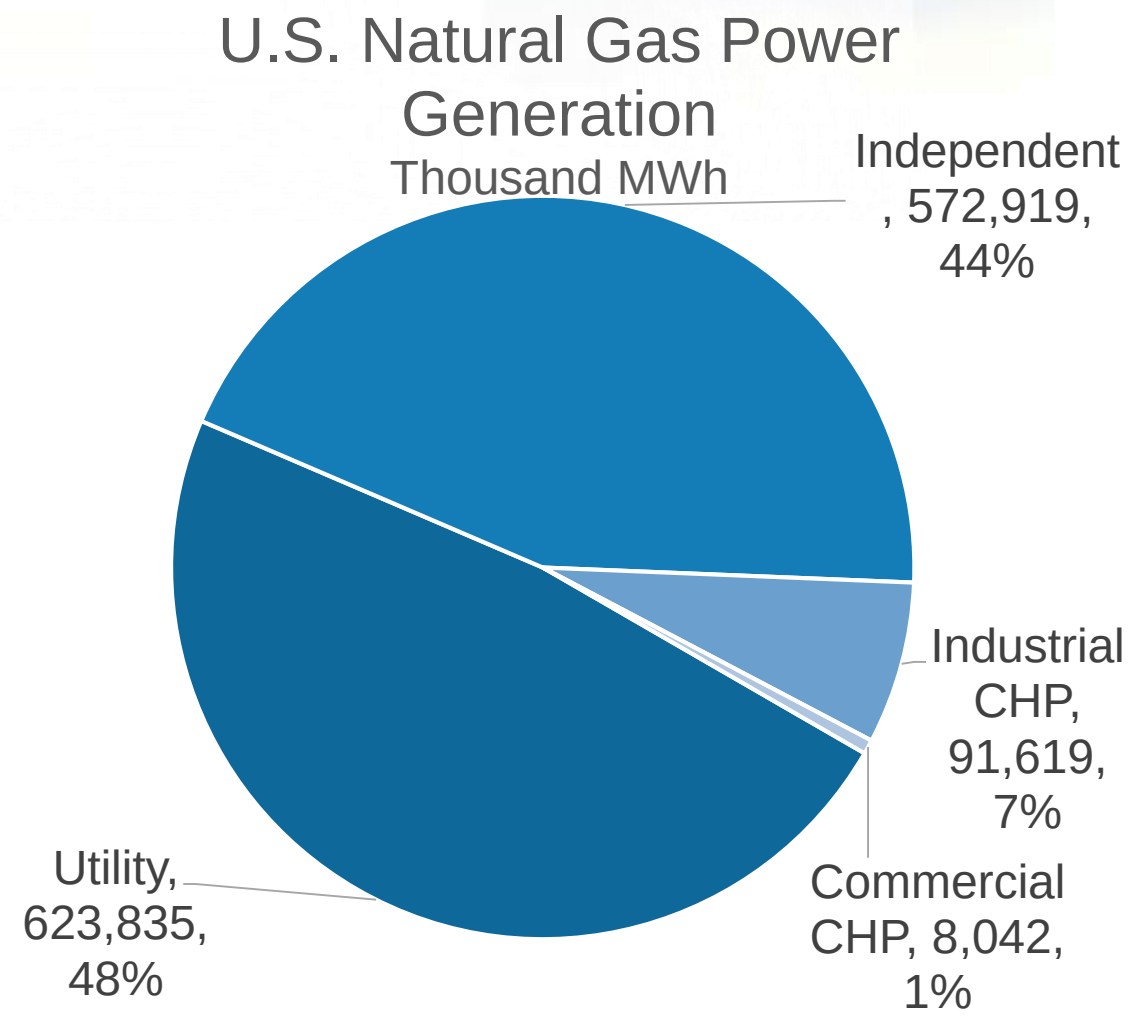


Steady growth in natural gas combined-cycle power plant capacity.

From 2004 to 2017, over 88 GW of added capacity and over $88 billion of new investment (at

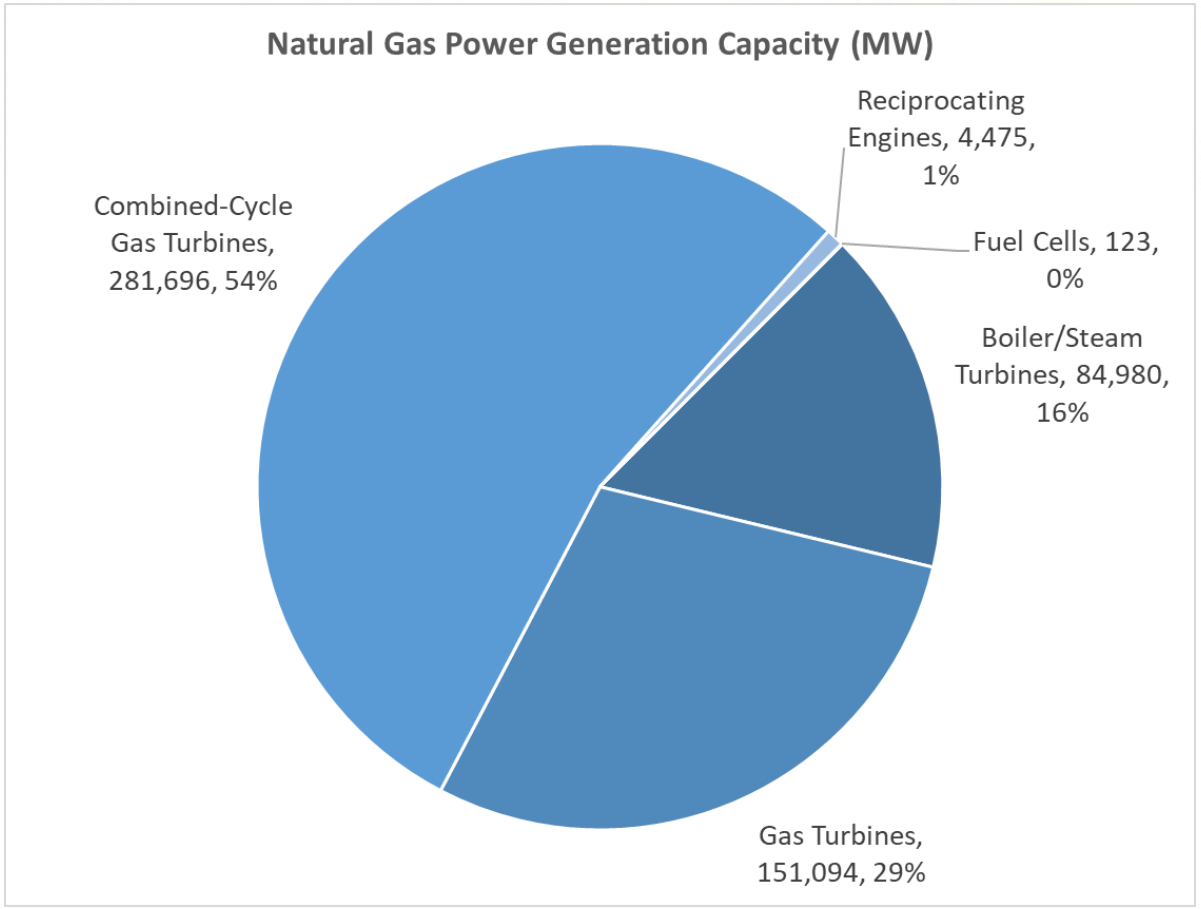
Power Generation and CHP Market Overview

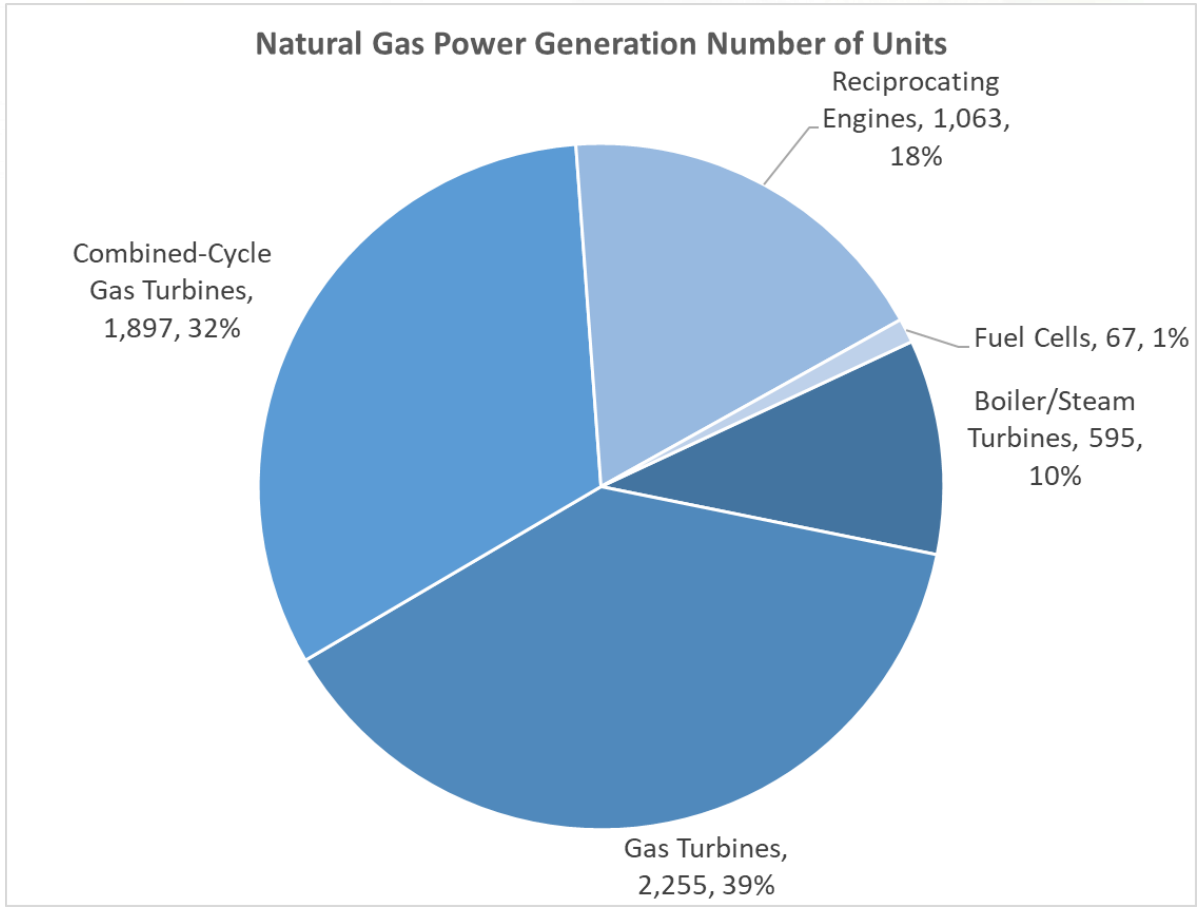
- Natural gas gaining share in power generation market
  - About 34% of generation output – mainly from large combined-cycle gas turbine plants
  - CHP use has grown over past 10 years



Source: DOE EIA (2017 data)

Natural Gas Power Generation





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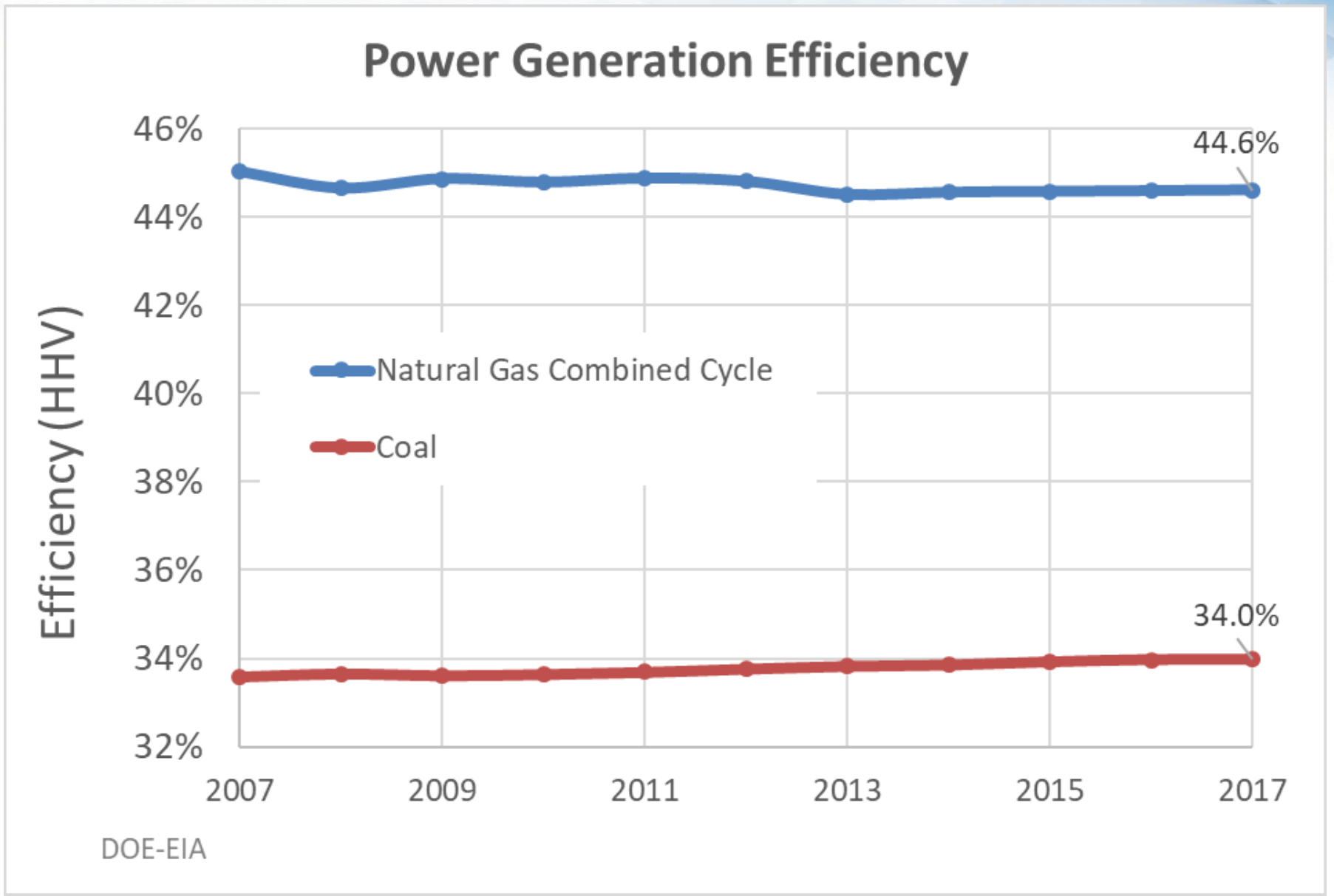
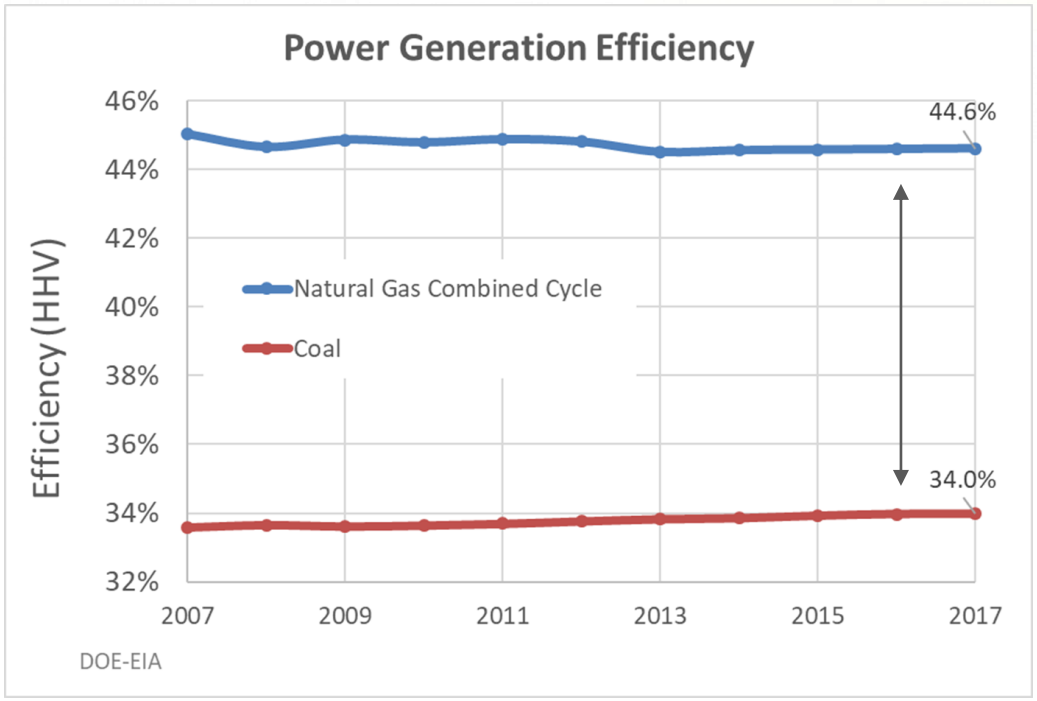

Power Generation Efficiency
46%
44%
42%
40%
38%
36%
34%
32%
Efficiency (HHV)
Natural Gas Combined Cycle
Coal
44.6%
34.0%
2007
2009
2011
2013
2015
2017
DOE-EIA

Coal & Natural Gas Comparisons

1. Technical Performance Advantage



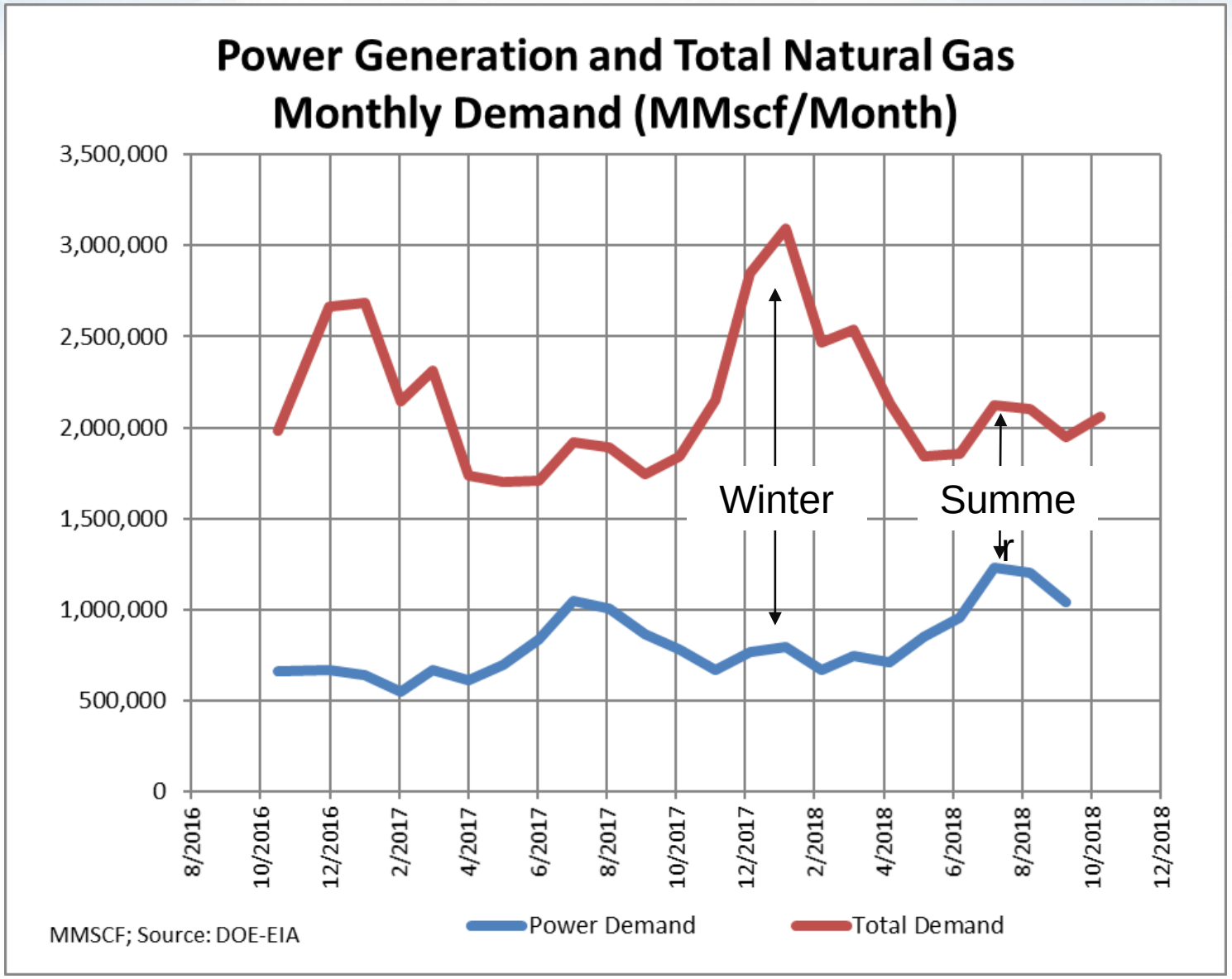
Natural gas combined-cycle power plants generate electricity 31% more efficiently than from coal. State-of-the-art combined cycle can extend advantage even further (as high as 50% relative improvement over coal).

2. Fuel Attribute Advantage*

	lb CO2/MMBTU
Coal	205
Natural Gas	117
% Lower	43%

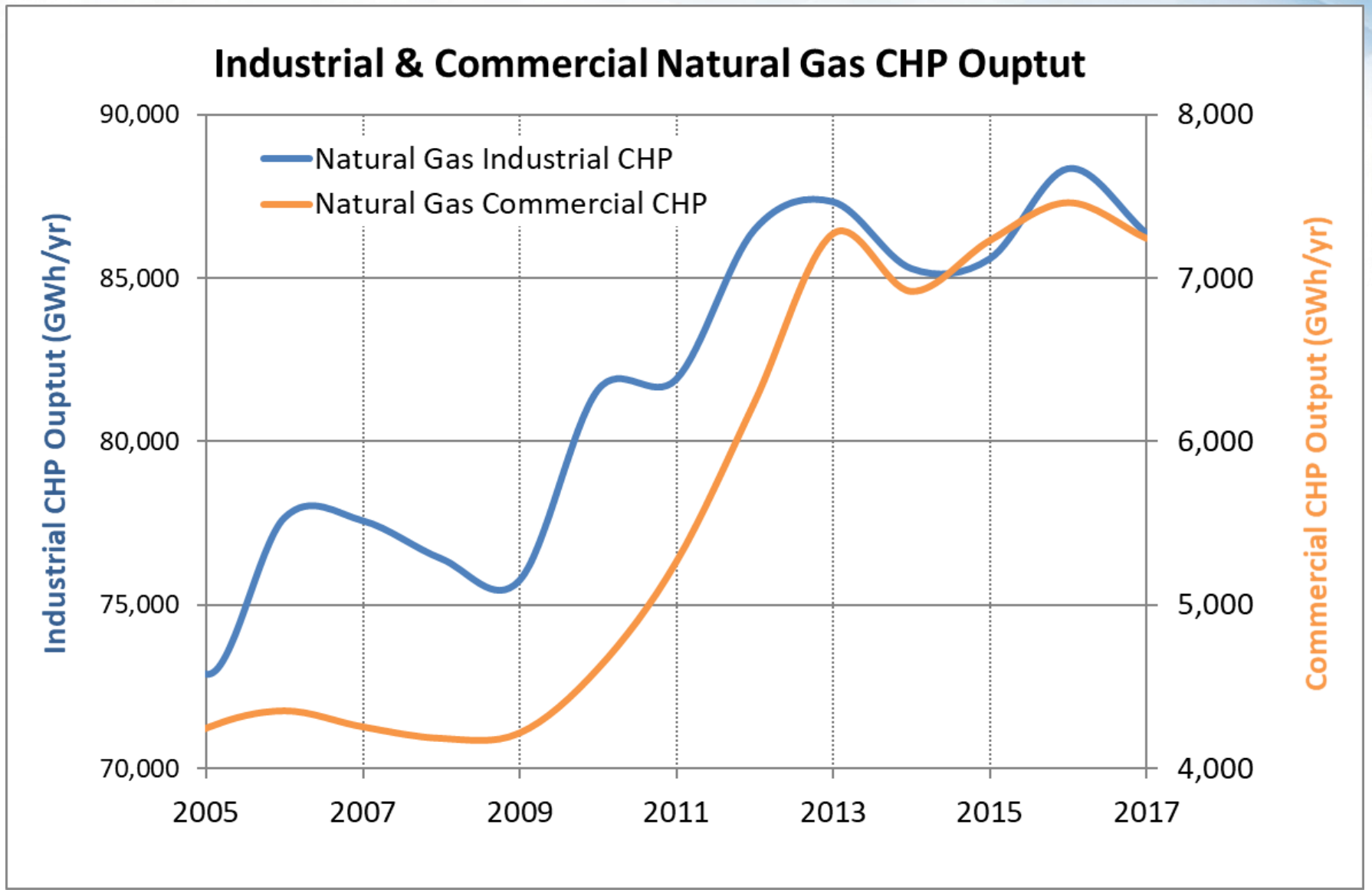
* Can vary depending on coal properties.

Together, technical & fuel factors result in a 55-63% reduction in carbon dioxide emissions per kWh produced with natural gas in place of coal.



Monthly natural gas use has a strong winter peak from December – March, with peak use about 50% higher than summer usage.

Monthly gas use for power generation is growing. Natural gas power generation represents about 20-25% of peak winter demand. Peak gas usage for power is during hot summer months and represents about 55% of summer gas use.



Source: DOE EIA

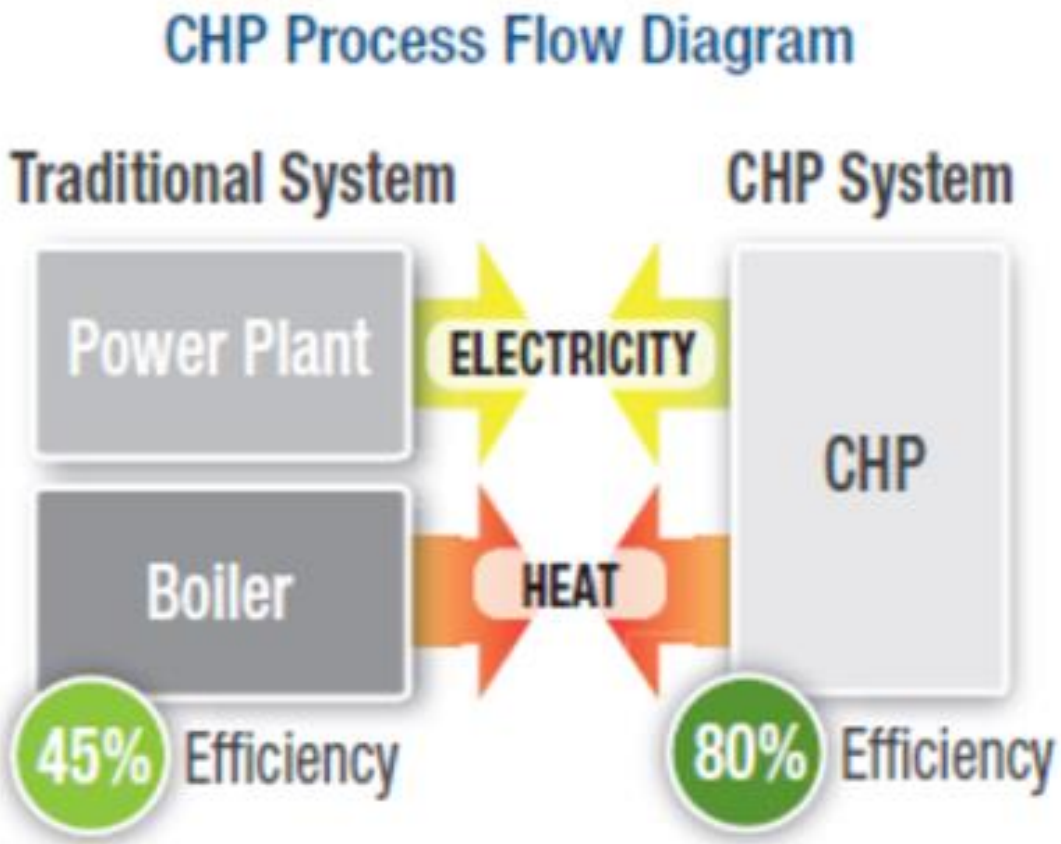
Distributed Generation and CHP

- **Standby or Emergency Power**: Used for customers that cannot tolerate an interruption of electrical service for either public health and safety reasons, or where power outage frequency or costs are unacceptably high

- **Peak Shaving**: Used by customers to reduce their energy demand during high cost peak periods
- **Grid Support**: Used by utilities to provide additional power system support during peak power usage and to delay grid investment
- **Combined Heat & Power**: Combines power and thermally activated technologies to provide customers both power and thermal energy from the power generation process

Natural Gas Combined Heat and Power

- Efficient option for distributed production of power and thermal energy (e.g., steam, hot water)
  - Industrial
  - Institutional
  - Commercial



Natural Gas Distributed Generation and CHP Products

Gas Engines

Gas Turbines

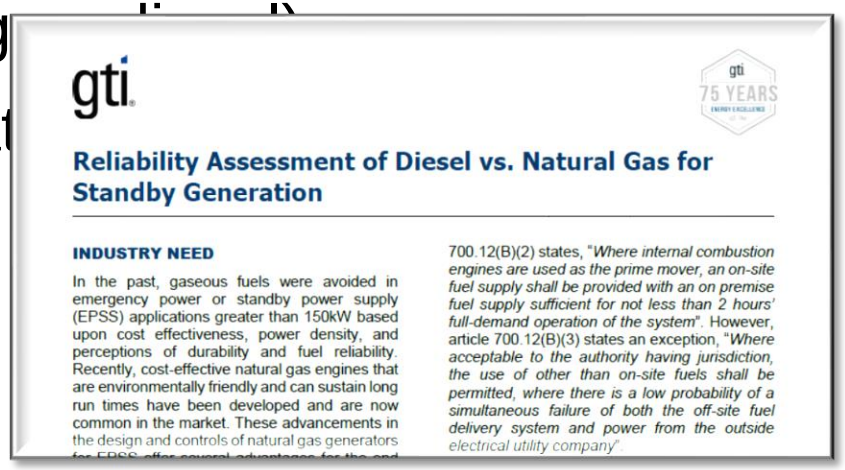
Fuel Cells

Microturbines

Natural Gas Standby & Emergency Power
Reliable, Resilient

- GTI working with industry partners such as Generac to document benefits of natural gas for emergency power supply systems (EPSS)
  - Benefits of natural gas over diesel
  - Reliability white paper
  - Calculators comparing lifecycle costs (natural g
  - Work with NFPA 70, AHJs to permit pipeline nat gas as alternative to onsite diesel storage
  - Demand response (DR) program opportunities

GENERAC | INDUSTRIAL POWER


gti

gti 75 YEARS

Reliability Assessment of Diesel vs. Natural Gas for Standby Generation

INDUSTRY NEED

In the past, gaseous fuels were avoided in emergency power or standby power supply (EPSS) applications greater than 150kW based upon cost effectiveness, power density, and perceptions of durability and fuel reliability. Recently, cost-effective natural gas engines that are environmentally friendly and can sustain long run times have been developed and are now common in the market. These advancements in the design and controls of natural gas generators

700.12(B)(2) states, "*Where internal combustion engines are used as the prime mover, an on-site fuel supply shall be provided with an on premise fuel supply sufficient for not less than 2 hours' full-demand operation of the system*". However, article 700.12(B)(3) states an exception, "*Where acceptable to the authority having jurisdiction, the use of other than on-site fuels shall be permitted, where there is a low probability of a simultaneous failure of both the off-site fuel delivery system and power from the outside electrical utility company*".

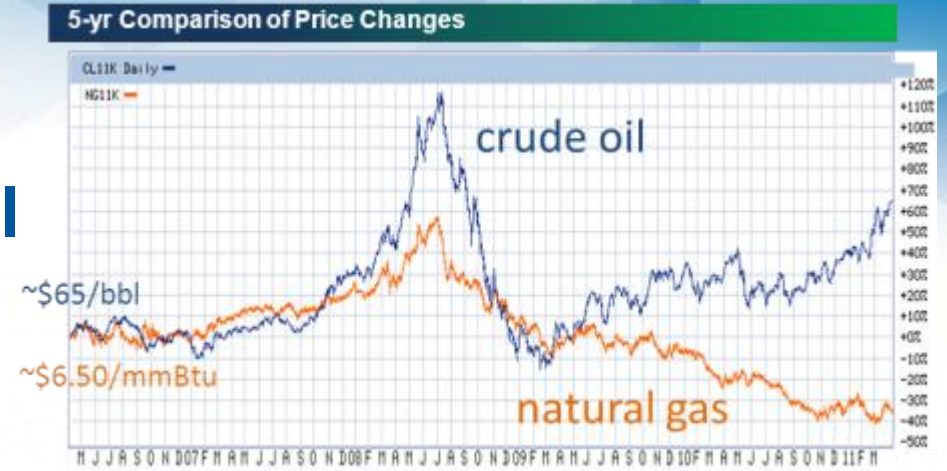
For more information: http://www.natgasgen.com

Increased interrelationship between energy production and water management

- Minimizing water use for shale fracturing operations
- Disposal and clean-up of produced water

- Minimize impact of water on infrastructure (MIC, deposits, etc
- Reduce cost of water management

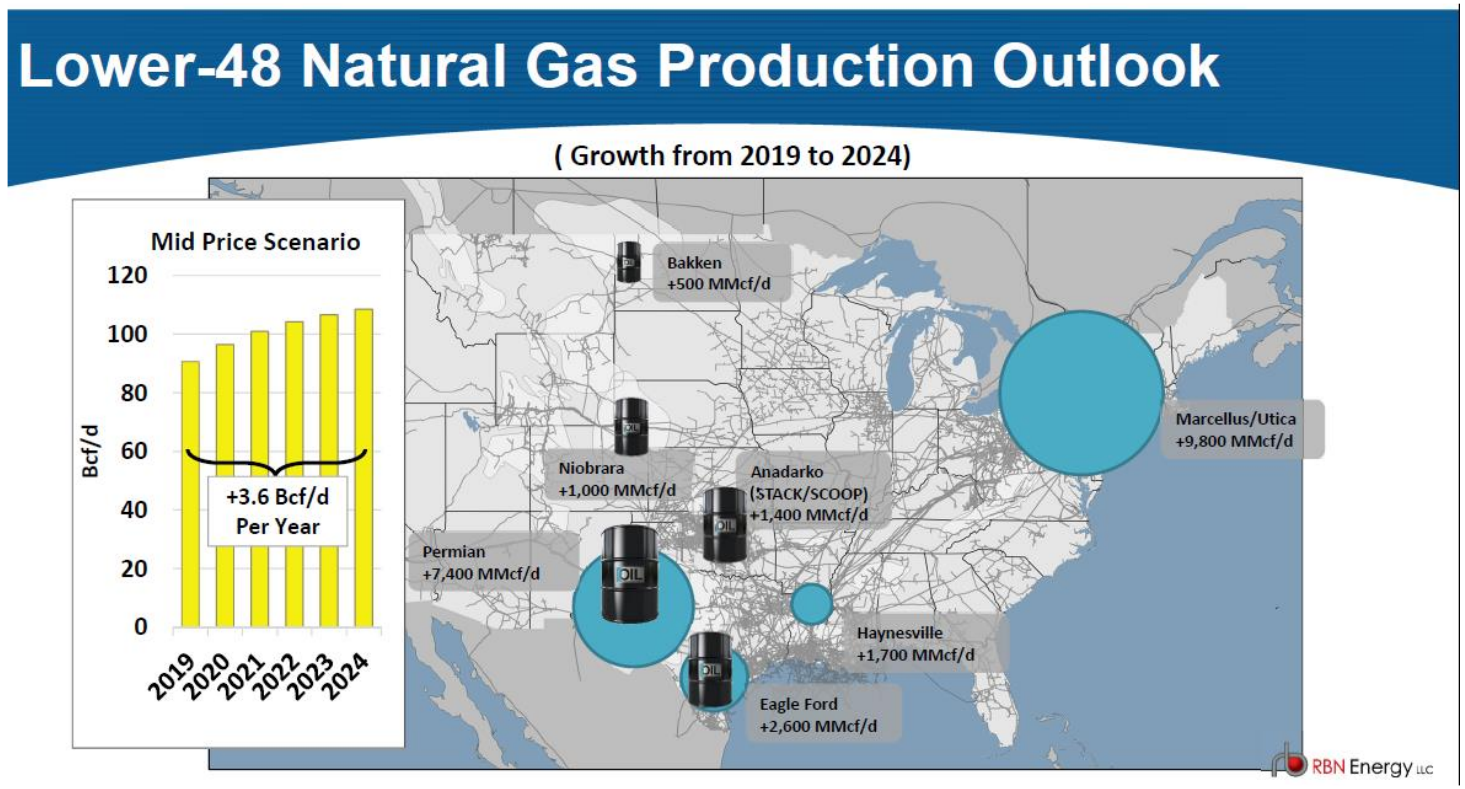
Natural Gas as an important transportation fuel



- Strong market interest, driven by fuel price differential
  - Medium and heavy-duty fleet vehicles are core market
  - Off-road opportunities (e.g., marine)
  - Light duty (and home fueling) is long-term goal
- Main challenges: cost reduction for vehicles, infrastructure
  - Growth & volume will move market towards improved pricing over next five years
- Emerging off-road applications

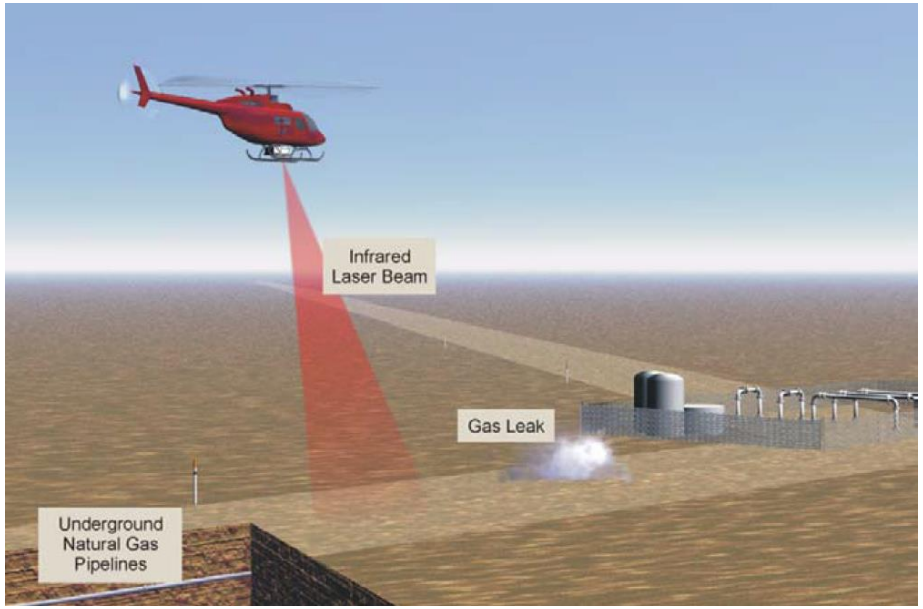
Infrastructure: Re-engineering energy delivery network for a new paradigm

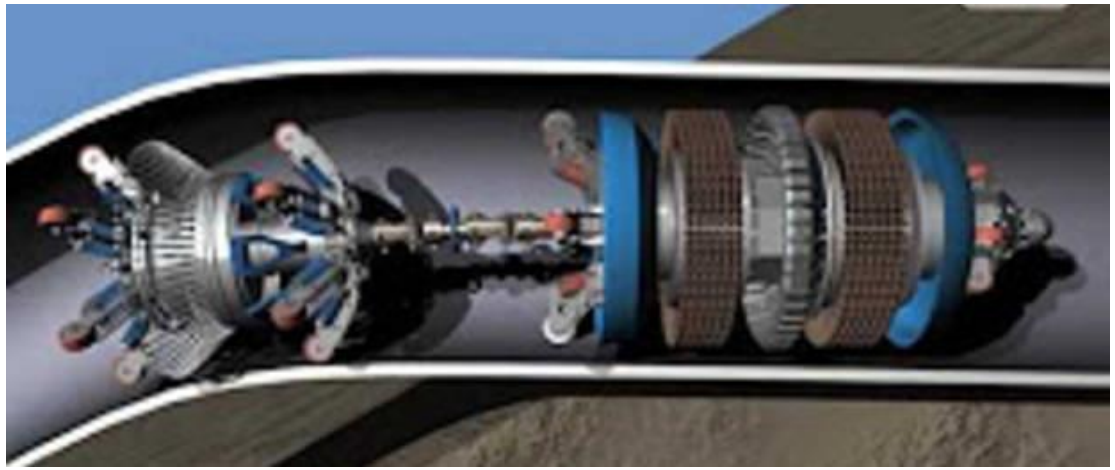
- Transmission Pipelines
  - $6-10 billion per year
  - Over 10 million hp of installed compression capacity
- Local Distribution Pipelines
  - **$12 billion year**
    - **$8.2 billion repair/replace**
    - **$4.0 billion new construction**
- Natural Gas **STORAGE**
  - Substantial volumes of stored **CNG, LNG**
- Export Infrastructure



IT / Data Management

- A.I. can supplement “experience” for new workers. No shortage of workers with “education”, but big shortage of workers with useful experience. Inexperienced worker can consult with A.I. to figure out problems.
- Over 90% of data available to the energy industry has been generated in the last 5 years. Tools still need development for understanding it all.





Decarbonization: Natural Gas takes the lead in a low carbon future

The zero-emissions, low-cost, convenient, domestically produced, hazard-free, non-polluting, fuel is yet to be developed.

HOW GREEN ARE BIOFUELS?

Biofuels are getting a bad rap as stories of rising food prices and shortages fill the news. But the environmental, energy and land use impacts of the crops used to make the fuels vary dramatically. Current fuel sources – corn, soybeans and canola – are more harmful than alternatives that are under development.

FUEL SOURCES		GREENHOUSE GAS EMISSIONS* Kilograms of carbon dioxide created per mega joule of energy produced	USE OF RESOURCES DURING GROWING, HARVESTING AND REFINING OF FUEL				PERCENT OF EXISTING U.S. CROP LAND NEEDED TO PRODUCE ENOUGH FUEL TO MEET HALF OF U.S. DEMAND	
CROP	USED TO PRODUCE		WATER	FERTILIZER	PESTICIDE	ENERGY		PROS AND CONS
Corn	Ethanol	81-85	high	high	high	high	157%-262%	Technology ready and relatively cheap, reduces food supply
Sugar cane	Ethanol	4-12	high	high	med	med	46-57	Technology ready, limited as to where will grow
Switch grass	Ethanol	-24	med-low	low	low	low	60-108	Won't compete with food crops, technology not ready
Wood residue	Ethanol, biodiesel	N/A	med	low	low	low	150-250	Uses timber waste and other debris, technology not fully ready
Soybeans	Biodiesel	49	high	low-med	med	med-low	180-240	Technology ready, reduces food supply
Rapeseed, canola	Biodiesel	37	high	med	med	med-low	30	Technology ready, reduces food supply
Algae	Biodiesel	-183	med	low	low	high	1-2	Potential for huge production levels, technology not ready

* Emissions produced during the growing, harvesting, refining and burning of fuel. Gasoline is 94, diesel is 83.

Source: Martha Groom, University of Washington; Elizabeth Gray, The Nature Conservancy; Patricia Townsend, University of Washington; as published in Conservation Biology

SEATTLE P-I

Natural Gas technologies leading to a lower carbon footprint:

- Energy Conversion Technologies
  - Small scale GTL and LNG to utilize stranded gas
  - Biomass/gas Blends
- Displacement of higher carbon fossil fuels in powergen and transportation
- Hybrid technologies:
  - CHP
  - Integrated renewable/fossil fuel systems
- Renewable Natural Gas
- Carbon Capture Utilization and Storage (CCUS)
- Increased Use of Hydrogen (Blending, Energy Storage, Mobility)
- “If I was given $10 Billion to invest in low carbon technologies, I would not know where to put it. There’s not enough certainty in what will succeed”, Bob Dudley, CEO, BP.

3-5 Year Outlook – "There is a flood coming; and it's called Associated Gas" Reed Olmstead, Director NA Upstream Gas Markets, IHS

The next few years will be a time of stable oil and gas commodity prices, and reliable supplies in the U.S. No major disrupters or geopolitical events predicted for the immediate future that will impact domestic supplies or prices beyond usual fluctuations. Natural gas continues to be seen as the "go-to" fuel for transportation and power generation market growth and its rate of growth will outpace everything except renewables (from a much smaller base). Consensus opinion is that electrification (particularly for passenger vehicles) will continue but questions remain on how the power grid can support EV growth beyond single digit market penetration. Concern over climate change is unlikely to abate and increased government regulation on emissions is expected. Emerging export presence has made U.S. energy supply a tool of US foreign policy.

- U.S. natural gas prices unlikely to significantly exceed $3 for the next five years.
- In 2018, there were a few skeptics about the staying power of the US energy supply – this year, there are none.
- Supply growth continues to come from Permian, Marcellus, and Utica. Exports are key to growth.
- Pipeline capacity constraints for bringing oil out of Permian are being relieved faster than expected. By 2020, most production will find outlets, but gas will still be constrained.
- Heavy-handed regulation is coming for heavy-duty trucks in Europe.
- Companies are beginning to understand limits to electrification (in current form) and turn to CCUS and hydrogen for solutions. Policy-makers still lagging.
- U.S. infrastructure investments will be focused on exports.

3-5 Year Outlook Continued... "…fundamentally, the world has always been on a path toward reliable, affordable, cleaner energy." Mike Wirth, CEO, Chevron

- Auto industry continues its race toward EV's by rolling out new models. Electric F150 on its way. Little impact on oil or natural gas demand.
- Europe has over 60 power-to-gas demonstration projects underway. Data/results should start becoming available and influence whether these projects are working.
- U.S. power generation coal-fired fleet average age is 42 years. Retiring plants will continue to be replaced by gas and wind.
- Rate of coal plant capacity growth in China has dropped to "only" 25% and will continue to drop. Average coal plant fleet age is 11 years with retirement decades away in both China and India. Big implication for practical ability to reduce global GHG emissions.
- Lack of gas pipelines and growing gas demand is driving the need for small-scale LNG to move Marcellus gas to markets via truck and rail.
- Natural gas flaring continues to grow and needs cost-effective solutions but problem perceived as short-term until pipeline capacity is built-out.