Transformative Technology Impacting Traditional Energy Systems

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Designing An Optimal Energy System

- Begin With Traditional Fuels At Scale
- Determine System Constraints & Establish Objectives
- Maximize Efficiency
- Synergistically Add Renewables
- Make The System Smart, Very Smart
- Simultaneously Continue To Work On Energy Transformations

Integration, Not A Silver Bullet, Is The Key Today

Getting The Bigger Picture: Ball Bearings

It’s

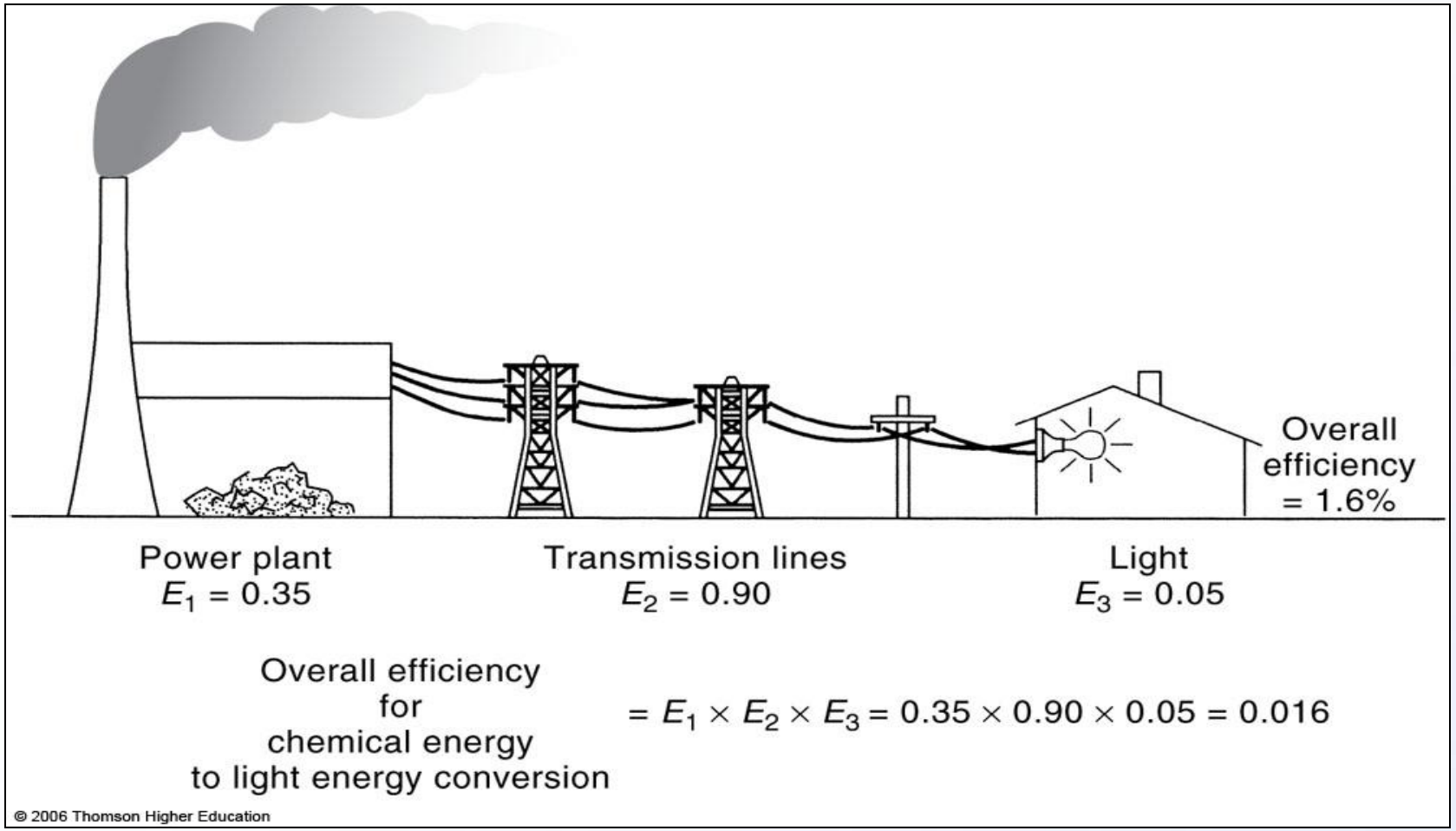
All

About

Optimizing

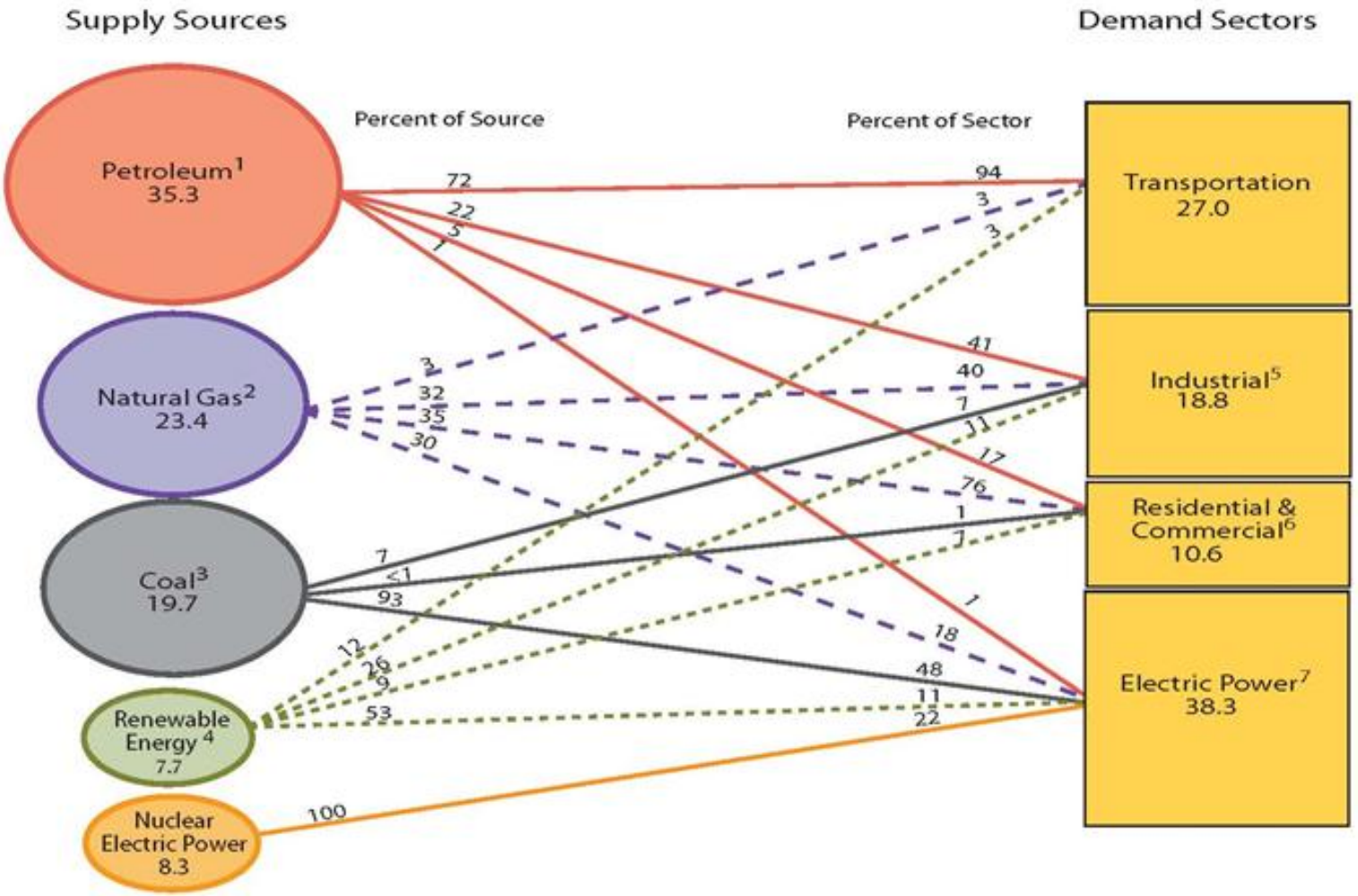
Components

Optimizing Any Component Can Improve The System



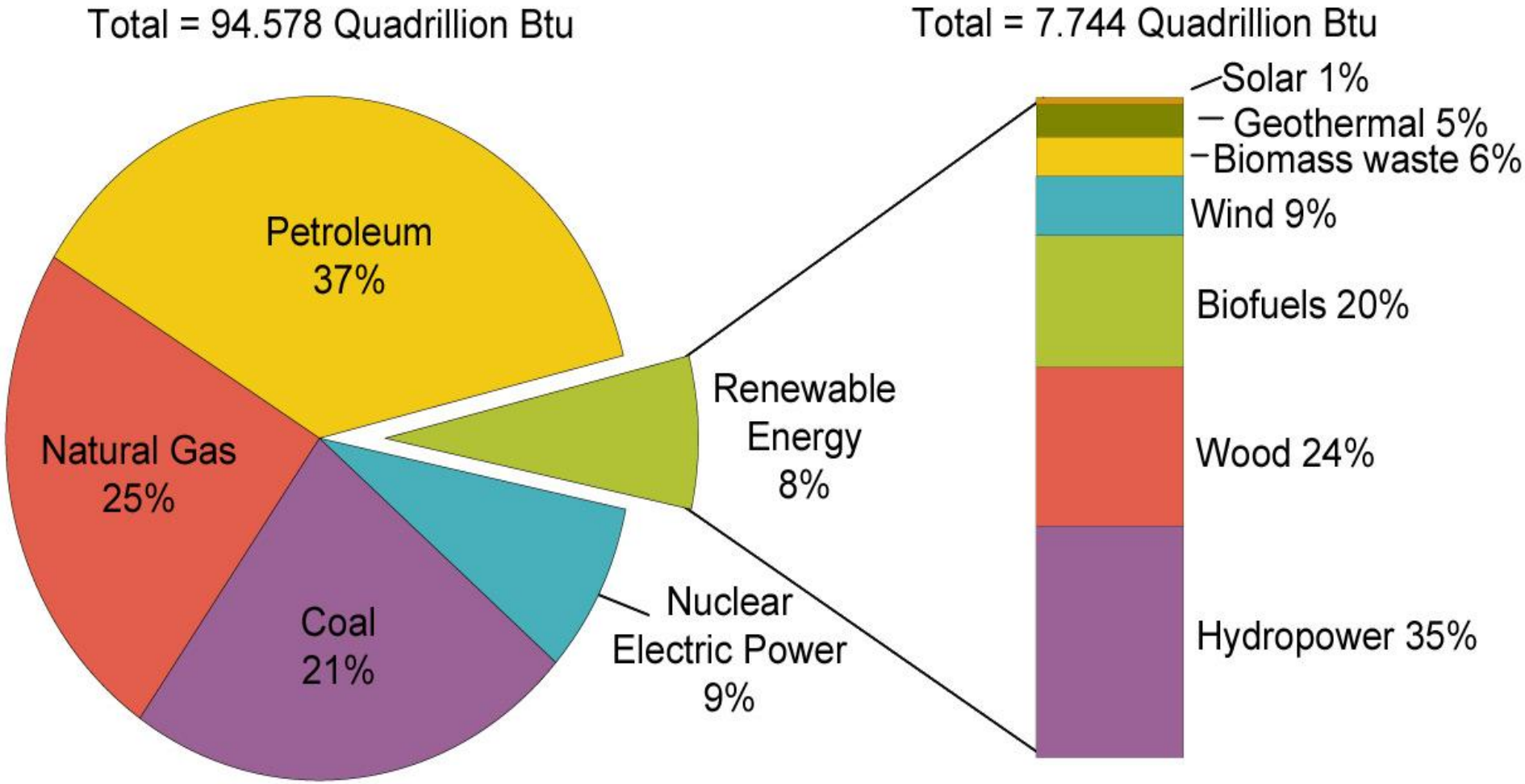
Source: Hinrichs/Kleinbach, Energy – Its Use and the Environment

Figure 2.0 Primary Energy Flow by Source and Sector, 2009
(Quadrillion Btu)



Source: EIA, 2009

U.S. Energy Consumption by Energy Source, 2009



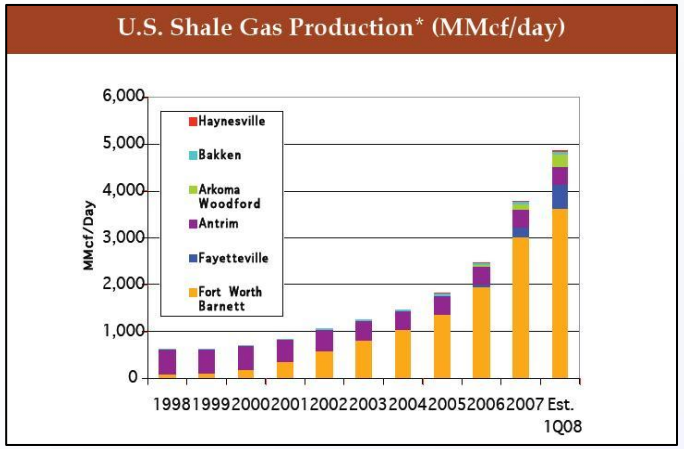
Note: Sum of components may not equal 100% due to independent rounding.
Source: U.S. Energy Information Administration, *Annual Energy Review 2009*, Table 1.3, Primary Energy Consumption by Energy Source, 1949-2009 (August 2010).

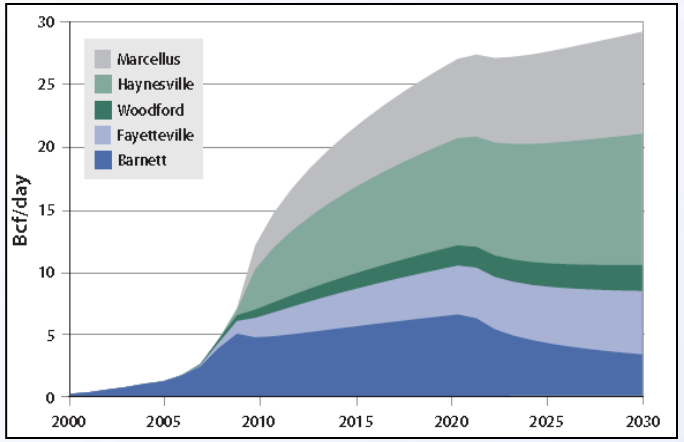
Exceeding Expectations

PHOTOGRAPH BY JEFF RIEDEL FOR TIME

The U.S. Gas Shale Ramp

- The Barnett grew 3000% from 1998 to 2007
- The Eagle Ford, Fayetteville, Haynesville, Marcellus, and Woodford will dwarf this
- Technology improvements in horizontal drilling and fracturing have economically enabled vast new unconventional and conventional resources.





Source: Smead, Navigant Consulting, June 2009; MIT, The Future of Natural Gas 2010

Natural Gas Demand

Resilience in gas use across sectors

Potential major growth areas:

Electricity

- Natural gas substitution for coal
- Intermittent sources/variability & uncertainty

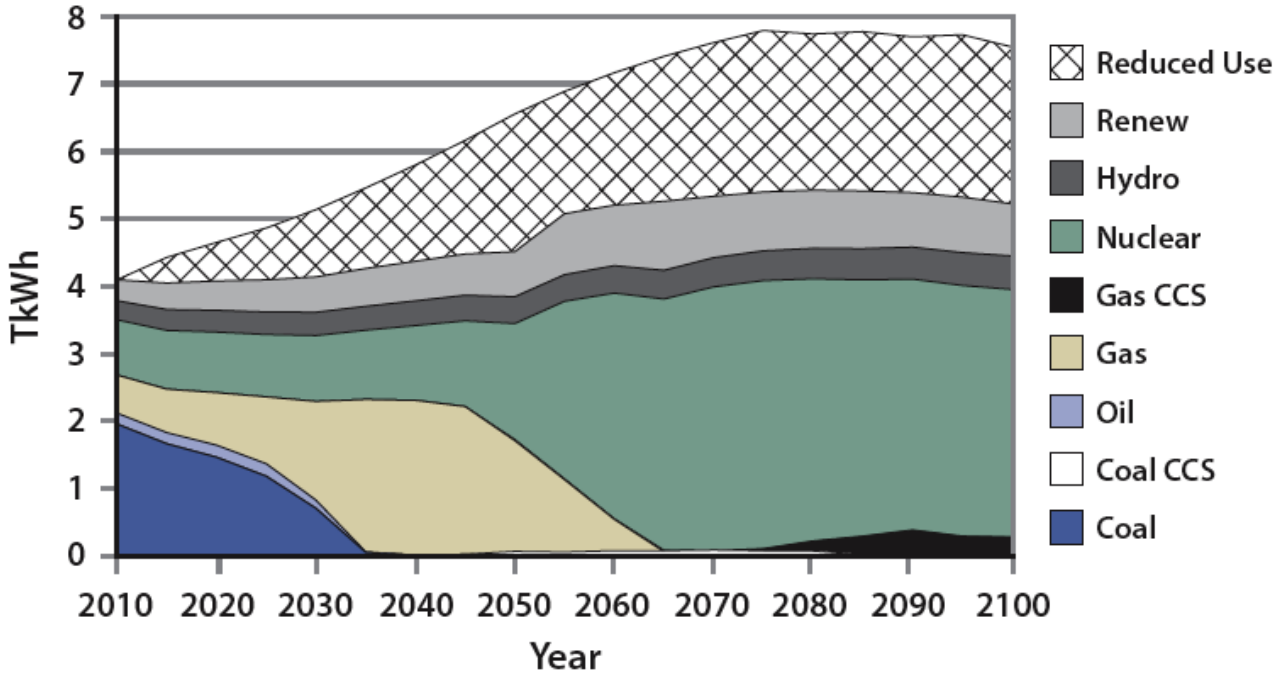
Transportation

- Long term potential for CNG
- LNG not currently attractive

Source: MIT, The Future of Natural Gas 2010

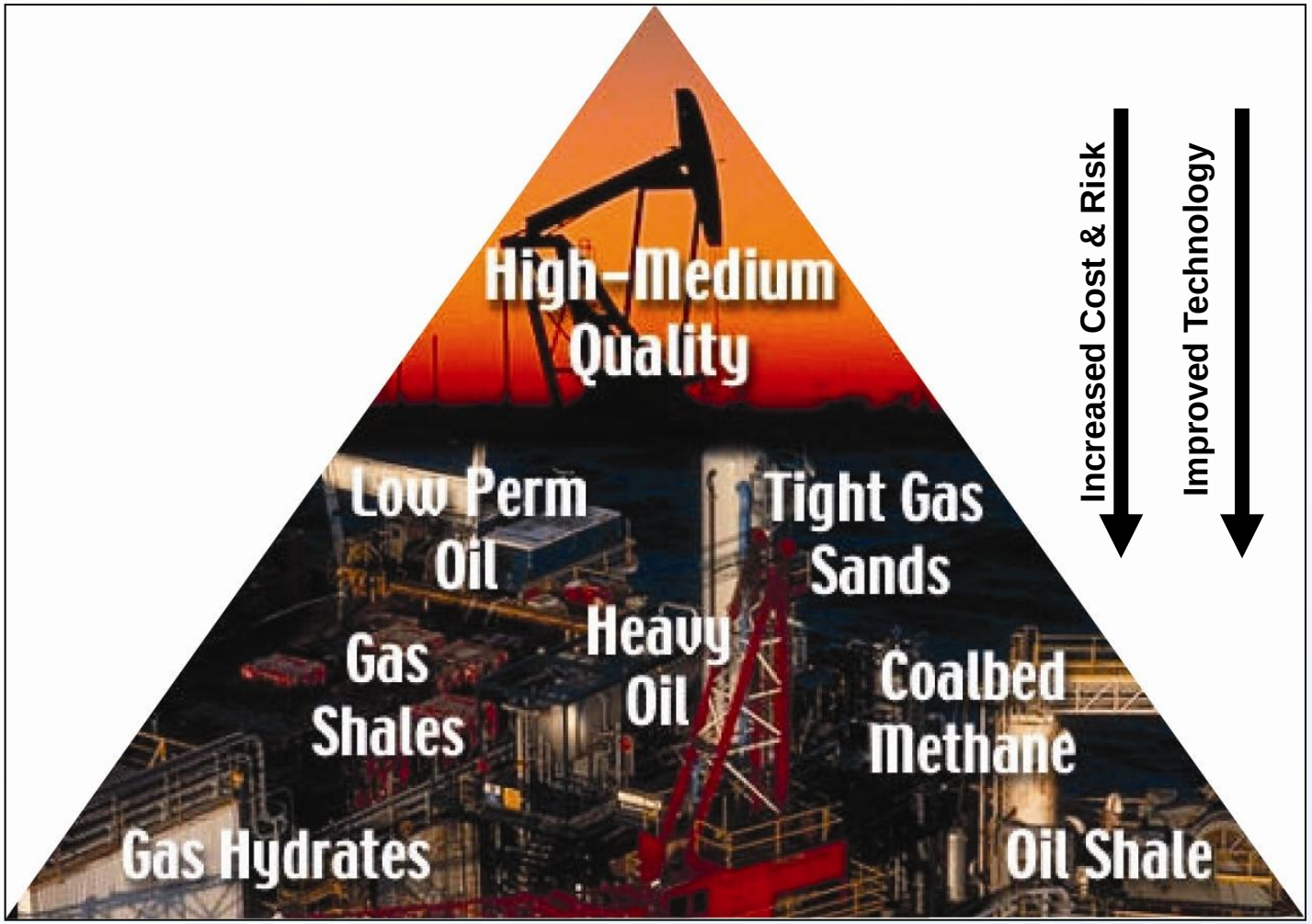
Natural Gas, A 60-year Bridge (At Least)

Figure 3.9 Energy Mix in Electric Generation under a Price-Based Climate Policy, Mean Natural Gas Resources and Regional Natural Gas Markets (TkWh)



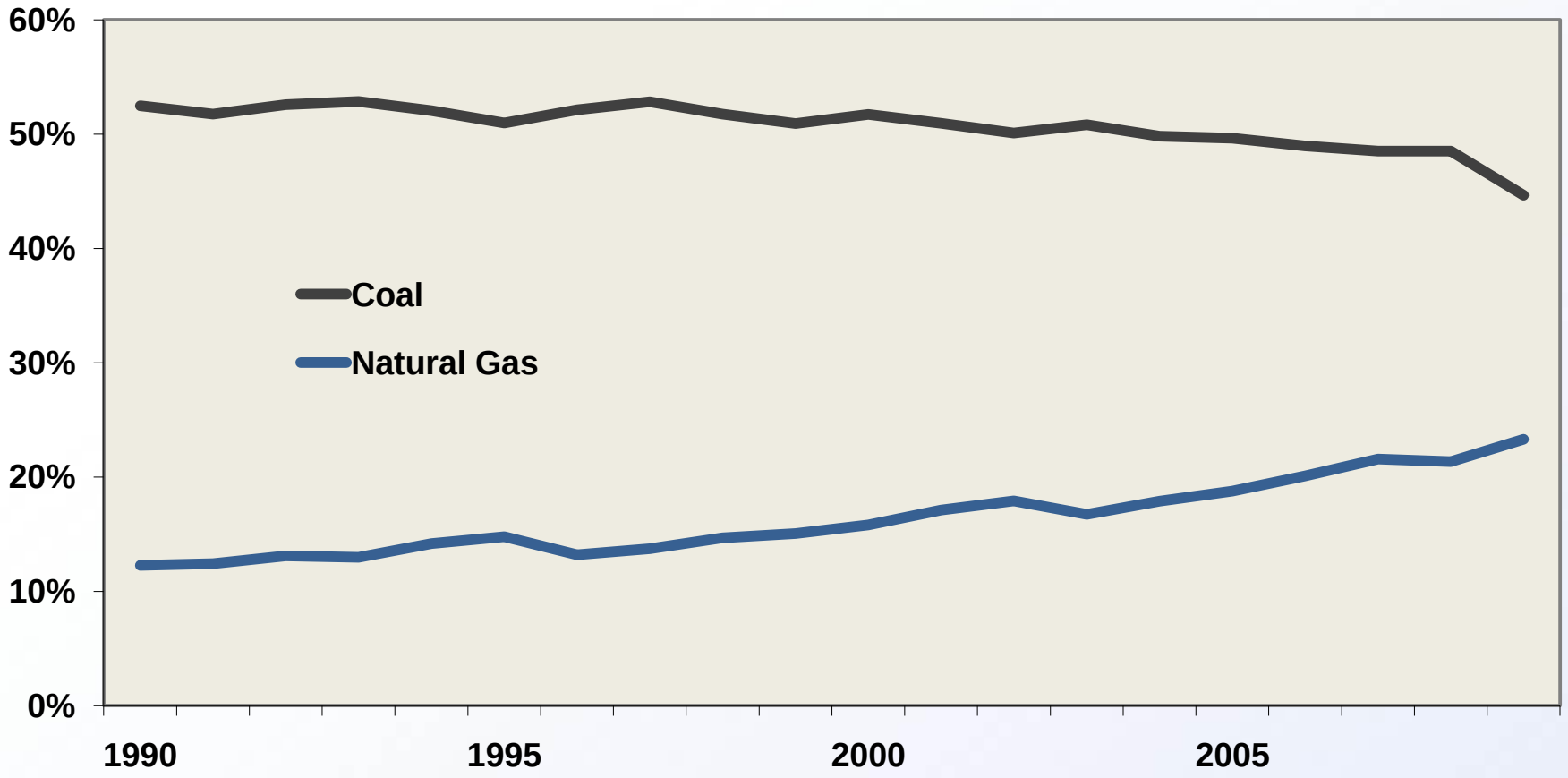
Source: MIT, The Future of Natural Gas 2010

Technology Has Driven The Growth



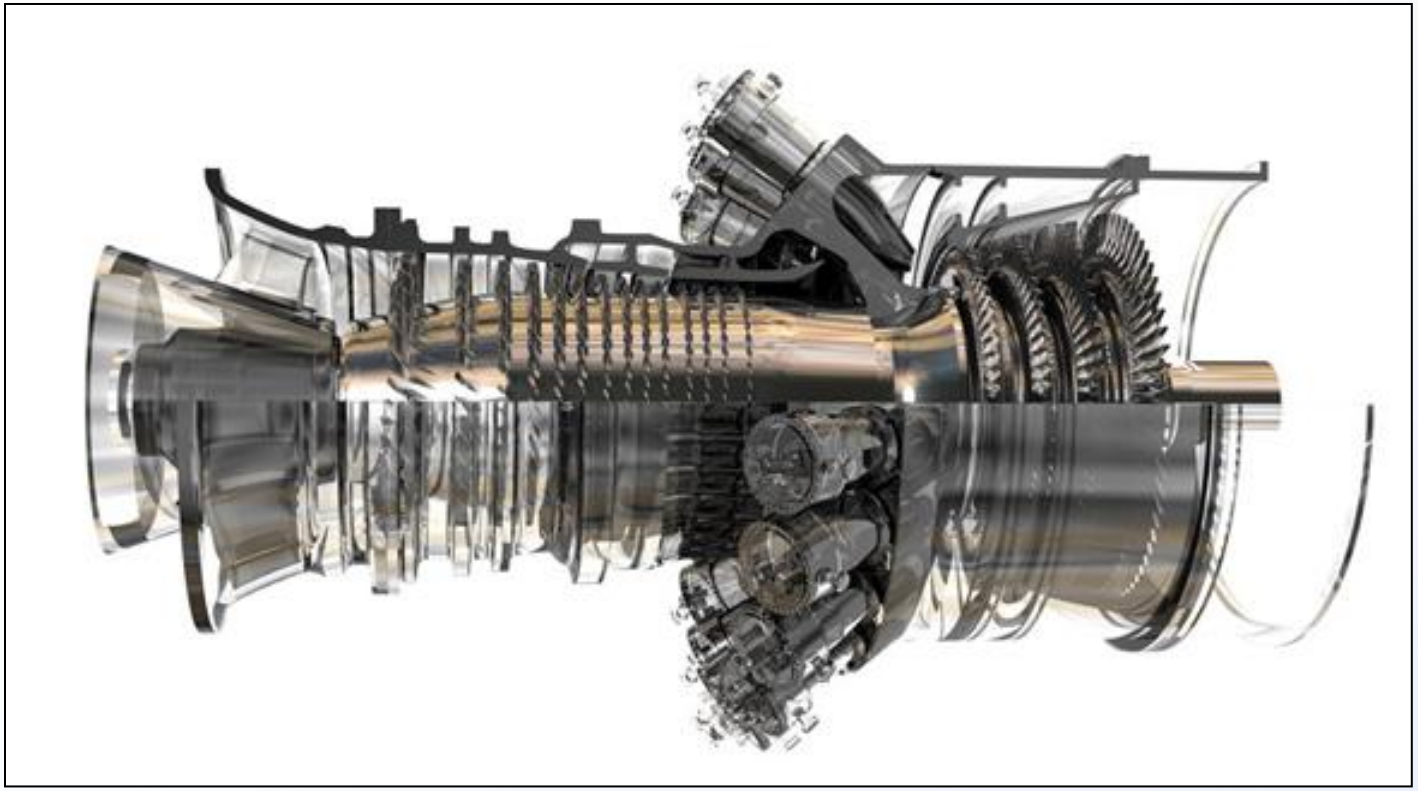
Source: Steve Holditch

Share of U.S. Electric Generation from Coal and Gas, 1990-2009



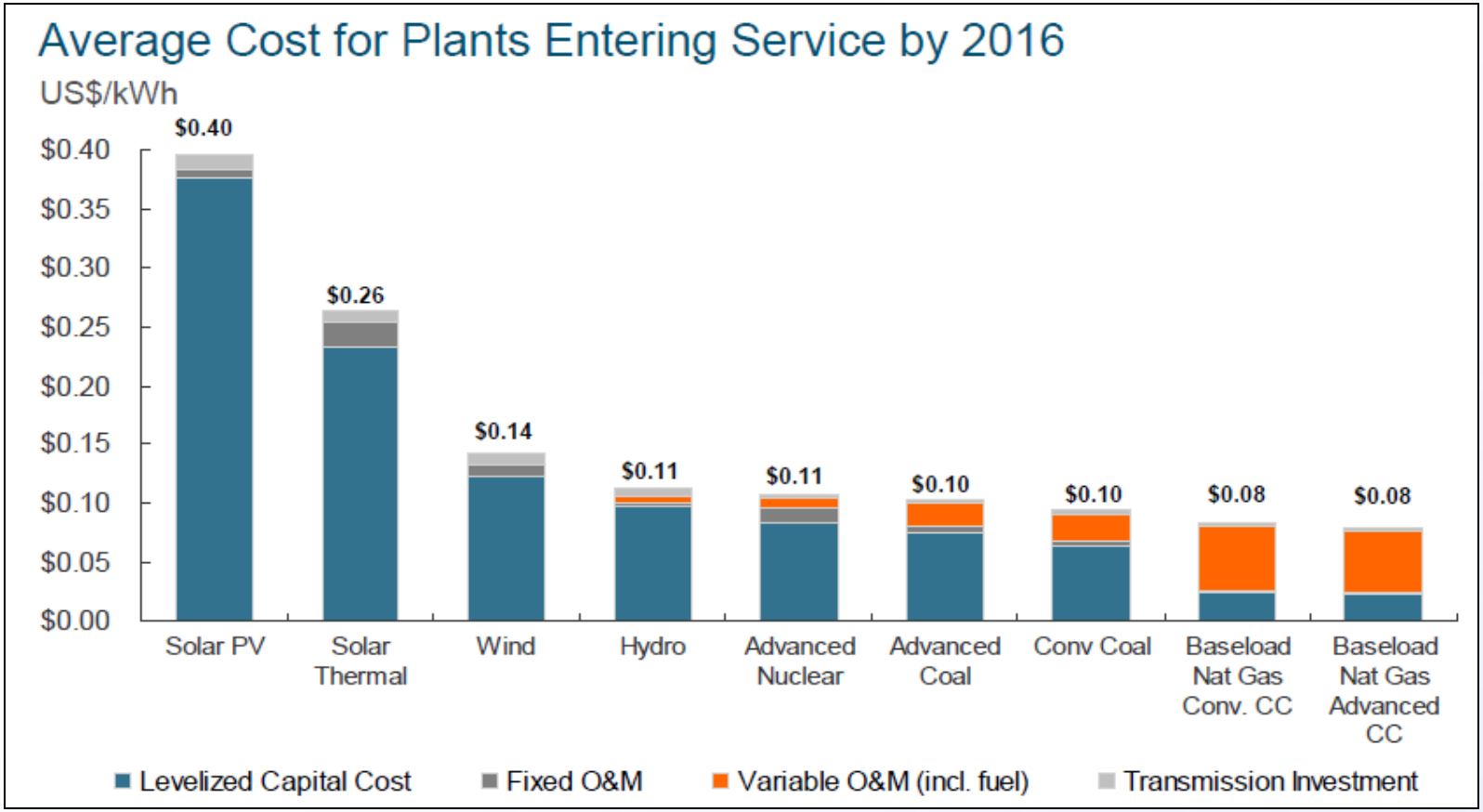
Source: Worldwatch Insitute, EIA

Designing Smarter, Flexible & Efficient Solutions



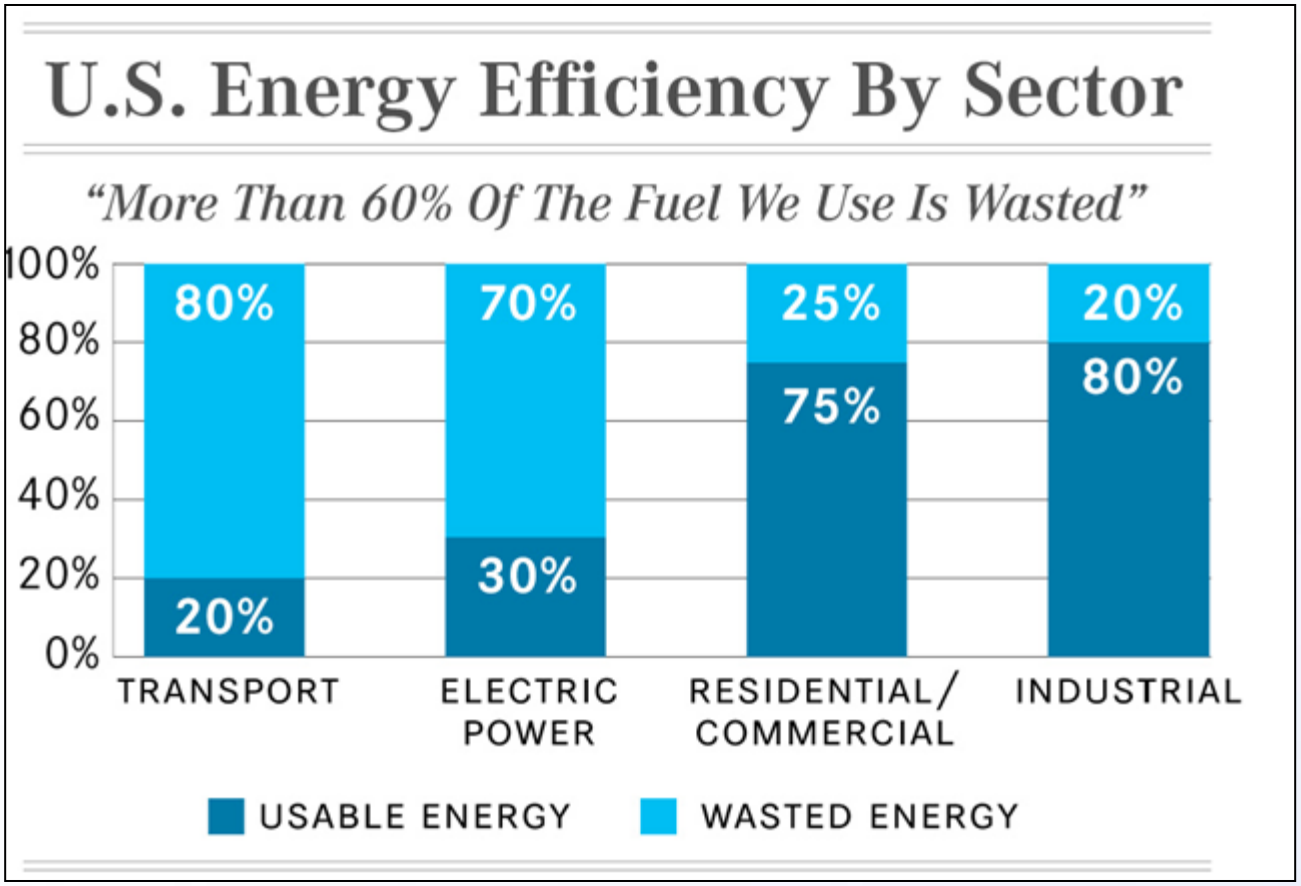
GE FlexEfficiency 50 Combined Cycle Turbine*

Natural Gas is the Least Cost Option for New Power Generation



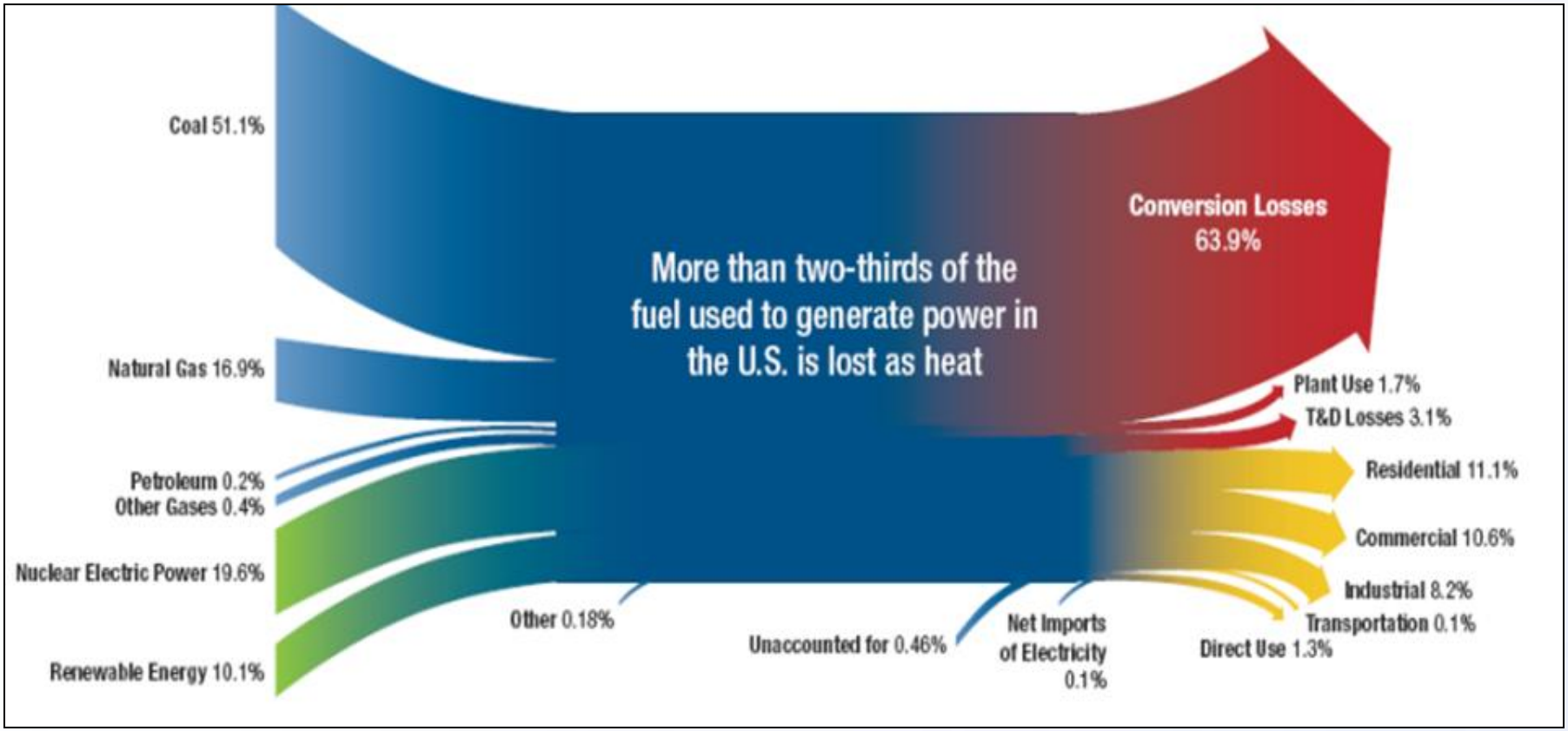
Source: EIA Annual Energy Outlook 2009, EnCana

Comparative Efficiency By Sector



Source: https://EED.LLNL.GOV/FLOW/00FLOW.PHP

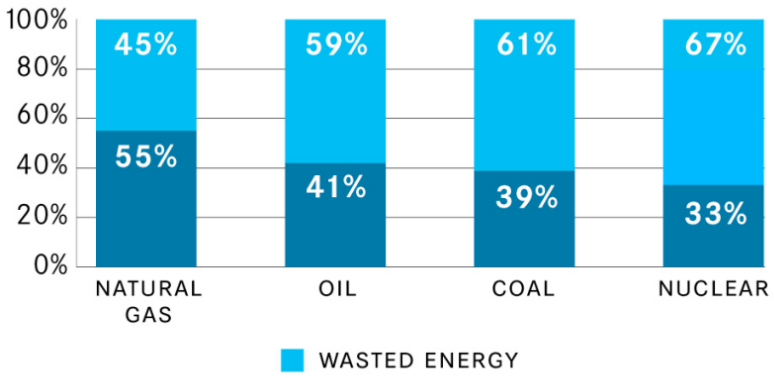
Efficiency Must Start At The Point Of Conversion



Source: EIA, 2007; GE Energy, 2009

An Optimal Energy System Lowers Emissions

Power Generation Efficiency By Fuel



Emission Levels: Natural Gas vs. Oil & Coal

Pounds per Billion Btu of Energy Input

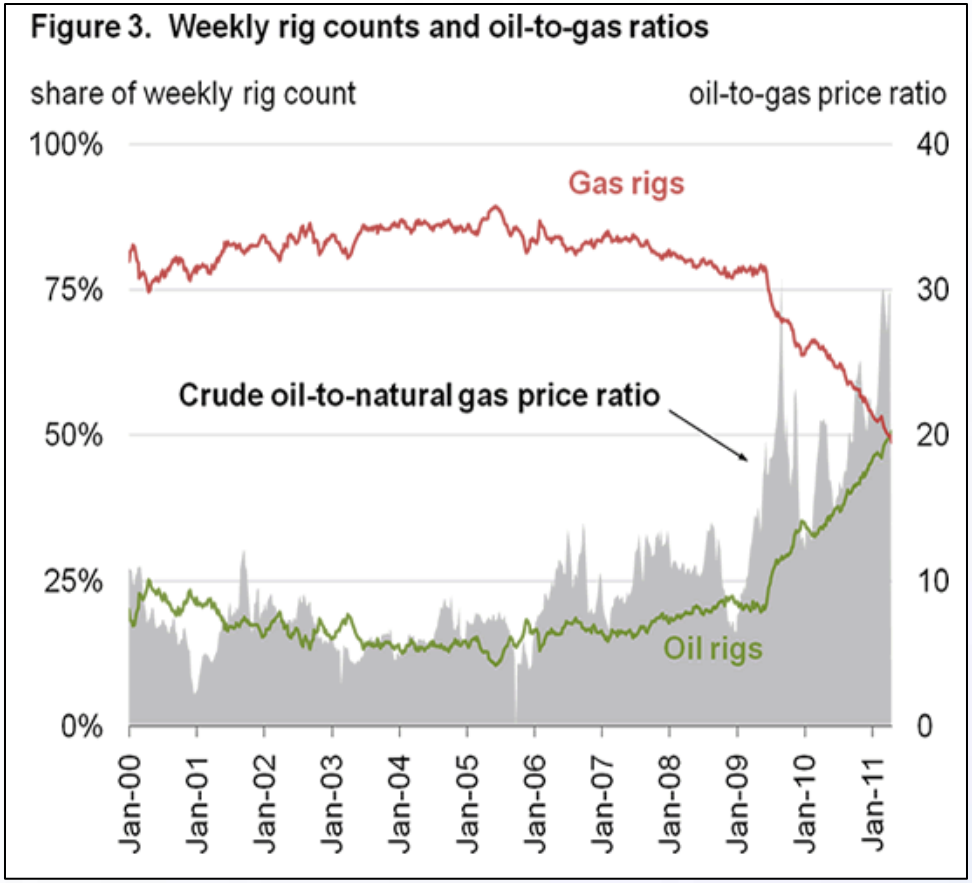
POLLUTANT	NATURAL GAS	OIL	COAL
CARBON DIOXIDE	117,000	164,000	208,000
CARBON MONOXIDE	40	33	208
NITROGEN OXIDES	92	448	457
SULFUR DIOXIDE	1	1,122	2,591
PARTICULATES	7	84	2,744
MERCURY	0.000	0.007	0.016

At minimum a 60% reduction in CO_2 intensity, not even accounting for other potential efficiencies!

Source: American Clean Skies Foundation; EIA

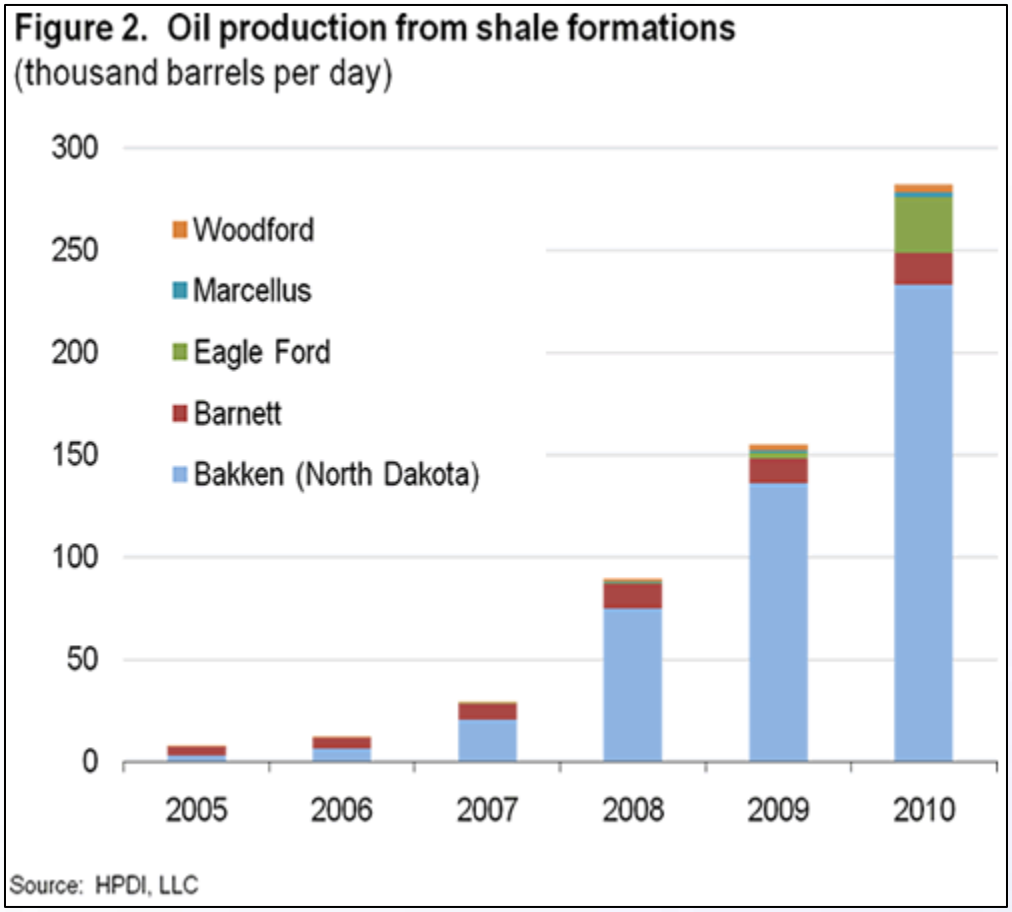
New Supplies Are Fueling New Demands

The Resurgence Of US Oil?



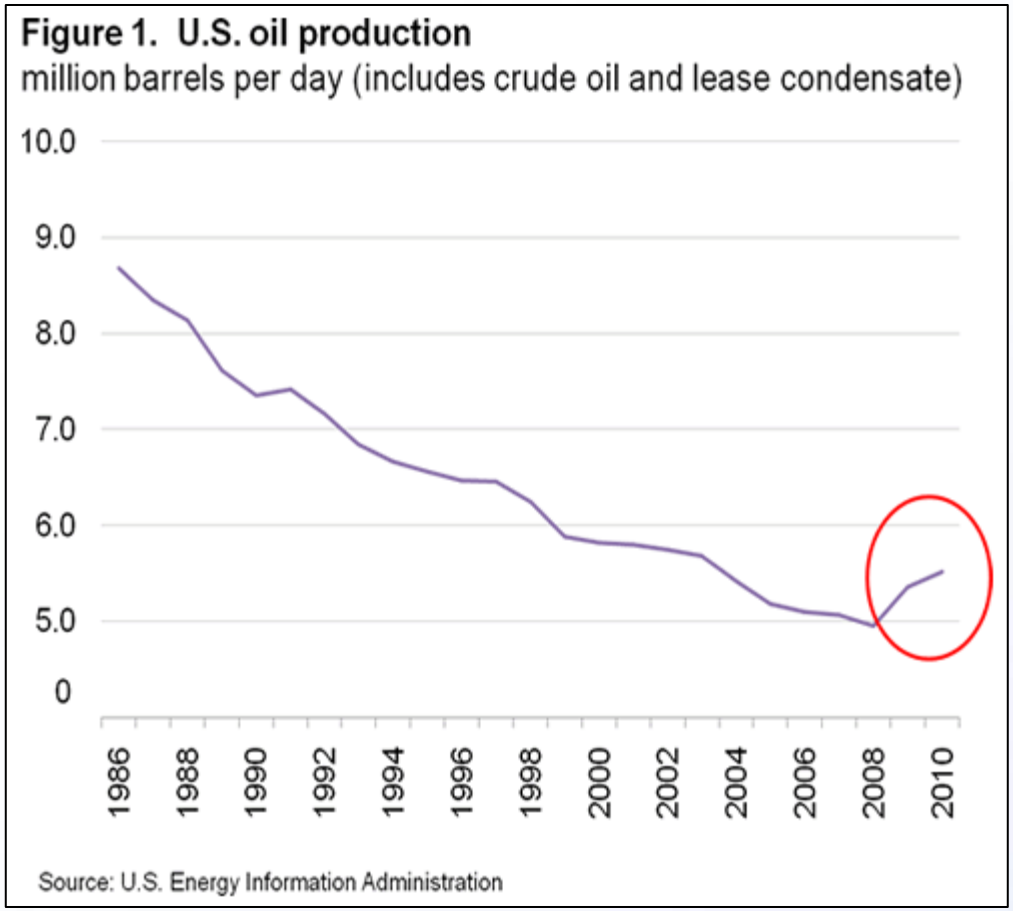
Source: EIA, 2011

The Catalyst: Unconventional Gas Technology



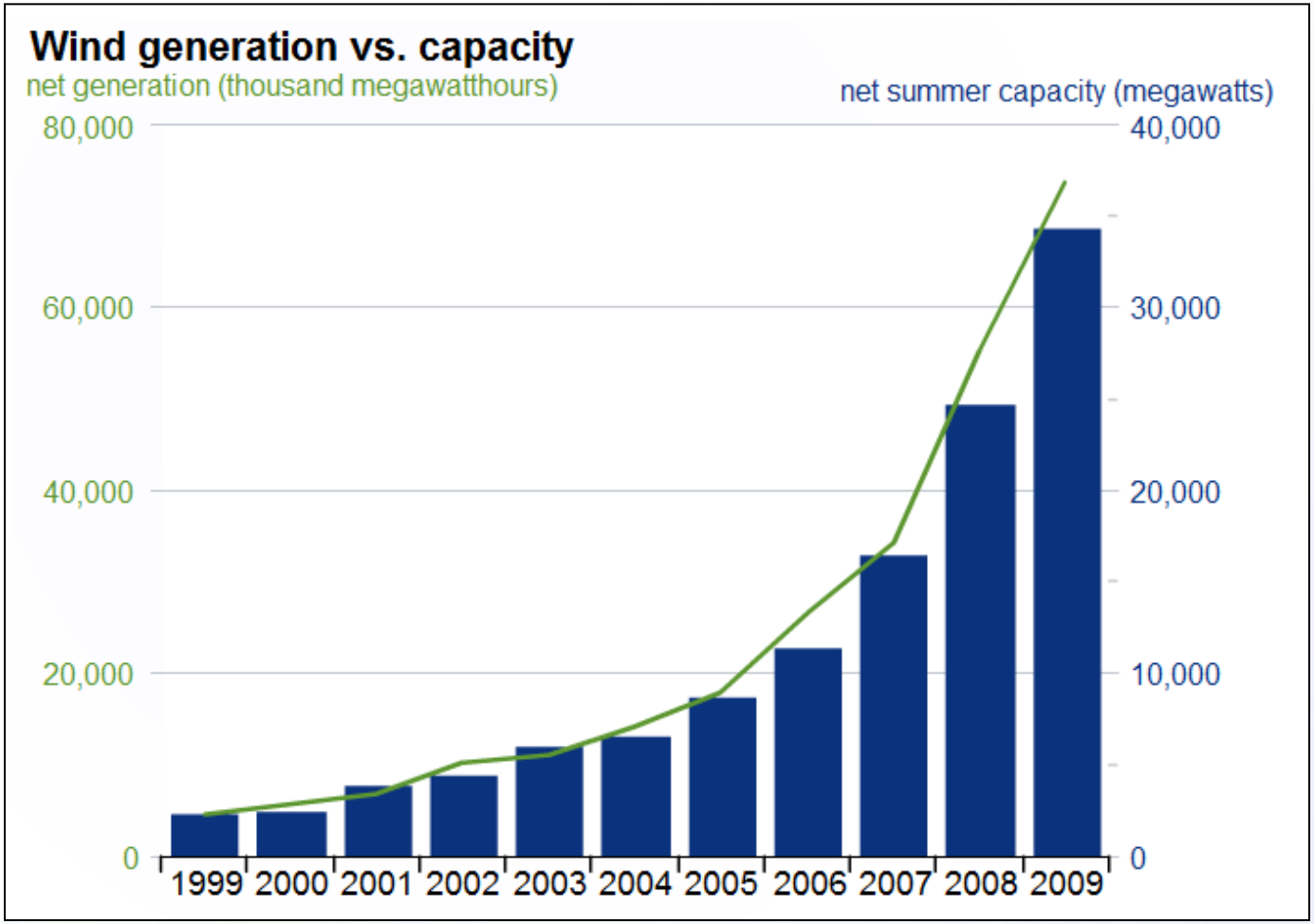
Source: EIA, 2011

Reversing The Trend



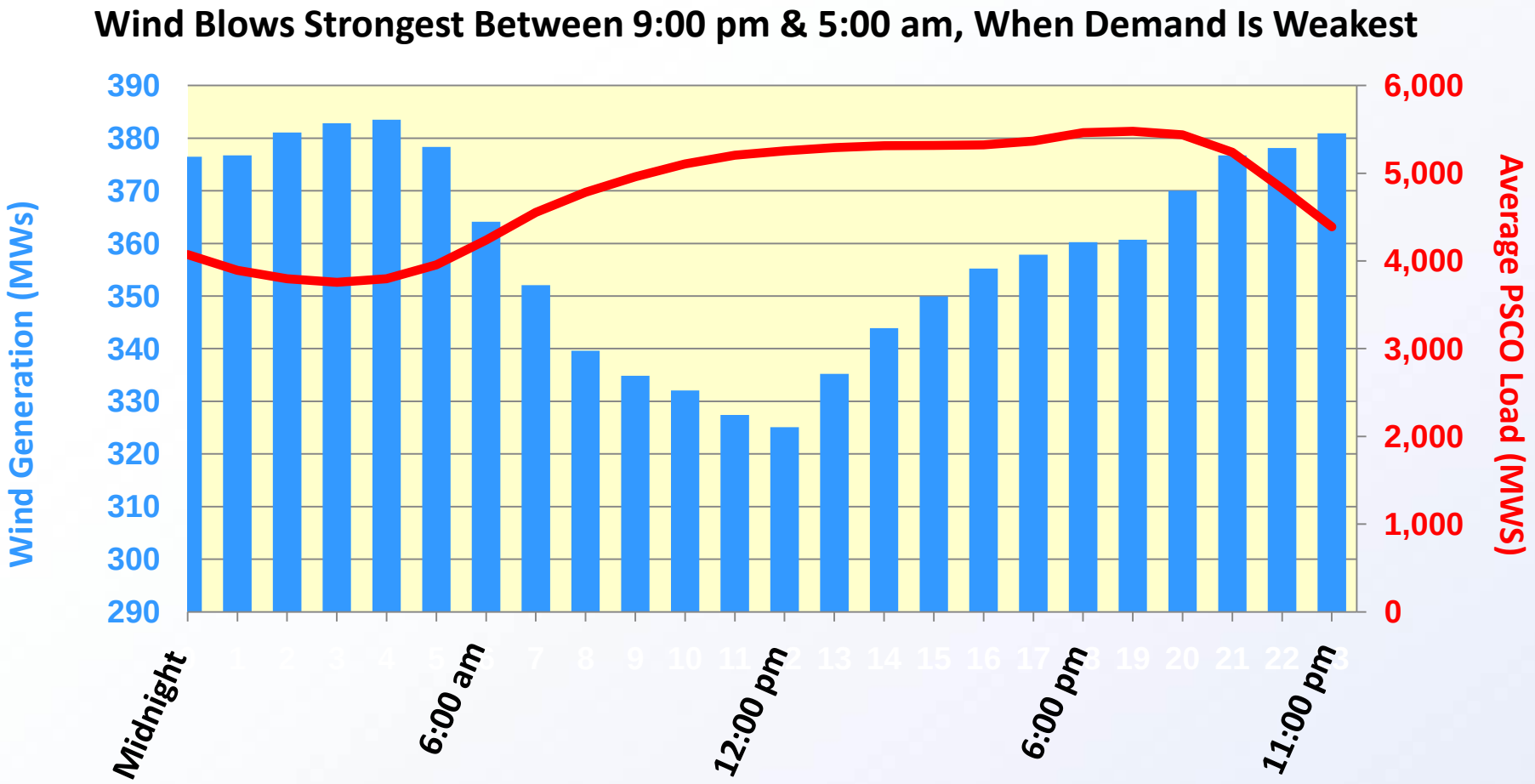
Source: EIA, 2011

Exponential Growth Of The U.S. Wind Industry



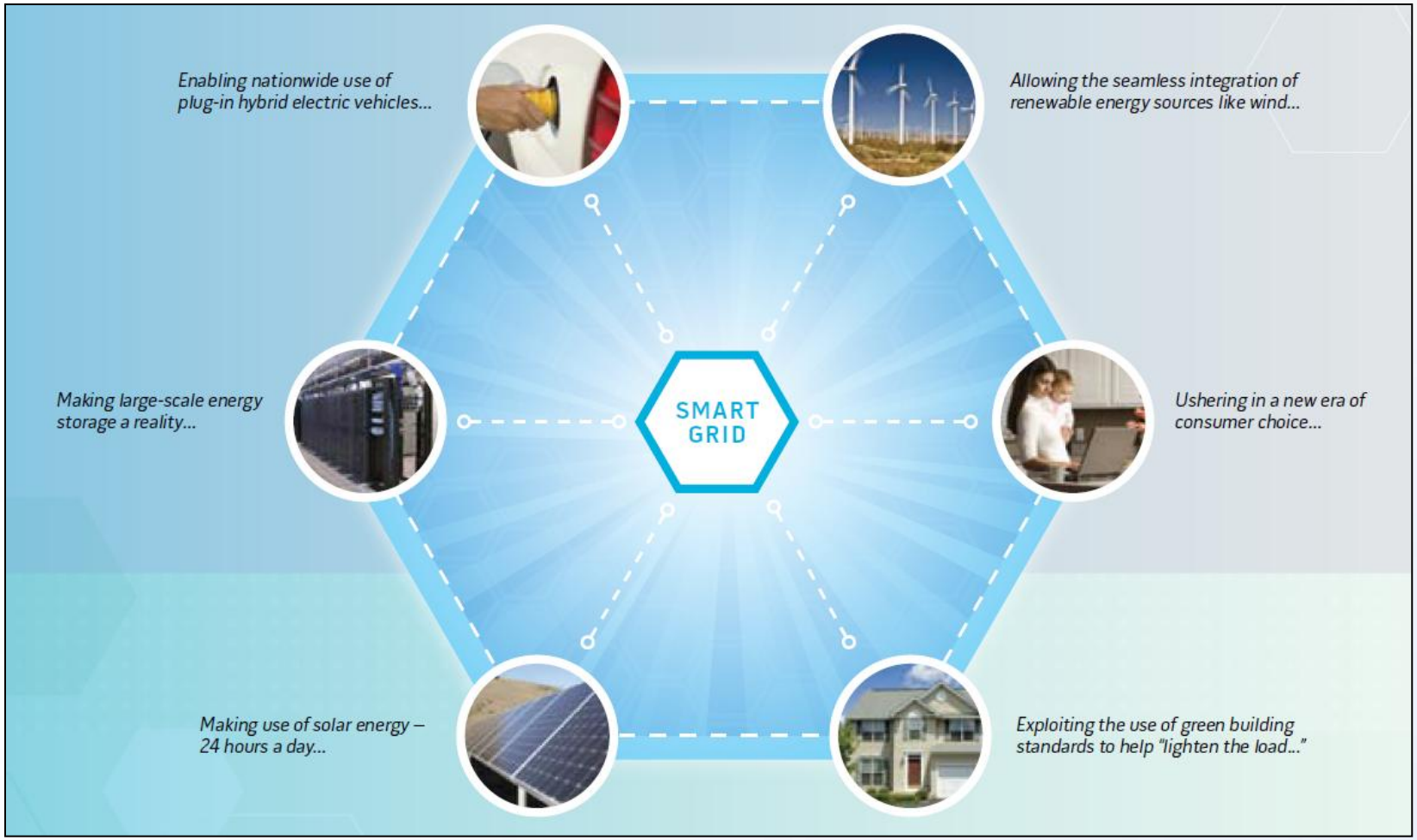
Source: EIA 2009

In CO & Elsewhere The Wind Blows Most Intensely At Night



Source: Bentek; Wind data - NREL WWIS 2006, PSCO load 2008 FERC 714

Making The System Smarter: Smart Everything



Source: The Smart Grid: An Introduction, DOE 2008

Transformative Technologies

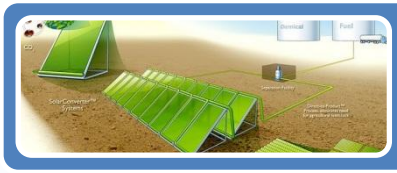
Hydrogen Economy (Emission Free)

Nuclear Fusion (No Waste)

Mobile Fuel Cells (Reusable)

oklahoma bioenergy center

Advanced Generation Biofuels (Renewable)



Utilizing CO2 For Fuels (CO2 Capture)

“You miss 100% of the shots you don’t take.”

Wayne Gretzky

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