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Evolving a Cleaner Grid: Uses of Natural Gas in Transportation

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Abstract

Achieving greenhouse gas emissions reduction goals from the transportation sector will be a monumental challenge. Various alternative vehicle technologies such as plug-in hybrids, battery and fuel cell electric vehicles offer the promise of sharply reducing end use emissions. However, when considering the full fuel cycle, it is clear that a dramatically cleaner electricity grid will also be necessary if we ever hope to meet ambitious long-term reduction goals.

To demonstrate the importance of achieving this dramatically cleaner grid, our analysis implements Argonne National Laboratory's GREET model and the latest Annual Energy Outlook data to evaluate the relative merit of various alternative vehicles on a well-to-wheel basis while taking into account projections for the evolution of the U.S. electricity supply.

Fortunately, significant progress is now underway to transform the electricity sector. The emergence of substantial supplies of shale gas, at low cost and substantial abundance, has dramatically reshaped the energy landscape. There are multiple pathways for this abundant supply of natural gas to help reduce the transportation sector emissions footprint, whether through greater utilization in highly efficient natural gas combined-cycle electricity generators, direct use in compressed natural gas vehicles, or steam reformation to provide hydrogen for fuel cell vehicles.

Greater reliance on high efficiency natural gas combined cycle generators, combined with the steady expansion of renewable generation and energy efficiency, is providing a critical alternative to continued reliance on dirty, legacy generators. This emerging new clean power paradigm can multiply the benefits of more rapid growth in electric drive vehicles.

Keywords: well-to-wheel analysis, greenhouse gas emissions, shale gas, electricity sector

Why the Grid Matters for Cleaning Up the Transportation Sector

While electrification of transportation eliminates important tailpipe emissions, reductions over the full fuel cycle are bounded by the relative cleanliness of the source of the electricity supplied to these vehicles. In 2010, the latest year available, the U.S. relied upon a generation supplied from 44.7% coal, 23.9% natural gas, 19.5% nuclear, 6.3% hydroelectric, 4% other renewables, and the remainder from other sources.[i] Yet, as Fig.1 below demonstrates, each region of the country is unique, with none actually resembling the national average.

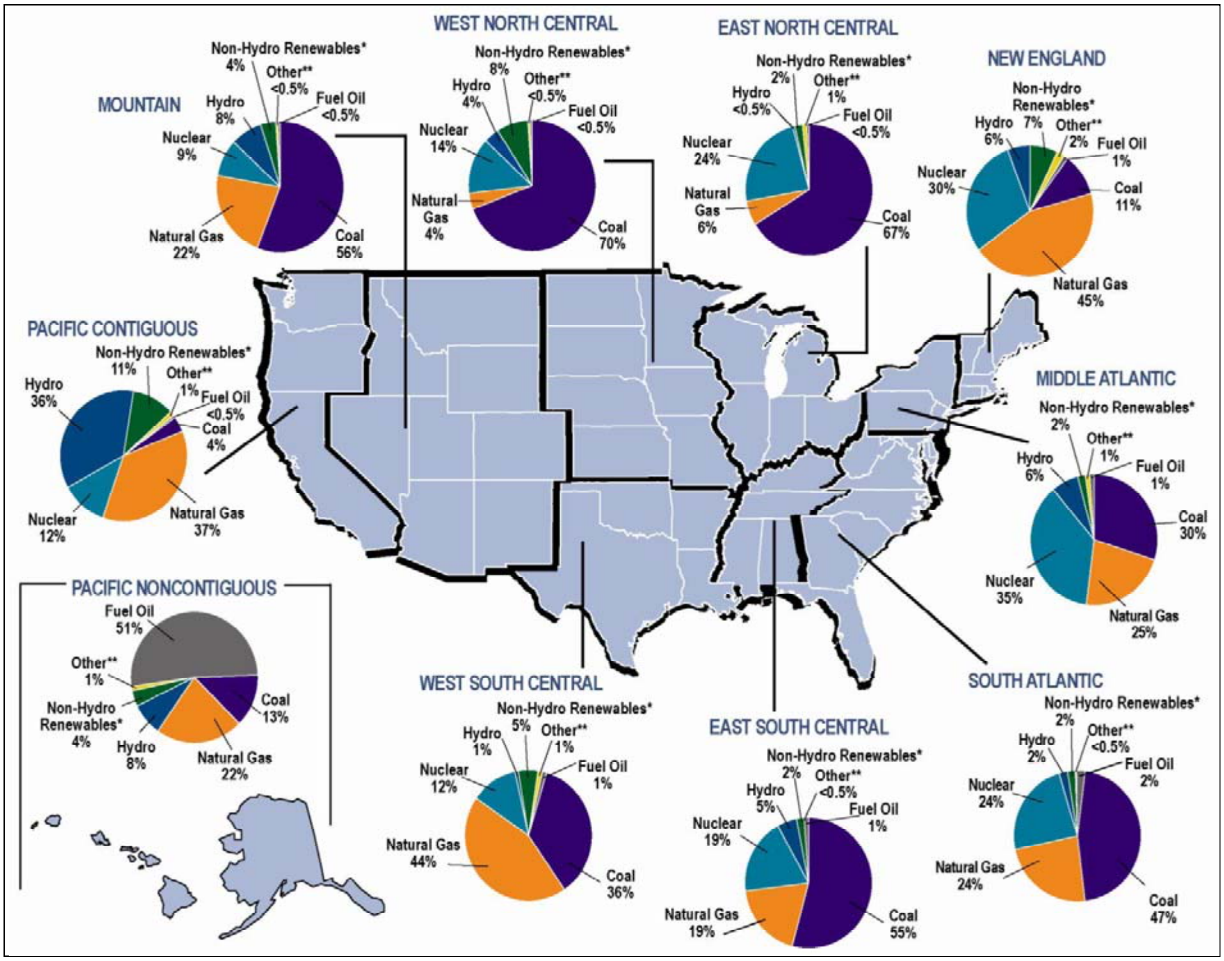


Figure 1[ii]

These distinct supply mixes translate to large regional variations in the carbon intensity value of electricity. Fig. 2 shows this as a function of the share of each region's reliance on coal-based generation.

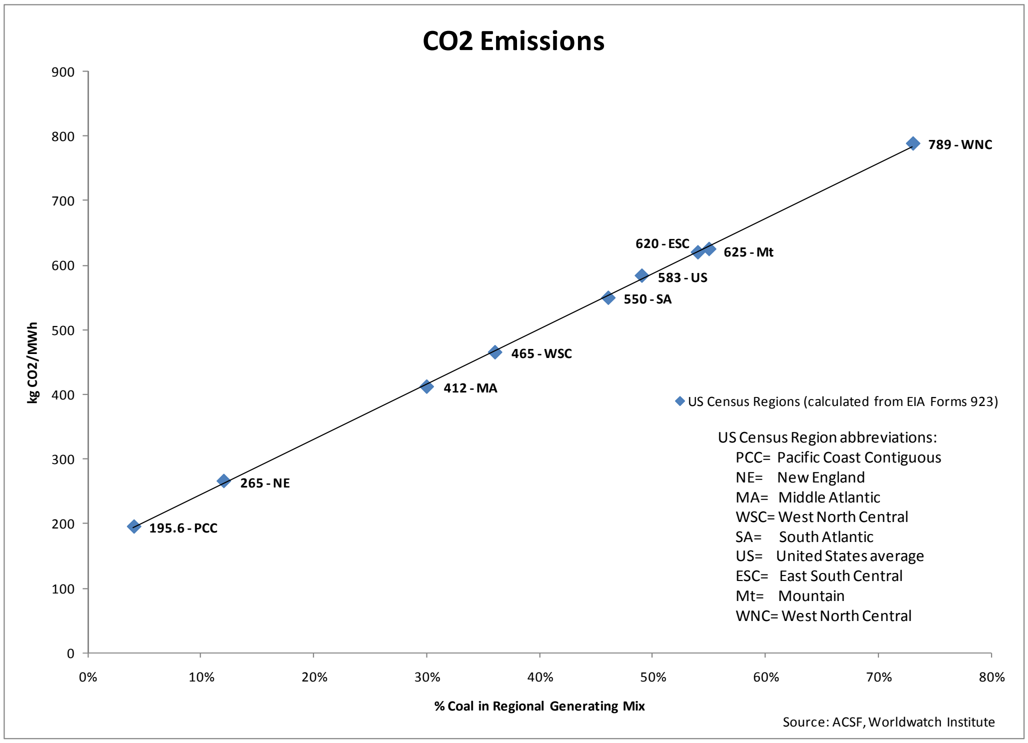


Figure 2[iii]

Notably, grid-dependent and hydrogen fuel cell vehicles would be cleaner on a well-to-wheels (WtW)[1] basis in the Pacific Regions (4% coal, 195 kgCO_2/MWh), and worst in the West North Central (73% coal, 789 kgCO_2/MWh)—although the Pacific region has only a quarter of the carbon intensity of the West North Central census region, a battery electric vehicle (BEV) in the Pacific region has only is one-third of the CO_2 emissions of one in West North Central. So, in higher density service areas like the Pacific or Middle Atlantic, BEVs would be most effective in reducing WtW carbon emissions from light-duty vehicles (LDVs), but in all 9 of the other census regions, hydrogen fuel cell vehicles (HFCVs) would work best, since they are not grid dependent.

To further explore this concept, we commenced our analysis by using *The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model* (GREET model) with 2010 regional net generation data to compare the WtW greenhouse gas (GHG) emissions for several vehicle technologies on a census region basis.[iv] Table 1 below shows how drastically grid mix impacts the emissions characteristics for various alternative vehicle technologies.

[1] Well-to-wheel analysis, also commonly referred to as full fuel-cycle or life-cycle analysis, is an accounting tool used to incorporate effects over the entire footprint of emissions, including fuel extraction, processing, manufacture, and distribution, in addition to the characteristics for end use of a given fuel. It is utilized to provide an equivalent unit of analysis for comparing different technologies or fuels.

Table 1

What's The Cleanest Alternative Vehicle? Depends Where You Live.
Well-to-Wheel GHG Emissions from Various Light-Duty Vehicles (grams CO2e/mile)

	Electricity Census Region										
	East North Central	East South Central	Middle Atlantic	Mountain	New England	Pacific Contiguous	Pacific Noncontiguous	South Atlantic	West North Central	West South Central	US Average
Vehicle Technology											
Conventional Gasoline ICV	448	447	443	448	442	439	448	447	449	446	446
CNGV	397	395	385	397	381	375	396	393	398	393	392
E-85 ICV	377	375	364	377	359	353	376	373	379	372	371
Gasoline HEV	325	324	322	325	320	319	325	324	325	324	323
CNG HEV	293	291	284	292	281	277	292	289	293	289	289
Gasoline PHEV-10	319	315	298	318	292	282	317	312	321	311	310
CNG PHEV-10	293	289	267	292	260	248	291	284	296	284	282
BEV	406	380	259	401	215	146	394	354	420	353	341
HFCV	261	258	245	260	240	233	259	255	262	255	254

Source: ACSF analysis. Data computed using Argonne National Laboratory's GREET Model (GREET1_2011 version). Simulation compares average passenger cars for model year 2015. All default GREET parameters were used except for electricity supply mix, where the average for each respective US census region was used. Average supply mix was calculated based on 2010 net generation data derived from EIA Form 923 (the latest year available). Gasoline values assume 10% ethanol blending. Ethanol assumed to be entirely corn-based and includes land-use considerations. Hydrogen assumed to be entirely derived from stationary reformation of natural gas.

BEVs do not provide much of an emissions advantage in the regions that are most reliant on coal-based electricity generation, whereas they can provide enormous benefits in areas like the Pacific Coast where generation is supplied by a lower-carbon mix of hydroelectric, nuclear, renewable and/or natural gas generators. Hydrogen fuel cell vehicles, assumed to use fuel entirely derived from steam reformation of natural gas, also provides sizable benefits in each scenario (though its benefits would be subject to BEV-like variations if the hydrogen were instead supplied by electrolysis of water with electricity). Clearly, the environmental attributes of electricity are not an insignificant consideration for transportation sector alternatives.

Therefore, the goal in undertaking our analysis was to demonstrate the greenhouse gas reductions possible through mass-scale adoption of various vehicle technologies, coupled with the relative significance of also cleaning the electricity sector. Lastly, we examine the importance of the dramatic emergence of North America's shale gas resources, recent progress towards reducing electricity sector pollution, and the extent of the challenge of achieving carbon-reduction goals from the transportation sector.

Emissions reductions and various vehicle scenarios

To conduct our analysis, we expanded our use of the GREET model by calculating well-to-wheel GHG emissions factors that allowed us to compare the full environmental attributes of various light-duty vehicle technologies between several alternative scenarios. We examined all vehicle technologies that the Energy Information Administration's (EIA) *Annual Energy Outlook* (AEO) includes and expects will be traveling on U.S. roads between now and 2035. The GREET model was run for every year between 2010 and 2020 [the latest year available in the newest version of GREET], using all of GREET's default parameters with the sole exception of the electricity supplied to the vehicle. Here we instead utilized EIA's latest version of the AEO, *Annual Energy Outlook 2012 early release* (AEO2012e.r.) electricity projections for annual net generation to take into account EIA's best estimate of the current trajectory of the U.S. electricity sector.[v] Table 2 shows the results of this process.

Table 2

Well-to-Wheels GHG Emissions for Various Light-Duty Vehicles (grams CO2e/mile) Assuming a BAU Electricity Grid

Technology Type	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Conventional Cars											
Gasoline ICE Vehicles	473	467	461	456	451	445	437	428	420	412	404
TDI Diesel ICE	409	404	399	395	390	386	379	371	364	358	351
Alternative-Fuel Cars											
Ethanol-Flex Fuel ICE	402	395	388	382	376	369	360	351	343	335	327
100 Mile Electric Vehicle	372	358	348	339	329	321	312	306	298	291	283
200 Mile Electric Vehicle	372	358	348	339	329	321	312	306	298	291	283
Plug-in 10 Gasoline Hybrid	348	340	331	323	315	307	299	292	284	277	270
Plug-in 40 Gasoline Hybrid	394	384	375	365	356	348	339	331	323	315	307
Electric-Diesel Hybrid	308	304	301	297	294	290	285	279	274	269	264
Electric-Gasoline Hybrid	343	338	334	331	327	323	316	310	304	298	293
Compressed Natural Gas ICE	455	440	427	414	402	390	382	374	367	359	352
Compressed Natural Gas Bi-fuel	474	465	457	449	441	434	423	413	404	395	386
Liquefied Petroleum Gases ICE	435	425	416	407	398	389	381	374	366	359	352
Liquefied Petroleum Gases Bi-fuel	435	425	416	407	398	389	381	374	366	359	352
Fuel Cell Hydrogen	282	275	269	263	257	252	244	237	230	224	217
Conventional Light Trucks											
Gasoline ICE Vehicles	638	626	614	602	591	580	571	562	553	544	536
TDI Diesel ICE	552	541	531	521	512	503	495	487	480	473	465
Alternative-Fuel Light Trucks											
Ethanol-Flex Fuel ICE	543	529	516	504	492	481	471	461	451	442	433
100 Mile Electric Vehicle	475	452	433	417	399	385	374	366	356	346	336
200 Mile Electric Vehicle	475	452	433	417	399	385	374	366	356	346	336
Plug-in 10 Gasoline Hybrid	453	446	439	432	425	419	412	406	399	393	387
Plug-in 40 Gasoline Hybrid	535	529	523	517	511	504	498	494	488	482	476
Electric-Diesel Hybrid	415	407	399	392	385	378	372	366	361	355	350
Electric-Gasoline Hybrid	479	470	461	452	444	436	429	422	415	408	402
Compressed Natural Gas ICE	613	589	567	546	526	507	499	491	482	475	467
Compressed Natural Gas Bi-fuel	639	623	607	592	578	564	553	542	531	521	511
Liquefied Petroleum Gases ICE	587	570	553	537	521	506	498	490	482	474	467
Liquefied Petroleum Gases Bi-fuel	587	570	553	537	521	506	498	490	482	474	467
Fuel Cell Hydrogen	390	378	367	357	347	338	330	322	314	307	299

Data computed using Argonne National Laboratory's GREET Model (GREET1_2011 version). All default GREET parameters were used except for electricity supply mix, where the projections for US electricity generation from Energy Information Administration's AEO2012 Early Release were used. Gasoline values assume 10% ethanol blending. Ethanol assumed to be entirely corn-based and includes land-use considerations. Hydrogen assumed to be entirely derived from stationary reformation of natural gas. Outlined values (PHEVs prior to 2015) were imputed.

As Table 2 shows, hydrogen fuel cell vehicles are shown to offer the lowest WtW GHG emissions, though many of the alternative technologies provide significant reductions from conventional gasoline internal combustion vehicles. In order to project out to longer terms, we then used the average annual reductions in emissions intensity observed for each category to impute values for each out to 2035 (to match the time horizon used in the most current AEO).

Total light-duty vehicle miles traveled data from AEO2012e.r. were then used to calculate a baseline transportation GHG emissions scenario. Fig. 3 shows slow but steady reductions in total GHG emissions despite continual growth in annual vehicle miles traveled. Lines have also been added to Fig. 3 to illustrate levels 50% and 80% below 2010 emissions levels, which were arbitrarily added to provide a quick frame of reference towards potential emissions reduction targets—approximately 200 Million fewer tonnes of CO_2 would be emitted by LDVs on a WtW basis. These reductions are primarily due to vehicle efficiency improvements and the impacts of shrinking CAFE standards. One could consider this to be the emissions trajectory of a 'business as usual' future.

While the grid is projected to evolve significantly in AEO2012e.r., it only accounts for about 10% of the WtW transportation emissions reductions. This is largely because in this newest EIA reference case, electric vehicles (EVs) still only represent about 6% of all annual light-duty vehicle miles traveled by 2035. However, the impact of the grid becomes much more interesting if alternative vehicles are able to attain a greater presence in the market.

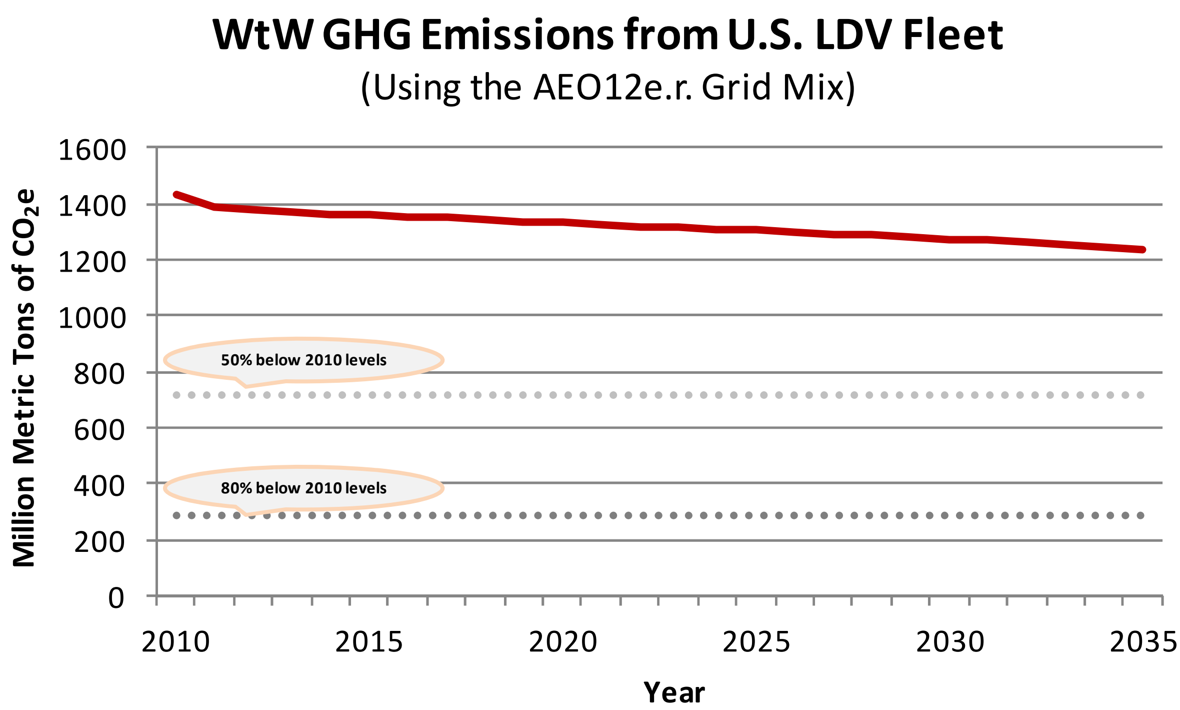


Figure 3

We then created a model to analyze the magnitude of emissions benefits possible through mass-scale adoption of each of these various alternative vehicle technologies, done as a series of sensitivity cases, without any explicit projection of the likelihood of different mixes of technologies or their market penetration. To provide a few illustrative examples, we created several scenarios where extreme levels of electric drive vehicles displace conventional gasoline and diesel vehicles by 2035. Fig. 4 shows reductions possible with a hypothetical fleet of hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs) and BEVs displacing all conventional gasoline and diesel LDVs—fairly dramatic reductions in CO_2 emissions result, a 38% reduction from the reference case. Fig. 5 shows the a scenario where hydrogen fuel cell vehicles, utilizing fuel that is 100% derived from steam reformation of natural gas (at local fueling stations, with no CO_2 capture and storage), displace all conventional gasoline and diesel vehicles—a 62% reduction in GHGs. Fig. 6 shows reductions possible in a scenario where BEVs displace all conventional gasoline and diesel vehicles—a 45% drop from the reference case.

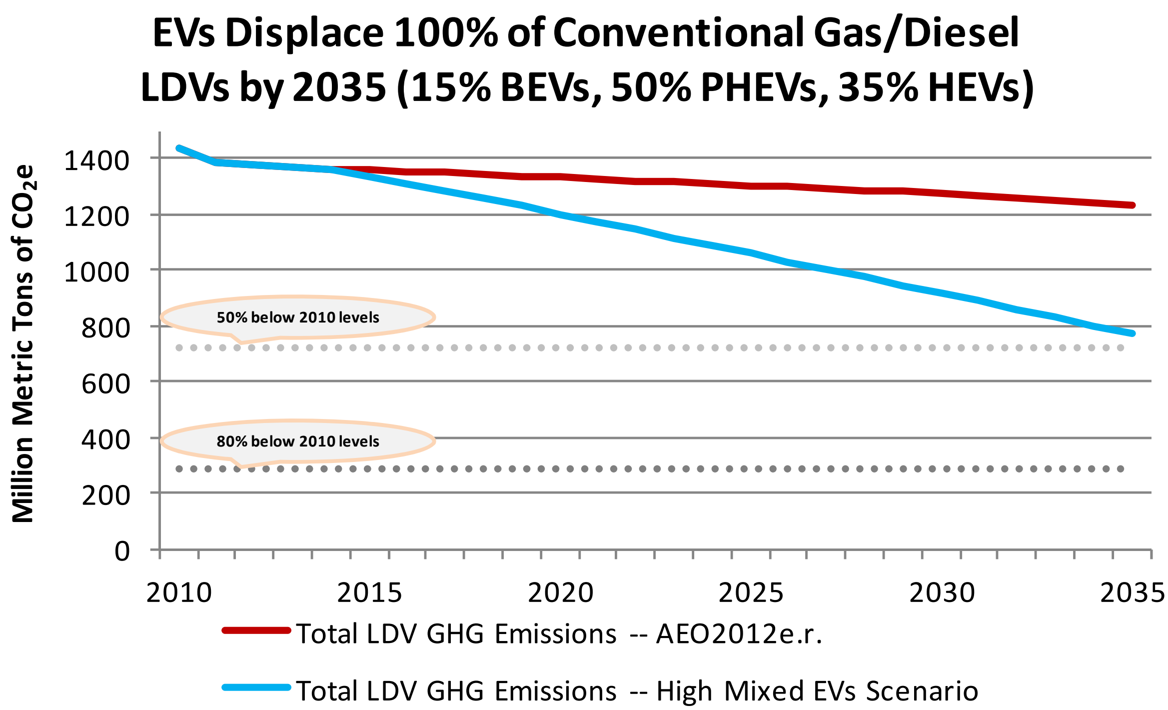


Figure 4

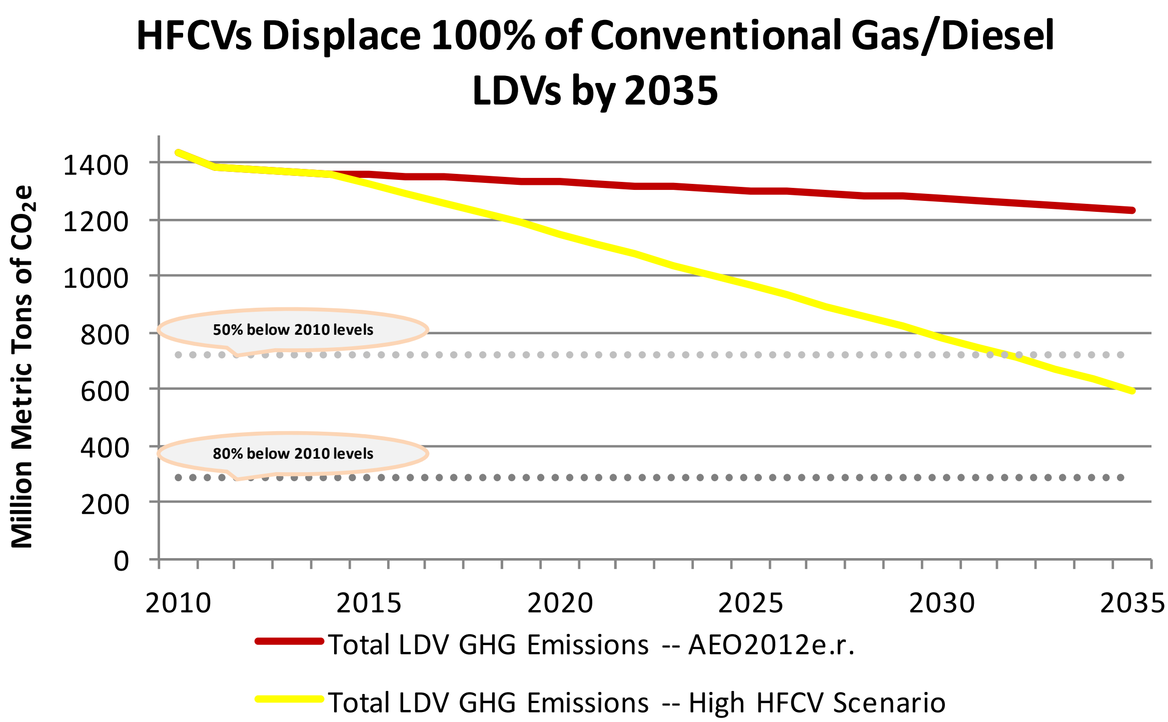


Figure 5

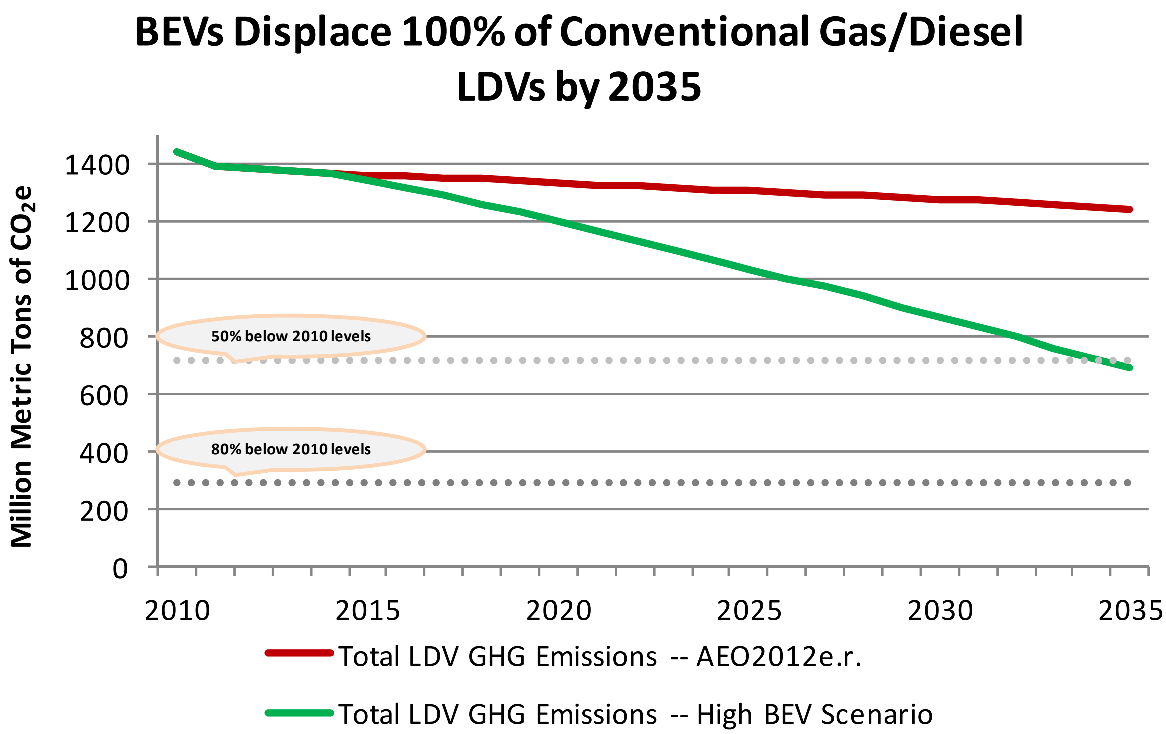


Figure 6

As each of these Figures demonstrates, while enormous gains could be realized through massive conversion to alternative vehicle technologies, meeting once discussed 80% below 1990 emissions levels remains well out of reach if we are still relying on the grid embedded in the AEO2012e.r. While this is not intended to suggest that achieving reduction goals is unattainable or must be entirely accomplished by 2035, we are merely intending to display the impossibility of meeting ambitious reductions goals without significant changes to improve both the transportation *and* electricity sectors.

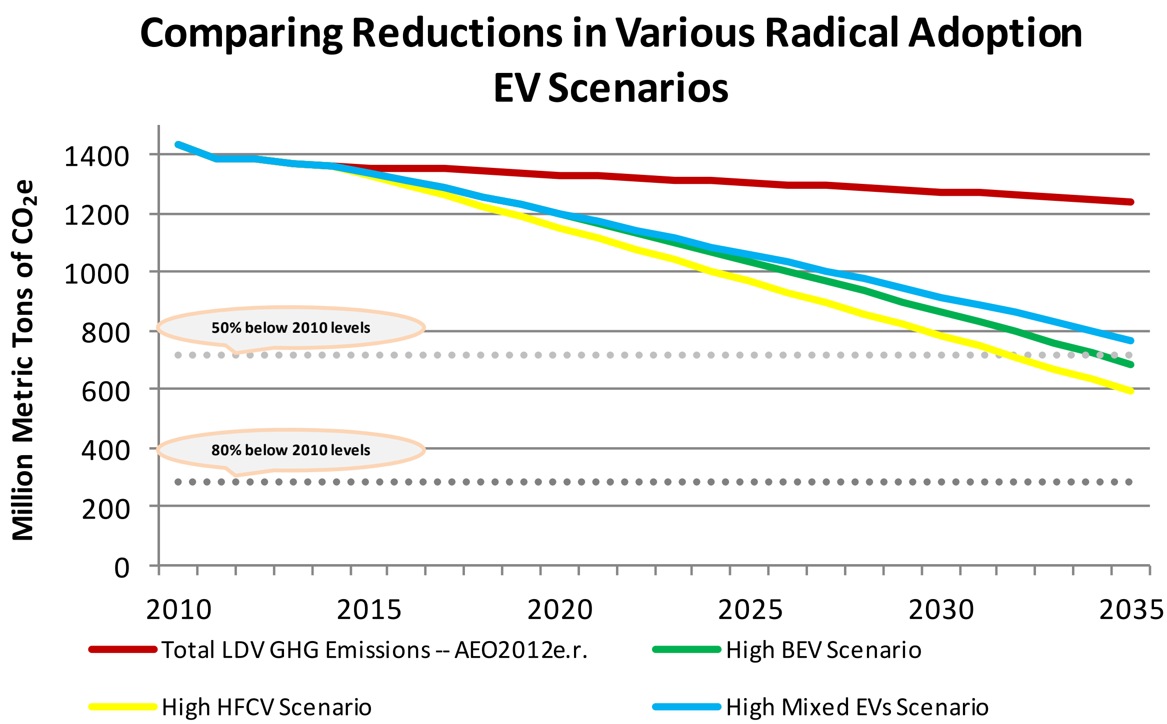


Figure 7

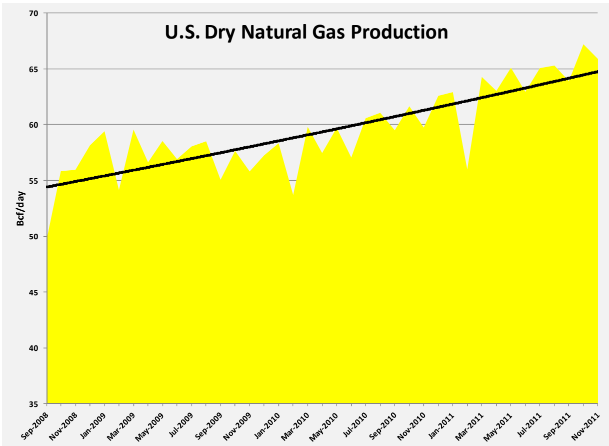
Good News: markets are also working to clean the grid

Despite the challenges in meeting meaningful GHG emission reduction targets, significant progress is both underway and achievable. The shale gas revolution of the last five years has quickly opened the door to a new, clean energy paradigm for the electricity sector. While this new natural gas abundance can reduce transportation emissions through direct use in either compressed natural gas (CNG) vehicles or conversion and use in HFCVs, its most significant pathway to date has been in the electricity sector.

Shale gas abundance

Since 2005, there has been a dramatic upward reassessment of North America's long term natural gas resource base, largely stemming from the new potential of shale and other unconventional resources. More efficient and cheaper production techniques have increased shale gas supply at steadily lower cost, radically changing the future price outlook for natural gas and making it increasingly competitive as a base load fuel for electricity generation.

Figs. 8, 9, and 10 show just how influential shale gas production has become in the U.S. Approximately 30% of U.S. dry natural gas production is now from shale gas. This supply stream bolsters overall natural gas price stability expectations, as Fig. 11 shows with the evolution of NYMEX gas futures prices. Prices during late 2011 and early 2012 have moved steadily lower, with Henry Hub futures prices now hovering around just $2.60/mmBTU for March 2012 contracts. Longer term expectations rise slightly but remain steady in the $3-6 range until 2020.



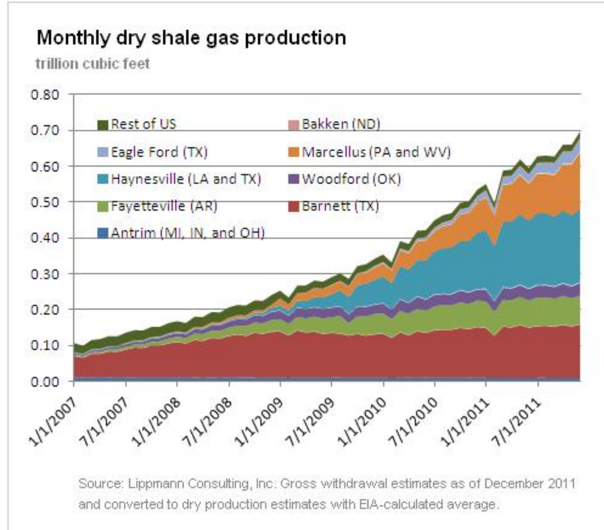
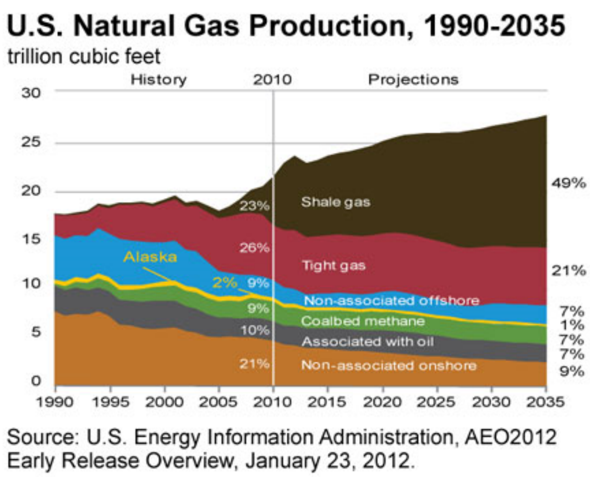


Figure 8 **Figure 9**



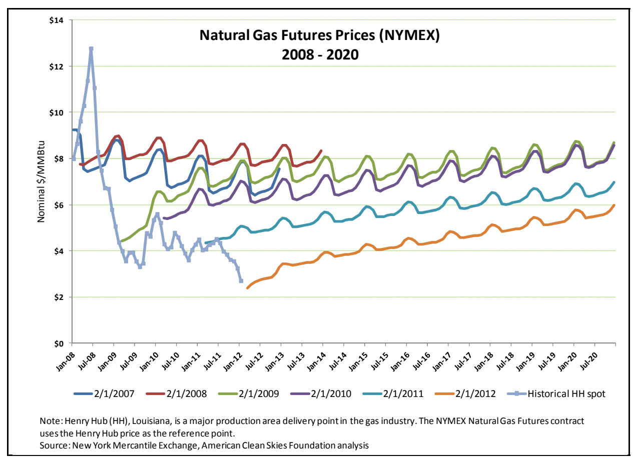


Figure 10 **Figure 11**

This new cheap and abundant outlook for natural gas is having a profound effect on the electricity sector. Where only a few years ago, EIA was projecting a steady and growing reliance on high carbon fuel sources, their more recent projections are increasingly showing a clean transformation for the electricity sector. Fig. 12 below demonstrates this fact by charting the electricity supply projections forecasted in the Reference Case of the *Annual Energy Outlook 2008* (AEO2008) as compared with those of the most recent AEO2012e.r., illustrating just the cusp of a rapidly evolving electric sector.

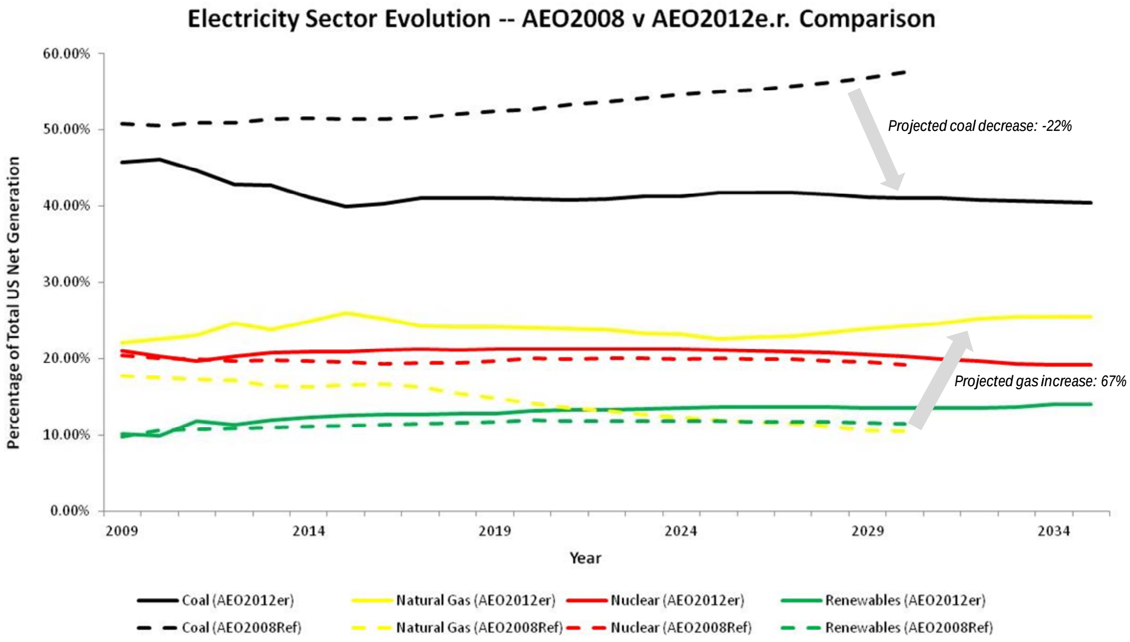


Figure 12

To demonstrate the impact, we performed the same GREET-based modeling exercise described in the previous section, using for contrast the electricity projections that EIA offered in the AEO2008 Reference Case. Not surprisingly, as shown in Fig. 13, a slightly cleaner grid doesn't make an enormous impact on cleaning the full fuel-cycle emissions of the transportation sector—if we are still relying primarily upon gasoline-burning vehicles.

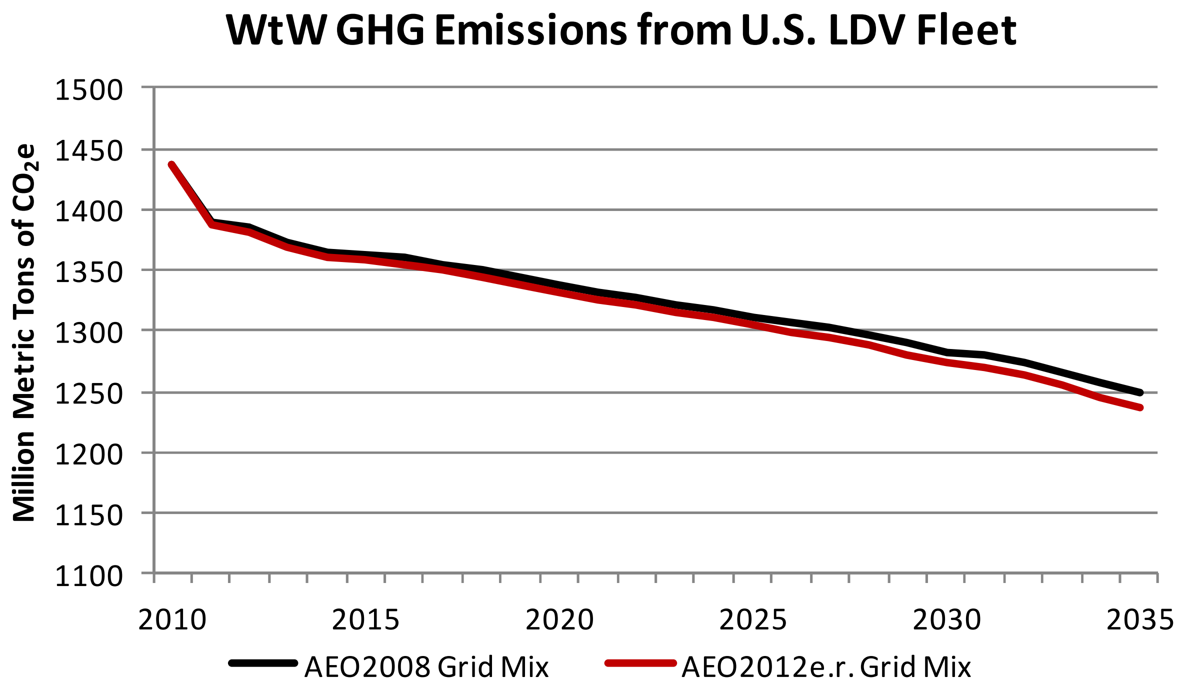


Figure 13

However, Fig. 14 demonstrates that in the extreme BEV adoption scenario, even the incrementally cleaner grid now being projected by EIA would already result in significant (about 11% lower by 2035) emissions reductions.

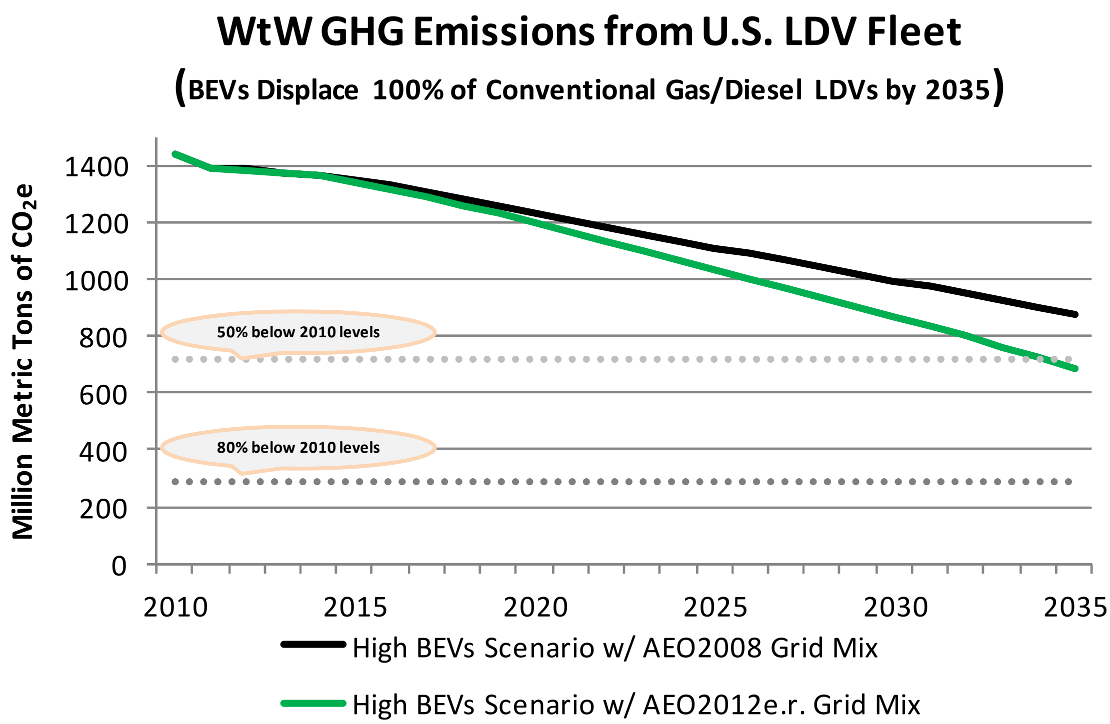


Figure 14

Trends in grid evolution

The trends of the last five years are anticipated to continue fundamentally altering the U.S. electricity sector. The sharp drop in natural gas prices, combined with coal price increases and stagnant electricity demand growth, have all contributed to eroding margins for electric power producers. Many marginal coal plants have already announced retirement, while the long-awaited issuance of new air pollution regulations from EPA is anticipated to result in a continuing wave of retirements.

As the map from SNL Financial (Fig. 15) shows, over 26 GW of coal generating capacity will be retired between 2011-2020.[vi] Announced coal plant retirements recorded by SNL have expanded since the beginning of 2011:

- February 2011—16 GW
- June 2011—23 GW
- September 2011—26 GW
- Deutsche Bank Climate Change Advisors, November 2011—60 GW by 2020, with another 92 GW retired by 2020-2030
- Fitch Ratings, in late November, estimates at-risk coal capacity to be 83 GW
- Other studies estimate a range of 35-101 GW between 2010 and 2020.

When being evaluated for shutdown or replacement on a cash flow and regulatory compliance basis, the generating capacity supplied by that plant could be surplus to future demand needs, especially accounting for increased demand response and efficiency gains; replaced by a combination of low-carbon natural gas combined cycle generators (NGCCs) and renewables; retrofitted with more modern emissions cleanup devices;

or it simply runs less often. The SNL map suggests how differently this may work itself out across the U.S. landscape.

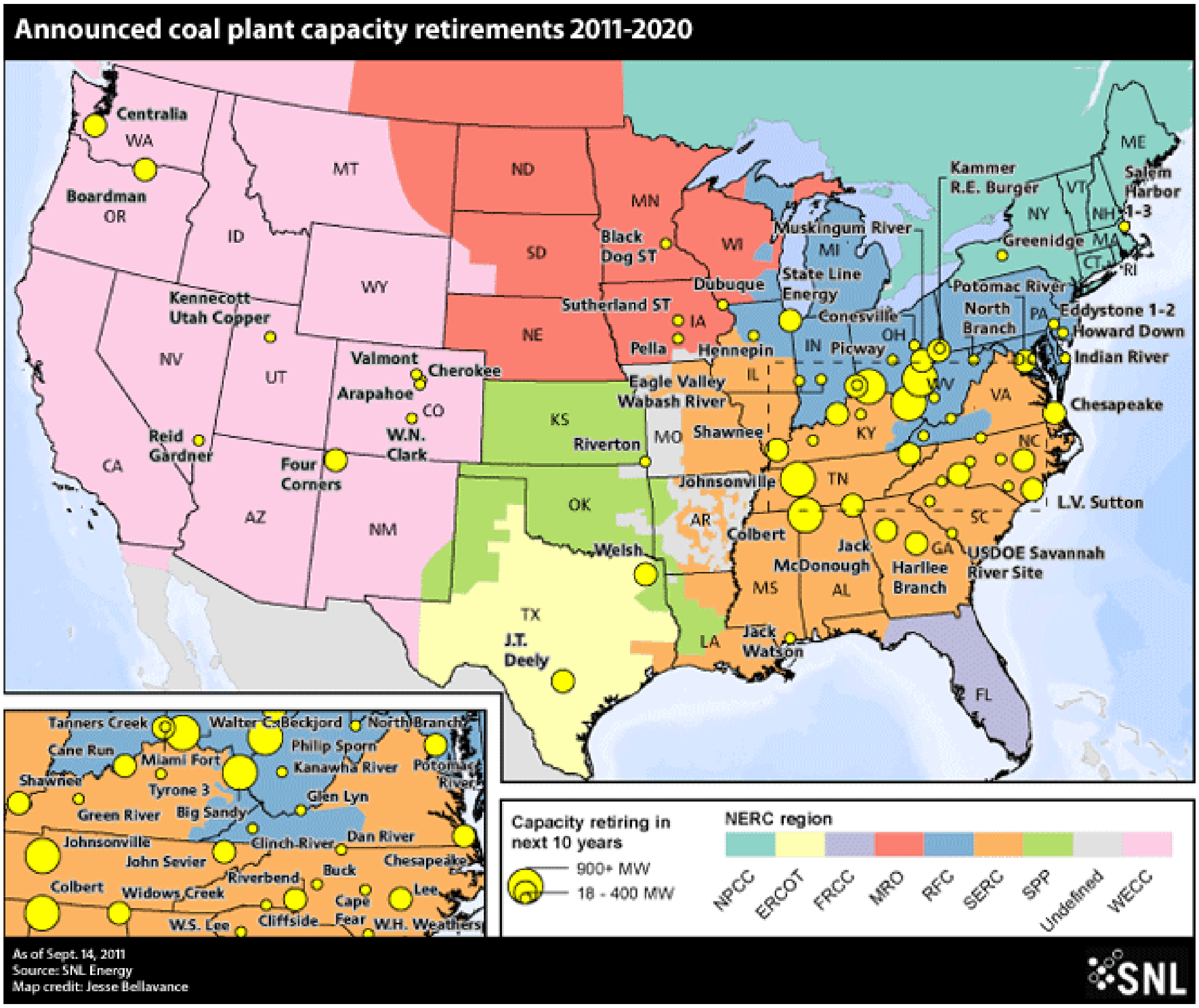


Figure 15

Driven by market forces, a growing fuel price gap between coal and gas, regulatory pressures from Clean Air Act enforcement actions, profitability concerns and grid reliability requirements, the closing of marginal coal plants creates an historical opportunity for utilizing new and existing NGCCs and other clean generation. To highlight a couple examples of how the grid might evolve to meet this opportunity, Fig. 16 compares the electricity supply forecasted by AEO2012e.r. with alternative visions from Deutsche Bank Climate Change Advisors and an alternative scenario from the *Annual Energy Outlook 2011* (AEO2011).

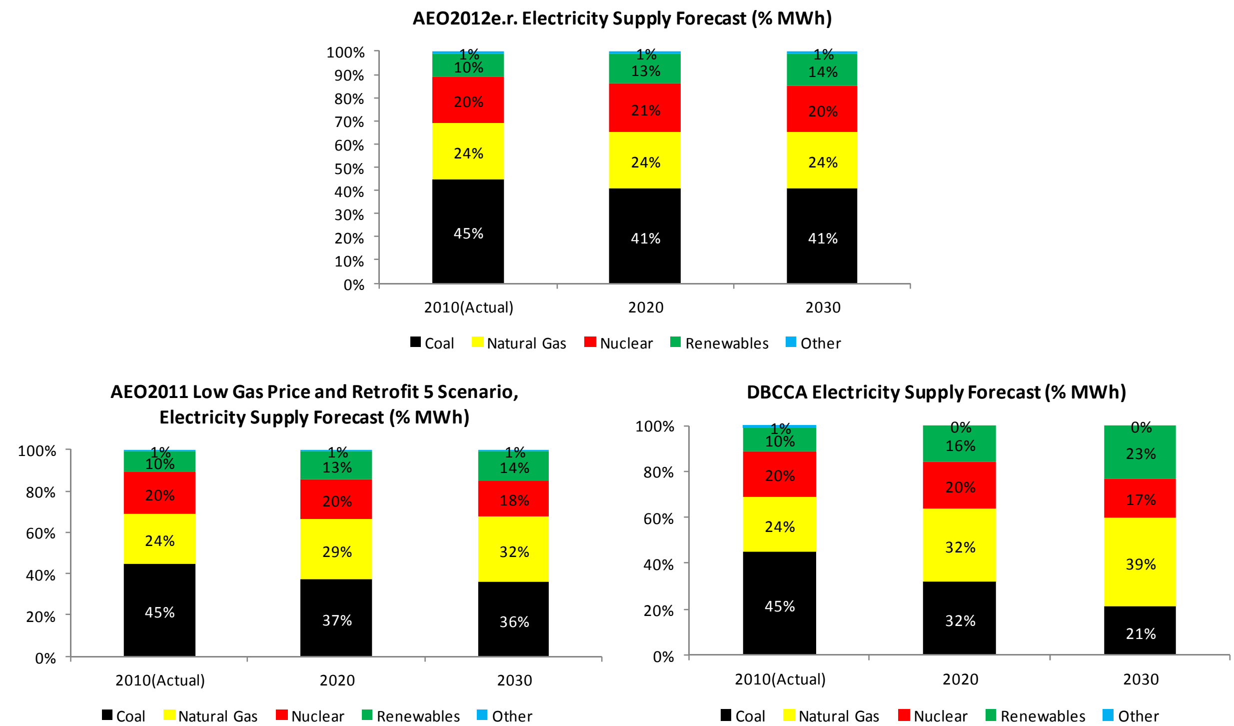


Figure 16

The scenario developed by the Deutsche Bank Climate Change Advisors is notable for the large differences in natural gas (39% of generating capacity by 2030) and renewables (23% of capacity by 2030). This differs significantly from the *AEO2012e.r.*, which, despite strong growth in natural gas and renewables over their previous years' forecasts, is still projecting a grid mix by 2030 of 41% coal, 24% natural gas, 20% nuclear and 14% renewables by 2030. The Deutsche Bank analysis concludes that the "U.S. is capable of almost halving its CO_2 emissions by 2030 (up to 44 percent) through a secure and reliable mix that is based on known technology that can easily be deployed at reasonable cost."[vii]

An alternate scenario from the AEO2011 family of integrated assessments [the counterparts for 2012 have yet to be published by EIA] is the "Retrofit 5, Low Gas Price" scenario (this analysis assumes a five-year payback period on retrofitting all unscrubbed coal plants, plus a low natural gas price that is much closer to what is actually being witnessed now [see the previous Fig. 11 showing the progression of NYMEX futures strip out to 2020]). Similar to the work from Deutsche Bank, this scenario increases the share of both natural and renewables in the grid mix, and results in envisioning a somewhat comparable reduction of its carbon footprint.

The collective effect of the factors detailed above is to raise the likelihood that a much larger amount of gas and renewables will be used in the electric power sector by 2030-2050, sharply diminishing the sheer amount of CO_2 (as well as reductions in important criteria pollutants like NO_x, SO_2, particulates and mercury emitted from the power sector), and raising its overall energy conversion efficiency. This slowly eases the carbon emission problem with or without carbon regulation, and could be a very practical system companion to much more widespread use of electric drive vehicles.

Observations and conclusions

- Widespread introduction of electric drive light duty vehicles, when matched with the cleaner trends in U.S. grid investment, continue to show much promise in dramatically lowering all emissions from the electricity and transportation sectors.
- As the grid evolves, each plant replacement essentially guarantees a more stable and efficient supply of cleaner electricity—perhaps as long as 50-60 years of plant life.
- Natural gas and renewables are effective partners in a cleaner grid—quick-ramping NGCC plants serve as an essential balancing supply to dampen the variability of both wind and solar, providing important resource flexibility to grid operators.[viii]
- There is ample belief from industry analysts that the electricity grid is cleaning up more rapidly than observed by EIA, thus preparing cleaner supply that can multiply the benefits of more rapid growth in electric drive vehicles.

References

[i] Calculated using data from Form EIA-923 data. Available: Hhttp://www.eia.gov/cneaf/electricity/page/eia906_920.htmlH

[ii] Edison Electric Institute, July 2011, Hhttp://www.eei.org/ourissues/ElectricityGeneration/FuelDiversity/Documents/map_fuel_diversity.pdfH

[iii] Hhttp://cleanskies.org/pdf/ACSF_Comments_on_Full_Fuel_Cycle_filing_10_29_10.pdfH

[iv] "The Greenhouse gases, regulated emissions and energy use in transportation model," by the Argonne National Laboratory, available: Hhttp://greet.es.anl.gov/H

[v] AEO2012 early release, available: Hhttp://www.eia.gov/forecasts/aeo/er/H

[vi] Upcoming, recent coal-fired power unit retirements. Michael Niven and Jesse Gilbert, SNL Energy, September 26, 2011.

[vii] Natural Gas and Renewables: A Secure Low Carbon Energy Plan for the United States. November 2010. Deutsche Bank Climate Change Advisors. p. 4.

[viii] The Business Case for Integrating Clean Energy Resources to Replace Coal. Joel N. Swisher. June 2011. Available: Hhttp://www.cleanskies.org/wp-content/uploads/2011/06/Swisher-final.pdfH