Decarbonization and the Natural Gas Fuel Chain*

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Today's Business Case for Integrating Clean Energy Resources to Replace Coal




- The electric power generation industry is confronted with the confluence of three powerful, game-changing forces:
  - Environmental regulation increasing the cost of legacy coal-fired generation plants
  - Availability of under-utilized gas-fired generation capacity
  - Mandated expansion of renewable generation, requiring more flexibility in the generation fleet

Today's Business Case for Integrating Clean Energy Resources to Replace Coal

- These forces create an historic opportunity to replace obsolete coal-fired generation fleet with a portfolio of:
  - Flexible, natural gas-fired generation, mostly existing
  - Variable renewable generation, mostly mandated
  - A range of demand-side energy and peak-capacity resources, mostly less expensive than any new generation source

Longer term, a vision of the Next Generation Utility, which relies on demand-side, renewable and low-carbon resources

- Massive improvement in energy efficiency in industry, buildings, and vehicles
- De-carbonize the electricity supply through aggressive renewable usage with gas-fired & demand-side firming
- Electrify direct fossil fuel loads, including cars/trucks

ICEs to PHEVs

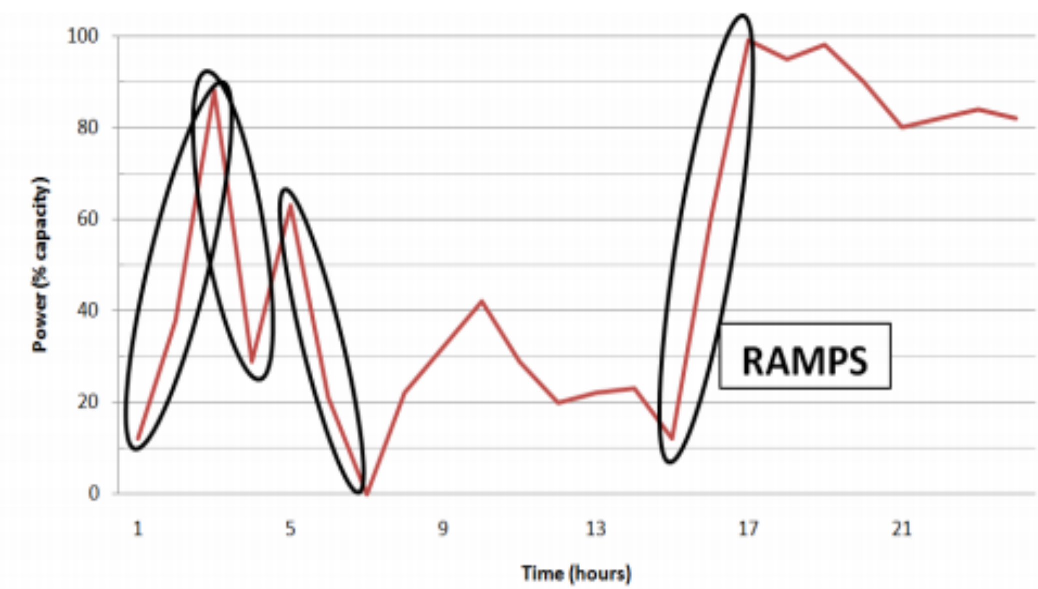
- Smart grid to match time-varying loads and supply, including energy storage and demand-side resources

Advantages of gas-fired generation in the next generation utility

- Low-carbon generation
  - *Natural gas: 53, coal: 95 kgCO2/MMBtu from combustion*
  - *Gas-fired CCGT generation: 0.35, coal-fired steam: 0.85 kgCO2/kWh (we'll address upstream emissions later)*
- Co-generation
  - *Distributed production of power, heating (and cooling) makes maximum use of the fuel energy of natural gas (but not very compatible with CCS)*
- Flexibility to balance variable renewable generation
  - *A high-renewables generation fleet will need fast ramping resources to respond to the variations of both load and variable generation*
- Potential to displace gasoline via vehicle electrification
  - *Electricity from renewable and gas-fired generation, plus the efficiency advantages of electric drive, reduces vehicle CO2 intensity up to 80%*

What resources can provide flexibility?

- Steam Plants (coal and nuclear)?
  - Much variation but generally steam plants make a fleet less flexible, not more, due to increased startup and cycling costs, higher wear and tear, corrosion, shorter boiler & turbine life
  - Increases the need to curtail clean renewable power or risk operational problems or costly shut-downs of steam plants
- Demand response?
  - Cheap, limited frequency, duration



What resources can provide flexibility?

- Gas-fired combined-cycle gas turbines (CCGT)
  - Pre-2000 units designed for baseload efficiency,but limited flexibility
  - New, efficient models with fast-start, high ramp rate, low minimum kW, moving to “hot start on the fly”
  - New CCGT products from GE, Siemens, Alstom can also be retrofitted
- Gas-fired combustion turbines and recip engines (gas or oil)
  - Simple-cycle gas turbine, engine peakers are flexible, <42% efficient

=> Gas-fired plants are the primary option for providing flexibility to enable renewables to grow

The greenhouse gas (GHG) emission footprint of natural gas use

Based on EPA inventories of US annual GHG emissions:

- Direct combustion CO2: 53.2 kgCO2/MMBtu (negligible N2O in addition)
- Fugitive methane (CH4) leaks: ~5 – 11 kgCO2e/MMBtu
  - Methane's Global Warming Potential (GWP) ratio is 25 (from IPCC 2007), although EPA still uses 21 (from IPCC 1995)
  - Based on leakage rates of 1-2.3% from EPA 2010, 2011 GHG inventory
  - Yes, the EPA more than doubled their estimated leakage rate!
  - Other (DoE) estimates: EIA 1.9%, NETL 1.7%
  - Other (widely refuted) literature estimates of leakage are as high as 8%!

The greenhouse gas (GHG) emission footprint of natural gas use (continued)

Based on EPA inventories of US annual GHG emissions:

- Direct combustion CO2: 53.2 kgCO2/MMBtu
- Fugitive methane (CH4) leaks: ~5 – 11 kgCO2e/MMBtu
- Upstream fuel combustion CO2: ~4.0 kgCO2/MMBtu
- Upstream venting/flaring CO2: ~1.4 kgCO2/MMBtu
- Total GHG footprint of natural gas: 63.6 – 69.6 kgCO2e/MMBtu
- Indirect non-combustion GHGs: 10.4 – 16.4 kgCO2e/MMBtu
  - 20% (2010 values) - 30% (2011 values) of the direct combustion footprint is GHGs not available for CCS

Reducing the upstream GHG footprint of gas

Gas producers (El Paso, Devon, etc.) disagree with the EPA's methods in the (much higher) 2011 inventory

- IHS/CERA observed the EPA's new leakage estimates are based on *rates of gas captured* during well completion, *not on measured rates of gas leaked*
- High leakage estimates would imply badly sub-standard safety, economic performance
- Of course, higher literature estimates considered discredited

Looking forward, the key is better data & documenting reductions

- Questionable EPA leakage estimates result of thin data sets from the field
- Advanced early production process (green completion) and other reduction/capture methods should become industry standards *with full documentation*

CO_2 from electricity generation

CO_2 from electricity generation {$kgCO_2/kWh$}

$$= \underset{kgCO2/MMBtu}{\text{Carbon content of fuel}} * \underset{Btu/kWh}{\text{Generation heat rate (efficiency)}} \; / \; \underset{MMBtu/Btu}{\text{1 million MMBtu/Btu}}$$

Comparison coal and natural gas-fired generation GHG emissions:

	Coal	Natural Gas	% increase/ decrease
Direct combustion CO2 (kgCO2/MMBtu)	95	53	-44%
Upstream & other GHGs (kgCO2e/MMBtu)	3	6	+120%
Fugitive methane leaks (kgCO2e/MMBtu)	4	5-11	+25 – 175%
Total GHG footprint (kgCO2e/MMBtu)	102	64 - 70	-32 - 37%
Heat rate of new generation (Btu/kWh)	8900	6500	-28%
New generation GHG rate (kgCO2e/kWh)	0.90	0.41 - 0.45	-50 - 54%
Non-combustion GHGs (kgCO2e/kWh)	0.06	0.07 – 0.11	+10 – 70%

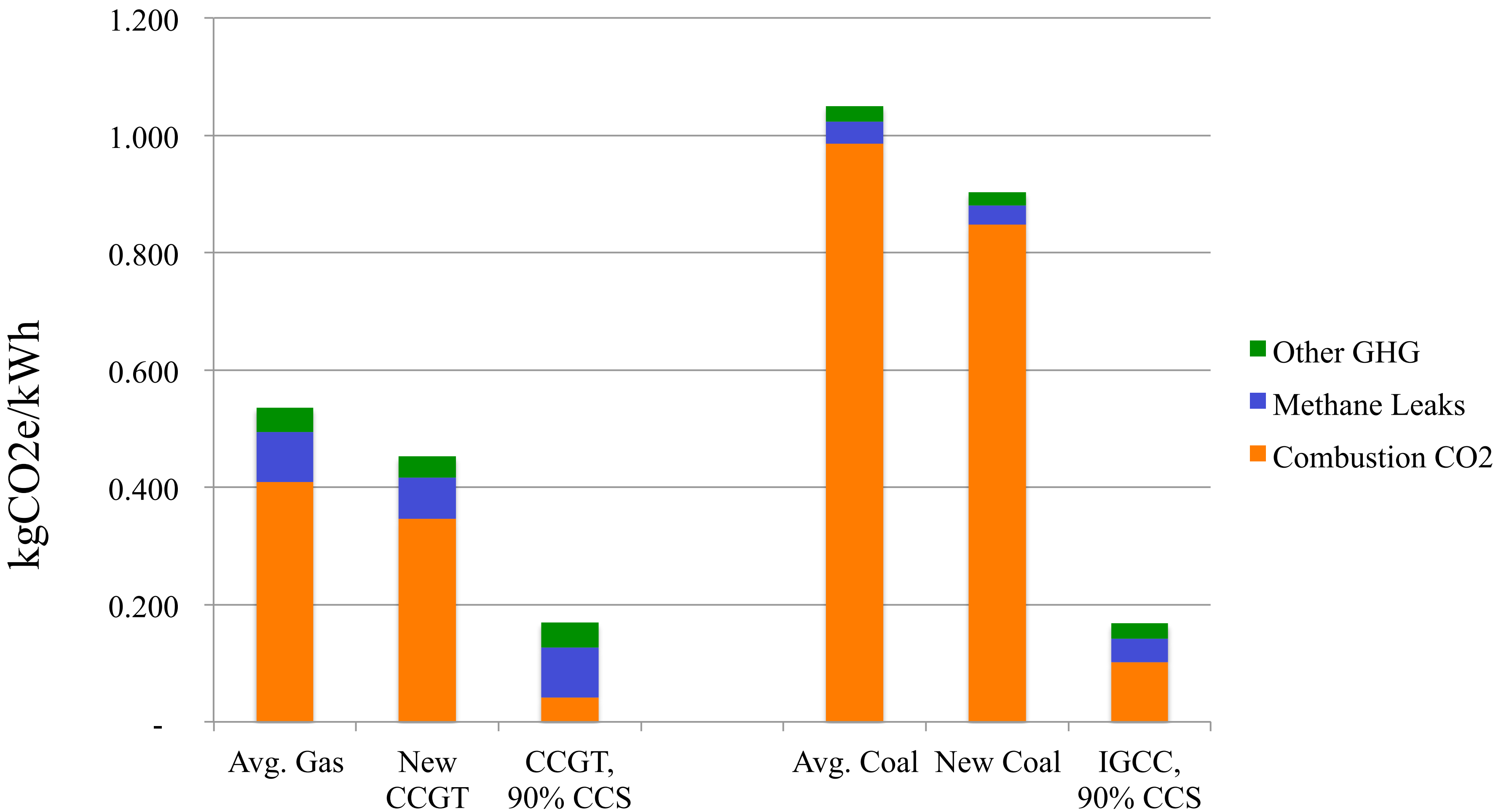
*Upstream emissions from 2010, 2011 EPA GHG inventory, adjusted for methane GWP = 25

Coal vs. gas GHG emissions advantage*

Plant type:	Heat rate Btu/kWh	kgCO2 / MMBtu	kgCO2e / MMBtu	kgCO2e / kWh
Average Gas	7700	53.2	69.6	0.54
New CCGT	6500	53.2	69.6	0.45
CCGT w/ 90% CCS	7800	5.3	21.7	0.17
Average Coal	10,350	95.3	101.5	1.05
New Coal	8900	95.3	101.5	0.90
IGCC w/ 90% CCS	10,700	9.5	15.7	0.17

* Upstream emissions from 2011 EPA GHG inventory, adjusted for methane GWP = 25

Coal vs. gas GHG emissions advantage*
At 2.3% gas leakage, gas/CCS = coal/CCS



* Upstream emissions from 2011 EPA GHG inventory, adjusted for methane GWP = 25

Natural gas-fired generation with CCS in a low-carbon generation portfolio

- Depending on upstream methane leakage rates, net GHG emissions from gas-fired CCGT with CCS could be very low
- Gas-fired CCGT with CCS is completely compatible with vehicle electrification with low-carbon power sources
- But not so much with distributed co-generation…
- The remaining question is the role of gas-fired generation with CCS in providing “flexibility” to balance variable renewables…

Can gas-fired generation with CCS deliver flexibility to balance variable renewables?

- Does C capture facility make gas-fired CCGTs strictly baseload plants that must run at nearly constant output?
- If so, they will not contribute flexibility to balance renewables…
- Such plants would still fit in a low-carbon portfolio with more flexible sources, but would provide only baseload or daily cycling

Can gas-fired generation with CCS deliver flexibility to balance variable renewables?

- On the other hand, if the CCS facility and its parasitic power consumption could be *ramped down during operation of the generation plant*:
  - Net power output would increase significantly on demand
  - CO2 emission rate would increase but only to the level of a CCGT and only when the plant's capacity is essential for grid reliability
  - To enable this "peaking" capacity, the CCS facility would have to be designed for cycling during continued operation – is this possible?