Environmental implications of carbon limits on market penetration of combined heat and power with the U.S. energy sector

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Audience

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Abstract

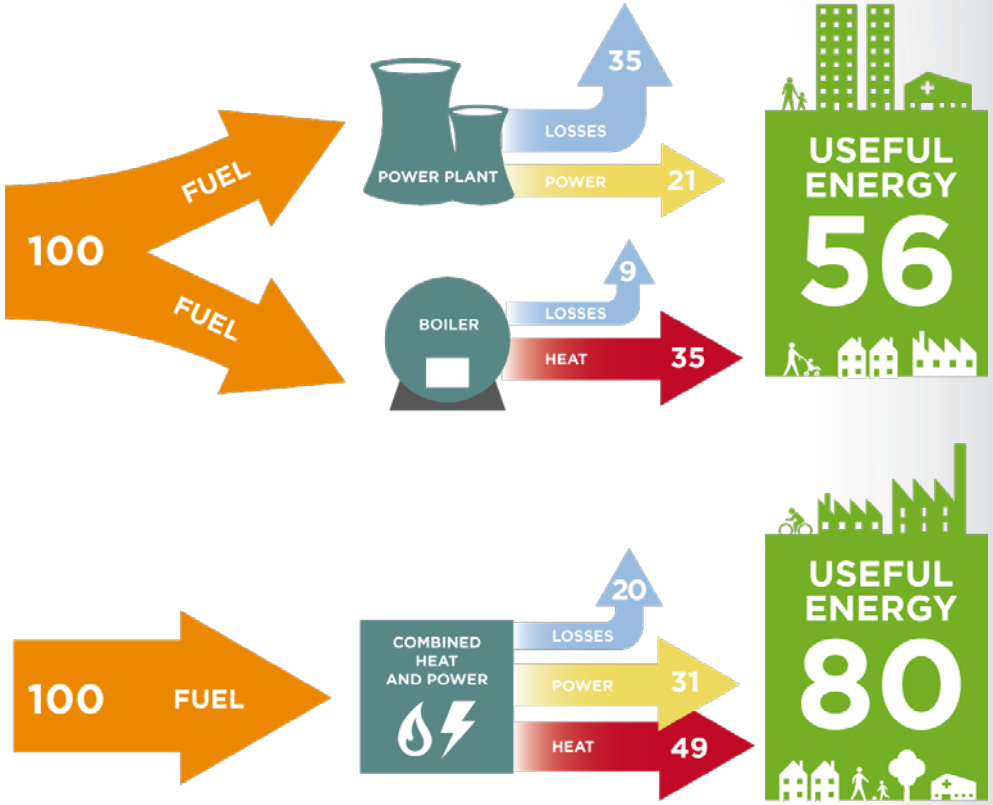
Combined heat and power (CHP) is promoted as an economical, energy-efficient option for combating climate change. To fully examine the viability of CHP as a clean-technology solution, its market potential and impacts need to be analyzed as part of scenarios of the future energy system, particularly those with policies limiting greenhouse gas (GHG) emissions. This paper develops and analyzes scenarios using a bottom-up, technology rich optimization model of the U.S. energy system. Two distinct carbon reduction goals were set up for analysis. In Target 1, carbon emission reduction goals were only included for the electric sector. In Target 2, carbon emission reduction goals were set across the entire energy system with the target patterned after the U.S.'s commitment to reducing GHG emissions as part of the Paris Agreement reached at the COP21 summit. From a system-wide carbon reduction standpoint, Target 2 is significantly more stringent. In addition, these scenarios examine the implications of various CHP capacity expansion and contraction assumptions and energy prices. The largest CHP capacity expansion are observed in scenarios that included Target 1, but investments were scaled back in scenarios that incorporated Target 2. The latter scenario spurred rapid development of zero-emissions technologies within the electric sector, and purchased electricity increased dramatically in many end-use sectors. The results suggest that CHP may play a role in a carbon-constrained world, but that role diminishes as carbon policies become more stringent.

The problem

- ***WHY?*** *Combined heat and power (CHP) is promoted as an economical, energy-efficient option for combating climate change. CHP applications are poised to satisfy a significant portion of the U.S.'s growing electricity needs, while continuing to meet our thermal demands.*
- **We examine the viability of CHP as a clean-technology solution, its market potential and impacts through future energy system scenario considering the following:**
  - *Technology assumptions*
  - *Resource assumptions (natural gas price and quantity)*
  - *Greenhouse gas (GHG) emissions reductions goals*
- **Impacts explored include:**
  - *Air quality implications*
  - *Interactions among sectors*
- **This analysis is conducted using a bottom-up, technology rich optimization model of the U.S. energy system.**

What is CHP?

- CHP currently makes up about 8% of U.S. total generating capacity.*
- The present installed capacity of CHP in the U.S. is about 82 GW.
- The Obama administration has set an official goal of 40 GW of additional CHP capacity by 2020.
- Additionally, with the establishment of CO_2 reduction goals for power plants, CHP has been identified as a critical tool to reduce CO_2 cost-effectively.

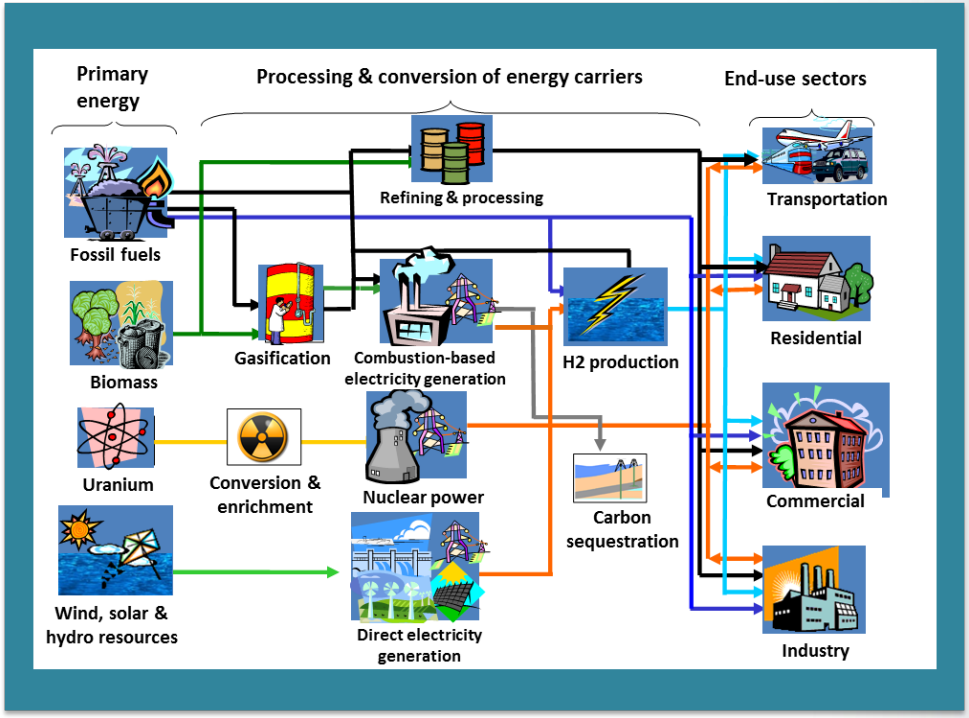


Source: http://www.theade.co.uk/what-is-combined-heat-and-power_15.html

"CHP: A Clean Energy Solution"(2012) USDOE/USEPA. DOE/EE-0779
http://www1.eere.energy.gov/manufacturing/distributedenergy/pdfs/chp_clean_energy_solution.pdf

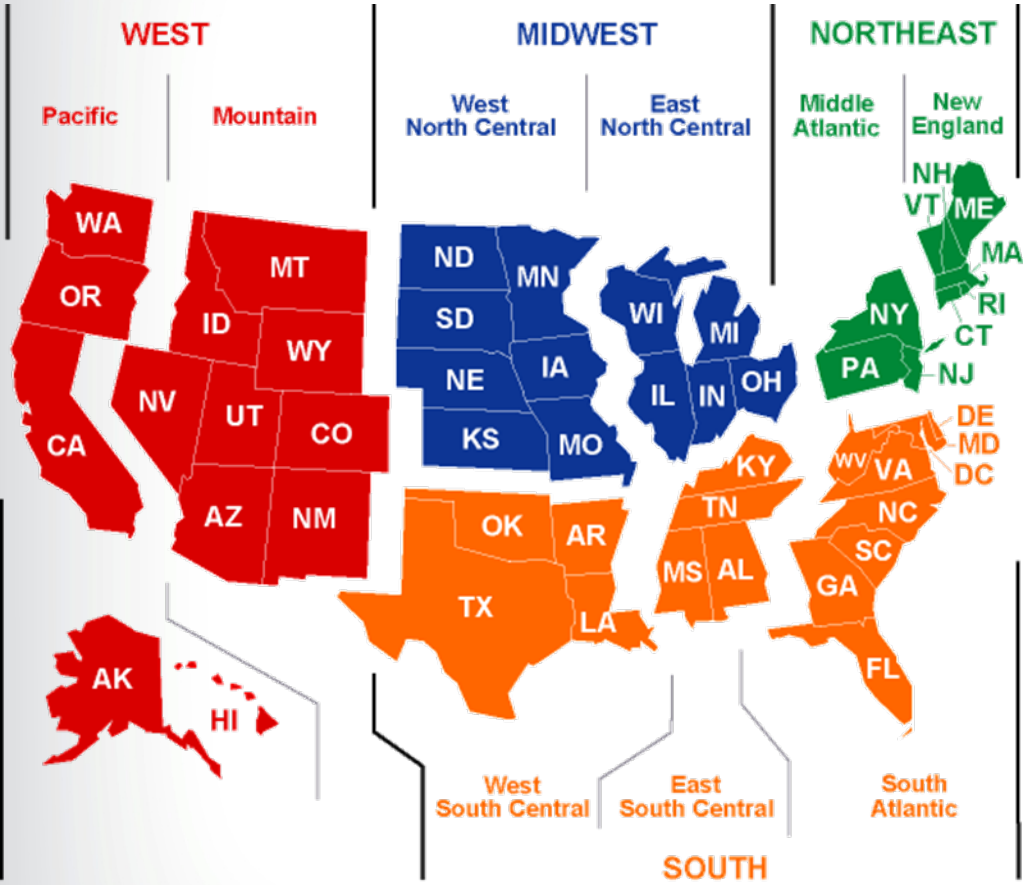
Energy system model: MARKAL

- **Bottom-up** and **technology-rich**
  - Captures the full **system** from energy resource supply/extraction technologies to end-use technologies in all sectors
  - **Energy technologies** (existing and future techs) are characterized by cost, efficiency, fuel inputs, emissions
  - Technologies are connected by **energy flows**
- **Optimization**
  - The model picks the "best" way (lowest system-wide cost) to meet energy demands choosing from the full "menu" of energy resources and technologies
  - The model makes these choices from 2005 to 2055, giving us a snapshot of possible future energy mixes



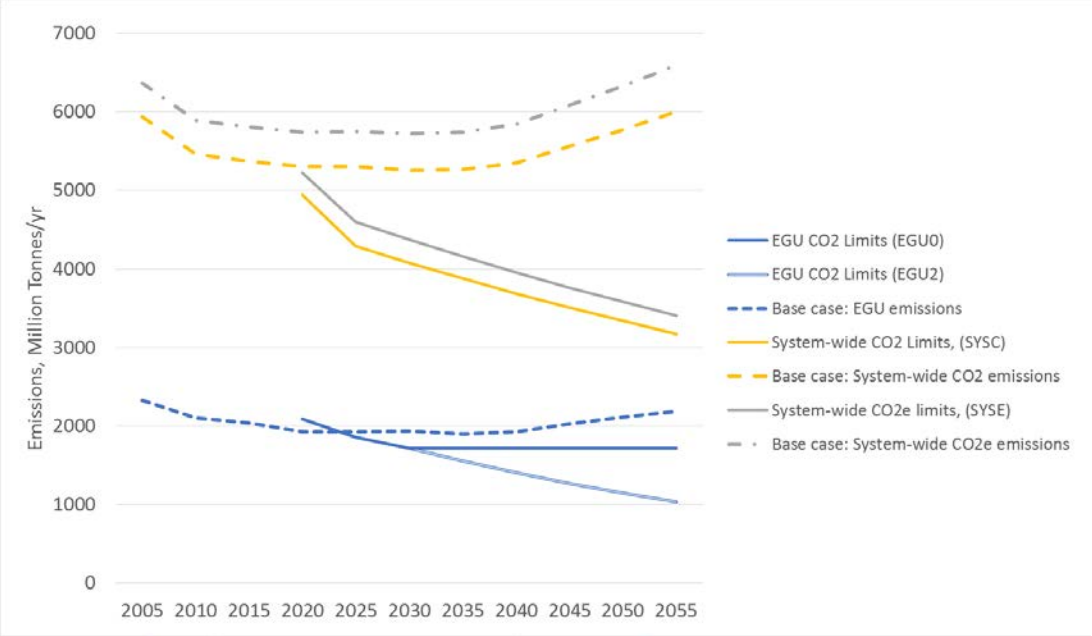
- **Emissions and impacts**
  - All technologies and fuels have air and GHG emissions characterized
  - Standards and regulations are included in the baseline, and additional policies can be modeled

U.S. EPA MARKAL Regional Database: EPAUS9r



- **Coverage**: U.S. energy system
- **Spatial resolution**: Nine Census divisions
- **Modeling horizon**: 2005 to 2055 in five year increments
- **Sectors**: Electricity production, transportation, industrial, residential, commercial, biomass
- **Main data source:** Annual Energy Outlook (2014)
- **Pollutants**: NO_x, SO_2, PM_{10}, $PM_{2.5}$, CO, VOC, CO_2, CH_4, N_2O, BC, OC, water use for electricity generation
- **Maintenance:** Updated and calibrated to Annual Energy Outlook every two years; housed at EPA/ORD; publicly available

Emission reduction goals for the scenarios



CO_2 limits on Electric Generating Units (**EGU**): reduction of 33% by 2030

1. CO_2 emissions targets are kept constant after 2030 (**EGU0**)
2. CO_2 emissions targets are decreased by 2% annually until 2055 (**EGU2**)

GHG limits on U.S. Energy System (**SYS**): patterned after the U.S.'s commitment and ratification post COP21 meeting in Paris

1. CO_2 emissions are reduced by 28% by 2025 from 2005 levels and then the emissions are decreased by 2% annually starting in 2025 until 2055. (**SYSC**)
2. CO_2e (CO_2 + GWP x CH_4) emissions are reduced by 28% by 2025 from 2005 levels and then the emissions are decreased by 2% annually starting in 2025 until 2055. (**SYSE**)

GWP for CH4 = 28 (IPCC AR4)

Scenario descriptions

CHP technology and fuel price drivers →	CHP growth limits imposed (AEO'14 REF case)	Doubling cost of natural gas supply	No exogenous CHP capacity limits	Doubling cost of natural gas supply	Disallow new CHP addition
Carbon policies ↓					
No carbon policy	Base		CHP		
CO_2 reduction goals on EGUs	Base_EGU0	Base_EGU0_NG	CHP_EGU0 CHP_EGU2	CHP_EGU0_NG CHP_EGU2_NG	NI_EGU0 NI_EGU2
CO_2 reduction goals on EGU and energy system			CHP_EGU0SYC		
CO_2e reduction goals on EGU and energy system			CHP_EGU0SYSE	CHP_EGU0SYSE_NG	NI_EGU0SYSE
CO_2 reduction goals on energy system			CHP_SYSC	CHP_SYSC_NG	
CO_2e reduction goals on energy system			CHP_SYSE	CHP_SYSE_NG	

- In the scenarios, 2005 and 2010 are calibration time periods, and while 2015 through 2055 the model is selects technology penetrations based on optimization.
- CHP plants are assumed to have a lifetime of 35 yrs. Therefore most of the installed capacity in the industrial sector will retire at around 2040. However, the model has the option to build new CHP depending on the scenario structure.
- A scenario, "**Base_EGU0_NR**", where installed CHP capacity lifetime was extended to 50 years and not retired, was included for comparison purposes.

Results

Following slides will go over the results of our scenarios which are organized in two sections:

1. Scenarios with CO_2 limits on Electric Generating Units (**EGU**): reduction of 33% by 2030
   a. CO_2 emissions targets are kept constant after 2030 (**EGU0**)
   b. CO_2 emissions targets are decreased by 2% annually until 2055 (**EGU2**)
2. Scenarios with GHG limits on U.S. Energy System (**SYS**): patterned after the U.S.'s commitment and ratification post COP21 meeting in Paris
   a. CO_2 emissions are reduced by 28% by 2025 from 2005 levels and then the emissions are decreased by 2% annually starting in 2025 until 2055. (**SYSC**)
   b. CO_2 e (CO_2 + GWP x CH_4) emissions are reduced by 28% by 2025 from 2005 levels and then the emissions are decreased by 2% annually starting in 2025 until 2055. (**SYSE**)

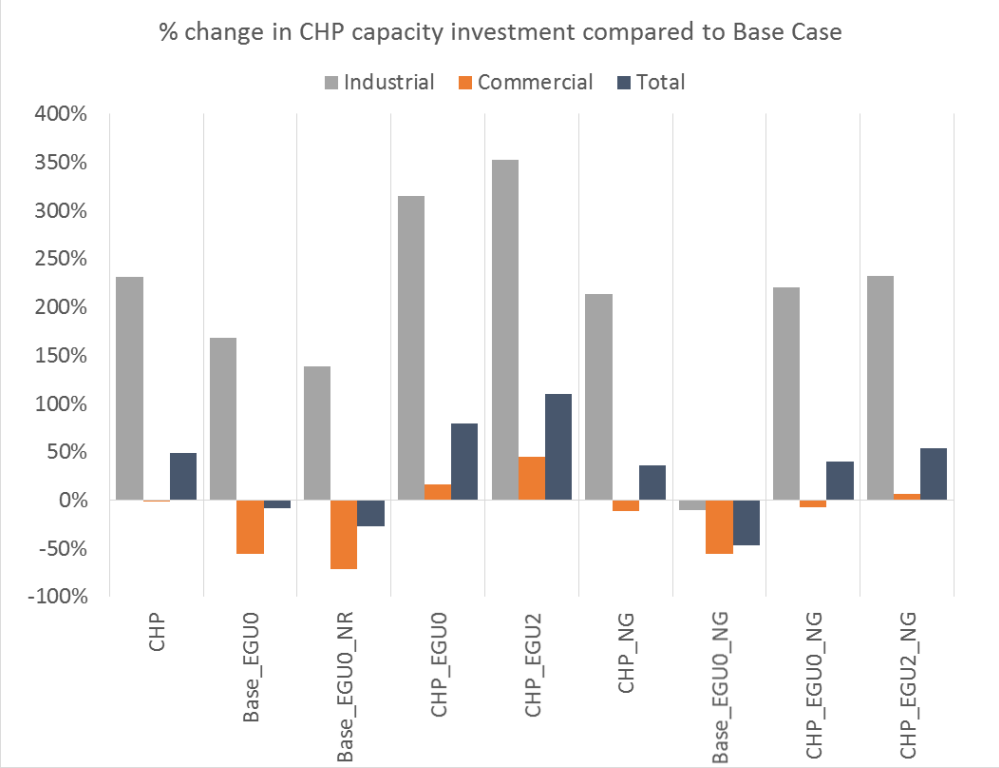
EGU target scenarios: CHP capacity changes

CHP capacity in 2010 (GW)

	Industrial	Commercial	Total
Base	63	4	67

CHP capacity addition over the modeling horizon (2015-2055) (GW)

	Industrial	Commercial	Total
Base	11	40	50



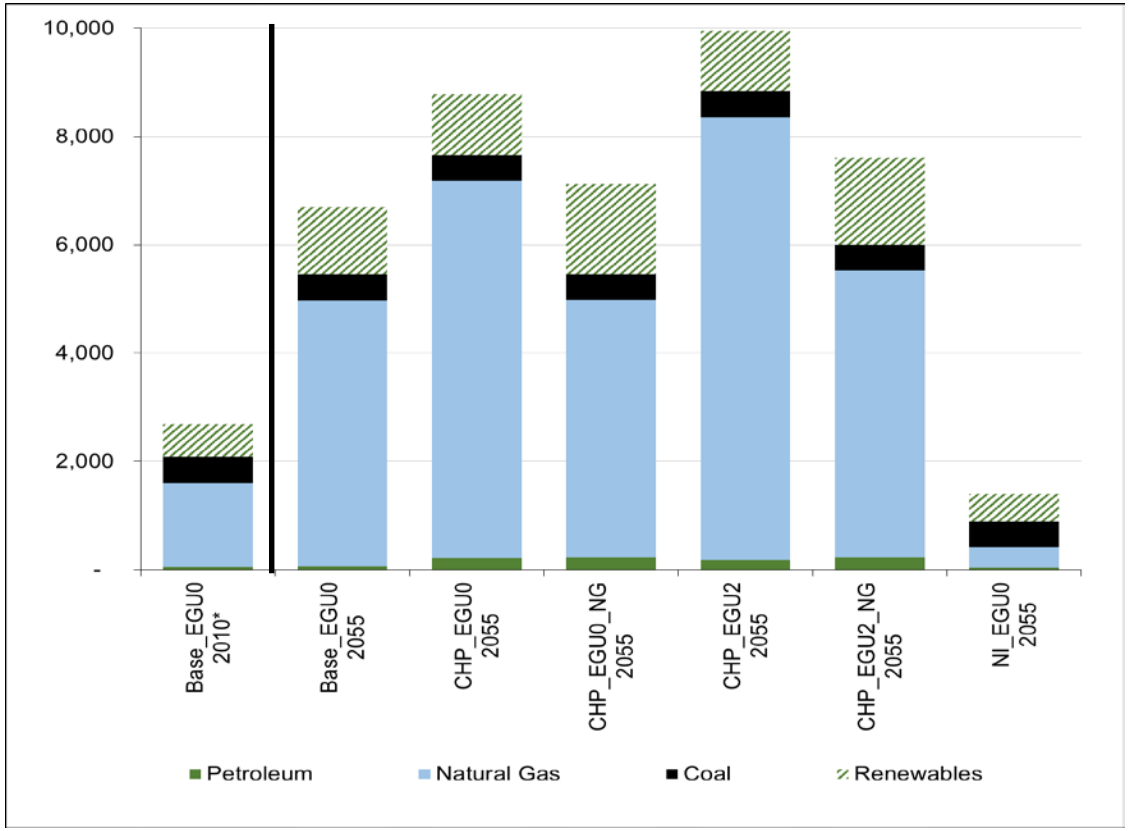
- EGU sector reduction goals resulted in additional industrial sector CHP with the exception of **Base_EGU0_NG**
- Higher reduction goals post 2030 yielded additional CHP in industrial sector is seen (**CHP_EGU2**)
- CHP capacity additions increased relative to Base case in **CHP_EGU0** and **CHP_EGU2** scenarios
- High NG prices still resulted in increased CHP capacity; however, instead of tripling the capacity, the scenarios doubling the capacity in industrial the sector (**CHP_EGU0_NG** and **CHP_EGU2_NG**)

EGU target scenarios: CHP capacity distribution

	CHP	CHP_EGU0	CHP_EGU2	CHP_SYSE	CHP_SYSC
Food	26%	21%	19%	31%	30%
Paper	5%	5%	7%	9%	8%
Chemicals	23%	29%	32%	27%	26%
Non-Metals	3%	3%	3%	1%	1%
Metals	2%	2%	2%	3%	3%
Other	40%	39%	36%	29%	32%

- Historically food, chemicals and paper industries utilize CHP extensively due to their high temperature heat and electricity needs.
- In 2010, of the **63 GW** of industrial CHP capacity, **12%, 20% and 50%** were located in **food**, **paper** and **chemicals** industries, respectively. The rest of the manufacturing was only **6%** of the total capacity.
- The distribution of CHP capacity additions observed between 2015 to 2055 under carbon reduction scenarios showed an emergence of different patterns.
  - Food and chemicals industries were still a major user of CHP at 20-30% of range
  - Almost 30% of the new additions were seen in other manufacturing sectors

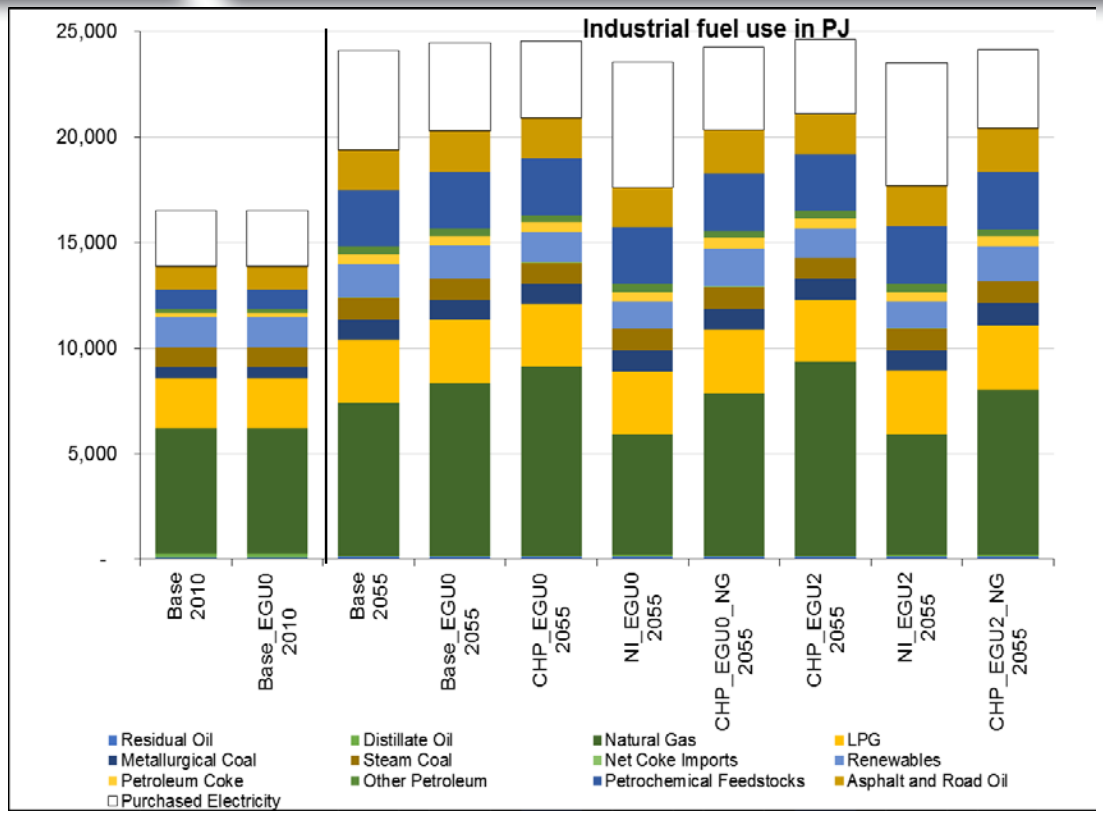
EGU target scenarios: CHP fuel use (PJ)



*. Base and Base_EGU0

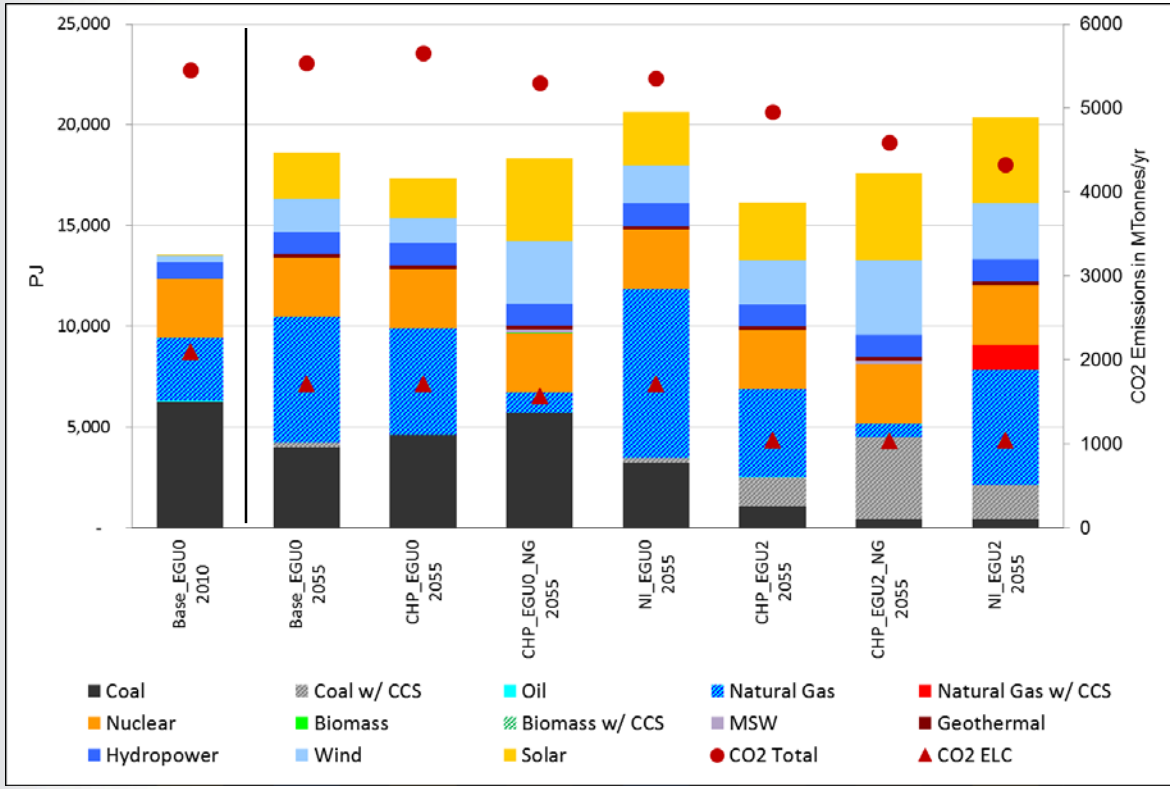
- Natural gas is the primary major fuel to power CHP plants
- Under high natural gas prices, the scenarios resulted in a slight increase in use of renewable forms of energy to power CHP plants

EGU target scenarios: Industrial fuel use (PJ)



- CO_2 reduction goals targeted to EGU sector, resulted in reduction of purchased electricity in the industrial sector
  - Yielded slight increase in fuel use, mostly natural gas, in 2055 (compared to Base)
- 30% increase in fuel use in 2055 from 2010 levels is observed, except for **NI_EGU0** and **NI_EGU2** scenarios where no new investment in CHP resulted

EGU target scenarios: EGU fuel use (PJ) and CO_2 emissions



	Base_EGU0 2010	Base_EGU0 2055	CHP_EGU0 2055	CHP_EGU0_NG 2055	NI_EGU0 2055	CHP_EGU2 2055	CHP_EGU2_NG 2055	NI_EGU2 2055
LCOE Index	1.00	1.98	1.91	1.96	2.15	2.08	2.10	2.34

- The most CO2 emissions reduction were seen in the **NI_EGU2** scenario where the ELC generation was higher than the other EGU scenarios and the deployment of renewables and CCS were the highest.
- **CHP_EGU2** resulted in lowest ELC generation
- **CHP_EGU2_NG** resulted in reduction in NG use in ELC sector and deployment of more renewables compared to **CHP_EGU2**

System-wide target scenarios: CHP capacity changes

CHP capacity in 2010 (GW)

	Industrial	Commercial	Total
Base	63	4	67

CHP capacity addition over the modeling horizon (2015-2055) (GW)

	Industrial	Commercial	Total
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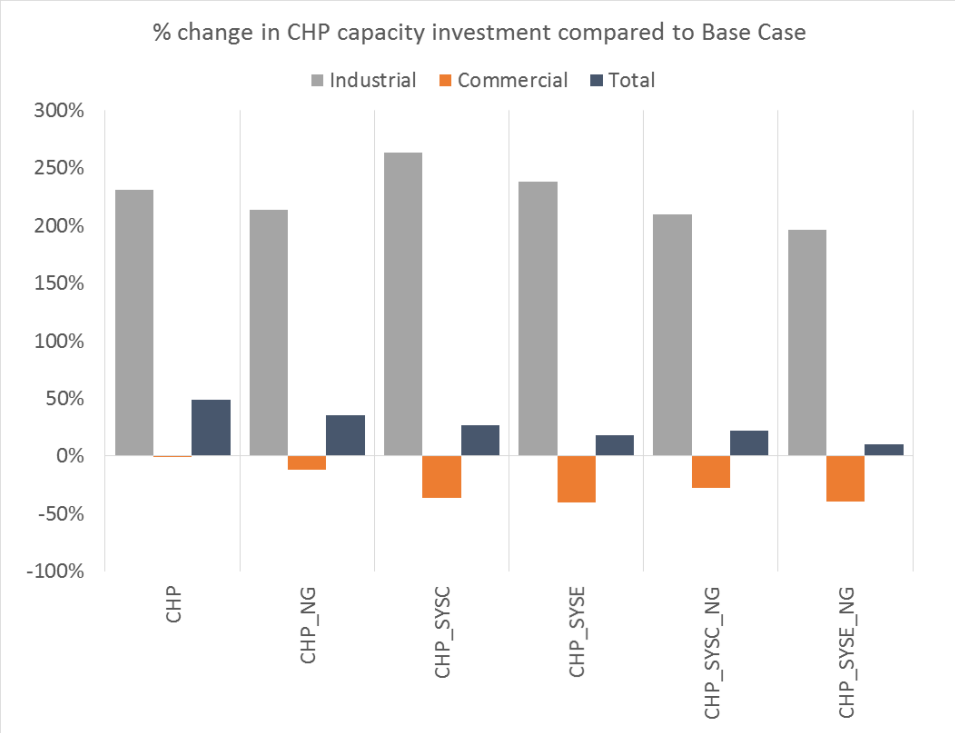
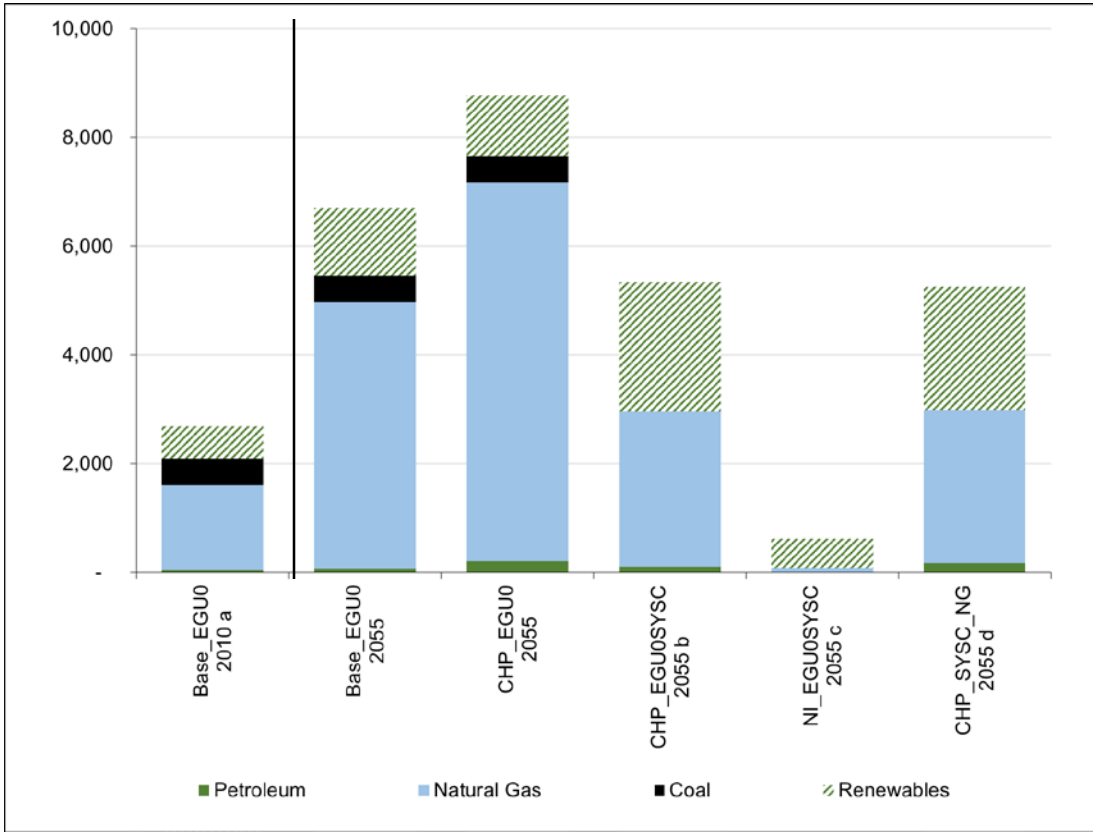


- CHP capacity addition doubled under system-wide reduction goals
- The capacity expansion slightly decreased under high NG price scenarios
  - The fuel and technology choices were impacted more with CO_2 reduction goals rather than NG prices
- Although addition CHP capacity is observed in commercial sector, the CHP capacity additions were lower than the Base case

System-wide target scenarios: CHP fuel use (PJ)

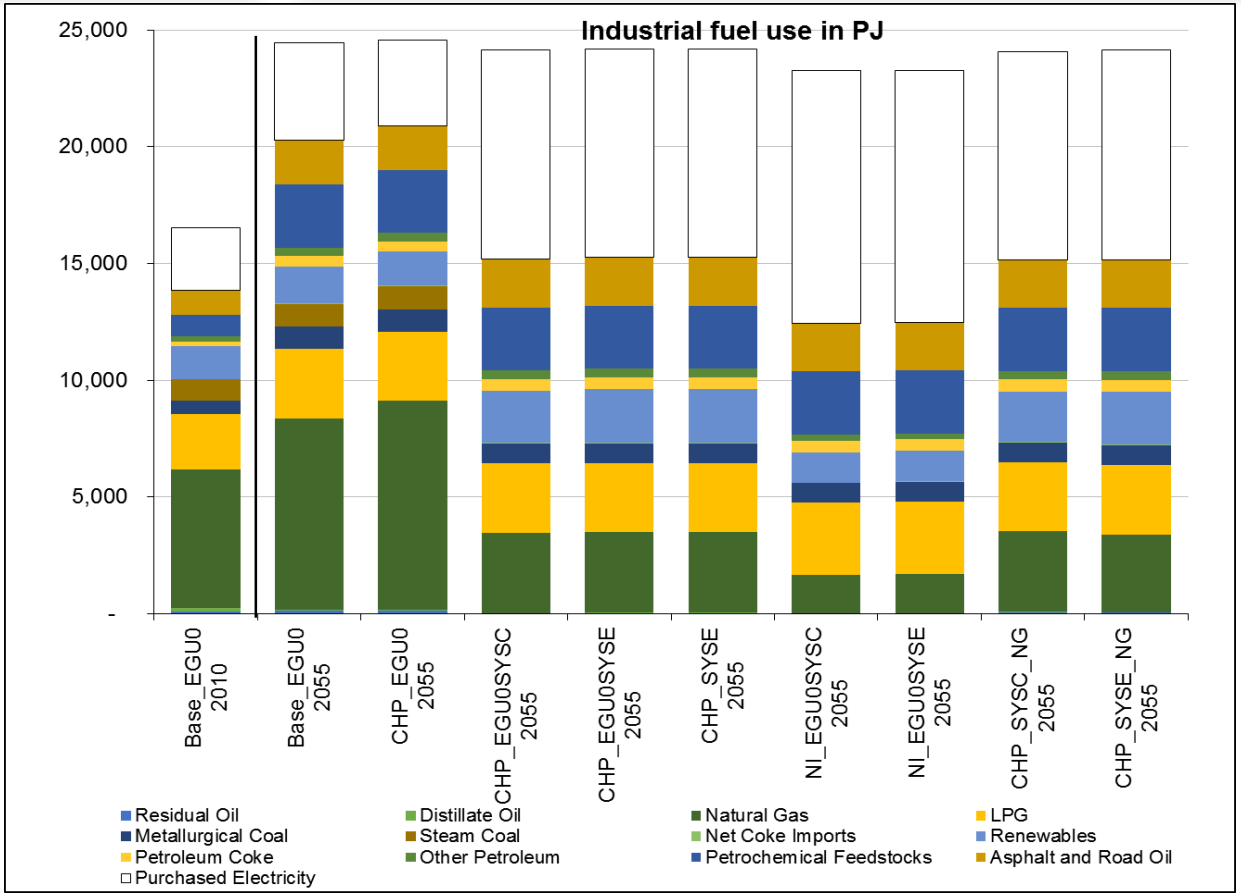


Following runs had the similar levels of fuel use in CHP:

a. Base and Base_EGU0
b. CHP_EGU0SYSC, CHP_EGU0SYSE, CHP_SYSC and CHP_SYSE
c. NI_EGU0SYSC and NI_EGU0SYSE
d. CHP_SYSE_NG, CHP_SYSC_NG, CHP_EGU0SYSC_NG and CHP_EGU0SYSE_NG

- Similar to EGU target scenarios, natural gas is the major fuel to power CHP plants
- The CHP capacity additions were lower compared to **EGU** scenarios in **SYSC** and **SYSE** scenarios
- The fraction of renewables, mostly biomass, powering the CHP plants have increased to almost 50%, where rest is powered by natural gas

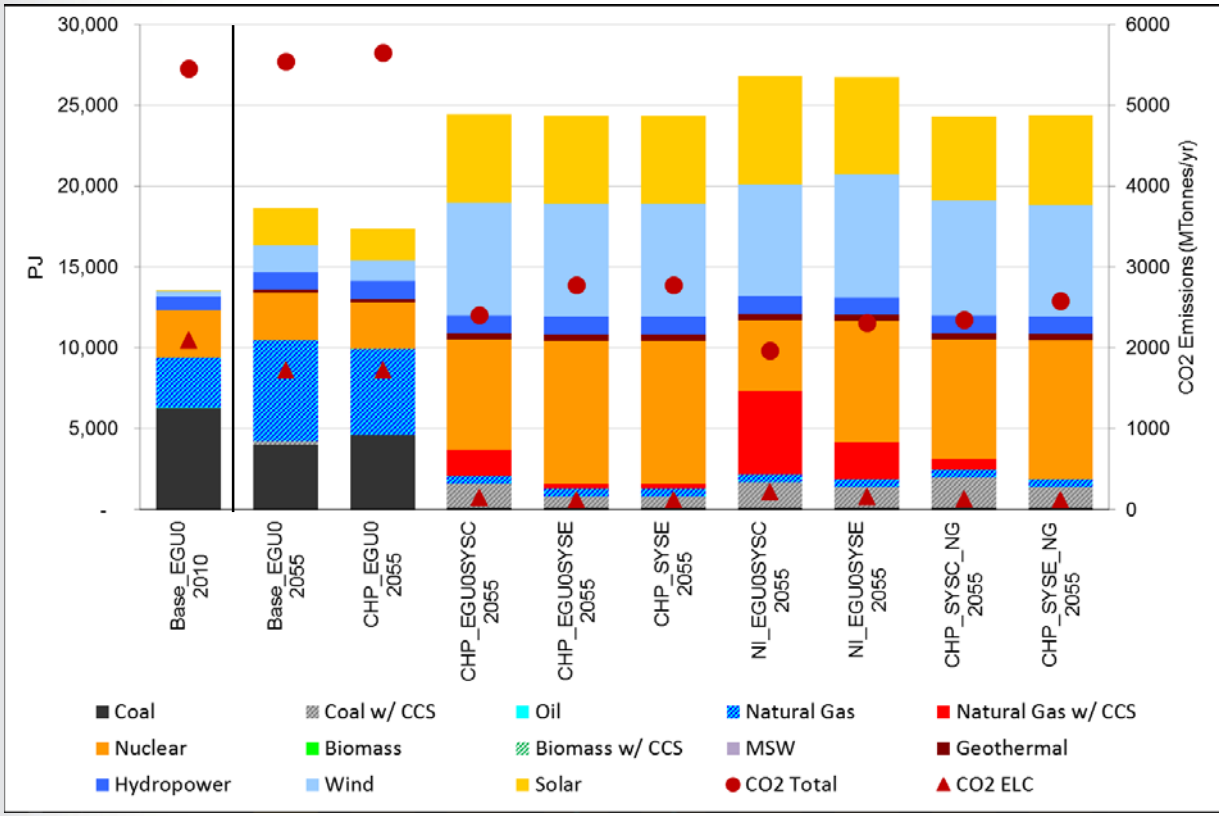
System-wide target scenarios: Industrial fuel use (PJ)



System-wide reduction goals resulted in:

- Electrification of industrial sector with major decrease in fuel use
- At least 40% of the energy is supplied through purchased ELC from the grid
- The fuel use in 2055 was almost at same levels at 2010

System-wide target scenarios: EGU fuel use (PJ) and CO_2 emissions



	Base_EGU0 2010	Base_EGU0 2055	CHP_EGU0 2055	CHP_EGU0SYSC 2055	CHP_EGU0SYSE 2055	CHP_SYSE 2055	NI_EGU0SYSC 2055	NI_EGU0SYSE 2055	CHP_SYSC_NG 2055	CHP_SYSE_NG 2055
LCOE Index	1.00	1.98	1.91	2.83	3.00	3.01	2.79	2.97	2.89	3.00

- System-wide CO_2 and CO_2 e reduction targets resulted in almost elimination of coal and natural by 2055
- Almost half of the ELC is supplied by wind and solar, and in some instances high penetration of natural gas with CCS
- Scenarios with **EGU** and **SYS** reduction combinations resulted in lower CO_2 emissions in ELC sector than the CO_2 emissions in EGU-only reduction scenarios (**CHP_EGU0** vs. **CHP_EGU0SYSC**)

Preliminary insights

- CO_2 reductions targeted only at EGU sector spur the development of CHP in the industrial and commercial sector
  - Natural gas is the main fuel powering the CHP plants across the sectors
  - System level CO_2 emissions in 2055 decreased in the range of 6-28% with respect to CO_2 emissions levels in Base case in 2055
- CO_2 and CO_2 e reductions targeted at energy system level
  - Required deeper reductions in all energy sectors i.e., resource extraction, production of fuels, conversion and use at transportation, industrial, residential and commercial sectors
  - Resulted in high electrification of sectors via centralized grid with high renewables
  - Compared to Base Case, still increased CHP capacity additions were seen but not as much of addition seen in EGU-only emission reduction scenarios
  - System level CO_2 emissions in 2055 decreased in the range of 54-67% with respect to CO_2 emissions levels in Base case in 2055

Future directions

- Conduct and report out sensitivities to technology assumptions for various CHP technologies
- Report out detailed industrial sub-sector analysis
- Analysis the trade-offs and co-benefits achieved through these reduction scenarios in the context of air quality and health impacts

Thank you for your interest

We welcome any questions and comments.

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