# Compare the CO2 emissions from three different ways to heat your home

- Project: Energy efficiency
- Calc: 001
- Revision: 2
- By: Kevin Dorma
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## Authentication

## >

## Revision History

| Revision | Date | Description | By | Reviewer |
|---|---|---|---|---|
| 2 | April 6, 2020 | DRAFT | KCD | |

In [23]:
```
# import standard
import pandas as pd
import matplotlib.pyplot as plt
```

# Abstract

We can use natural gas or electricity to heat our homes. And we can generate electricity with a coal fired power plant or a combined cycle gas turbine. How does this mix of supply and demand impact our net production of $CO_2$?



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# References

In the spirit of transparency, here are the references. Some of the data is a bit old, but it is consistant and well vetted.

- Table 8.2. Average Tested Heat Rates by Prime Mover and Energy Source, 2007 - 2017, https://www.eia.gov/electricity/annual/ (https://www.eia.gov/electricity/annual/)
- Carbon Dioxide Emissions Coefficients, https://www.eia.gov/environment/emissions/co2_vol_mass.php (https://www.eia.gov/environment/emissions/co2_vol_mass.php)
- High efficiency cold climate heat pump, https://www.energy.gov/sites/prod/files/2016/04/f30/32212_Shen_040616-1135.pdf (https://www.energy.gov/sites/prod/files/2016/04/f30/32212_Shen_040616-1135.pdf)

Source code (Jupyter notebook and PDF file) are available on my blog here.

# Basis

I will do the calculations based on 10 GJ of heat energy consumed for heating a home (pretty typical from my utility bill for October or November in Calgary).

I will describe the effectiveness of either gas or electricity for providing heat to our homes, and the efficiency of producing electrical power from the two thermal sources, and

In [24]:

```
# Energy consumption, typical value in the fall for my utility bill in Calgary Alberta

heatDemandGJmonth = 10.0  # I will take this as the GJ of heat needed by the house
```

In [25]:

```
# CO2 produced for electricity production
elecSources = pd.read_excel('energySources_1.xlsx', sheet_name='elecSources') # ref EIA document
heatSources = pd.read_excel('energySources_1.xlsx', sheet_name='heatSources') # ref EIA
specificCO2 = pd.read_excel('energySources_1.xlsx', sheet_name='specificCO2') # ref for heat pump
```

## Heat Sources

In [26]:
```
heatSources
```

Out[26]:

| | heatSource | energyUtilization | basis | heatProdn |
|---|---|---|---|---|
| 0 | NatGasFurnace | 0.9 | NatGas | 0.9 |
| 1 | resistanceHeat | 1.0 | Electricity | 1.0 |
| 2 | heatPump52F11C | 4.0 | Electricity | 4.0 |
| 3 | heatPump32F0C | 3.3 | Electricity | 3.3 |
| 4 | heatPump0F-18C | 2.6 | Electricity | 2.6 |

The natural gas furnace is assumed to be 90% efficient. Resistance heating is 100% efficient, but we recognize that electricity is a much higher value form of energy than burning fuel.

The Coefficient of Performance for an air source heat pump depends on the ambient temperature (values taken from Shen article). At 11 C (52 F), one unit of electrical energy can supply the house with 4 units of heat. At a low winter temperature of -18 C (0 F) the heat pump would only supply the house with 2.6 units of heat.

## Electrical generation sources

In [27]:
```
elecSources
```

Out[27]:

| | generator | BTU_per_kWhr | fuel |
|---|---|---|---|
| 0 | BoilerCoal | 10353 | Coal |
| 1 | BoilerNatGas | 10353 | NatGas |
| 2 | simpleGT | 11176 | NatGas |
| 3 | CCGT | 7649 | NatGas |
| 4 | Wind | 0 | Wind |

The efficiency fo a combined cycle gas turbine (50% from this data) over a coal fired boiler (37%) is obvious. This data is a few years old and there have been improvements in turbine efficiency in the last 5 or 10 years.

## CO2 intensity

In [28]:
```
specificCO2
```

Out[28]:

| | fuel | kgperMMbtu |
|---|---|---|
| 0 | NatGas | 53.07 |
| 1 | Coal | 95.35 |
| 2 | Wind | 0.00 |

In [29]:
```
# common basis for CO2 emission per unit energy from each fuel type
# 1 MMBtu = 1.05587 GJ
# 1.05587 GJ per MMBtu

specificCO2['kgperGJ'] = specificCO2['kgperMMbtu']*1.05587
```

## Energy Demand

Now we calculate the amount of energy (gas or electric) needed to provide 10 GJ of heat to the home.

In [30]:
```
# CO2 produced for heating home
# for each method to heat home, tabulate the amount of utility needed
# examples to get 10 GJ of heat
# a 90% efficient furnace needs 11.1 GJ of fuel
# a heat pump with a COP of 3 needs 3.33 GJ of electricity


heatSources['baseHeatGJ'] = heatDemandGJmonth
heatSources['heatConsumedGJ'] = heatSources['baseHeatGJ']/heatSources['heatProdn']
heatSources['gasGJ'] = 0
heatSources['elecGJ'] = 0

for i, row in heatSources.iterrows():
    if heatSources.loc[i,'basis'] == 'NatGas':
        heatSources.loc[i,'gasGJ'] = heatSources.loc[i,'heatConsumedGJ']

    if heatSources.loc[i,'basis'] == 'Electricity':
        heatSources.loc[i,'elecGJ'] = heatSources.loc[i,'heatConsumedGJ']
        heatSources.loc[i,'gasGJ'] = 0



heatSources
```

Out[30]:

| | heatSource | energyUtilization | basis | heatProdn | baseHeatGJ | heatConsumedGJ | |
|---|---|---|---|---|---|---|---|
| 0 | NatGasFurnace | 0.9 | NatGas | 0.9 | 10.0 | 11.111111 | 11 |
| 1 | resistanceHeat | 1.0 | Electricity | 1.0 | 10.0 | 10.000000 | ( |
| 2 | heatPump52F11C | 4.0 | Electricity | 4.0 | 10.0 | 2.500000 | ( |
| 3 | heatPump32F0C | 3.3 | Electricity | 3.3 | 10.0 | 3.030303 | ( |
| 4 | heatPump0F-18C | 2.6 | Electricity | 2.6 | 10.0 | 3.846154 | ( |

In short, supplying 10 GJ to our use requries 11 GJ of natural gas. Or, if we are using a heat pump, between 2.5 -- 3.8 GJ of electricity (depending on the outside temperature).

# Electrical power generation

Determine the CO2 emissions from each of our thermal power plants.

In [31]:
```
# sort out the CO2 emissions per unit energy for electricity productio
n
# 1.05587 GJ per MMBtu
elecSources['kW_per_kWhr'] = elecSources['BTU_per_kWhr']*1.05587
elecSources['spConsumption'] = elecSources['kW_per_kWhr']/3600
elecSources['effic'] = 1.0/elecSources['spConsumption']
elecSources['kgperGJ'] = 0.0  # CO2 emissions

# we need to account for the amount of thermal energy to produce unit
energy of electricity
# and then the mass of CO2 per unit thermal energy
# messy code, but it works
for i, row in elecSources.iterrows():
    if elecSources.loc[i,'fuel'] == 'Coal':
        elecSources.loc[i,'kgperGJ'] = specificCO2.loc[1,'kgperGJ']*el
ecSources.loc[i,'spConsumption']

    if elecSources.loc[i,'fuel'] == 'NatGas':
        elecSources.loc[i,'kgperGJ'] = specificCO2.loc[0,'kgperGJ']*el
ecSources.loc[i,'spConsumption']

elecSources
```

Out[31]:

| | generator | BTU_per_kWhr | fuel | kW_per_kWhr | spConsumption | effic | kgperGJ |
|---|---|---|---|---|---|---|---|
| 0 | BoilerCoal | 10353 | Coal | 10931.42211 | 3.036506 | 0.329326 | 305.706950 |
| 1 | BoilerNatGas | 10353 | NatGas | 10931.42211 | 3.036506 | 0.329326 | 170.150685 |
| 2 | simpleGT | 11176 | NatGas | 11800.40312 | 3.277890 | 0.305074 | 183.676621 |
| 3 | CCGT | 7649 | NatGas | 8076.34963 | 2.243430 | 0.445746 | 125.710672 |
| 4 | Wind | 0 | Wind | 0.00000 | 0.000000 | inf | 0.000000 |

Our coal fired power plant produces the most CO2 for a GJ of electrical energy. A simple cycle gas turbine is slightly less efficient than a coal fired plant, but benifits from the lower CO2 intensity of natural gas compared to coal. The clear winner for emissions is the combined cycle gas turbine.

## Supply and Demand

Now we can look at the impact of heating our home with different methods, in terms of CO2 emissions. We need to consider which source of energy ramps up to meet the demand from the additional load provided by our house. If there are different electrical generators on the grid (coal fired, CCGT, wind), it is not obvious if the coal fired plant or the CCGT will increase output when there is an increase in the base load (from an additional home).

I will construct a table for comparison.

In [32]:
```
# OK, now we can calculate the total amount of CO2 for each source of electricity and fuel fur heating
# later
heatSources['BoilerCoal'] = 0
heatSources['BoilerNatGas'] = 0
heatSources['simpleGT'] = 0
heatSources['CCGT'] = 0
heatSources['Wind'] = 0

#thisSource = 'BoilerCoal'  # sample
gasSpecificCO2    = specificCO2.loc[specificCO2['fuel'] == 'NatGas','kgperGJ']

for j, rowj in elecSources.iterrows():
    thisSource = elecSources.loc[j,'generator']
    powerSpecificCO2  = elecSources.loc[j,'kgperGJ']
    powerSpecificFuel = elecSources.loc[j,'spConsumption']

    for i, rowi in heatSources.iterrows():
        # I need GJ energy for heating, GJ fuel per GJ heat, kg CO2 per GJ fuel
        gasHeat      = heatSources.loc[i,'gasGJ']
        elecConsumed = heatSources.loc[i,'elecGJ']
        heatSources.loc[i,thisSource] = gasHeat*gasSpecificCO2[0] + elecConsumed*powerSpecificCO2
```

kg CO2 emissions for 10 GJ of heat to the house.

In [33]:
```
heatSources[['heatSource','BoilerCoal','BoilerNatGas','simpleGT','CCGT
']]
```

Out[33]:

| | heatSource | BoilerCoal | BoilerNatGas | simpleGT | CCGT |
|---|---|---|---|---|---|
| 0 | NatGasFurnace | 622.611343 | 622.611343 | 622.611343 | 622.611343 |
| 1 | resistanceHeat | 3057.069498 | 1701.506851 | 1836.766210 | 1257.106723 |
| 2 | heatPump52F11C | 764.267374 | 425.376713 | 459.191552 | 314.276681 |
| 3 | heatPump32F0C | 926.384696 | 515.608137 | 556.595821 | 380.941431 |
| 4 | heatPump0F-18C | 1175.795961 | 654.425712 | 706.448542 | 483.502586 |

# Discussion

First off, electrical resistance heating has the highest CO2 emissions for all of the methods. Even if my electricity were generated by wind and there was a coal fired power plant on the grid, the planet would be better off if I burned natural gas for my home and used the wind power to back out the coal fired power plant.

If the balance for electrical supply comes from a coal fired power plant, then a natural gas furnace will always result in fewer CO2 emissions than an electrical powered heat pump.

The story changes if the balance for electricaly supply comes from a CCGT. Here, the heat pump is the clear winner, even in fairly cold temperatures of -18 C (0 F). This result surprised me, but the math does not lie. We should be making energy decisions based on statistical cases (not rare extremes): we need to consider the merits of a heat pump with CCGT, particularly in climates with moderate winters.

But what about those rare winter cases that stretch the power generation capacity to the limit (ie, the Texas cold snap)? One backup would be a natural gas fireplace (70% efficient, no electricity needed) as a heat source that is independant of the power grid. Camping out in the living room is much better than the alternative. A more expensive (but less reliable) backup would be to use a mid-efficiency (80%) gas furnace as the air handler for the heat pump. Home-owners would then be able to heat their homes with natural gas, off-load the power generating facility, and allow electricity to be used where there are not options for energy supply.