The Oil Drum
DISCUSSIONS ABOUT ENERGY AND OUR FUTURE

The Cogeneration Stopgap

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The prospect of going through a cold winter with inadequate heat is a real one. More and more Americans are putting their winter heating fuel on credit, increasing their level of debt and the burden of servicing it. This cannot continue indefinitely. When the ARM resets or the credit cards max out, the whole house of cards (including paying the mortgage) falls down. Foreclosure is the problem in the mid-term, but freezing strikes as soon as there's no fuel for the furnace.

This problem is made much worse by fuel shortages and the consequent price spikes. As fuel supplies go down, prices go up. The alternative is rationing, but this has costs too; if commerce is shut down, employees don't get paid and the problem of paying for heat is much the same.

The problem comes down to affordability. Whether there is a limit to the gas available, or if incremental supplies command unaffordable prices, the alternatives are to do more with less, or do without. As N. American gas supplies are already shrinking, any good solution has to involve getting out in front of the problem and staying there.

So what can we do?

In the end, natural gas will be too expensive to burn just for space heat. The obvious long-term solution for most areas is a combination of superinsulation and passive solar design; if you need no fuel, you don't care how much it costs. Does anyone care about the cost of spermaceti anymore? But that's a 50-year goal; the immediate problems are going to center around keeping existing buildings warm and lit until they are finally renovated or replaced.

If we have a relatively fixed building stock and a declining supply of gas for heat, the problem becomes one of getting the same amount of heat out of less fuel. The big question is if we can do that, and how?

Can we do it? I believe the answer is "yes".

Why should you believe me? Because I see a way for it to be done. The technologies have been with us for decades, though newer ones will improve the performance. It's attractive enough that some businesses have been moving this way for years; all we have to do is accelerate the existing trends.

How do we do it? In the longer term, we replace natural gas with electricity. But this takes a relatively long time to plan and build generators, transmission lines, and so forth. In the short term, we do jiu-jitsu with entropy.

The nature of the fix

Getting into the details requires a discussion of entropy.

Entropy is a rather arcane concept, and hard to grasp without at least an introductory course in thermodynamics. I'm not going to ask that of readers here, or take the time and space for the digression. I'm just going to ask you to accept three things:

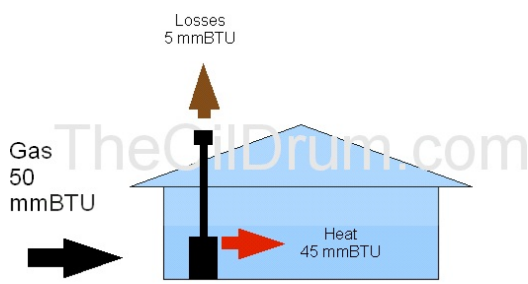
- That energy is conserved; any energy in a system came from somewhere, and can neither be created ex nihilo nor disappear.
- That energy in the form of *work* (turning a shaft, electricity) is more useful than energy as heat.
- That *work* can be used to move other energy around in useful ways. One is to push heat from a lower temperature to a higher temperature.

How does this help fix things? It helps if I restate the problem.

The nature of the problem

We have a lot of building stock which was constructed with relatively poor insulation and little attention to passive heat gain and thermal mass. Most of this building stock is heated by burning fuel in an open flame at a couple of thousand degrees F, then diluting the heat down to a comfortable temperature.

This dilution of heat involves an enormous increase in entropy. Allowing an increase in entropy means throwing away an opportunity to do useful work. What kind of useful work could we want? Simple: we could use some work to push more heat (a *lot* more) to where it does us some good! And how do you do that? A few pictures might help:



House #1

Here is house #1. It needs 45 million BTU of heat per year to stay warm in the winter. If it is heated by a condensing gas furnace at 90% efficiency[1], it will use 50 million BTU/year of gas (and 5 million BTU goes up the chimney). At near-future prices of perhaps $1.50/therm (100,000 BTU), the gas will cost about $750/year. As natural gas supplies shrink, the price of natural gas will tend toward parity with the price of oil. Oil at $100/barrel is roughly $1.70/therm; since natural gas is interchangeable with oil for some purposes, we can expect this to be a price floor relatively soon.

90% efficiency may sound like a lot, but it isn't in this context. The gas furnace is essentially taking the expensive energy as high-temperature heat and, by diluting it, immediately throwing a great deal of its usefulness away. We don't have to do this. What we want to do is take the fuel and extract some of the energy as work; we can use the waste heat for heat, and the work as the muscle for our jiu-jitsu. [Climate Energy] even has complete systems for sale; not the exact specifications desired, but proof that it works.

Climate Energy's cogenerator efficiency is our major point of interest. They claim 18.5 thousand BTU/hr in to get 1.2 kW of electricity out (about 4100 BTU/hr of electricity). This is a thermal efficiency of about 22%. Losses come to another 2400 BTU/hr, or about 13%. The losses are a bit high (probably due to the design), but the efficiency seems about par for an engine of that size.

When the heat demand goes over 12,000 BTU/hr, the Climate Energy system has to fall back to a conventional furnace. This sacrifices the advantage from cogeneration. We can improve the system efficiency with two changes:

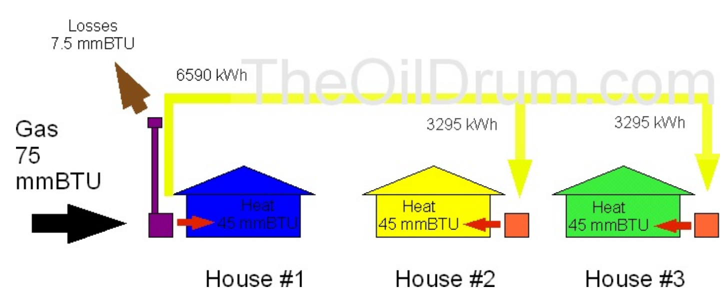
1. Making the engine bigger, to supply all heating demand from the engine and reduce heat losses to the cylinder walls.
2. Using outside air to feed the engine and recover latent heat in the exhaust.

With these changes, we can almost certainly hit 30% thermal efficiency in the cogenerator, and 90% total efficiency[2].

Assume that we've got it. What do we do with it? Using this in just one house wouldn't help. Gas demand would go from 50 million BTU/year to 75 million BTU/year per house. How does this improve matters?

Sharing is caring

The twist comes when we get to houses #2 and #3. In the process of heating itself, house #1 would generate 22.5 million BTU (6590 kWh) of electricity. Electricity is energy, but it isn't just some random form of energy; it represents *work*, which is far more useful than heat. As a matter of fact, it can be used to push heat from colder temperatures to warmer ones using a heat pump. The best heat pumps can achieve leverage of 4:1 and more (HSPF of 13.6 or greater).



House #1's cogenerator makes 6590 kWh of electricity, or 22.5 million BTU worth. House #2 needs 45 million BTU of heat, but its heat pump only needs 11.25 million BTU of electricity (3295 kWh) to supply it. The surplus passes on to house #3, which is completely heated by the remaining 3295 kWh. We're now heating *three* houses on the gas that it formerly took to heat *one and a half*; given that it would have taken 150 million BTU to heat all three houses using gas furnaces, the net reduction is 50%. At $1.50/therm, the total cost of heating all three houses is just $1125/year, or $375 each. The reduced demand for gas will help hold the price of gas down. If oil goes to $200/bbl and natural gas prices follow suit, gas will cost about $3.45/therm and the combination of cogeneration and heat pumps would save about $2600/year.

I hear you saying "Wait! You can't make 135 million BTU of heat out of 75 million BTU of gas!" You're right; there is something missing from this diagram. The part that isn't shown is the 67.5 million BTU of heat taken from the outdoors by the two heat pumps and pushed indoors, courtesy of the capabilities of energy in the form of *work*. Energy is conserved throughout. Entropy also increases at every step, satisfying the Second Law of Thermodynamics.

What would this cost? In mass production of several million units per year, I suspect a cogenerator could cost as little as $2500 (this is about what a much more powerful car engine, with 4 times as many cylinders and much more complexity, costs). A single-cylinder engine making 6 kW of power at 30% efficiency would generate 14 kW (47,800 BTU/hr) of waste heat. One such engine could replace a small-size furnace. If the price of natural gas is equivalent to $200/bbl oil, the cogenerator would pay for itself in less than 5 years.

Half a loaf will get you to the store

The final objection, and also valid: "This only gets us halfway. Once gas supplies fall below 50% of today's, we're stuck again."

That's true as far as it goes, but nothing happens in isolation:

- We can get better than 30% efficiency. Delphi and other companies are working to make solid-oxide fuel cells for automotive use. These are already achieving efficiencies in the neighborhood of 50%. At 50% efficiency, one house with a fuel cell can power FOUR houses with heat pumps, and fuel demand falls another 20%. Even 50% isn't the limit; direct-carbon fuel cells (DCFC's) can turn charcoal into electricity with efficiency as high as 80%.
- The cogenerator is (remember the title?) a *stopgap*. Cogenerators can make up the difference between the rapidly-increasing power needs of heat pumps and the slower increase of other electric generation (esp. renewable generation), the decline of gas supplies and the renovation and replacement of the building stock. We will probably spend the next 10 years installing engine cogenerators, another 20 years building fuel cell cogenerators to replace worn-out engines, and the last 20 years phasing them all out as the building stock gets updated.

Can we build this many cogenerators? It looks easy. The USA currently buys about 17 million light vehicles per year, and 99% of them come with some sort of piston engine. Many of these engines have 6 or more cylinders, and can produce at least 100 horsepower (75 kilowatts) per engine. There are roughly 50 million buildings heated with natural gas; converting 10% of them per year would require just 5 million cogenerators. If each cogenerator has one cylinder producing 6 kW, this is about 5% as many cylinders and less than 2.5% as much power as each year's vehicle fleet.

Other twists

Nothing happens in isolation, and the cogenerator/heat pump scheme would be no exception; it would be intimately connected to the electrical grid, and by extension it would connect to *everything else that's plugged in.* The effects snowball, and they're all good:

1. Any other source of power offsets demand for natural gas; if houses 1-3 have wind power available 30% of the time, about 5900 kWh (1/3 for the heat pumps, 2/3 for a resistance heater to substitute for the cogenerator) would cut gas use by 30%. If off-peak wind power costs 4¢/kWh, this would use $236 of electricity to displace $338 of natural gas at $1.50/therm. If natural gas climbs to $3.45/therm, the wind would displace $776 of gas.
2. Electric vehicles or PHEVs could be charged from the extra generation resource; shortage of electricity would be put off for quite some time.
3. Adding to #2, displacing petroleum from motor fuel would allow it to be used as heating

fuel... in cogenerators, further extending the supply of both heat and electricity.

4. Adding as much as 300 GW of cogeneration to the grid, most of it within a block of the point of use, would add stability to the grid and slash transmission losses.
5. Any community with enough cogenerators would be able to operate as an "island" during a winter grid outage, making power interruptions far less troublesome. Given electric vehicles with V2G capability, these islands could be as small as one house.

As you can see, there are many reasons to start on this path now.

Summary

A large part of the USA needs heat in the winter, and much of this is supplied by natural gas. N. American gas supplies are shrinking rather rapidly, so we must do something about it for both the long and short term. While we wait for the building stock to turn over, the combination of cogenerating furnaces, heat pumps and other grid-connected devices can shrink our total fuel demand, allow us to make substitutions much more easily and turn big problems into minor inconveniences. If we want a warm, clean, secure and affordable future, this is a good place to start.

Footnotes:
1. 90% is on the low end of efficiency figures for condensing furnaces (which go up to about 97%), but it makes the numbers neater. The broader conclusions are the same.
2. These numbers are also chosen to make the arithmetic come out more neatly; small changes make small differences.

Further reading

Ground Source Heat Pumps, by Heading Out.