Intro Gas and Electricity

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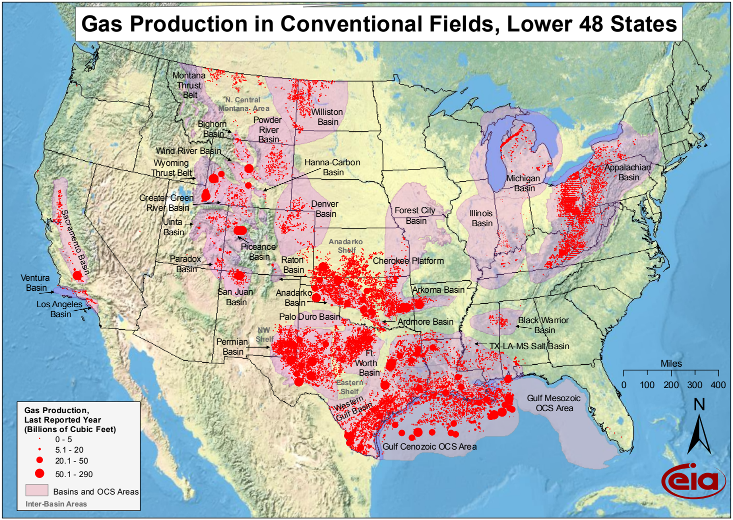
Objectives

- Need some idea of how we get natural gas and electricity
- Need to know some of the ways we regulate those two at both state and federal level
- Some background on Distributed Generation

Natural Gas

Where is it produced? Just conventional



Source: Energy Information Administration based on data from HPDI, IN Geological Survey, USGS
Updated: April 8, 2009

Figure 1:

More in the shale areas.

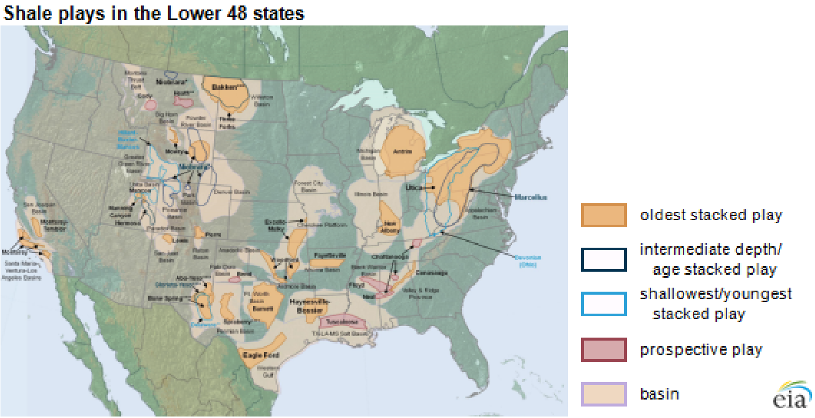


Figure 2:
https://www.eia.gov/todayinenergy/images/2015.04.17/main.png

How do you move it within the US? Pipelines (Interstate only).

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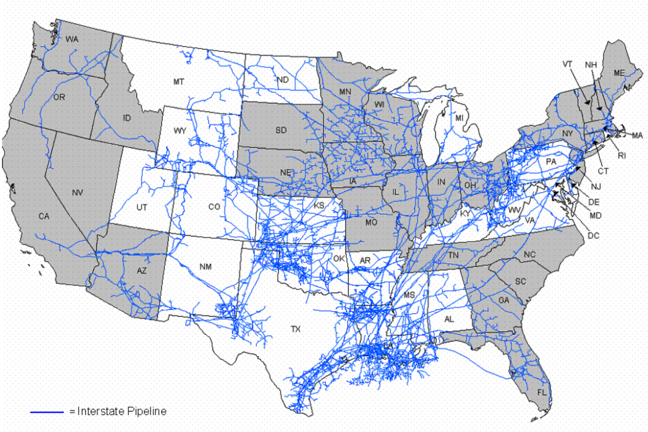


Figure 3:

What about those pipelines?

- There are more intrastate pipelines than shown, plenty in TX and CA but also other states
- Read more here https://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/ngpipeline/transcorr.html
  - Picture pipes ranging from a foot to three+ feet for trunk lines.
  - Compressor stations every 50-100 miles, ~1,500 total
  - 200 psi to 1,500 depending
- They are privately owned https://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/ngpipeline/MajorInterstatesTable.html
  - Open access, posted prices, is a thing.
  - For intrastate, within, state PUC regulate
  - For interstate, FERC regulates (You can find current Tariffs at http://etariff.ferc.gov/TariffList.aspx)

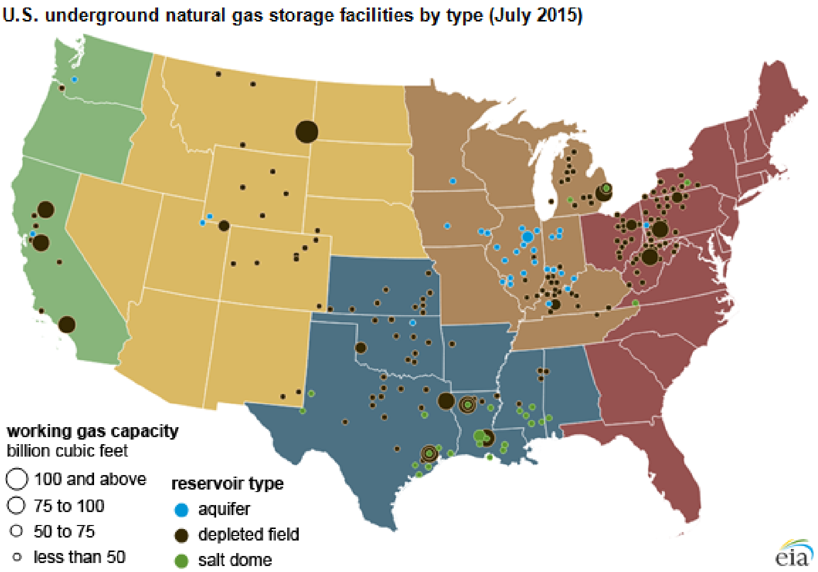
Compressors

Figure 4:

Compressor Station

Figure 5:

Storage is important



Most Storage is just old gas wells

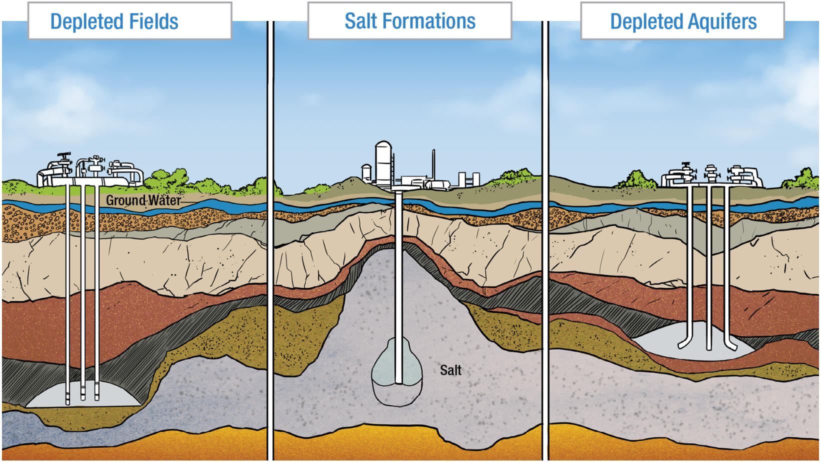


Figure 7:

Storage is very seasonal

There is a weekly report on storage by EIA
http://www.eia.gov/dnav/ng/hist/nw2_epg0_swo_r48_bcfw.htm

- Note the seasonality
- Note the factor of 2+ changes over the term

Hubs, where transactions are made

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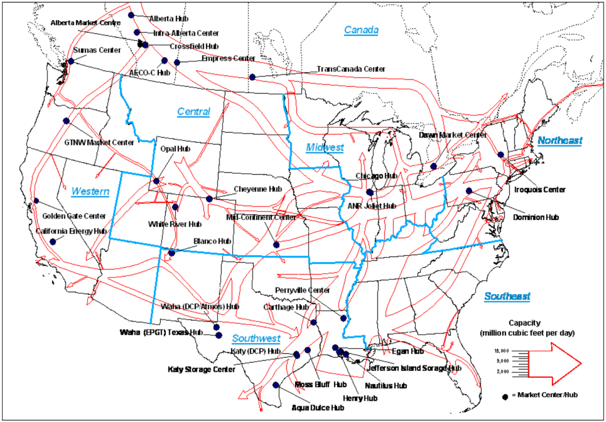


Figure 8:

Figure 8:

Part of Henry Hub LA

Figure 9:

Getting to Prices

- You will see wellhead prices, but
- Most references prices are at the hubs.
  - Henry Hub in LA is the most common reference hub for prices
  - There are fairly firm relationships between other hubs and HH except when there is congestion.
  - Changes in the usual difference are usually called basis blowout. Term is not specific to energy.
- Intercontinental Exchange for Gas Itself
  - https://www.theice.com/products/OTC/Physical-Energy/Natural-Gas
- FERC for transportation tariffs (Regulated)
  - http://etariff.ferc.gov/TariffList.aspx
  - Some are fixed and some have a market rate component.

It is hard to talk about gas separate from transportation.

Electricity

What Makes Electricity Interesting

- We somehow start with a fuel (Counting wind, geothermal and sunlight in this).
- Transport it from where we found it to a generating facility.
- Turn it into electricity losing some energy as heat.
- Run it along long wires to where people want to use it, losing yet more energy.
- From there send it out to every small location (losing more), and
- Because electricity is not *easily* stored, adjust the rate at which we generate electricity moment-by-moment to make sure there is just enough.

This is a logistical miracle.

Basic Units

- $Watts = AmpsVolts$ first thing everyone learns.
  - Pro tip on units, if it is someones name, capitalize it.
  - Volt is analogous to height.
  - Amp is analogous to a weight.
  - Watt is what it happens when that weight is dropped from that height.
  - DC is easy; AC is "complex"
- AC because it is a wave, has a few more components.
  - Real Power, measured in W, it is what does the work.
  - Reactive power, measured in volt-amps (var),"r" tells you it is reactive, is what pushes the electricity around.
  - Apparent Power, is in volt-amps too (VA) is when you add the two together in a vector sense.
  - Power Factor is the Real(W)/Apparent(VA), the sign is interesting because assumes induction.

What?

Caveat IANAE and I will do thing like call current amps and the like. Also, this is the simple, single phase, view with lots of simplifications. Reality is for engineers.

- The alternating part of AC is what causes the complication.
  - You can talk about instantaneous power but
  - Tend to talk about average power.
- With a resistive load, think light bulb, amps and volts are in sync
- Inductors and Capacitors throw amps and volts out of sync
  - Capacitors store energy in electric fields. Think a very burst battery.
    - Amps peak *before* volts
  - Inductors store energy in magnetic fields. Think about an electromagnet in a motor.
    - Amps peak *after* volts

Picture for this

AC Power to a Resistive Load

AC Power to a Inductive Load

AC Power to a Capacitive Load

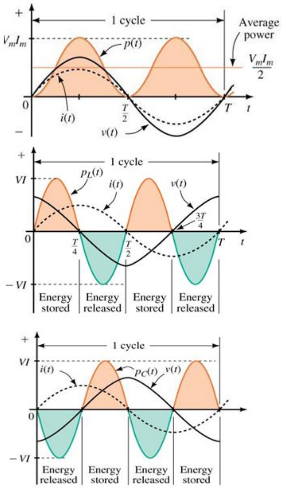


Figure 10:

Power Factor

- Measure it
  - Henrys are the unit for inductance/capacitance and engineers use that in calculations
  - There are also power factor meters
  - You can also check out the difference between amps and volt on oscilloscope.
- Low numbers mean the utility needs to generate more power than customer uses.
  - Can happen with low load, like a motor barely moving, but you still need the electromagnet
  - Common solution is to install capacitors somewhere to cancel out the inductor

Why do we care about reactive power and power factors?

- Engineers have to design systems to accommodate not just the real, but real plus reactive, i.e., apparent power.
- Reactive power has to be generated.
- Not residential tariffs, but commercial and industrial tariffs charge for reactive power or have penalties for low power factors.

kW vs kWh

- kW is instantaneous and called power
- kWh is the integral over time and called energy.
- 100 W light bulb uses 100 Wh $=$ 1/10 kWh per hour
- Get used to flipping between 1,000,000,000 W $=$ 1,000,000 kW $=$ 1,000 MW $=$ 1 GW

Lets Generate Some Electricity

- Turbine – spin something in a magnetic field to induce a current.
- Lots of ways to spin a turbine
  - Coal, grind it up, burn it, make steam, use steam to spin the turbine.
  - Nuclear, use the heat to make steam, use steam to spin a turbine.
  - Biomass, burn stuff to ...
  - Gas, burn it to spin a turbine ...
  - Fuel Oil or Diesel
  - Solar thermal, use the sun to make steam ...
  - Water, falling water hits a turbine and spins it
  - Wind, spin a turbine
  - etc.
- Or don't spin a turbine and go for photo-voltaic, PV.

Characteristics

- Nameplate, fully loaded under ideal conditions (MW)
- Ramp rate, how fast power (MW) can change MW/min
  - Not always constant, can differ by capacity factor (fraction of nameplate)
  - Not always symmetric, up different from down.
  - Used to follow the load.
- Heat rate, BTU in/ BTU out, only used for generation that uses a fuel.
  - 1 is impossible but 1 kW $=$ 3412 BTU.
  - Recent average from EIA, https://www.eia.gov/electricity/annual/html/epa_08_01.html

Coal from the outside

Source
http://appvoices.org/images/uploads/2012/02/Asheville-coal-plant-e1432059203783.jpg

Coal on the inside

- Pulverize the coal, picture something that can do 20 Tons/hr
- Blow it into combustion chamber to burn
- Steam turns turbine, etc. https://youtu.be/IdPTuwKEfmA
- Clean up
  - NOx with ammonia common but plenty of others
  - Recover fly ash and sell it, great for concrete.
  - SOx, Mercury and other. BTW Radiation

Nuclear

Radiation to heat water and then . . . similar to coal. Just a reaction chamber

Local Reactor Columbia Generating Station

- 1,170 MW usually runs as load following. It reacts fast enough.
  - France is ~70% nuclear and they load follow.
- Most nuclear is run as base load, i.e., all the time since low variable cost and high fixed cost.
- Palo Verde (AZ) is larger 3.3GW

So, about nuclear

- So what to do with spent fuel.
- They probably produce less radiation than coal
- Can produce cheap, in the marginal cost sense, power. More on this later.

Natural Gas Conventional and Combined Cycle

- Combined cycle means
  - Taking more than one pass at extracting energy.
  - Spin the turbines first.
  - Take the heat and run a steam turbine.
  - Take the remaining heat and use a different working fluid (with different phase change properties) to extract more.
- CCNG
  - Plants are more expensive
  - Have lower heat rates, which means more efficient.
- Conventional
  - Cheap
  - Commonly run as peaking units.

Biomass

- Tend to be combined heat and power. Another way of using waste heat.
  - Cogeneration like this is common.
  - We have steam and chill water systems on campus
- While renewable, it is not, in general, clean
  - Particulates
  - Heavy metal concentration
  - etc.
- All this is improving.

Biomas One in Eugene. 30 MW and keeps catching on fire.

Figure 12:

Geothermal

- Drill a hole down to where the temperature is high enough.
  - If it is dry, add water to make steam.
  - If wet, get steam
  - If temp is not high enough, use a few working fluids to generate electricity.
- Run through a turbine.

Neal Hot Spring in Malheur. 30 MW

Figure 13:

Diesel and other Fuel Oils

- You know the drill ...
- Less than 1% in the US for electricity generation.
  - Still common heating fuel.
  - Backup fuel for NG generation
  - May be used in small distributed generation
- More common in less developed countries

Solar Thermal

- You have see the low and mid temperature designs for heating and cooling.
- High temperature designs are:
  - Dish
  - Tower
  - Trough
- Fluids:
  - Oil
  - Salt
  - Water steam
- Low and mid temperature are similar to roof top residential that you have seen.

Hydro

So, you spin a turbine

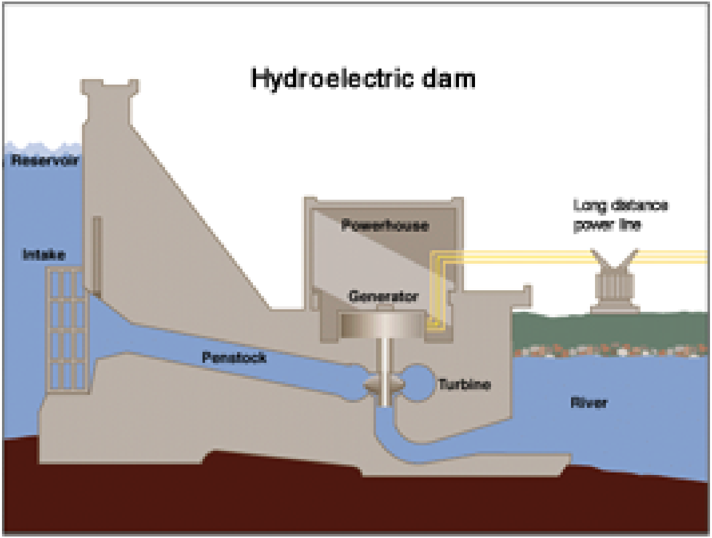
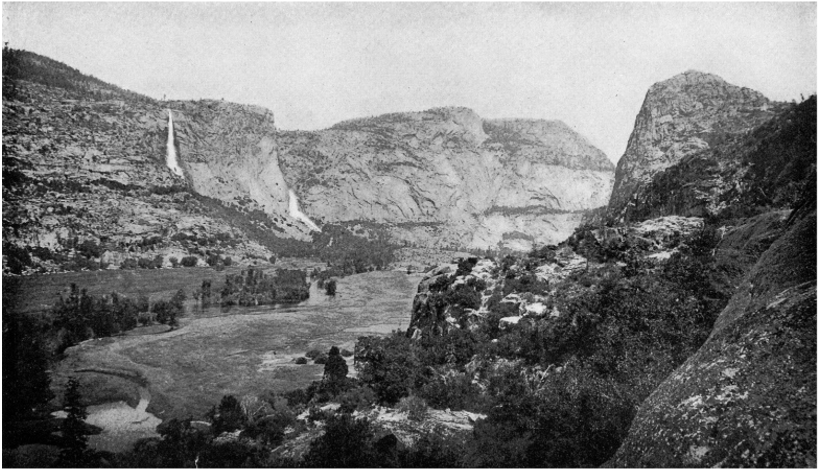


Figure 14:

Hydro can be complex

- Many constraints
  - Intra and interseason storage requirements
  - Temperature and turbidity constraints
  - Treaties and contracts
  - Minimum and maximum flow constraints
  - Dredging
  - Water quality
- Can you go all hydro?
  - US $\sim$6%
  - Norway $\sim$95%

Everything Comes with a cost



Hetch Hetchy Valley 1908. Photo by Isaiah West Taber

Figure 15:

Wind

- You find a good wind resource NREL Class 3 and up (http://www.nrel.gov/gis/wind_detail.html)
- Put up a suitably rated 2.5–3 MW windmill (Larger over time). 8MW is the largest I've hear about.
- Maintain them, upgrade them and if need be demo them.
- What people complain about
  - Noise – Can't hear after a mile or two
  - Raptor and bat kills – Less now with larger slower moving designs.
  - Ugly – In in the eye of the beholder.

PV

- Does not spin a turbine.
- PV effect generates DC electricity which is then converted to AC though an inverter

Levelized Cost of Electricity (LCOE) and Levelized Cost of Avoided Electricity (LACE)

- https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf Table 1
  - CC is Carbon Capture.
  - CCS is Carbon Capture and Storage

Distributed Generation

DER vs DG

- DG $=$ Distributed Generation
- DER $=$ DG $+$ Storage

May seem like semantics but small storage grew in potential since 2005

What is in DER

- Definitions vary but Small (< 49MW) generation seems to count with < 1MW most common.
  - Plenty of renewable
  - Small turbine
  - Backup generators
  - Battery banks.
- Combined Heat and Power
  - Steam Generation
  - Chill Water
  - District Energy

Why Would I (Private) Build It?

- Power Quality
  - Equipment is sensitive to voltage drops or spikes
  - Equipment is sensitive to frequency variation.
  - Wave shape and harmonics
  - High reactive power needs (Often avoids utility charge.)
- Reliability (Often combined with quality)
  - High cost of interrupted power, e.g., hospital
  - Two common measures
    - System Average Interruption Duration Index (SAIDI), average total time without power over a year.
    - Customer Average Interruption Duration Index (CAIDI), average time without given your power is out.
    - Many more relating to frequency and cost of lost service.
  - You could have lower rates if you have an interruptible tariff.

Why Would I (Private) Build It? (Cont)

- Peak reduction
  - If you have demand (kW) charges, your maximum use.
  - If you have a coincident peak (kW) charge, you use at system peak.
- Cogeneration Opportunity
  - Already need Steam or Chill water
  - Electricity generation is a bonus
- Reduction in volumetric (kWh) charges
  - Net metering just a bit to shave off the high block charges
  - Peak Pricing Tariff
  - Real-time Prices.
  - Nice subsidy.
  - Actually, social cost, cheaper.
- The utility side is significantly more complicated.

Why The Controvoursy

- Limited markets for local reactive power.
- Limited markets for local reliability.

Three simple ways of thinking about costs

- The Make vs Buy trade-off (TC).
- The Minimum Efficient Scale (AC), i.e., volume such that AC is at a minimum.
- Investment Delay, a time value of money concept.

With all cost estimates the key conceptual problem is to only look at incremental costs.

- It is often unclear what those incremental costs are relative to.
- Cost does depend on your point of view.

Example Make vs Buy

- Assume cost functions of $C = F + \alpha q$ form.
  - Fixed cost
  - Constant average variable cost
- Make vs Buy: Given known q, Choose the least cost technology

Example MES

- Several definitions of MES
  - Quantity such that $MC = AC$.
  - Quantity such that AC decreases very little as quantity increases.

Example Investment Delay

- Pushing costs into the future can be valuable.
- Value of delay increases as interest rates increase.
- Exponential discounting $P = \frac{F}{(1+i)^N}$.
- Example: Maintenance expenditures of \$100 a year forever. What is the value of skipping a year?
  - $PW(Maintenance) = \frac{100}{i}$ At i = 10% this is 1000.
  - Delay for 1 year is $\frac{\frac{100}{i}}{1+i}$. This is 909.09.
  - The difference is the savings.

Report Example

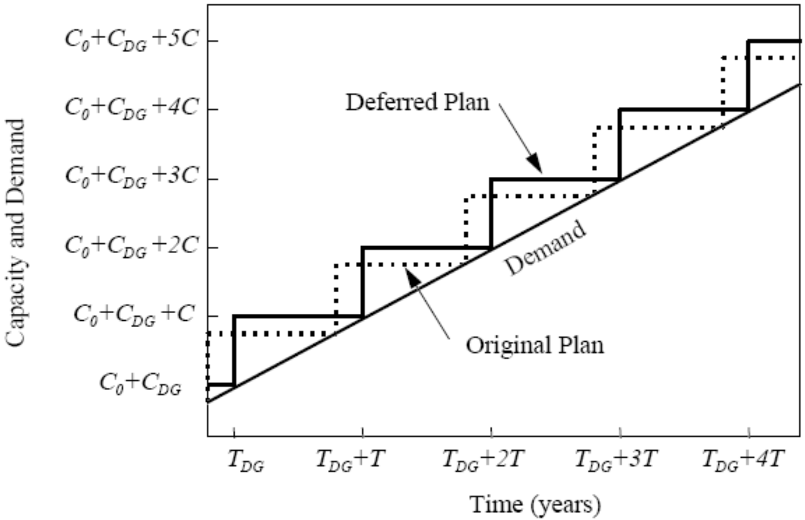


Figure 16:

How Did We Get to the Current G-T-D Arrangment (MES Argument)

- Both large scale and small scale originally existed.
- Large scale developed
  - Lower AC
  - Higher MES
  - Speed of change up till 60s made this the dominant form.
- Small scale continued to develop
  - Right sized scale and MES
  - Decreasing AC
  - 1978 Qualifying Facilities Era was when they could sell power under some conditions.

Private Choice of Technology (Make vs Buy Argument)

- Have access to utility power and DG.
- Several States of Opportunity Costs
  - If you have no special needs and need to pay full cost of fuel.
  - If you have 'Free' access to fuel, e.g., wood chips, AC of DG is lower.
  - If power quality or interruption is not what is desired, AC of utility power is higher.
  - If you face a Peak, Time of Use or Demand Charge.
  - More complicated diagrams can be made but this works.

Utility Point of View

Please note that lots of power quality issues need to be solved on the D side, with capacitors and transformers. Power quality may actually get worse with new equipment and DG.

- Utility: Supply customer needs with T+G or with DG. Trade-offs between the two in an isoquant/isocost sense.
- Customer: Decide to take utility solution or provide with private DG. (Make vs Buy).

What is going on NOW

- Proposed rule for virtual power plants, though not by that name, as well as new definitions so DER can participate at the wholesale level. (Nov 17, 2016)
  - https://www.ferc.gov/whats-new/comm-meet/2016/111716/E-1.pdf
  - CAISO has had them for a few years http://www.caiso.com/Documents/Non-GeneratorResourceRegulationEnergyManagementImplementationP pdf
- New York is on the topic too. (Oct 27th, 2016) http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId={59B620E6-87C4-4C80-8BEC-E15BB6E0545E}

The FERC Proposal

- Elimination of Barriers to Electric Storage Resource Participation in Organized Wholesale Electric Markets.
- Participation of Distributed Energy Resource Aggregators in the Organized Wholesale Electric Markets

The Barriers

Please note that many market definitions vary by ISO/RTO. FERC gives directions.

- Rules are set up to accommodate existing technology:
  - How long they can provide service
  - How they provide service
  - Often restricted to regulation service
- Examples
  - ISO-NE requires registered Generator Assets to participate in all wholesale markets
  - Common vision of storage is pumped storage with under an hour use.
- Some RTO/ISOs are better
  - PJM Energy Storage Resource Model
  - CAISO Energy Storage Resource model
- But all are found wanting by their own assessment or others that wish to participate.

Connection to Demand Response

Demand response is typically:

- Things done on the consumer side of the meter
- Remote turn of of equipment
- Agreements to turn off with notice
- Getting paid for not consuming electricity

The reason is that demand response is considered a residual definition, if not generation then demand response.

Virtual Power Plants, aka, Aggregators

- Typically there is a minimum size to participate in the wholesale markets. Minimum size is defined by the unit.
- Aggregation allows you to combine many small units and operate them as one large unit.
- Common practice
    - Banks are savings agregators
    - Corporations are investment aggegators to accommodate small investments.

The FERC Proposal for Participation Model

- Electric storage resources must be eligible to provide all capacity, energy and ancillary services that they are technically capable of providing in the organized wholesale electric markets;
- The bidding parameters incorporated in the participation model must reflect and account for the physical and operational characteristics of electric storage resources;
- Electric storage resources can be dispatched and can set the wholesale market clearing price as both a wholesale seller and a wholesale buyer consistent with existing rules that govern when a resource can set the wholesale price;
- The minimum size requirement for electric storage resources to participate in the organized wholesale electric markets must not exceed 100 kW; and
- The sale of energy from the organized wholesale electric markets to an electric storage resource that the resource then resells back to those markets must be at the wholesale LMP.

Commentary Bidding Parameters

- Not just about storage. This is aiming for technology neutrality.
- Bidding parameters could include things like state of charge, like CAISO and NYISO.
- MISO is more detailed requiring hourly max levels, storage rates,etc.
- Proposal is: "RTOs/ISOs establish state of charge, upper charge limit, lower charge limit, maximum energy charge rate, and maximum energy discharge rate"

Commentary (Con't)

- Balance between the additional costs and complexity to the ISO/RTOs and the benefits of technological development
  - Makes it harder to manage the grid.
    - NG that has connection to pipeline and backup diesel is easier to optimize than battery with limited storage.
    - It literally increases the mathematical difficulty and will require new models. Basically, convert to pumped storage model.
  - May produce "Gresham's law"" power with increased market monitoring costs.
  - New technology does not get developed unless there is a way for it to make money.
- Spinning Reserves requires spinning, but batteries don't spin.

Commentary, Buyer and Seller

- Some existing limitations
  - MISO in real-time market but as demand response
  - NYISO as negative prices on generation side with other restrictions.
- This is a proposal to submit bids as both a buyer and a seller in the same period.
  - Makes sense since this is a special feature of storage but;
  - ENRON did some manipulation of congestion pricing with this. They did it through wheeling but there may be a dynamic analog.

Commentary on size

- Smaller than most ISO/RTO, CAISO is low with 10kW
- 100kW puts high-end Teslas on the list.
- 100kWh Powerpack, at $145K, with $52K inverter buys in.

No Arbitrage Rule or is it?

- Avoids people buying at wholesale and then net metering.
  - I bet there is a way around this!
  - But they used the distribution network to get the power.
- Need new rules for a firewall between the retail and wholesale markets.
  - Can I buy wholesale (G+T) to avoid retail (G+T+D)?

This will be where the next round of trouble will be. How will the load serving entity, i.e., the utility survive?

Aggregation, Virtual Power Plants

- Idea
  - Get a bunch of small DER together.
  - Contract to control market interactions subject to limitations.
  - Pay them for their power/storage
  - Take a slice.
- CAISO idea as far as I can tell but others have done it.
  - Was usually just demand response, i.e., getting paid for not using power.
  - NYISO puts limitations on the size of the individual units, less than 10kW.
- Would allow more behind the meter storage, think PV to participate, but currently many limitations on them injecting power.

Why this is really interesting.

- LMP don't often provide the right incentives for new generation.
  - Prices are high now but
  - Once you enter, prices would be low.
- This allow you to build a power plant for an area a bit at a time.
- May offset some smart grid costs, the generator pays rather than the Load Serving Entity.
- Connects with making the nodes as broad as possible to increase competition.