Optimizing Future Heat and Power Generation

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Executive Summary

This paper seeks the optimum way to supply electric load growth and finds that full reliance on distributed generation (DG) would supply power for 5.8 cents per kWh versus 8.9 cents per kWh from new central generation. **DG reliance would avoid $291 billion in capital by 2020, reduce 2020 incremental power costs by $52 billion and reduce NOx by 68%, SO_2 by 91%, PM10 by 5% and carbon dioxide emissions by 46% versus total reliance on new central generation.** We find that markets have largely chosen central generation due to outmoded laws and regulations that are effectively unintentional barriers to efficiency and we list those barriers in appendix 1.

Our conclusion is unambiguous. States and countries that remove barriers and aggressively implement distributed generation will gain significant competitive advantages over those polities that cling to yesterday's optimal technology – central generation – and fail to remove barriers to more efficient distributed generation. Distributed generation achieves savings versus the traditional reliance on central generation by eliminating the capital cost and losses from transmission and distribution (T&D) of centrally generated power, by recycling the normally wasted heat from electric generation and by producing power with renewable energy. The savings of transmission and distribution and avoidance of T&D line losses are generic to all DG. The table below summarizes key results.

DG as % of Total US Generation

Impact of Generating 2020 Load Growth with Central or Decentralized Generation

	100% CG	100% DG	Savings	% Change
Total Capital Cost (Capacity + T&D) Billions of Dollars	$853	$562	$291	34%
2020 Incremental Power Cost Billions of Dollars	$149	$97	$52	35%
2020 Incremental Power Cost Cents / KWh	8.89	5.78	3.11	35%
Emissions from New Load Thousand Metric Tonnes				
NO_x	255	80	175	68%
SO_2	175	16	159	91%
PM10	155	146	9	5%
Million Metric Tonnes CO_2	720	387	332	46%

Problem Statement

US electric use is forecast to grow 43% over the next 20 years[1] and the T&D system is already over taxed and congested. US thermal and electric energy generation cost about $400 billion in 2000 and the Electric Power Research Institute concluded power quality problems add costs of $119 billion annually. The power industry has not improved delivered efficiency in forty years and is unlikely to select optimal generation choices for load growth, given monopoly protection from competition, regulation put in place long before the emergence of improved decentralized technology. Average pricing camouflages the on-peak costs of power and further lessens the chance of optimal generation selection. Finally, heat and power generation cause 68% of greenhouse gas emissions.

Adam Smith and his intellectual progeny explained how free markets optimize production. Econometric models and the public assume that heat and power generation and distribution are nearly optimal, given current technology. US energy policy has long supported research to find better energy technologies, based on this view. If today's energy system is optimal, then forcing environmental improvement will increase power costs. However, if the energy system is not optimal, optimization could produce economic and environmental gains.

Heat and power are not optimally produced because energy markets are not free. Electricity has been a protected monopoly for 90 years, and the regulatory rules have made it difficult for insurgent firms to challenge incumbent monopolies with new approaches and new technologies. The monopoly rules were designed to 1.) induce rapid electrification by granting monopolies of generation and distribution, and 2.) prevent excessive profits to the monopolists. Given the pervasive electric industry regulation, much of which has not changed for decades, the various actors have not optimized the heat and power market.

Over the past four decades, many decentralized generation technologies have been developed and improved. Today's DG options offer lower capital and operating costs than new central generation with supporting new T&D. But on-site generation by others penalizes monopoly electric companies, and typical state utility regulations offer no reward to the utilities to build more efficient plants. If DG were built, monopoly logic would evaporate, speeding the transition to open competition. This threatens many utility executives.

Heat production is not regulated, but barriers to decentralized generation prevent thermal optimization. Combined heat and power (CHP) plants achieve up to 95% overall efficiency – three times central generation -- by recycling normally wasted heat, but must be located at or near thermal users. The artificial barriers to distributed generation of electricity have prohibited the thermal market from optimizing.

Thus, the actions or inactions of regulators, legislators and policy makers are key to how each state/country supplies incremental electric and thermal demands and these actions will affect economics, environment, power quality and system vulnerability.

A New Tool To Inform Heat and Power Production Regulations

We are electric industry *insurgents*, in Clayton Christensen's *Innovators Dilemma* nomenclature.[2] Over the past 25 years, we have sought to overcome regulatory barriers to develop decentralized generation that enhances value to customers. Although DG advantages are compelling, electric industry regulatory rules are stacked against on-site generation and lead incumbent companies to continue centrally generating most electric power. Even though most regulatory barriers remain, the United States has doubled decentralized generation reliance from four percent of all power in 1978 to eight percent today. We believe that DG would dominate all new generation, but for barriers. To test this hypothesis, we built a model to calculate the key results of generating incremental electric load between

2000 and 2020 for nine scenarios. The scenarios vary from all new central generation to all new decentralized generation and include seven steps in between.

The new model described below is designed to answer the question. "What is the optimal mix of power generation to meet the projected electric load growth?"

We identified seven key goals for any heat and power system expansion, namely to minimize: 1) capital cost, 2) future operating costs, 3) use of fossil fuel, 4) emissions of regulated pollutants, 5) emissions of greenhouse gases, 6) vulnerability to extreme weather and terrorists, and 7) power failures. Some choices for future power generation involve tradeoffs between these seven goals.

Vital Inputs and Relationships

The model was filled with baseline data of existing US generating capacity including capacity of each technology, load factor, fuel efficiency (heat rate per kWh), retirement rate and system reserve margins. This history is separated into central generation that requires transmission wires to deliver power to users and decentralized generation built at or near users. We specified capital costs per kilowatt of new capacity for each technology by reviewing literature, industry web sites and colleagues experience, plus visits to the National Renewable Energy Labs in Golden Colorado for help on renewable technologies. The model incorporates load growth forecasts from the US Energy Information Agency (EIA), which projects consumption of power to grow by 43% over the next 20 years.[3] For each assumption, a model user can choose the default data or change certain assumptions. The model itself is not country specific, and by inputting baseline data for a state, country or region, a user can calculate the optimal way to generate that region's incremental electric load.

Electric generation has locational value. EIA data for 2000 show that only 91% of all centrally generated power reached users, down from 95% reaching users 20 years ago. Growing transmission congestion causes the increasing percentage losses.[4] The losses during peak hours are higher, on the order of 15%, and this determines how much new central generation will reach users during peak hours. Because 15% of centrally generated power is lost during peak hours, 118 megawatts of new central generation capacity and a like amount of T&D must be built to satisfy an incremental peak load of 100 megawatts. (100 MW new load divided by .85 or 117.6 MW new capacity.)

To calculate operating costs of each generating technology, the model has starting assumptions about net efficiency, after credit for fuel saved if heat is recycled. The model asks users to specify the projected mix of new generation technologies for both central and decentralized plants. There are inputs for each possible technology including combined heat and power fueled by gas, oil or by coal. There are cost assumptions for decentralized hydro, wind, solar and biomass capacity, and for generation capacity based on recycled energy. The model defaults to load factors for each technology and rates of progress for heat rates, emissions and capital costs, which the model averages over the forecast period.

T&D Costs

Transmission and distribution (T&D) costs are reported in conductor line miles and each customer requires a differing mix of transmission at high voltages, transformation to distribution voltage, distribution wires and final transformation to user voltages. Consulting firm Arthur D. Little calculated the average cost of a kilowatt of new transmission and distribution at $1260 per kW for 1999.[5] The model assumes that the US transmission congestion is already excessive and adds T&D capacity to serve any new central generation.

Electricity flows from generation to the nearest user, regardless of contract path, so all decentralized generation relieves the overall T&D system. Centrally generated power flows from remote central plants through transmission lines to substations where it is transformed into local distribution voltage. That power then flows through distribution wires to local area transformers and/or user transformers. New DG power is often generated at user voltage, freeing up all of the existing T&D. When DG generation exceeds on-site power needs, the surplus power flows to the nearest user, relieving most of the T&D system.

DG installations have occasional outages during which time the load is supplied by the grid. With thousands of DG plants, the individual outages will be spread across the year, following actuarial patterns. Backing up DG will require dedicated grid for only a small fraction of the load. The model assumes incremental T&D equal to 5% of new DG capacity.

The model defaults to EPA published emissions data for each generation plant type but users can input future emission expectations. Recycling waste heat avoids burning incremental fuel and avoids all incremental emissions. To incorporate this efficiency/emissions link, the model has a correction for efficiency. If the user assumes improved efficiency of a particular generation plant type, the emissions per mWh are reduced accordingly. The emissions of criteria pollutants will be affected by improvements in emission control technology, which have been dramatic for all technologies. For example, new gas turbines emit roughly 2% of the NOx of 25-year-old gas turbines or old thermal power plants, and piston engine builders have made similar improvements. These emission control advances do not extend to carbon dioxide emissions, the major greenhouse gas. There are no known practical ways to capture CO_2 once released by burning fuel without using more energy, compounding the problem. The model calculates CO_2 emissions based on fossil fuel burned in each scenario.

Emissions are often lower per kilowatt-hour for small, DG technologies than for large CG plants, reversing economics of scale. Kawasaki is shipping a one-megawatt gas turbine using a catalytic combustor that is the cleanest gas turbine in the world. This small turbine emits 2 PPM of NOx versus roughly 9 PPM NOx from the best new 250-megawatt gas turbine. Fluid bed boilers with limestone are the technology of choice for coal-fired combined heat and power plants and these decentralized generation projects emit very little NOx or SO_2, but fluid bed technology has not been scaled to central generation sized utility boilers. Consequently, large utility coal boilers have higher emissions than the smaller CHP coal plants. Several companies now offer fuel cells for decentralized generation which have very close to zero emissions, but the technology is not likely to scale to central generation sized plants. Finally, recycled energy is by nature decentralized and has no incremental fuel or incremental emissions.

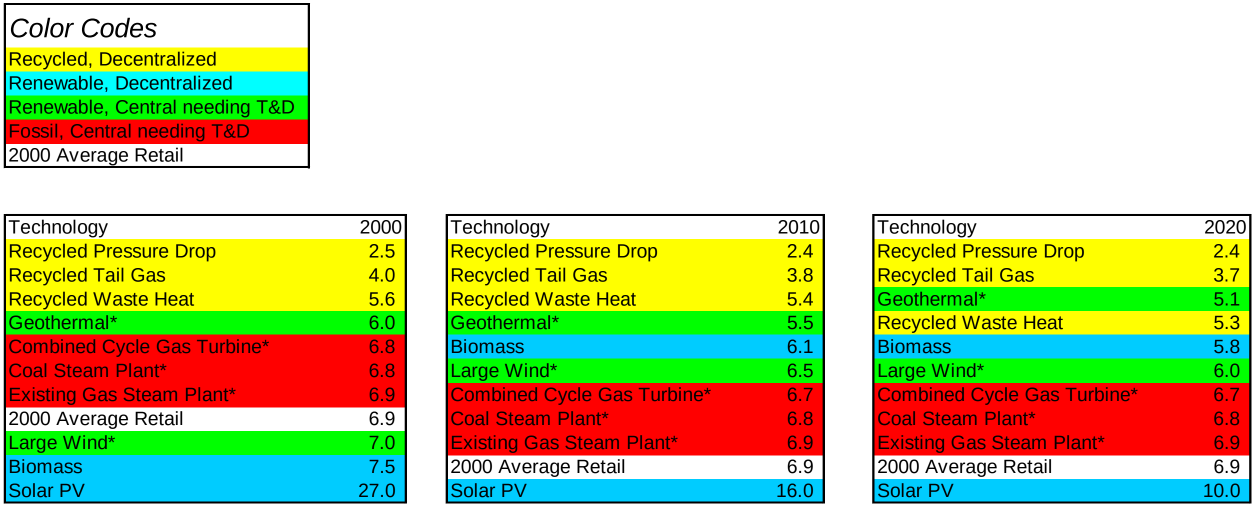
Levelized Costs for Renewable and Recycled Energy

To illustrate the differences between renewable and recycled energy technologies and the relative improvement expected over the next 20 years, we calculated the levelized cost needed to cover fuel, operations and maintenance and capital amortization for the major technologies in 2000, 2010 and 2020. The renewable costs are from NREL Energy Analysis Office, June 2002. We added in three central generation technologies to illustrate the competitive position of each technology. The chart below color codes technologies into four categories, recycled DG, renewable DG, renewable CG and fossil fueled CG. Note that the only renewable technology with a lower levelized cost than CG in 2000 is geothermal, but with projected improvements, wind and biomass have lower levelized costs per kWh by 2010 than CG options and the margin of savings grows in 2020. The recycled energy technologies have dramatically lower levelized costs than all other approaches in 2000 and continue their advantage over most technologies.

The model defaults to percent improvement in cost per kWh over the time period using NREL projections for renewables. The expected annualized improvements are: solar PV -- 4.9%, biomass – 1.3%, geothermal -- .8%, wind -- .77%. Our internal estimate of improvement per year for recycled energy is .3%, given the relative maturity of the technology.

Levelized Retail Costs per Kilowatt-hour, by Technology

Sorted cheapest to most expensive



Color Codes

- Recycled, Decentralized
- Renewable, Decentralized
- Renewable, Central needing T&D
- Fossil, Central needing T&D
- 2000 Average Retail

Technology	2000
Recycled Pressure Drop	2.5
Recycled Tail Gas	4.0
Recycled Waste Heat	5.6
Geothermal*	6.0
Combined Cycle Gas Turbine*	6.8
Coal Steam Plant*	6.8
Existing Gas Steam Plant*	6.9
2000 Average Retail	6.9
Large Wind*	7.0
Biomass	7.5
Solar PV	27.0

Technology	2010
Recycled Pressure Drop	2.4
Recycled Tail Gas	3.8
Recycled Waste Heat	5.4
Geothermal*	5.5
Biomass	6.1
Large Wind*	6.5
Combined Cycle Gas Turbine*	6.7
Coal Steam Plant*	6.8
Existing Gas Steam Plant*	6.9
2000 Average Retail	6.9
Solar PV	16.0

Technology	2020
Recycled Pressure Drop	2.4
Recycled Tail Gas	3.7
Geothermal*	5.1
Recycled Waste Heat	5.3
Biomass	5.8
Large Wind*	6.0
Combined Cycle Gas Turbine*	6.7
Coal Steam Plant*	6.8
Existing Gas Steam Plant*	6.9
2000 Average Retail	6.9
Solar PV	10.0

Source: Private Power, compiled NREL Energy Analysis Office, EIA

Reasonableness of Nine Scenarios

As noted, the model calculates nine scenarios for generating and transmitting the incremental electric load of 2020, ranging from all central plant to all decentralized generation. There is an interaction with the existing generation and 2000 load that is generated by the present stock of plants, less some retirement. To assess reasonableness, the scenarios vary by percent of total US power from decentralized generation. Roughly 8% of the electric load in 2000 was generated in decentralized plants. Building only new central generation for the next 20 years would reduce overall percentage of power from DG to 6%, which is the model's minimum case. At the other extreme, building all decentralized generation to meet load growth would result in roughly 40% of all US power from DG by 2020.

Is this range of overall power from DG reasonable? Denmark, the Netherlands, and Finland each produce more than 40% of their current generation from decentralized plants, proving industrial economies can operate with high percentages of DG. These economies used less primary energy per $1000 of gross domestic product than the US, ranging from 58% of US for Denmark to 87% of US in the Netherlands and Finland.[6]

We also analyzed a private database of US distributed generation production by state. Nationally, 8.1% of all electricity was generated in decentralized power plants in 2000, but there was a large variance between states. Three states generate virtually none of their electric power with DG (Kentucky, South Carolina and South Dakota) while five states generate from 22% to 33% of the power consumed with distributed generation (CA = 22.1%, LA = 24%, NJ = 29%, HA = 32% and ME= 33.6%) See Appendix 2 for details. In a country with one set of national laws and common federal tax code and roughly common prices for fossil fuels, the variation in DG reliance is quite amazing.

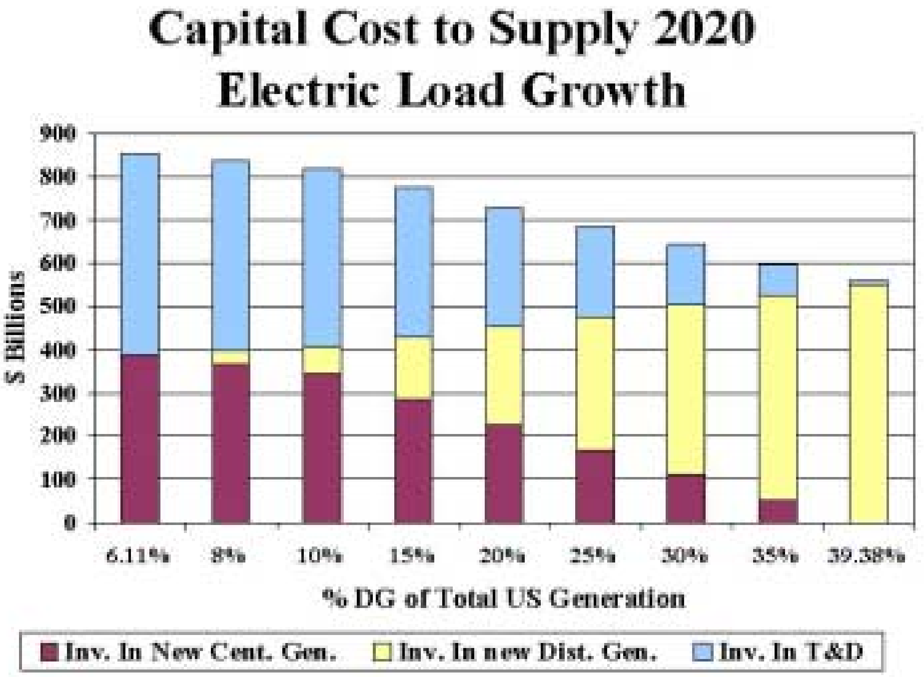
We looked at several potential explanatory variables including percent of electricity to industrial users, past twenty years load growth, power prices and reliance on oil and gas and found no significant correlation with the percentage of distributed generation in the state. Experience suggests the real reason for differences among states is outmoded local regulations that were originally designed to protect monopoly suppliers and reflected technology options of yesteryear.

In view of DG penetration exceeding 40% in developed countries and over 30% in some states, it seems reasonable that the US could, with regulatory modernization, reach 40% levels DG penetration by 2020.

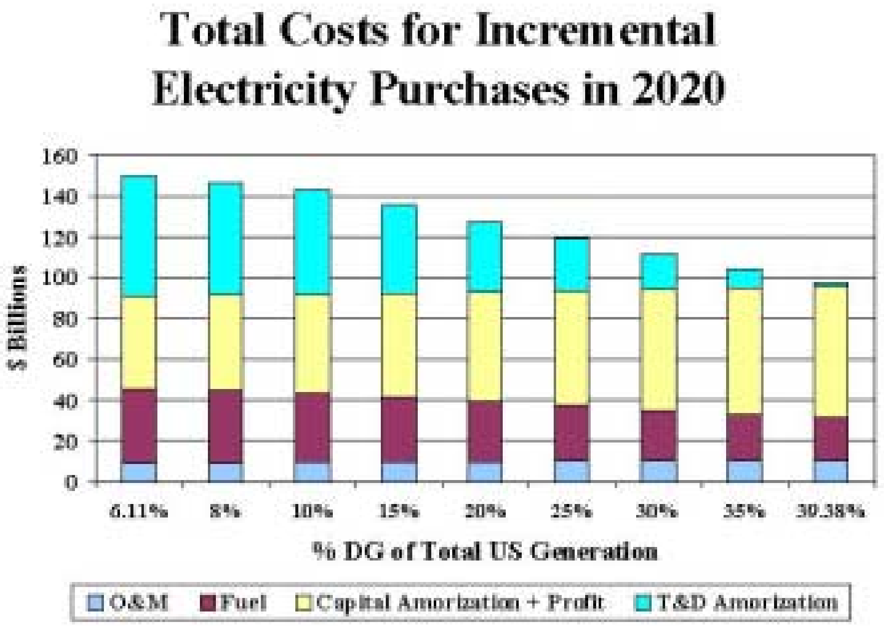
Results for the US

The US can achieve strong improvements in every goal by meeting 2020 load growth with 100% decentralized plants. The model runs show that producing the incremental power with 100% central generation will cost just over 8 cents per kWh in current dollars, while 100% decentralized generation will cost 5.2 cents per kWh, saving 35%. As a reference point, the 2000 average retail prices were 6.9 cents per kWh. The all-central generation scenario increases current real prices, reversing recent trends. Average inflation adjusted retail power costs have fallen for seventeen straight years from 9.8 cents/kWh in 1983.[7] But during this period, much of the load growth did not require new T&D, but used existing lines, reducing the spare capacity to its present state of congestion. Future load growth supplied by central plants will require new T&D. Specific results follow.

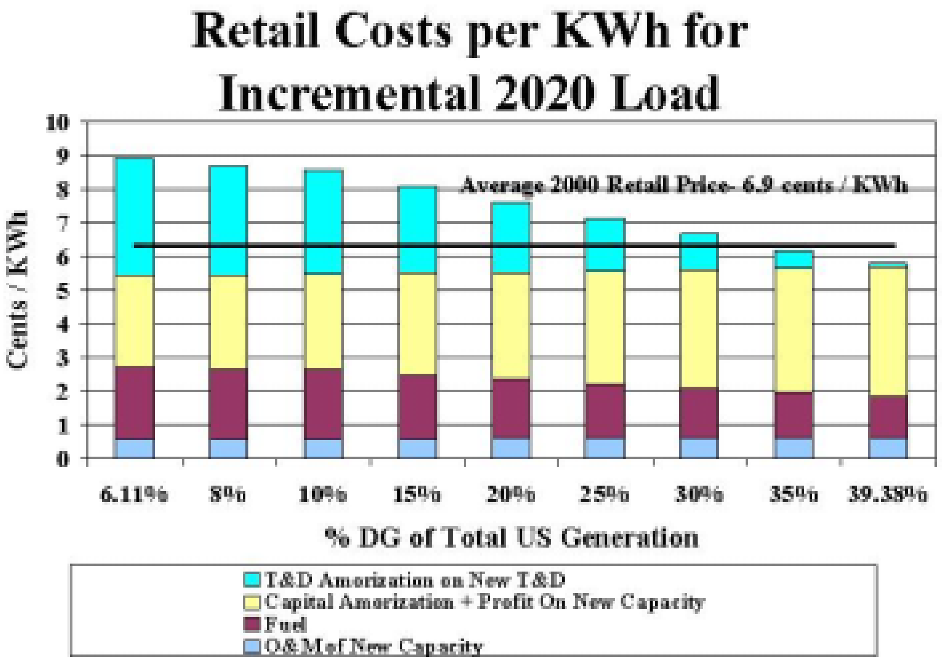
- The first graph shows the capital cost to meet 2020 load growth, separating capital needed for new CG, new DG and new transmission and distribution (T&D). The total capital costs to satisfy incremental load were $853 billion for all new central generation and $562 billion for all new DG, a savings of $291 billion or 34% as reliance on DG increases.



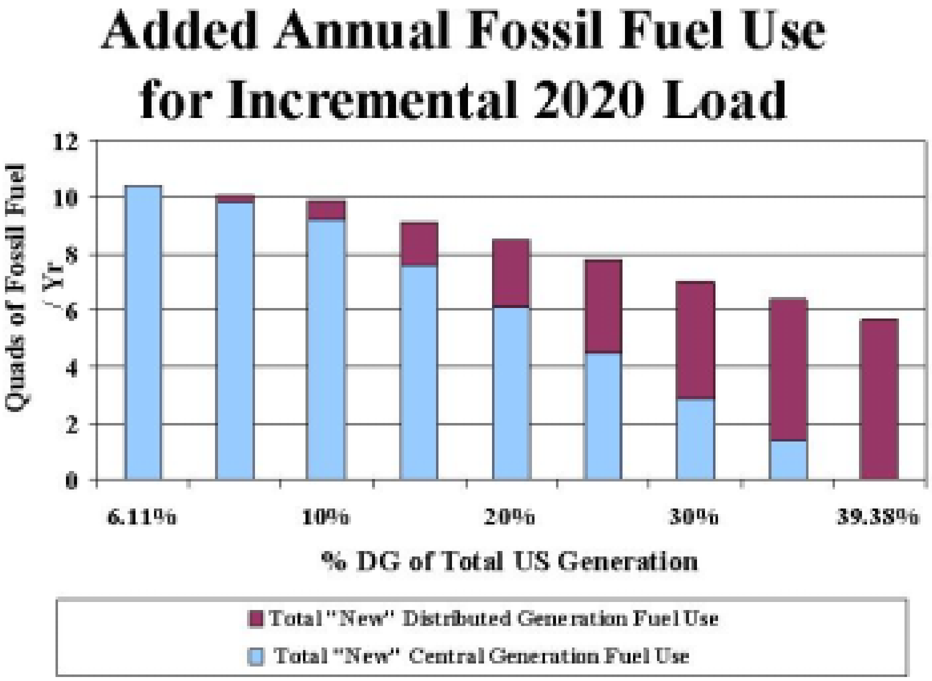
- The next graph shows total cost of incremental power in 2020 by four components -- O&M, fuel, and capital amortization for generation and capital amortization for T&D. Total operating costs decline by 35% from $149 billion in the 100% new CG scenario to $97 billion in the 100% new DG scenario. The model assumes all capital is funded with 50% equity earning a 12% return, and 50% debt amortized over 20 years at 8% interest.



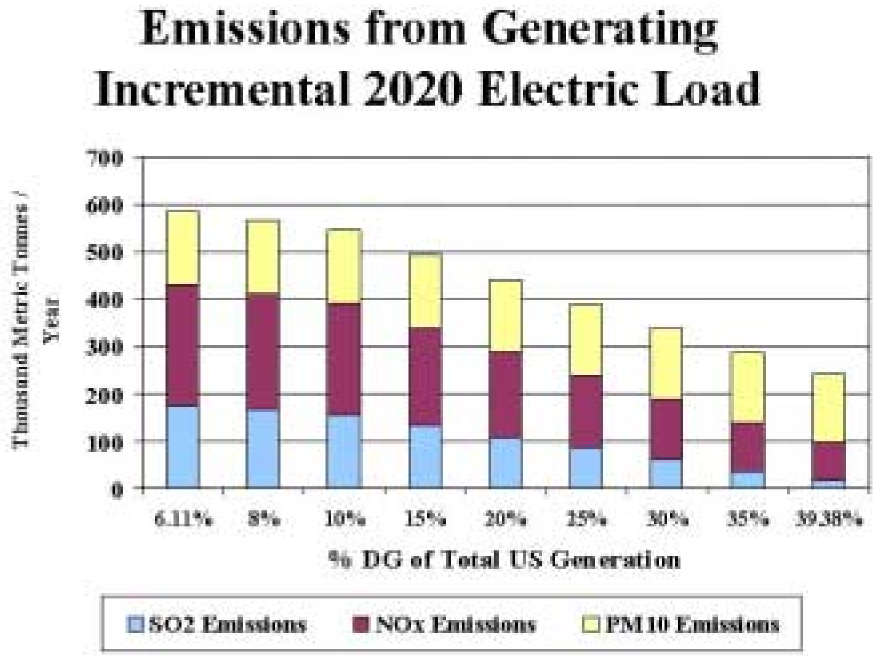
- The third graph shows average retail costs per kWh for incremental power in 2020, all in 2000 dollars. The line at 6.9¢ per kWh is the 2000 average US price. The 5.8¢ per kWh from full reliance on DG represents a 35% savings versus 8.9¢ per kWh with full reliance on CG.



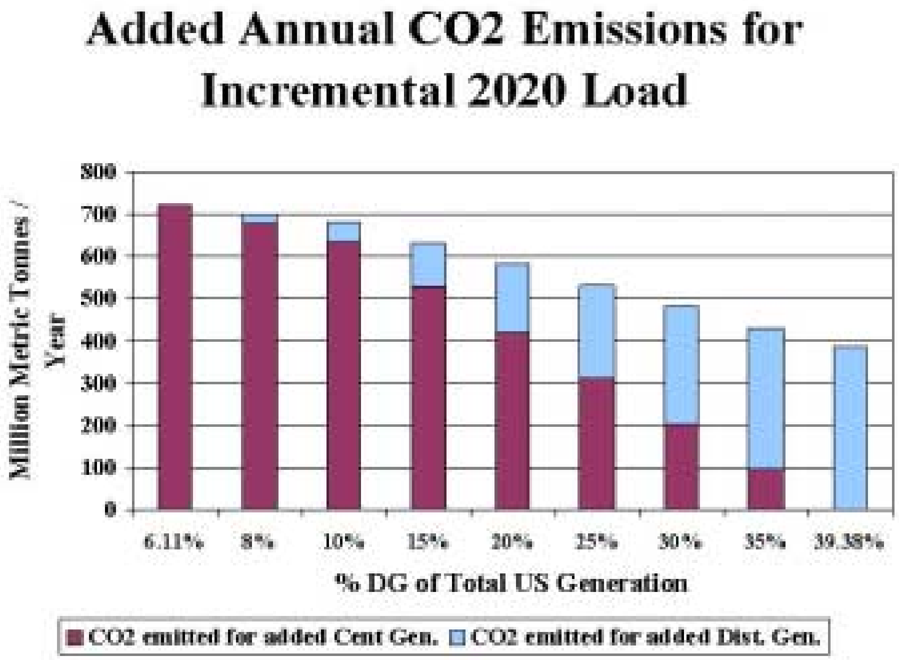
- The fourth graph shows the fossil fuel burned to generate the incremental power in 2020 for each scenario. Total fossil fuel use falls by 44% from 10.3 quadrillion British thermal units to 5.8 quads as DG reliance increases.



- The fifth graph shows NOx, SOx, and particulate matter emissions from generating the incremental power in 2020. Emissions fall dramatically with increased reliance on DG, with total tons of pollutants dropping 59% as reliance on DG increases.



- The sixth graph shows CO_2 emissions from generating the incremental power in 2020. CO_2 emissions drop 46% from 720 million tonnes to 387 million tonnes as reliance on DG increases.



Conclusions

Maximizing decentralized generation to supply incremental power in 2020 improves every measurable policy goal using base assumptions about current technology, efficiencies, costs and emissions. We have explored a range of options, and every reasonable mix still shows a uniform advantage for DG. All that varies is the margin of victory over new CG. Furthermore, since decentralized technologies are in the early part of their learning curve, it is reasonable to expect further DG improvement as deployment increases. System vulnerability to extreme weather and terrorist actions will improve as the power system moves to more distributed sources of generation. Power quality will be improved by moving to a hybrid system of DG & CG[8].

The current approach of supplying 92% of US power from central generation plants is not optimal. If there are no glaring mistakes, then it is time to change policies in every state to encourage a more optimal future built around decentralized generation of heat and power. The results square with our experience over the past 25 years, namely that decentralized generation saves money and lowers pollution while improving power quality. We challenge readers to either point out mistakes, or to change their views to adopt decentralized generation.

Model and Details

The model is designed for use by any city, state, country, or region. We offer it as a public service to anyone who so requests by e-mail to mcollins@privatepower.net. The response will include a technical document explaining the detailed working of the model.

The Authors

Thomas R. Casten has spent 25 years developing decentralized heat and power as founding President and CEO of Trigen Energy Corporation and its predecessors from 1977 through 2000 and currently as founding Chairman and CEO of Private Power LLC, an Illinois based firm specializing in recycling energy. These organizations have deployed over $1.0 billion in decentralized heat and power plants that all achieve at least twice the efficiency of the US average electric generation. Tom currently serves as the Chairman of the World Alliance for Decentralized Energy (WADE), an alliance of national and regional combined heat and power associations, wind, photovoltaic and biomass organizations and various foundations and government agencies seeking to mitigate climate change by increasing the fossil efficiency of heat and power generation. Tom holds a BA in Economics from Colorado University and an MBA from Columbia University. Tom's book, "Turning Off The Heat," published by Prometheus Press in 1998, explains how the US can save money and pollution. E-mail: tcasten@privatepower.net

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Appendix 1.

Policy Changes to Encourage DG

We offer the following brief list of State and Federal laws and regulations that are barriers to widespread deployment of DG and refer readers to chapter 8 of "Turning Off The Heat," by Thomas R. Casten, published in 1998[9]. The short list of barriers includes:

- Bans in every state against private electric wires across any public street, forcing DG developers to deal with their competitors to move electricity to users.
- Electric rates that average monthly costs and do not send time of use price signals to users.
- State electric regulatory rules that simply pass fuel costs to users with no reward to the utility for improving efficiency.
- Lack of standard interconnection requirements for grid connected DG.
- State approved backup power rates that assume every DG plant will fail at the peak hour and thus require 100% dedicated backup of generation and T&D. (3% to 5% is probable).
- Bans against anyone but the local monopoly providing backup electricity to DG plants.
- Absolute state prohibitions against third party sales of electricity, even to the on-site host (15 states, mostly southern).
- State rules that do not recognize the locational value of power and allow the wires companies to charge DG generators an uplift charge, even though the power flows to nearest users and lightens the T&D system load.
- Federal tax depreciation rules with longer tax lives for more efficient generating plants and the same lives for small DG as for large utility grade industrial turbines.
- Federal EPA rules that regulate pollution in per unit of fuel input instead of per MWh of output.
- Grandfather environmental permits that allow existing central plants to emit up to 100 times more pollution per MWh than is allowed from new DG plants.

Appendix 2, DG by State

The table below shows total electric consumption in each state in terawatt-hours and the total electric production from distributed generation plants. COG plants are cogeneration plants built before PURPA, FOG plants are FERC qualified cogeneration plants, and FCP plants are small power plants using alternate fuels that generate heat and power. The information is from a Private Power database that has gathered information from many sources.

State Symbol	State name	Net Generation TWh	COG + FOG +FCP Net Generation TWh	COG + FOG + FCP as % of Net Generation
DC	Dist. of Col.	0	0.0	0.0%
KY	Kentucky	93	0.0	0.0%
SC	South Carolina	90	0.0	0.0%
SD	South Dakota	11	0.0	0.0%
KS	Kansas	42	0.1	0.1%
MO	Missouri	74	0.3	0.4%
NE	Nebraska	30	0.2	0.5%
ND	North Dakota	31	0.2	0.5%
VT	Vermont	6	0.0	0.5%
RI	Rhode Island	6	0.1	0.8%
UT	Utah	37	0.3	0.9%
OH	Ohio	142	1.4	1.0%
AZ	Arizona	84	0.9	1.1%
OR	Oregon	57	0.7	1.3%
NH	New Hampshire	16	0.2	1.5%
WY	Wyoming	44	0.7	1.6%
MT	Montana	31	0.6	1.9%
IL	Illinois	164	3.7	2.3%
NM	New Mexico	33	0.7	2.3%
WV	West Virginia	95	2.3	2.4%
MD	Maryland*	52	1.5	2.9%
TN	Tennessee	93	2.9	3.1%
IN	Indiana	122	3.9	3.2%
IA	Iowa	39	1.5	3.8%
NC	North Carolina	118	4.8	4.1%
WI	Wisconsin	59	2.6	4.4%
GA	Georgia	118	6.0	5.1%
AR	Arkansas	47	2.5	5.4%
PA	Pennsylvania	196	10.7	5.5%
MN	Minnesota	49	2.7	5.6%
ID	Idaho	14	1.0	6.7%
MS	Mississippi	35	2.5	7.1%
WA	Washington	117	8.6	7.3%
NV	Nevada	33	2.4	7.4%
AL	Alabama	121	9.7	8.1%
CO	Colorado	40	3.2	8.1%
FL	Florida	187	16.1	8.6%
OK	Oklahoma	55	4.8	8.7%
DE	Delaware	7	0.6	9.4%
AK	Alaska	6	0.6	9.7%
CT	Connecticut	29	2.9	9.9%
VA	Virginia	74	7.8	10.5%
MI	Michigan	103	13.8	13.3%
MA	Massachusetts	42	5.7	13.8%
NY	New York	145	23.3	16.1%
TX	Texas	359	59.6	16.6%
CA	California	192	43.5	22.7%
LA	Louisiana*	90	21.6	24.0%
NJ	New Jersey	57	16.8	29.4%
HI	Hawaii	11	3.4	32.2%
ME	Maine	13	4.4	33.6%
US	**Total US**	3,705	298.5	8.1%

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[1] US DOE, Energy Information Agency forecast, “Annual Outlook 2002 with Projections to 2020, www.eia.doe.gov.

[2] Christensen, Clayton M., *The Innovator’s Dilemma: When New Technologies Cause Great Firms to Fail*, HBS Press Book, 1997.

[3] US DOE, Energy Information Agency Forecast, “Annual Outlook 2002 with Projections to 2020.”

[4] Line losses are a function of the square of the current, such that as loads grow towards the maximum carrying capacity of the conductor or transformer, the losses rise by the square. For example, a wire capable of carrying 10 units of power will have losses of 4 times a factor when the load is 2 units, losses of 25 times a factor when the load is 5 units, and losses of 81 times a factor when the load is 9. As the US has increased its use for the past 20 years faster than the construction of new transmission capacity, the average losses have risen, and will continue to worsen.

[5] Arthur D. Little, Preliminary Assessment of Battery Energy Storage and Fuel Cell Systems in Building Applications, Final Report to National Energy Technology Laboratory, US DOE, Aug 2, 2000, pg 43.

[6] World Factbook, www.bartleby.com/151/a62 and OECD data, private power analysis.

[7] Casten, Thomas and Sean, “Transforming Electricity,” Northeast-Midwest Institute, Nov/Dec 2001.

[8] Electric Power Research Institute’s Consortium for Electric Infrastructure to Support a Digital Society (CEIDS). http://ceids.epri.com/ceids/home1.html.

[9] Casten, Thomas R., Turning Off the Heat, Prometheus Press, 1998.