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On-Site Generation of Electricity -- An Idea Whose Time Has Come

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Abstract

Generation of electricity, on-site, with recapture of waste heat can save many area concerns up to 50% on their total energy costs today and save up to 60% of the total fossil fuel presently used. The very favorable economics result from increased utility costs -- a phenomenon of the past three years. The efficient use of fossil fuel is a feature of on-site power generation. This article traces the history of "total energy" and describes how and where on-site generation of electricity makes sense.

1. INTRODUCTION

The better utilization of fossil fuel over the next several decades is generally considered essential if we are to maintain and increase world standards of living. Our major end form of energy -- electricity -- is not very efficiently generated and transmitted. On average in the USA, used electricity represents only 29% of the input BTU's -- less than one-third efficiency.

Over the last several years, we have explored the use of on-site generation with waste heat recovery as a way to improve the efficiency of fuel usage. This artical explains how up to two and one-half times the amount of useful work can be gotten out of each barrel of oil by using on-site generation or "Total Energy."

2. WHAT IS "TOTAL ENERGY"?

On-site generation of electricity is sometimes employed in place of utility power, using a prime mover such as a diesel engine and a generator to create electricity. A Power magazine survey of 1453 industrial firms found that 343 or 22.4% generated some electricity on premises. Self generation is obviously not a new or novel idea.

The mechanical output of any prime mover is roughly 1/3 of the BTU input of the fuel, whether the prime mover is a multi-megawatt steam boiler/turbine or a diesel engine. Gas turbines have even lower efficiencies of fuel conversion to mechanical energy.

Almost always, the other 2/3's of fuel BTU's are wasted or worse, cost mechanical energy to dissipate. The removal of heat from cooling water is a further user of energy in the modern central utility station.

The 2/3's of input BTU's that are typically wasted are low grade, i.e. below 1000°, but they can be largely reclaimed and made to do useful work in space conditioning and process heating. "Total Energy" is the label often given to any plant that reclaims some of the low grade by product heat of the prime mover. Total Energy plants are up to 75% efficient versus the national average for delivered utility power of 29%. Hence, a total energy plant achieves over twice as much work from a unit of energy as does conventional generation.

3. WHY DOESN'T EVERYONE USE TOTAL ENERGY?

In spite of the savings in fuel, most consumers continue to use purchased electrical power. Why? Several answers give us some insights into past, present and future economics of on-site generation.

Throughout the 50's and 60's, energy costs were low and falling. The energy portion of electrical cost was small relative to capital and labor costs. Further, utility central stations could be built for $100 to $150 per KW. This was cheaper than the cost of an on-site generating plant. And of course, labor per KW at a giant station was less than at a small, on premises plant.

The graph titled "Costs to Large Industrial Users" shows that economics have only recently swung towards on-site generation with diesel power. Reasons include:

(1) Fuel costs have quadrupled,

(2) Environmental and safety regulations plus other factors have pushed central generating plant costs to $500 to $1,000 per KW -- up to four times the present capital costs of on-site plants,

(3) Mass produced on-site generators have not increased nearly as rapidly in cost and currently average $250/KW,

(4) Local governments have levied special taxes against utilities, raising prices, and

(5) On-site plants have become more automatic, more durable, and require less labor and maintenance than earlier.

Figure 1 shows the changing economics of on-site diesel generation since 1960. (See rear of paper).

By 1974, a large user in the Northeast USA could save money with total energy, and the savings have grown steadily ever since. A recent typical total energy installation promises its owners a 35% rate of return and savings of 50% in fuel costs versus utility charges. Three years earlier there would have been no savings.

4. FUTURE PROJECTIONS

Ten year future projections suggest even greater savings for on-site generation versus commercial electricity. The summary reasons are:

(1) 5 to 7% growth in electrical demand plus 2-1/2% annual obsolescence forces utilities to add 7 to 10% new capacity each year at capital costs 3 to 6 times the average cost of today's installed generating capacity.

IMPACT -- Will raise national average fixed charges from 3.7 mills/KW to 11 mills/KW.

(2) Coal and uranium prices are still catching up with oil prices, but long term supply contracts are

running out. For example, Boston Edison has contracts for $8 per pound uranium which run out in 1980. Many utilities are in a similar expiring contract situation. Current market price is $40 per pound and predicted to rise to $75 - $100/pound.

IMPACT -- Utility fuel charges will rise about 10% per year.

(3) Utility operating costs have shown little productivity increase over the past decade and can be expected to increase with general inflation, each year.

IMPACT -- Operating costs will rise 6% per year.

TOTAL IMPACT -- Average US utility prices will rise 9% to 11% per year through 1985.

In contrast, self generation costs are likely to rise only 4-6% per year over 10 years. The key reasons are:

(1) OPEC cleverly fixed world oil prices near the break even point for other more exotic energy sources. At between $12 and $16 per barrel oil prices, shale oil, coal gasification and liquefaction and solar energy all become economically attractive. Any further increase in real oil prices will call these technologies forward, and OPEC's fear of new energy technology are now moderating price increases. Since 1973, oil prices have not kept pace with world inflation.

We do not see US oil prices rising anymore than general inflation and predict less than inflation rises in the world markets. Recent withdrawals from Colorado shale oil ventures confirm that knowledgeable oil people are unwilling to bet on $13/barrel plus oil prices in the next few years.

IMPACT -- Gross fuel oil costs for on-site power will rise by less than 6% and, after crediting heat reclaimed, fuel costs will rise at less than 3% per annum.

Operating costs of self generation are in part the cost of repair parts which are mass produced and historically subject to productivity increases.

IMPACT -- Operating costs will rise at or below overall inflation.

Capital costs are, thanks to mass production, relatively low and fixed. Starting at around $250 per KW of generating capacity, or 1/2 or 1/3 of the cost of new utility generating/transmission capacity, the on-site generation plant locks in capital charges. The plant lives for 12 to 20 years and becomes ever cheaper in real terms if there is any general inflation.

IMPACT -- There is no increase in amortization costs to self generation in times of inflating utility capital costs.

This summary look at the next 5 to 10 years predicts utility prices increasing 9 to 11% on average while self generation increases only 4 to 6%. The savings through self generation increase each year and even facilities which are presently marginal candidates for self generation become attractive.

5. HOW DOES A TOTAL ENERGY PLANT WORK?

A typical total energy plant begins with three to six diesel engines, efficient and reliable prime movers. To each is attached a generator and electronic governor which in conjunction with the engine control panel will provide even, 60 cycle current with voltage quality often exceeding utility power. A clock correction device is installed to automatically adjust governors so that average frequency is precise over time.

At any time from one to all but one generator set operate, according to the load demanded. At least one generator set is always kept in reserve. Thus, for the user to experience even partial power loss, two generators must fail without intervening repair and during peak demand.

Since most mechanical problems in diesel engines occur slowly and give warning signals which are picked up by approach safety monitors, problems that will arise are nearly always corrected before outage conditions are reached. An outage record of five minutes in six years was achieved by Southside Junior High School in Columbus, Indiana. Equipment is even more reliable today.

But this is only the electrical output. Each unit of energy output to the crankshaft is matched by a unit of energy to the cooling water and a unit of energy to the exhaust. About 6800 to 7000 BTU's of waste heat are thus produced for every kilowatt of electricity. The challenge is to recapture and use some of this waste heat.

Cooled water enters all diesel engines on the site and picks up 12° to 15°F. in temperature, collecting waste heat equal to the BTU content of the electricity.

Next, the heated water flows through exhaust heat recovery silencers. Exhaust gases at 1000° flow around tubes full of jacket water and give up 500 to 750° before being vented to the atmosphere. The water gains half again as many degrees as it gained in the engine.

Now the heated water is ready to do useful work. In most retrofit applications, this heated water flows through a heat exchanger where it may transfer its heat to building water. Space heating, domestic hot water heating, and absorption air conditioning are the three most common uses of the heat in this water. Whatever the use, the on-site generator saves fossil fuel and money.

An alternate scheme utilizes higher engine temperatures and makes steam. The form of the recovered waste heat is simply a function of the needs of the using facility. Balancing is essential and accomplished by automatic valves which are temperature driven. Any excess heat remaining in the engine water is vented in a remote radiator and cooling water returns to the engines at a uniform temperature.

Since the total energy plant is about 75% efficient, balancing upwards can be economically achieved by use of electric resistance or immersion heaters. Any shortfall of building hot water or steam can be made up by electric heaters, causing more load to be placed on the engines. The engines immediately increase fuel rate, generate more kilowatts, and reject additional heat to the jacket water and exhaust gases. This causes about 75% of the input fuel to be converted to heat. A well maintained boiler will not convert energy at over 85% efficiency, and many existing boilers are less than 75% efficient. So use of the on-site plant as a "boiler" is comparable to a pure boiler in cost, and an excellent balancing technique.

An example of these techniques in action is an ice cream plant in New England. Switching to on-site diesel generation of their annual 4 million kilowatts allowed the facility to scrap its two existing boilers and save 33% of the total BTU's formerly used. The overall impact of the plant saves society 166,000 gallons of diesel oil/equivalent per year.

6. COSTS

The capital cost of on-site generation, with waste heat recovery will range from $225 to $300 per KW generating capacity.

Gross operating costs vary slightly with load profiles but approximate 2.8¢ per KW for fuel and .7¢ per KW for repairs, maintenance, oil changes, and overhauls, or 3.5¢ total per kilowatt generated. Net operating costs are lower by whatever credit is due for fuel and maintenance saved by waste heat use. The 5000 BTU's of waste heat typically recoverable per kilowatt generated range in value from 1.4¢ per KW if replacing residual fuel oil to 3¢ per KW if replacing liquid gas.

Not all waste heat will be used each month, so average costs, net of generation may range from 2¢ per kilowatt to 2.8¢ per kilowatt.

Capital amortization adds .5¢ per kilowatt, but we typically consider all operating savings as a return on investment and then evaluate project feasibility based on total return. After tax returns of over 15% are attractive to most firms and can be taken as a hurdle rate.

Recent analyses have shown up to 50% after tax returns on investment. The extra reliability of on-site generation over utility power is not quantified normally, but certainly sweetens a self generation project. The last 12 years have seen major Northeast electrical failures three times including the August 9 Hurricane Belle. Nationally, electricity outages have averaged 3.2 hours per year over the last 20 years. Self generation facilities continued through each break in commercial service, often providing considerable savings to their owners.

This all means that self generation may make good sense to a medium sized user paying over 4¢ per kilowatt for electricity. If the facility has a good use for low grade heat, commercial rates of over 3.5¢ per kilowatt may make self generation attractive.

7. SIZE LIMITS

Self generation involves a series of fixed costs for any sized plant -- a fact which makes self generation for the user with less than 125 to 150 KW peak demand uneconomic. The more the peak demand exceeds 150 KW, the more economical the system -- but utility block rates begin to fall also as the user's consumption and peak demand are larger. The range of 350 to 3000 KW peak demand has to date proven most attractive on retrofit while larger jobs make sense in new designs.

8. FINAL NOTES

Self generation with heat recovery has been around since 1920 and is a typical feature of all ocean going vessels. Up to World War II, many firms generated their own power, but seldom recovered any heat. Between 1942 and 1973, utility rates made self generation with any fuel but natural gas uneconomic.

Throughout the post war period, diesel engines, modest sized generators, and control equipment have been improved and made more reliable. Today's high speed diesel will run 20,000 to 25,000 hours between major overhauls in on-site generation duty, and automatic control panels of utility station quality are available at affordable costs.

The USA is projected to spend $375 billion in the next 10 years for electrical generating equipment and transmission lines.* This capital sum can be cut by a factor of four wherever on-site generation is chosen, and each barrel of oil can be made to do two and one-half times as much useful work.

For all these reasons, on-site generation is an idea whose time has come.

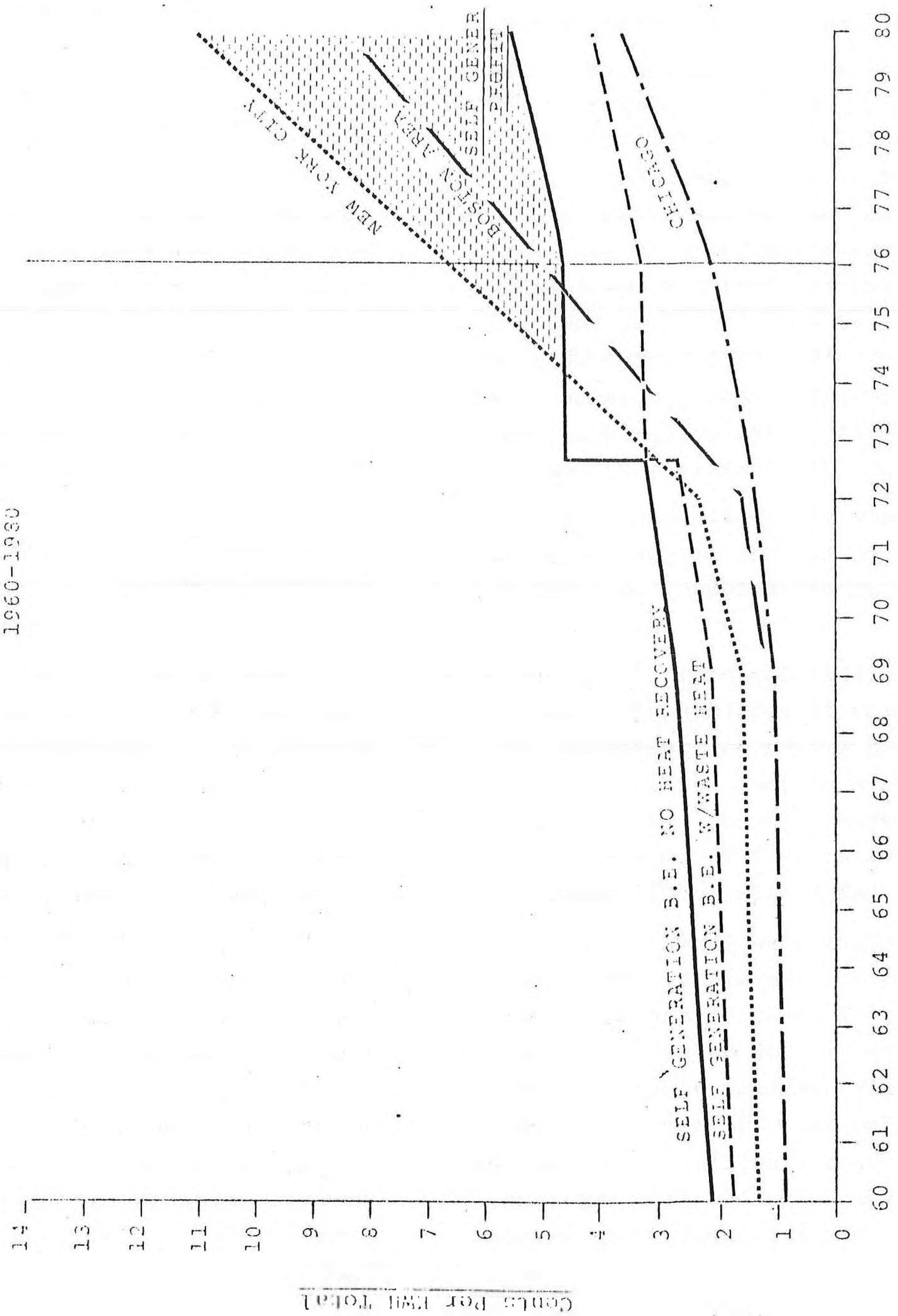

Figure 1

LARGE COMMERCIAL POWER COSTS COMPARED WITH FULLY AMORTIZED COSTS OF A CUMMINS GENERATING PLANT WITH WASTE HEAT RECOVERY

1960-1980

(a)* Arthur D. Little, "Electric Power Outlook to 1985"

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