INDUSTRIAL ENERGY FUTURE: ENERGY AND EMISSION REDUCTIONS VERSUS CHOICES OF NEW TECHNOLOGIES

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INTRODUCTION

The study[27] on which this paper is based showed the amount of energy, the tons of CO_2, and the pounds of NO_x that U.S. industry could save annually by utilizing fuel switching, heat recovery schemes and devices, and low NO_x burner systems. Most of the data used therein was derived from Gas Research Institute (GRI) reports which included information on energy usage within each industrial sector and identified the energy sources and type of application.

Study of each energy consuming process yielded sufficient information to break down heating processes into five process temperature categories. These studies were based on texts, industrial publications and interviews with industry personnel. Approximations were made of efficiencies and emissions associated with each process and temperature category for both electric power and heat and fossil fuel derived power and heat. That allowed a reasonably complete construction of how improvements of technology could effect changes in annual energy consumption and emissions of CO_2 and NO_x. NO_x was of interest for the study because it is a regulated emission as well as being a "greenhouse" gas. CO_2 was of interest because it is a major "greenhouse" gas that may be subject to regulation at a later date; and its rising concentration in the atmosphere is presently of great concern to many environmentalists. Energy consumption is of interest because of its cost and of a perception that we should attempt to use our fossil energy, particularly gas and oil, more efficiently.

As a simplification for the study, fossil fuels were considered as coal for electric power generation by central power plants and as natural gas for heating and direct drive engine systems.

Changes in demonstrated burner performance and heat recovery since the original study[26] was incorporated herein.

PATTERN OF U.S. INDUSTRIAL ENERGY USAGE

Table 1 shows U.S. industry's present energy consumption in the eleven industrial sectors as a function of type of energy used.

Table 2 shows the same energy usage broken down according to how the energy was used in terms of temperature, mechanical drive power, and steam generation. The definition of low heat and high heat, whether by electric or fossil heating, is heating temperatures below or above 1200° F.

PROCESS AND EQUIPMENT CHARACTERISTICS

Table 3 shows existing energy consumption, approximate average process efficiency, and specific NO_x production for the various industrial electric and fossil fuel applications. The heating energy usage is divided into five temperature ranges so as to better describe the effects of using heat recovery and low NO_x burners if they were applied. Energy usage is shown as both energy absorbed by the load (end use process energy) and energy delivered to the end processing device. The difference is due to the average overall process efficiency for each category of powering, driving, or heating. The NO_x values correspond to a reasonable average of present uses within each category.

Table 1: Industrial Energy Usage By Industry and Energy Source: Referred To Point Or Use (Trillion BUT/yr)

Industry Sector	Natural Gas	Electricity	Coal	Coke	Oil	Other	Wastes	Total
Food & Kindred Products	470	139	63	0	2	200	0	874
Paper	315	216	344	0	153	52	720	1,800
Chemical & Allied	1,049	285	312	0	211	92	332	2,281
Petroleum Refine & Related	921[a]	72	222[b]	222[b]	134	25	1123	2,719
Rubber & Plastics	280	216	67	0	63	7	0	633
Stone, Clay & Glass	565	62	397	3	120	0	0	1,147
Primary Metals	750	427	1,024	72	109	5	284[c]	2,387
Industrial Gases	0	37	0	0	0	0	0	37
Textiles	93	0	0	0	0	0	0	93
Lumber & Wood	1	0	0	0	0	22	0	23
Total	4,444	1,454	2,429	297	792	403	2,175	11,994

Notes:

a) Natural gas utilized in the process as a raw material.

b) Coal and petroleum coke for steam generation was 444 TBTU; this value was arbitrarily split evenly between coal and coke.

c) Part of coal energy, and accounted for accordingly.

Table 4 shows the same type of information, but with industry fully equipped with presently proven and available low NO_x burners and heat recovery devices.

Table 5 shows the same type of information if industry were to fully equip with technology that has been shown for fossil fuel firing to achieve excellent heat recovery and low NO_x even with highly heated air. Likewise, available high end use efficiencies for electrical devices were factored into this table. Also, improved NOx emissions and efficiency at the power generating plant has been factored into this table.

DISCUSSION

Table 6 shows total energy requirements, CO_2 production, and NO_x production as referred to the source of energy, assignable to U.S. industry as a function of equipment and fuel selection.

Case A: Performance As In Table 3

This, representing present practice for U.S. industry, forms the base case against which other practices will be compared. The source energy for electric energy is determined by dividing the end use energy by the power generation efficiency and by the line efficiency. For fossil energy, the source energy is end use energy divided by the delivery efficiency where pumping loss was assumed to be 10% (a pessimistic assumption).

Case B: Performance As In Table 4

This case allows for the use of presently marketed low NO_x burners and the use of heat recovery. The appropriate heat recovery effectiveness for a mix of regenerators and recuperators designed for the purpose would be about 60% as a "reasonable" average.

Heating the combustion air in any heat recovery device will cause a given burner to develop more NO_x than when fired with ambient temperature air. For this reason Case B was looked upon in two configurations: without heat recovery, and with heat recovery.

Table 2: Industrial Energy Usage By Industry Sector And Application Referred To Point Of Use (Trillion BTU/yr)

Industry Sector	Low Heat Electric	High Heat Electric	Low Heat Thermal	High Heat Thermal	Steam Process	Cooling & Refrig. Electric	Drives Electric	Other Electric	Other Thermal	Total Energy By Use
Food & Kindred Products	0	0	245	0	489	39	101	0	0	873
Paper	8	0	137	0	1,446	0	208	0	0	1,799
Chemical & Allied	0	0	0	620	1,370	2	175	108[a]	0	2,281
Petroleum Refine & Related	0	0	1,310	232	1,105	3	69	0	0	2,719
Rubber & Plastics	107	0	117	20	278	4	106	0	0	632
Stone, Clay & Glass	0	48	286	798	0	0	13	0	0	1,145
Primary Metals	15	90	233	1,638	47	0	120	202[b]	0	2,387
Industrial Gases	0	0	0	0	0	0	37	0	42[c]	37
Textiles	0	0	64	0	29	0	0	0	0	93
Lumber & Wood	0	0	0	0	23	0	0	0	0	23
Total (At Point of Use)[d]	130	138	2,392	3,314	4,787	48	829	310	42	11,990

Notes:

a) Electrolysis
b) Electro-Refine
c) Blanket Gases
d) Excludes losses in electric generation and electric and fossil fuel transport.

Table 3: Characteristics of Equipment and Processes; Technologies As Presently Used

Electric Energy Use				Heating (°F)				
	Electrolysis & Electro-Refining	Drives	Cooling & Refrig. Drive	<800	800-1200	1200-2000	2000-2600	2600
End Use Efficiency (%)	75	85	85	90	85	80	70	60
End Use Process Energy (TBTU/yr)	233	705	41	104	13	13	10	66
End Use Energy (TBTU/yr)	310	829	48	115	15	16	13	110
Approximate[a] NO_x Emissions (lbs/MMBTU)	0.9 lbs per million BTU of coal energy used for generating electricity							
Fossil Energy Use				Heating (°F)				
		Engine Drive	Steam Generation	<800	800-1200	1200-2000	2000-2600	2600
Energy Efficiency[b] (%)		30	80	75	65	45	25	75[c]
End Use Process Energy (TBTU/yr)		8	3,830	895	780	556	308	881
End Use Energy (TBTU/yr)		26	4,787	1,193	1,199	1,235	1,232	1,175
Approximate NO_x Emissions (lbs/MM BTU)		0.4	0.15	0.15	0.15	0.2	0.3	0.4

Notes:

a) NO_x generated in electrical arc furnaces appears to average 0.5 lbs/ton of steel melted, which equals about 0.3 lbs/MMBTU of heat at point of use (~20 MMlbs/yr for U.S.); this is not included in NO_x total included in this table or Tables 4 through 6.

b) Efficiency values for heating devices were assumed to include 10% heat leakage in addition to stack losses; and engine drive efficiency was assumed to be like a diesel engine operating at design load and speed (30%); very little heat recovery presently used except for >2600° F.

c) Most glass melters are equipped with regenerators to achieve this efficiency; and blast furnaces are counterflow devices and achieve this efficiency. These applications constitute most of the heating above 2600° F.

Case C: Performance As In Table 5

In this case, the NO_x production was assumed to be representative of the two or three lowest NO_x burners that have been tested, even though they were not necessarily ready for production at this time. Also, the heat recovery effectiveness was assumed to be 85%, corresponding to the performance of a well designed regenerator. Increased specific NO_x production using the resultant high air preheat is reflected in the tabulated results. Electric power would be provided from a plant operating at 40% efficiency.

It should be noted that with application of advanced technology the largest remaining components of NOx production are in the power generation area and in the highest temperature heating range (greater than 2600° F) which is mostly glass making and steel making. The NO_x generated in these two industrial areas can be reduced. This is especially true of glass making where enough work has been done to say that the lowest value indicated in Table 5 (0.05 lb/MMBTU) is probably achievable. The 0.4 value, also listed in Table 5, was used as an upper limit value.

For steel making, new processes may be necessary to get a large reduction in NO_x production. In this case the 0.4 lb/MMBTU level may persist for years as the most probable. A realistic average value for the near future of NO_x production with advanced technology in the greater than 2600° F heating category could be in the 0.2 to 0.25 lb/MMBTU range.

Table 4: Characteristics of Equipment: Best New Technology That Can Be Purchased In 1997

Electric Energy Use				Heating (°F)				
	Electrol. & Electro-Refining	Drives	Cooling & Refrig. Drive	<800	800-1200	1200-2000	2000-2600	2600
End Use Efficiency (%)	75	85	85	90	85	80	70	60
End Use Process Energy (TBTU/yr)	233	705	41	104	13	13	10	66
End Use Energy (TBTU/yr)	310	829	48	115	15	16	13	110
NO$_x$ Emissions (lbs/MMBTU)	0.45 lbs per million BTU of coal energy used for generating electricity							
Fossil Energy Use				Heating (°F)				
		Engine Drive	Steam Gen.	<800	800-1200	1200-2000	2000-2600	2600
Energy Efficiency^a (%)		30	80	[75] // 85^b	[65] // 80^b	[45] // 68^b	[25] // 50^b	[75] // 75
End Use Process Energy (TBTU/yr)		8	3,830	895	780	556	308	881
End Use Energy (TBTU/yr)		26	4,787	[1,193] // 1,053	[1,200] // 975	[1,235] // 818	[1,232] // 616	[1,195] // 1175
NO$_x$ Emissions (lbs per MM BTU/ppm)		0.4	0.02/20	[0.025/25] // 0.025/25^c	[0.030/30] // 0.040/40^c	[0.04/40] // 0.07/70^c	[0.05/50] // 0.1/100^c	[0.4] // 0.4

Notes:

a) There are two possible configurations indicated by: [without heat recovery]//with heat recovery.

b) Medium performance recuperators and regenerators are available now.

c) Estimated increased NO$_x$ values that accompany use of air preheated in recuperators and regenerators suitable for each temperature band above.

Case D: Effects Of Fuel Switching And On-Site Power Generation; Performance As In Table 5

This case postulates using fossil heating throughout, rather than having some electric heating as presently utilized. What electrical power remains (mechanical drives by electric motors, electrolysis, and electro-refine) would be supplied with an on-site power generator driven by a gas-fired, regenerated, low-NO$_x$ gas turbine operating at 44% efficiency.

CONCLUSION

The results of the analysis indicate that simply retrofitting existing equipment with presently purchasable burners and heat recovery devices could cut U.S. industrial energy consumption by 9%, and CO$_2$ by 7%. Those changes, plus cutting NO$_x$ production of coal burning power generating plants, could reduce NO$_x$ by 57%.

Table 5: Characteristics of equipment: Advanced Technology Presently In Development

Electric Energy Use				Heating (°F)				
	Electrolysis & Electro-Refining	Drives	Cooling & Refrig. Drive	<800	800-1200	1200-2000	2000-2600	2600
End Use Efficiency^a (%)	95	95	95	95	93	91	89	87
End Use Process Energy (TBTU/yr)	233	705	41	104	13	13	10	66
End Use Energy (TBTU/yr)	245	742	29^b	109	14	14	11	76
NO$_x$ Emissions^c (lbs/MMBTU)	0.1 for coal fired electric generation; 0.03 for on-site power generation with natural gas fuel							
Fossil Energy Use				Heating (°F)				
		Engine Drive	Steam Generation	<800	800-1200	1200-2000	2000-2600	2600
Energy Efficiency^b (%)		30	90	89^d	87^d	81^d	65^d	85
End Use Process Energy (TBTU/yr)		8	3,830	895	780	556	308	881
End Use Energy (TBTU/yr)		26	4,256	1,006	897	686	474	1,036
NO$_x$ Emissions^e (lbs/MM BTU)		0.1	0.008	0.008	0.008	0.008	0.022	0.05 (0.4)

Notes:

a) Values are estimated as possible maximum efficiencies for future electrically heated or driven equipment.

b) Assumes improved technology raises COP by 50%.

c) Assumes best coal fired power generation for central power plant will meet 2000 AD NO$_x$ standards and will operate at 40% efficiency; and on-site power generation will be low emission, gas fired gas turbine, regenerated equipment, with overall thermal efficiency of 44%.

d) Efficiency reflects 85% heat recovery and 10% heat leak.

e) NO$_x$ values correspond to technologies already demonstrated to be achievable. NO$_x$ for >2600° F is shown with 2 values - one is expected to be achievable, the other reflects no improvement. Operating temperatures of >2600° F mostly represents glass melters, steel melters and blast furnaces.

Further, using advanced burners and regenerators, and further cutting NO$_x$ from coal burning power plants to 0.1 lb/MMBTU, energy consumption can be cut by 25%, CO$_2$ by 26%, and NO$_x$ by 87 to 93% of present values.

By switching all heating to fossil fuel energy (natural gas), generating the remaining electrical needs with an on-site high performance, low NO$_x$, gas turbine system, energy consumption can be cut by 28%, CO$_2$ by 45%, and NO$_x$ by 91 to 97% of present values.

These results mean that NO$_x$ traceable to industry can be halved in the near future by using existing low NO$_x$ burners. Subsequent retrofitting with existing heat recovery devices can instigate a cut in energy requirements by nearly 10%. Thereafter, on a somewhat longer retrofit and/or re-equip schedule, energy requirements can be cut 25 to 28% compared to the present, CO$_2$ by 26%, and NO$_x$ by 87 to 90%. A longer re-equip and fuel switch program including on-site power generation as the final step can yield 28% energy savings, 45% CO$_2$ reduction, and 93 to 97% NO$_x$ reduction from present usage for the U.S. industrial world.

Table 6: Potential Energy Consumption and CO_2 and NO_x Emissions With Alternative Technology Use Choices (Notes for Table 6 appear on the following page.)

Case	Description	Contribution of Electric Energy Component	Contribution of Fossil Energy Component	Total Energy and Emissions	Reduction (%)
A: Current Technology And Usage					
	End Use Energy (TBTU/yr)	1,456	10,847	12,303	–
	Energy at Source (TBTU/yr)	4,853	12,052	16,905	–
	CO_2 (MMTon/yr)	630	856	1,401	–
	NO_x (MMlb/yr)	4,368	2,416	6,784	–
B: New Best End Use Technology					
Without Heat Recovery	End Use Energy (TBTU/yr)	1,456	10,847	12,303	0
	Energy at Source (TBTU/yr)	4,853	12,052	16,905	0
	CO_2 (MMTon/yr)	630	771	1,401	0
	NO_x (MMlb/yr)	2,184	753	2,937	57
With Heat Recovery	End Use Energy (TBTU/yr)	1,456	9,450	10,906	9
	Energy at Source (TBTU/yr)	4,853	10.500	15,353	9
	CO_2 (MMTon/yr)	630	671	1,301	7
	NO_x (MMlb/yr)	2,184	760	2,944	57
C: Advanced End Use Technology, Low NOx, Coal Fired Power Generation @ 40% Efficiency, Max Heat Recovery For All Fossil Heating					
	End Use Energy (TBTU/yr)	1,240	8,381	9,621	22
	Energy at Source (TBTU/yr)	3,444	9,312	12,756	25
	CO_2 (MMTon/yr)	447	596	1,043	26
	NO_x (MMlb/yr)	344	120[a] (482)[b] (327)[c]	464[a] (826)[b] (671)[c]	93[a] (87)[b] (90)[c]
D: Effects Of Fuel Switching & On-Site Power Generation					
	End Use Energy (TBTU/yr)	1,016	8,622	9,638	22
	Energy at Source (TBTU/yr)	2,566	9,580	12,146	28
	CO_2 (MMTon/yr)	164	612	776	45
	NO_x (MMlb/yr)	77	125[a] (515)[b] (360)[c]	202[a] (592)[b] (437)[c]	97[a] (91)[b] (93.5)[c]

Notes:

a) Reflects 0.05 lbs of NOx/MMBTU at heating temperatures >2600o F. (Best to be expected with restructured technologies.)
b) Reflects 0.4 lbs of NO^x/MMBTU at heating temperatures >2600° F.
c) Reflects 0.25 lbs of NO^x/MMBTU at heating temperatures >2600° F.

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