The Mexican Power Sector and its Dependence on Natural Gas

Armando Llamas, Federico Viramontes,
Oliver Probst, Ruth Reyna, Aníbal Morones and Manuel González.
Energy Studies Center, Monterrey Institute of Technology—
Campus Monterrey

ABSTRACT

The price of electricity and fuels directly affects the competitiveness of energy-intensive industries. The expansion of the Mexican electric power sector is planned via natural gas combined cycle (NGCC) plants. This leaves the power sector more susceptible to the behavior of this particular fuel. In recent years, the price of natural gas showed high values and volatility. It would be wise to consider alternatives in order to have a reliable supply of energy. The integrated gasification combined cycle (IGCC) technology presents an opportunity to diversify the installed capacity, its main disadvantage compared to NGCC is higher CO_2 emissions. Self-supply has been able to secure the electric power supply. However, in some cases it has not been successful at providing electric power at a lower rate than CFE.

OVERVIEW OF THE POWER SECTOR

Installed Capacity and External Participation

Table 1 shows the installed power capacity by December 2003 ([1], [2] and [3]). The state companies, CFE and LFC, account for 76% of the overall power capacity. It is important to point out that, by now, the private share (IPP, self-supply and cogeneration) is about 20%. If all external participation is accounted for, the share rises up to 23.9%*. Before modification of the Electric Energy Public Service Law, in 1993, the only external participation allowed was in the form of "usos propios continuos"[4], with 600 MW total installed capacity by 1992. Since then, the expansion of the Mexican power sector has been based on private investment, by either independent power producers (IPP) or self-supply societies. There is an important difference between the IPP and the self-supply societies. The IPPs sell energy exclusively to CFE; the IPPS are also planned and dispatched by CFE. In contrast, the self-supply societies are driven entirely by private industry, aiming for a reliable and, hopefully, less expensive source of electric power.

Table 1. Installed Capacity, December 2003

	MW	*%*
CFE	36,971	74.4
LFC	834	1.7
PEMEX	1,822	3.7
PIP	6,756	13.6
Self-supply and/or Cogeneration	3,316	6.7
Total	**49,699**	**100**

Most of the new large-scale power-generation projects (IPP and self-supply) burn natural gas for fuel in combined-cycle plants. The cogeneration projects also are focused, mainly, on this fuel. This implies a growing susceptibility of the power sector to natural gas prices. This point will be further discussed in the next sections.

CFE- IPP Power Generation and Plant Factor

CFE's gross generation**, from September 1, 2002 to August 31, 2003, appears in Table 2 [5]. The installed capacity during the same pe-

*As written in the Electric Energy Public Service Law, the external producer is defined as the holder of a permit to have generation activities that not constitute public service. Among such activities are: selfsupply, cogeneration, small producer, exportation, independent power producers and PEMEX.

**The gross generation is the output at the generator terminals. To get the net generation, the internal services of the plant got to be discounted.

riod, taking into account the operating IPP, was 38,587 MW [5]. It can be pointed out that the power generation from fossil fuels is 83%, which denotes an important increase from the end of 2001, when the fossil generation was 77% [6]. It is important to note that the generation from hydroelectric plants is only 9.5% of the total energy, while the installed capacity of this kind of plant is about 19% of the overall capacity. That leaves a plant factor of only 24% for the hydroelectric plants.

Table 2. CFE Gross Generation

CFE gross generation by technology Sep-02/Aug-03	
Technology	*GWh*
Steam (fuel oil or natural gas)	76,756
Dual (coal or fuel oil)	14,447
Coal	17,093
Combined cycle	24,679
Turbogas	6,421
Internal combustion	568
IPP	28,315
Total Fossil	*168,280*
Hydro	19,389
Nuclear	9,340
Geothermal	5,728
Wind	6
Total non-fossil	*34,463*
Total	**202,743**
Fossil generation/ Total	**83.0%**

A national mean demand can be obtained from this data 202,743,000/(365 * 24) = 23,144 MW. An annual plan factor can also be calculated 23,144/38,587 = 60 %, which shows an intensive utilization of the national electric system.

On the side of renewables, 2.8% of energy is coming from geothermal plants and a negligible installed capacity in wind power (2 MW). Considering the big commercial development exhibited by wind power in the world (>39,000 MW installed by 2004), it can be stated that this resource has not been sufficiently exploited.

Fuel Consumption and Efficiency

CFE's fuel consumption between September 1st 2002 and August 31st 2003 is displayed in Table 3[5]. The quantities shown are in million Btu of high heating value. Table 3 also shows the high heating value of each fuel.

Table 3. CFE Fuel Consumption and High-heating Value

CFE FUEL CONSUMPTION SEP-02/AUG-03		HIGH HEATING VALUE	
Fuel	*10^6Btu*	*HHV*	*Units*
Fuel oil	679,789,985	39.76	MBtu/m^3
Natural Gas	476,634,022	36.68	MBtu/10^3m^3
Diesel	29,097,076	35.31	MBtu/m^3
Coal*	259,686,776	20.20	MBtu/ton
Total	**1,445,207,859**		

*Mix of national coal and international coal. The heating value shown is a weighted average of the mixture actually used.

As can be seen in Figure 1, a thermal efficiency can be calculated from the fuel consumption and the gross generation. The resultant thermal efficiency is 39.7%. In previous years, the average was 34% [7]. This rise in the efficiency may be the result of using modern combined cycle plants of the IPP (53,000 GWh = 31% of the fossil generation = 26% of total), whose gross efficiency easily exceed 50%.

GENERATION COST

Information in Table 4 comes from the Federal Institute for the Access to Public Information (IFAI) and provides generation cost by

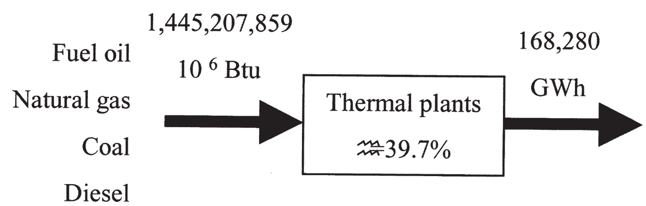


Figure 1. Thermal Efficiency of CFE and IPP

technology [8]. Although this information contains 2002 data, it is worth review. It may be observed that the IPPs not only increased the thermal efficiency but also helped to bring the generation cost down from 0.56 to 0.53 pesos/kWh. It can be also noted that the ratio in the price of the energy from CFE's combined cycle and those of the IPP is almost double.

With the information we have, it is not possible to determine precisely the cause of the difference. One possible reason is that some of the CFE's combined cycles were installed in the 70's and 80's, and its efficiencies are not so high.

The energy coming out of the hydroelectric plants is not as inexpensive as expected. It could be the result of the human resources involved, the retired workers fund, and/or a low plant factor. As mentioned before, lack of cost structure prevents us from making sound statements.

ELECTRICAL TARIFFS

Industrial Tariffs in Northeastern Mexico

Figure 2 shows the prices of the high voltage tariff in the Northeastern part of the country (HS NE). All prices are in December 2003 dollars, so the effect of inflation is avoided. It is easy to see the increase of prices. For example, the price of demand in November 2001 was $4.05 USD/kW; by February 2004 increasing to $5.17 USD/kW.

The rise in prices of the electric power is more evident when these are expressed in Mexican pesos. Considering a hypothetic plant with the same load factor of 0.6 in all (base, intermediate and peak) hours and the HS tariff in the NE gives the mixed cost per kWh shown in Figure 3. This cost includes the charges per energy and demand and the effect of inflation and exchange rate.

Table 4. Generation Cost by Technology 2002

Technology	*GWh*	*Cost (million pesos)*	*Unit Cost (pesos/kWh)*
Steam	78,803	$ 48,762	$ 0.62
CC	22,217	$ 13,820	$ 0.62
Turbo gas	6,013	$ 2,882	$ 0.48
Diesel	555	$ 811	$ 1.46
Coal plant	30,030	$ 7,527	$ 0.25
Geothermal	5,396	$ 2,002	$ 0.37
Wind	7	$ 7	$ 1.00
Nuclear	9,747	$ 7,934	$ 0.81
Hydro	24,277	$ 12,441	$ 0.51
Geothermal Projects Division		$ 881	
Civil Engineering Studies Division		$ 663	
Generation Subdivision		$ 741	
CFE TOTAL	**177,045**	**$ 98,471**	**$ 0.56**
Independent Power Producers	22,657	$ 7,452	$ 0.33
CFE & IPP's TOTAL	**199,702**	**$ 105,923**	**$ 0.53**

Adjustments in the Industrial Tariffs:
Fuel Portfolio, Fuel Prices and Inflation

Fossil fuel consumption of CFE from September 2002 to August 2003 in percentage is reported in Table 5. Table 6 has the "Alfa" coefficients used to reflect the fuel price in the tariffs adjustments. These "Alfa" coefficients were defined at the end of 2001, and have remained constants ever since. There are slight differences with the actual fuel consumption data in Table 5. It is important to note that the natural gas is underestimated in the Alfa coefficients in comparison with the real fuel consumption.

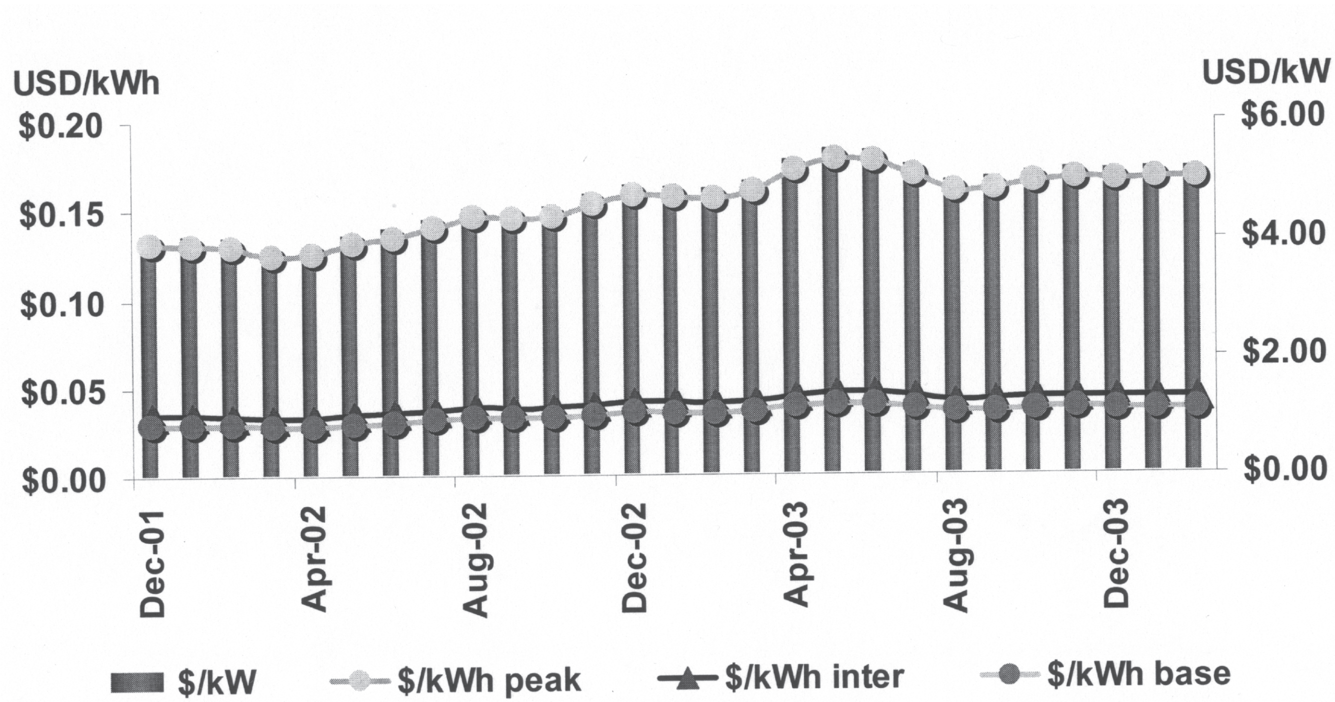


Figure 2. High Voltage Tariff HS NE in 2003 Dollars

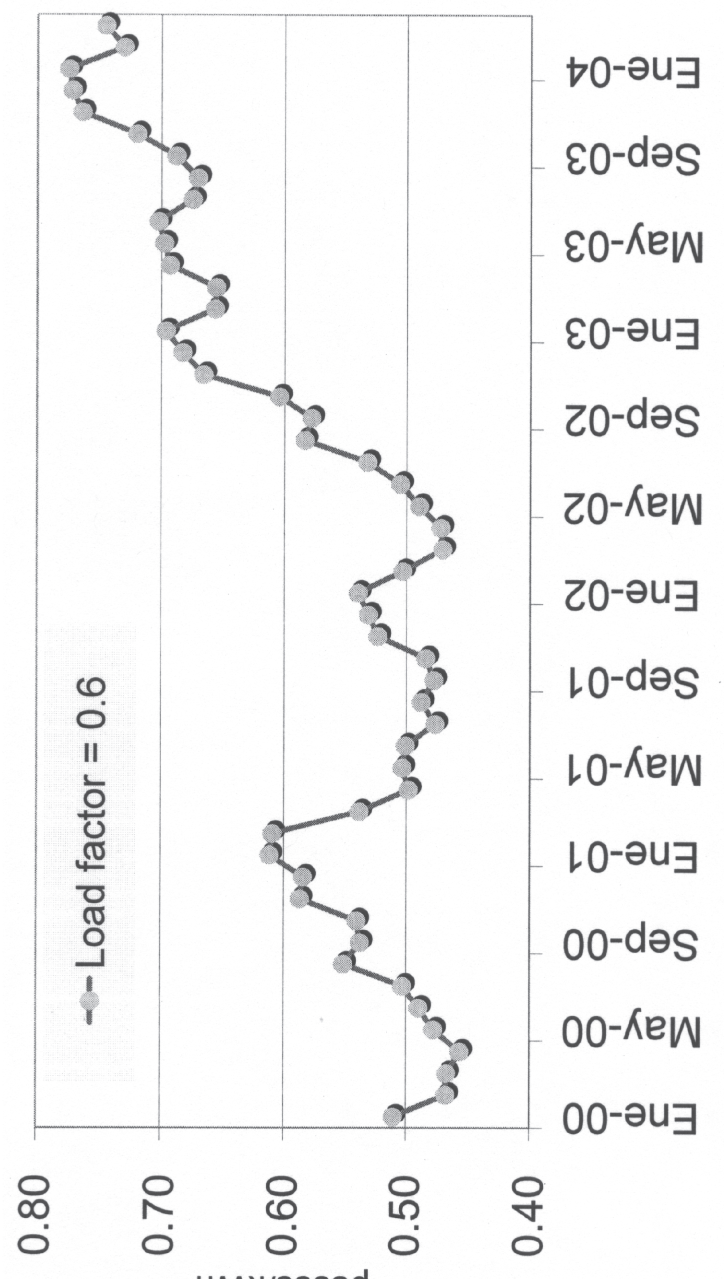


Figure 3. Mixed Cost per kWh in Nominal Pesos for the Tariff HS NE with a Load Factor 0.6

Table 5. Fuel Consumption of CFE from September 2002 to August 2003

Fossil fuel consumption			
Fuel oil	*Natural gas*	*Diesel*	*Coal*
47.00%	33.00%	2.00%	18.00%

Table 6. "Alfa" Coefficients Used to Reflect the Fuel Consumption in the Tariffs

"Alfa" coefficients			
Fuel oil	*Natural gas*	*Diesel*	*Coal*
52.10%	26.60%	1.20%	20.20%

CFE's industrial tariffs are adjusted every month relative to inflation, fossil fuel prices and the exchange rate [6].

It is relevant to study the significance of each fuel in the high voltage tariffs. In order to do it, the data in Table 7 will be the reference values.

Table 7. Exchange Rate and Fuel Prices in USD/million Btu in November 2001

Exchange rate	$9.22
Fuel Oil	
Imported	$3.54
Domestic	$2.69
Natural Gas	$3.00
Industrial Diesel	$6.02
Coal	
Imported	$1.64
Domestic	$2.12

If we double each reference price, the high voltage tariff would experience an increase. Those increases, in percentage, are in Table 8. For example, if the diesel reference price is doubled, the high voltage tariff would be affected only in 1%. By other hand, if the reference price of Mexican fuel oil is doubled, then the increase of the high voltage would be 16.9%.

Table 8. Impact in the High Voltage Tariff by Doubling the Price of each Fuel

Fuel Oil	
Imported	5.4%
Domestic	16.9%
Natural Gas	11.9%
Industrial Diesel	1.0%
Coal	
Imported	2.1%
Domestic	3.7%

Generation Cost versus Industrial Tariffs

During 2002, the mean price of the electricity, for the user described in Figure 3, was 0.56 pesos/kWh. If this value is compared with the generation cost in the same year, in Table 4, it can be concluded that the tariff barely covers the cost of generation.

FUEL PRICES

Figure 4 has fossil fuels prices in the last years. All the prices are in US Dollars as of December 2003.

The most expensive fuel is industrial diesel, even though it has a special tax discount for non-mobile applications. Natural gas exhibits more volatility. In March 2003, the price of natural gas reached $9 USD/

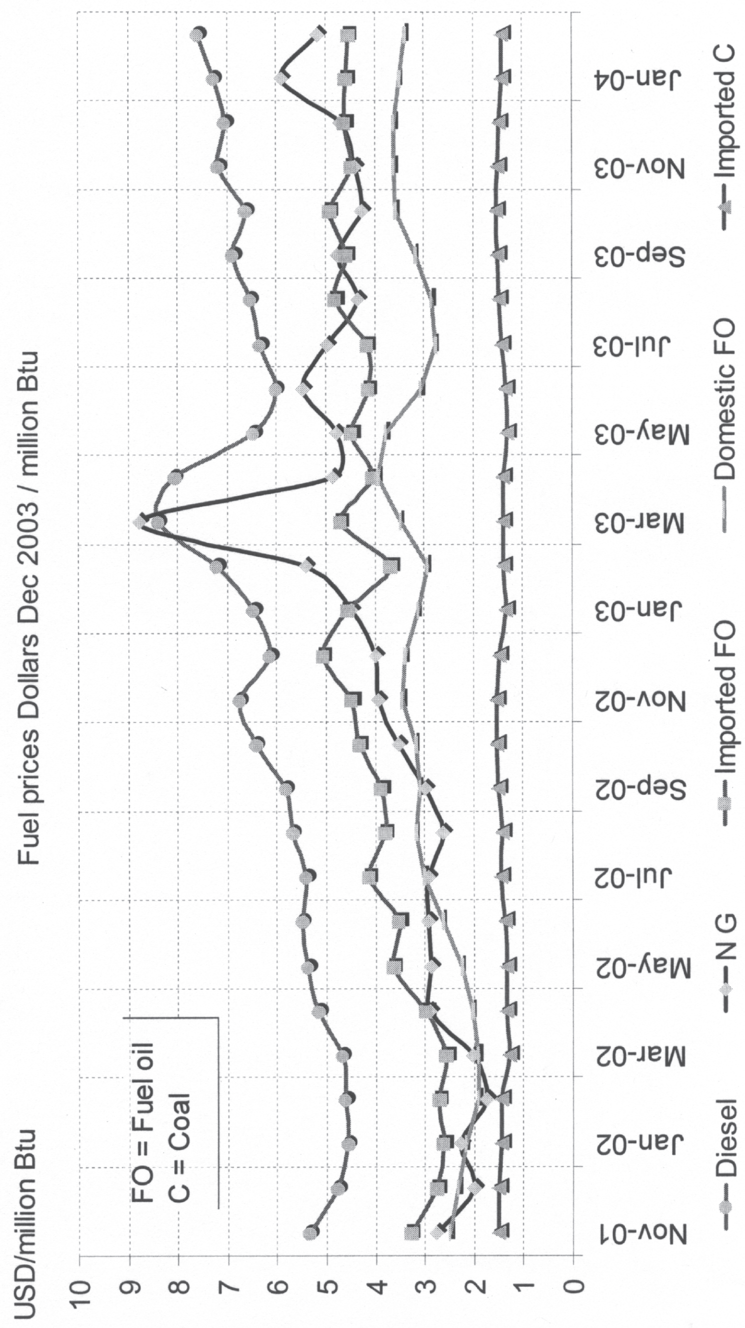


Figure 4. Fuel Prices in US Dollars as of December 2003

million Btu. The reference used in Mexico to determine the price of natural gas is the average of the TETCO and EPGT indexes, from the south of Texas [9]. After the peak in the price of natural gas, the Ministry of Finance and Public Credit and the Ministry of Energy decided to use an average of the last four months for the adjustments to the electrical tariffs.

Figure 4 does not show national mineral coal because it has exhibited a flat price behavior, $2 USD/million Btu. The imported coal from China and Australia, for the "Petacalco" plant is cheaper, $1.5 USD/million Btu, and is better quality. In general, oil products show more volatility than coal.

Pet coke is also omitted in Figure 4. This fuel does not have a developed market in Mexico, but some companies consider it seriously as an alternative to their energy needs. Such is the case of a cement company that has invested $180 million USD to reconvert its Mexican plants to burn pet coke instead of fuel oil or natural gas [10]. At least two other industrial groups in Northeast Mexico are in a similar situation [11 and 12]. It is possible to see this incipient demand reflected in the increase of the national pet coke production. In 2002, the production was 1000 barrels per day; a year after, the average was 16,000 barrels per day [13].

CONSUMPTION AND PRODUCTION OF NATURAL GAS IN NORTH AMERICA

Mexico

The major gas consumers could be grouped by sectors as following:

1. Oil industry (internal use and recirculations)
2. Industrial (PEMEX petrochemistry and private industry)
3. Electric (public and private)
4. Rest (residential, services and transport)

In Figure 5, the evolution of the consumption of natural gas can be followed [14].

Since 2002, the electric power sector burns more natural gas than the industrial sector. The importance of natural gas among the rest of fossil fuels has been increasing because of the preference of the NGCC.

There is a significant reduction in energy consumption of the industrial sector between 2000 and 2001 because of the high prices. The same sector experienced just a slight recovery in 2002, despite the average price of $3 USD/million Btu during the year.

The oil sector had continuously increased its consumption but now is showing some saturation effect.

The imports of natural gas have been growing to meet the needs of the country, because the national production remains essentially constant. Figure 6 shows the average import rate from 1999 to date [15]. The line in Figure 6 and the secondary axis gives the percentage of imports in the national consumption. Over the last year, the import rate is 750 million ft^3/day. Assuming a constant price of $4 USD/thousand ft^3 (≈$4 USD/million Btu) and some simple operations, it is possible to estimate that Mexico is spending about $1,095 million USD/year. PEMEX is not able to follow the consumption growth rate because of its limited investment capability. An increase in the national production could reduce the imports and the trade balance deficit.

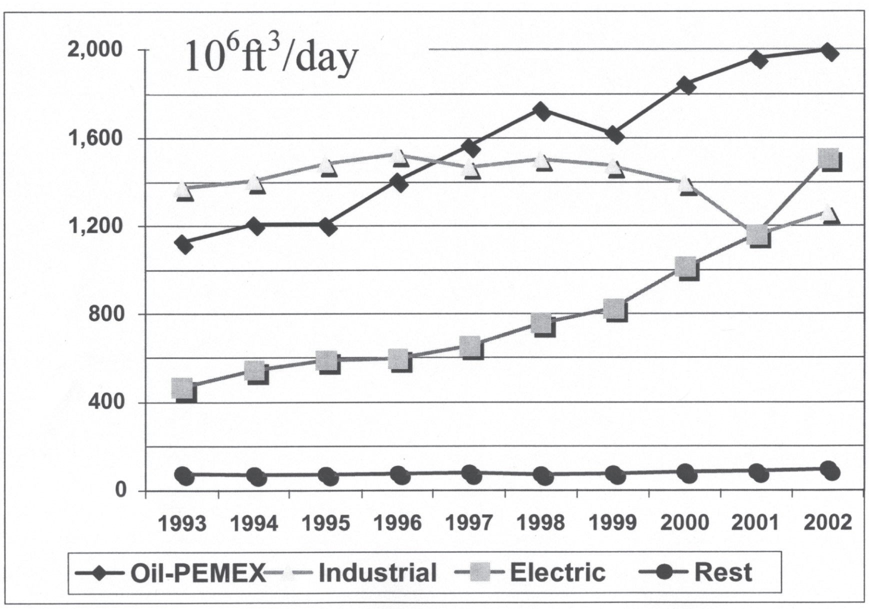


Figure 5. Natural Gas Consumption in Mexico

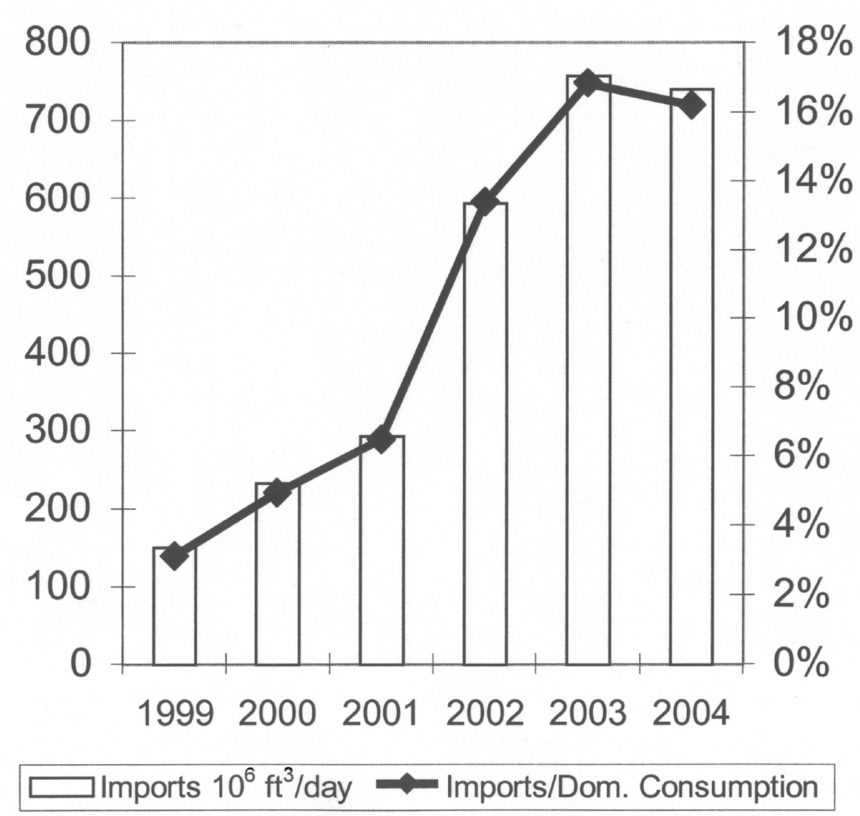


Figure 6. Natural Gas Imports

North America

The bars in Figure 7 represent the production and demand of natural gas in North America [16], and include a scenario for 2010. The current situation is that Mexico imports natural gas from USA, who also imports from Canada.

The USA added 175 GW (more than three times the total Mexican capacity), in plants fired with natural gas, to their power generation capacity between 2000 and 2003 [17]. This affects significantly the demand of the fuel in North America.

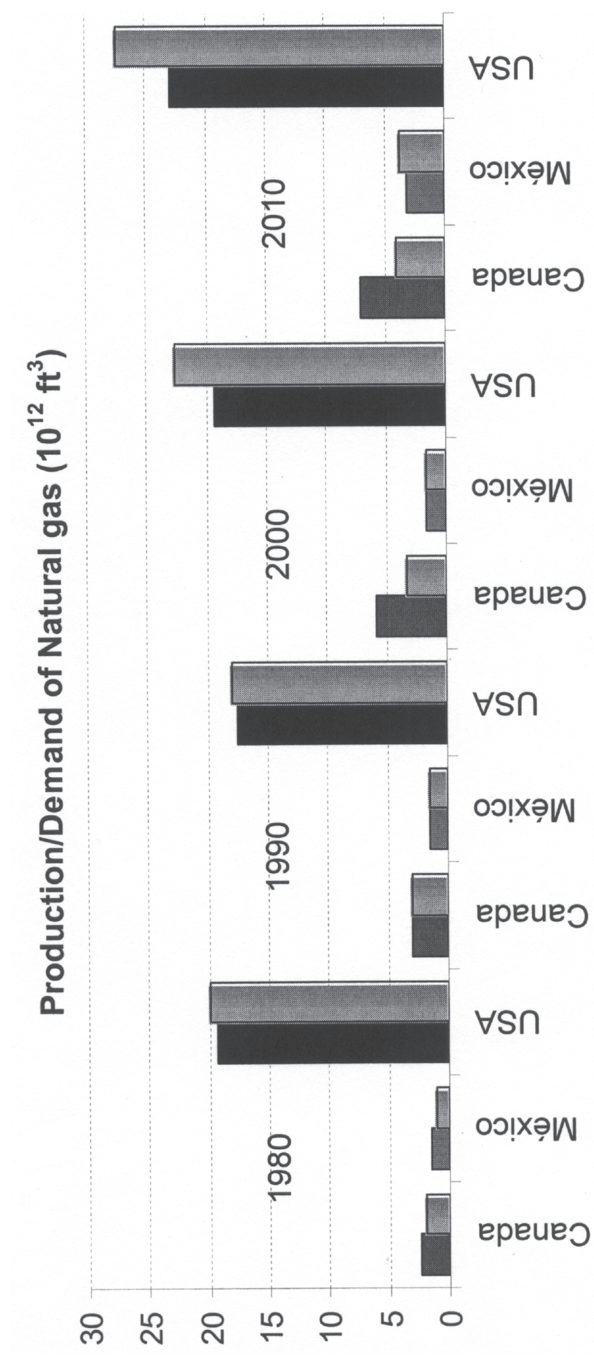


Figure 7. Demand and Production of Natural Gas in North America

SELF-SUPPLY SCHEME IN PRACTICE

The self-supply scheme is among the alternatives allowed in the Electric Energy Public Service Law for the acquisition of electric power [18]:

> "*...the use of electric power for the own consumption may be considered as self-supply only if that energy comes from plants meant to satisfy the needs of its society partners.*"

A society with the only purpose to satisfy the electrical needs of its members must be established. The society partner devoted to the power generation is known as permit holder; the rest of the members are load points or consumption centers. The permit holder may supply the electric power needs of its partners partially or totally. If it is partially, the rest of the energy will be provided by CFE.

In practice, the self-supply societies have to deal with some issues that make them doubt about the benefits of the scheme.

Purchased Capacity Selection

In the load profile of a given load center depicted in Figure 8, the lower area, delimited by the purchased capacity, represents the self-supply energy. The area above this line is the energy provided by CFE in normal supply.

A load duration curve, gives more information about the utilization of purchased capacity. Figure 9 shows the load duration curve of the same load center, and its purchased capacity. Now it is easy to see that this partner utilizes its full purchased capacity only 33% of the time. Such utilization makes the self-supply energy more expensive, because the fixed charges have to be paid whether the energy is consumed or not. It is advisable to make more intensive use of the purchased capacity. A purchased capacity within the limits of the shown band would be more appropriate.

Medium Voltage Wheeling

The methodology created to determine the wheeling cost considers an additional charge for those users in medium voltage [19]. The society partners in medium voltage pay, in average, three times per kWh more than the ones who receive the energy in high voltage. In some cases, this

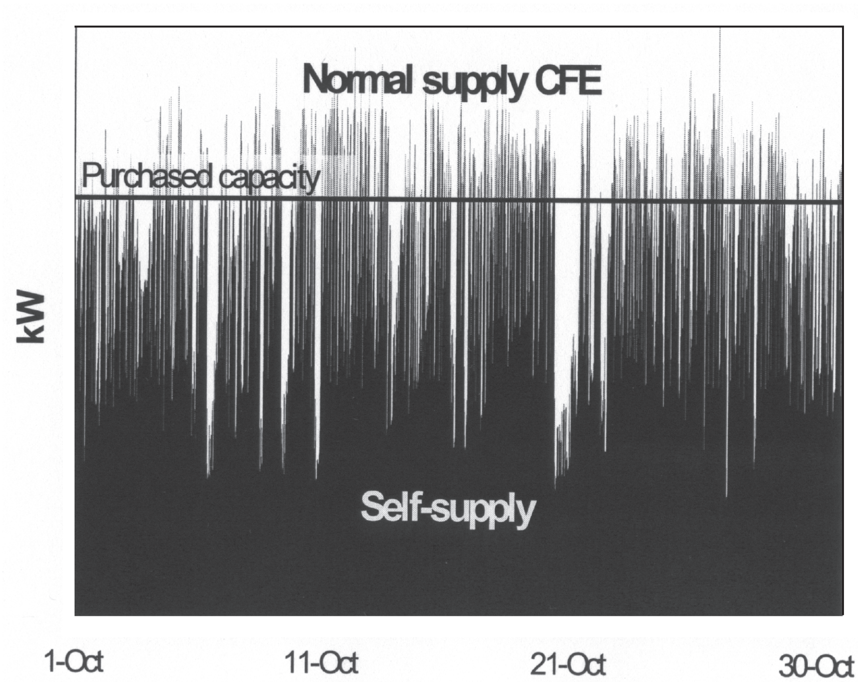


Figure 8. Load Profile

charge is comparable to the fixed charge per capacity of a combined cycle natural gas*.

Rigid Contracts

The load centers and the permit holder sign a 15-year PPA (power purchase agreement), which it is very difficult to modify. Any modification to the purchased capacities implies a wheeling study that takes more than 3 months and is expensive. The contract cancellation is not an alternative because of the high penalization involved.

Non-written Obligation to Sign a Contract with CFE's Union to Those Societies that Require Wheeling Services

The commercial operation of the permit holder is not allowed be-

*In these days, a reasonable capacity cost per kW for a NGCC plant is about $600 USD. Considering an economic life of 25 years and 12% interest rate, the $600/kW turns into a monthly capacity cost of $6.32 USD/(kW-month).

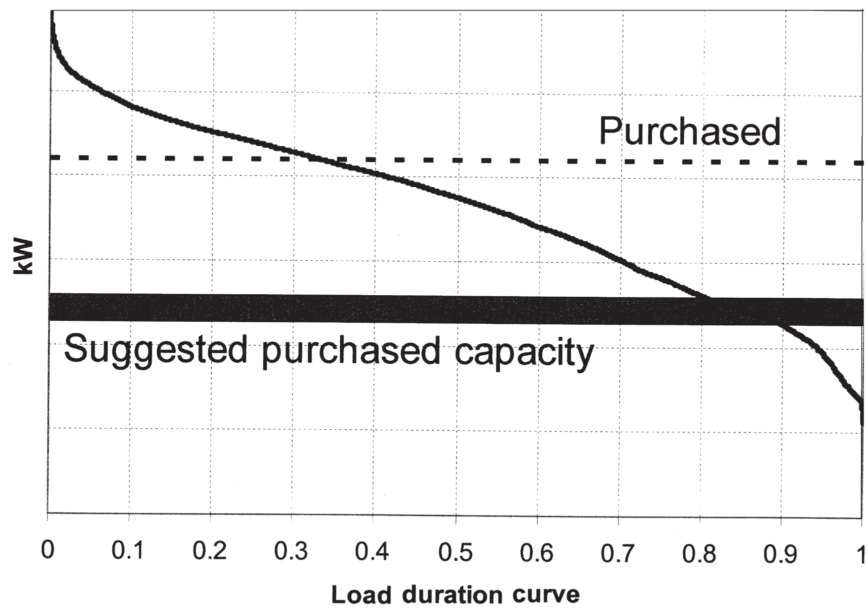


Figure 9. Load Duration Curve

fore a contract with CFE's Union is signed [20]. This situation economically affects the permit holder. The authors consider this arbitrary and illegal.

Volatility and Rise of Natural Gas Price

It is well known that this is an issue that threatens the self-supply projects. Some of the self-supply projects that are now operating were evaluated in 2000, when the average price was $2 USD/million Btu and the highest price registered was $4 USD/million Btu, as can be verified in Figure 10. Now the expected scenario is $4.5 USD/million Btu on average [21].

The share of the natural gas price in the overall cost of the self-supply energy becomes more significant as the price of the fuel goes up. For example, when the price of gas is $3.5 USD/million Btu, fuel cost represents about 60% of the cost of energy. But when the price reaches $7 USD/million Btu, its contribution to the electrical energy price goes to 75%. Figure 11 shows the dependence of the final cost of electric energy with respect to natural gas.

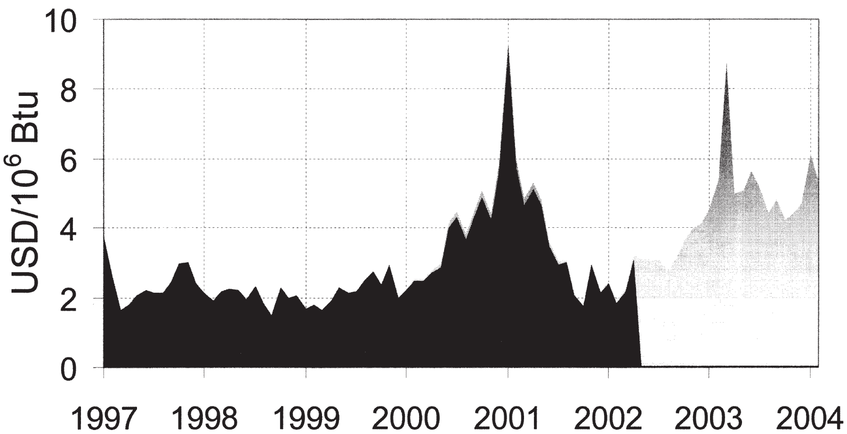


Figure 10. Natural Gas Prices

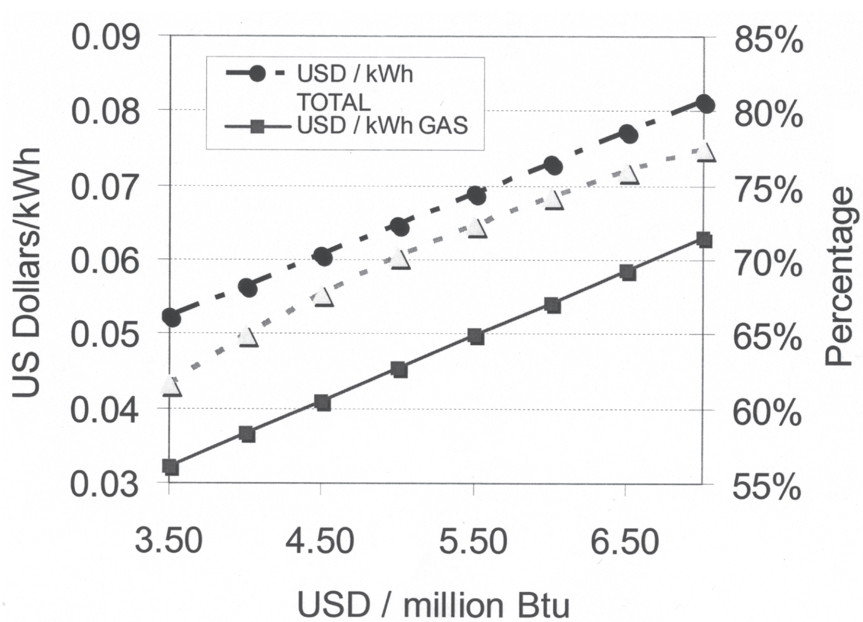


Figure 11. Final Cost of Self-supply Versus the Price of Natural Gas

Sell of Surplus Energy

In normal conditions, the permit holder generates enough constant power to satisfy the sum of all the purchased capacities of all its society partners. When the demanded energy of the load centers is less than the generation injected to the grid by the permit holder, there is surplus energy. This surplus energy is bought by CFE at 85% of the total short term cost of the electric energy (CTCP) [22]. This payment is not even enough to cover the permit holder's fuel costs. For instance, let us consider gas at $4.44 USD/million Btu, a heat rate of 7000 Btu/kWh. The cost of the kWh based on the natural gas cost is 3.08 US cents. In that same month (during 2003), the CTCP was 3.24 US cents per kWh. 85% results in 2.75 US cents per kWh. In this example, 2.75 US cents per kWh is not enough to cover fuel cost, even with an excellent heat rate. Of course, with a heat rate of 9000 Btu/kWh, the price paid by CFE is even less attractive.

Low Power Factor Penalization

When the power factor of a load center is above 0.9, the discount is calculated on the basis of the energy consumed by CFE. But when the power factor is poor (below 0.9), then there is a penalty that takes into account all energy consumed by the load center, including the self- supply energy.

Self-Supply Energy versus CFE

The case of a self-supply society in Northeast Mexico is considered here. The permit holder runs a natural gas combined cycle plant. Figure 12 shows the development of the cost of the energy consumed by two load centers with self-supply. The solid line is the real cost of energy paid by the load center, including the self-supply energy and the one provided by CFE when it is necessary*. The dashed line is the hypothetic cost of energy that the load center would have paid to CFE if all the energy were provided by it, that is, without self-supply. With self-supply, the energy for Partner 1 sometimes was less expensive. In contrast, Partner 2 would have preferred to be totally out of the self-supply scheme. It is important to say that Partner 2 has a purchased capacity above its own needs because of changes in production.

---

*Including fuel cost, capacity cost, operation and maintenance.

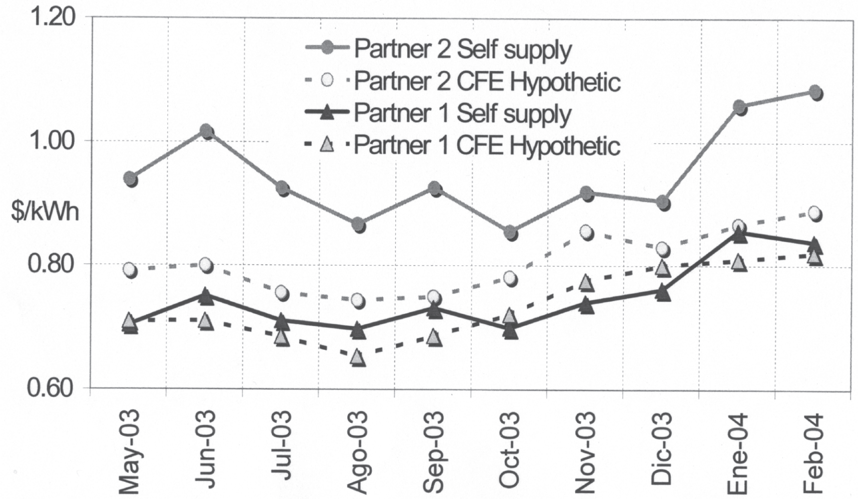


Figure 12. Cost per kWh of the Self-supply Energy Compared to that of CFE

ALTERNATIVE TO THE NATURAL GAS IN COMBINED CYCLES

It has been remarked that the expansion of the Mexican Power sector is mainly based in NGCC. Most of the self-supply and cogeneration projects also prefer this technology. Given the high prices and volatility this fuel has experienced, it is worth considering an alternative: synthesis gas.

Synthesis gas can be obtained by gasifying different kinds of fuels, like pet-coke and coal, residual plastics and waste oils. The initial investment of an integrated gasification combined cycle (IGCC) plant is higher than the conventional combined cycle, around $1,200 and $1,600 USD/kW [23]. A typical efficiency of an IGCC is around 41% or a heat rate of 8,530 Btu/kWh [23].

Both technologies, IGCC and NGCC, can be compared in terms of cost per kWh. This comparison will consider the monthly capacity cost, the fuel cost, a plant factor of 0.85, and also typical operation and maintenance cost: $0.003834 USD/kWh for NGCC and $0.008507 USD/kWh for IGCC [24].

Capacity Cost

The cost of generation, besides the fuel and the operation and maintenance cost, includes the capacity cost. The capacity cost depends on the technology. In these days, a reasonable capacity cost per kW for a NGCC plant is on the order of $600 USD. With the help of some economic management techniques, as it can be seen in Equation 1, this initial cost can be expressed as a monthly capacity cost. For example, considering an economic life of 25 years and 12% interest rate, the $600 USD/kW turns into a monthly capacity cost of $6.32 USD/(kW-month). This charge should be paid whether the plant generates energy or not.

$$CF_{CAP} = CU_{II} \frac{\frac{i}{12}\left(1 + \frac{i}{12}\right)^{12 \bullet n}}{\left(1 + \frac{i}{12}\right)^{12 \bullet n} - 1} \qquad \text{Equation 1}$$

where,

CU_{II} is the capacity cost in \$/kW,
i is the mortgage rate,
n is the number of years and,
CF_{cap} is the monthly capacity cost \$/(kW month)

This monthly capacity cost can also be expressed in terms of energy by dividing by the month hours and the plant factor, as in Equation 2.

$$CU_{CAP} = \frac{CF_{CAP}}{pf \bullet h_m} \qquad \text{Equation 2}$$

where,

CF_{cap} is the monthly capacity cost in \$/(kW-month)
pf is the plant factor,
h_m is the month hours,
CU_{cap} is the monthly capacity cost in \$/(kWh-month)

When a plant has a low plant factor, as wind turbines and peak plants, the monthly capacity cost per kWh becomes very high.

Fuel Cost

Fuel costs directly affect the cost per kWh. The impact depends on the heat rate (HR)—the heat (in Btu) needed to generate 1 kWh. The heat rate is inversely proportional to the efficiency. The heat rate is frequently expressed with the high heating value of the fuel, HRHHV. For example, if an NGCC plant has 50% efficiency, this is equivalent to a heat rate of 6,824 Btu/kWh. The cost of fuel per kWh can be calculated as:

$$CU_{fuel} = \frac{HR_{HHV} \times CC}{10^6} \qquad \text{Equation 3}$$

where,

HR_{HHV} is the heat rate with high heating value Btu/kWh,
CC is the fuel price in $US Dollars/million Btu, and
CU_{fuel} is the fuel cost per kWh

Comparison of IGCC and NGCC

The curves in Figure 13 and Figure 14 relate the fuel price to the cost per output kWh for a given initial investment in capacity. The monthly capacity cost, the fuel cost, the plant factor, and the operation and maintenance cost are included.

Taking a look at the $600 USD/kW curve in Figure 13, if the price of natural gas were $5 USD/million Btu, then the cost of output energy would be $0.04814 USD/kWh.

With the help of Figure 14, it is easy to find out what would be the

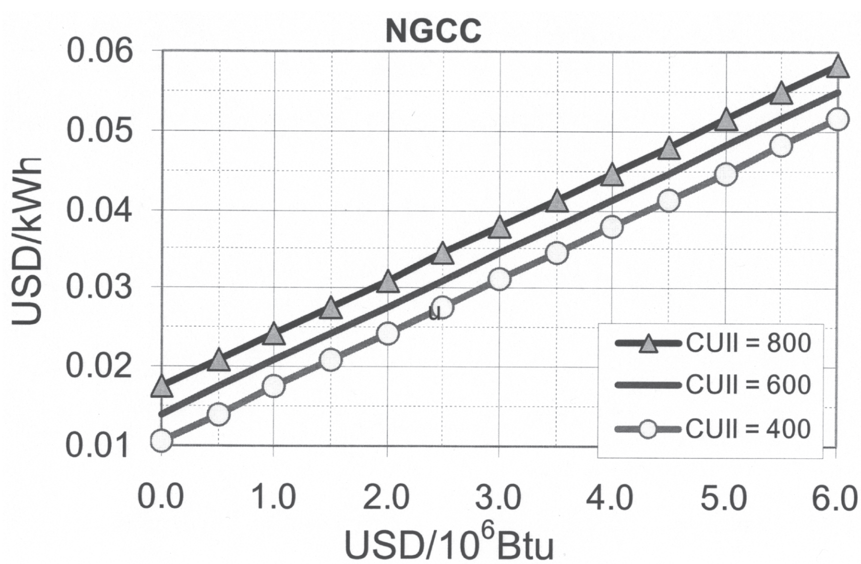
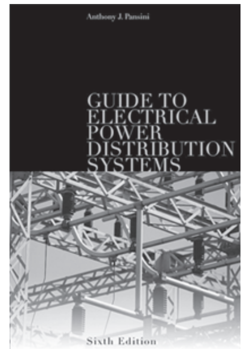


Figure 13. NGCC Cost per kWh

Covers the impact of distributed generation on power distribution systems…

GUIDE TO ELECTRICAL POWER DISTRIBUTION SYSTEMS



SIXTH EDITION

By Anthony J. Pansini

Written by a highly regarded power industry expert, this comprehensive manual covers in full detail all aspects of electric power distribution systems, both as they exist today and as they are evolving toward the future. A new chapter examines the impact of the emergence of cogeneration and distributed generation on the power distribution network. Topics include an overview of the process of electricity transmission and distribution, a thorough discussion of each component of the system – conductor supports, insulators and conductors, line equipment, substations, distribution circuits and more – as well as both overhead and underground construction considerations. Improvements in both materials and methods of power distribution are also explored, including the trend toward gradual replacement of heavier porcelain insulators with lighter polymer ones. The complex aspects of electric power distribution are explained in easy-to-understand, non-technical language.

ISBN: 0-88173-505-1

ORDER CODE: 0542

6 x 9, 265 pp., Illus.
Hardcover, $92.00

CONTENTS

BOOK ORDER FORM

① Complete quantity and amount due for each book you wish to order:

Quantity	Book Title	Order Code	Price	Amount Due
	Guide to Electrical Power Distribution Systems, Sixth Edition	**0542**	**$92.00**	
			Applicable Discount	
			Georgia Residents add 6% Sales Tax	
			Shipping Fees	**9.00**
			TOTAL	

② Indicate shipping address: **CODE: Journal 2004**

NAME (Please print) BUSINESS PHONE

SIGNATURE (Required to process order)

COMPANY

STREET ADDRESS ONLY (No P.O. Box)

CITY, STATE, ZIP

③ Select method of payment:

Make check payable in U.S. funds to: **AEE ENERGY BOOKS**

☐ **CHECK ENCLOSED**
☐ **CHARGE TO MY CREDIT CARD**
☐ *VISA* ☐ *MASTERCARD* ☐ *AMERICAN EXPRESS*

CARD NO.

Expiration date *Signature*

MEMBER DISCOUNTS
A 15% discount is allowed to AEE members.
☐ AEE Member (Member No.______________________)

√ Send your order to:
AEE BOOKS
P.O. Box 1026
Lilburn, GA 30048

INTERNET ORDERING
www.aeecenter.org

TO ORDER BY PHONE
Use your credit card and call:
(770) 925-9558

TO ORDER BY FAX
Complete and Fax to:
(770) 381-9865

INTERNATIONAL ORDERS
Must be prepaid in U.S. dollars and must include an additional charge of $10.00 per book plus 15% for shipping and handling by surface mail.

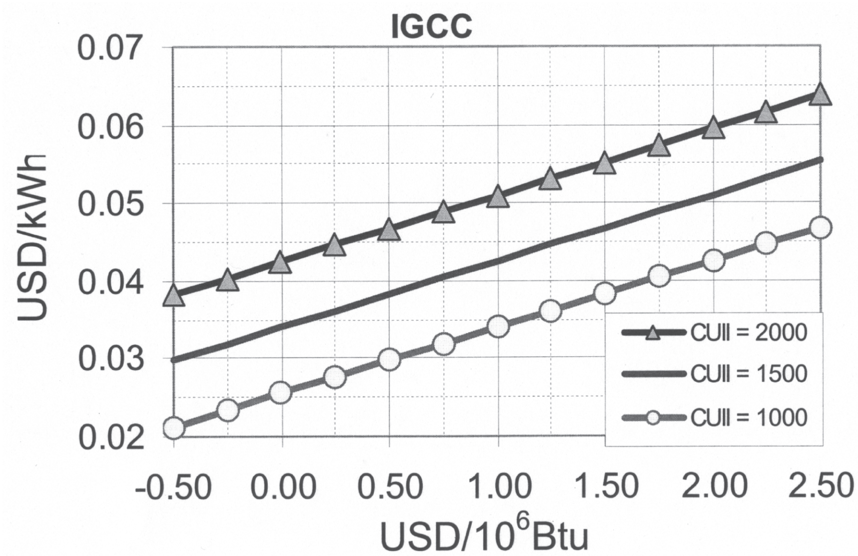


Figure 14. IGCC Cost per kWh

price of fuel needed to get energy at $0.04814 USD/kWh. Assume that the initial investment were $1,500 USD/kW, then price of the fuel needed to produce the synthesis gas needs to be $1.70 USD/million Btu. The imported mineral coal in Figure 4 can match this requirement.

CO_2 EMISSIONS

Table 9 shows typical thermal efficiency and the HRHHV of some generation technologies [25].

Some technologies can handle more than one fuel, so the emission of CO_2 per kWh depends on both, technology and burned fuel. The upper part of Table 10 shows the emission of CO_2 per kWh. The lower part of the same table shows how much CO_2 is emitted per each million Btu of fuel [26].

The lowest emissions per kWh are obtained with the NGCC plant. This is because the combined cycle plants have the highest efficiency and the natural gas is the fuel with the lowest emissions per million Btu.

CO_2 emissions per kWh of an IGCC plant are similar to those of a coal plant. But the NO_X and SO_X emissions are drastically lower, comparable to a NGCC plant [24].

Table 9. Thermal Efficiency by Technology

Efficiency		
	HR_{HHV} (Btu/kWh)	*$Efficiency_{HHV}$*
Vapor	10,083	34%
CC	6,764	50%
Dual	9.655	35%
Coal plant	9,916	34%
Turbogas	9,574	36%
Diesel	7.723	44%
GICC	8.530	40%

Table 10. CO_2 Emission per kWh and per Million Btu

Emissions by Technology and Fuel (gr CO_2/kWh)					
	F.O.	*NG*	*Coal*	*Diesel*	*Coke*
Steam	795	535			
CC		359		495	
Dual	762		931		
Coal plant			957		
Turbogas		508		701	
Diesel	609			565	
IGCC			823		871

Fuel Emissions (gr. CO_2/million Btu)				
F.O.	*NG*	*Coal*	*Diesel*	*Coke*
78,882	53,106	96,479	73,203	102,117

CONCLUSIONS

The external participation has enabled the Mexican power sector to grow in the last years. It had also contributed to increase the overall thermal efficiency and to reduce the generation cost. On the other hand, this external participation had preferred NGCC plants, leaving the power sector more sensitive to this fuel. This is especially true to cogeneration and self-supply projects because CFE has a diversified fuel portfolio. The gasification of other fuels could become a feasible alternative if the price of natural gas stays high. The issues discussed in the practical self-supply discourage new projects, and make existing societies doubt the advantages. Some of the limitations could be solved with better regulations.

References

[1] http://www.cfe.gob.mx/www2/queescfe/notaqueescfe.asp?seccion=queescfe& seccion_id=2271&seccion_nombre=Generaci%F3n

[2] http://www.lfc.gob.mx/

[3] Secretaría de Energía, Prospectiva Sector Eléctrico 2003-2012, cuadro 23, página 69.

[4]Secretaría de Energía, Prospectiva Sector Eléctrico 2003-2012.

[5] Tercer informe de labores de CFE, Septiembre 2002 a Agosto 2003.

[6] http://www.cfe.gob.mx/www2/factores/factores.asp?tarifa=ICC2002&seccion_ nombre=Factores+de+ajuste&seccion=canal+otros+giros&publicacion=45&anio=2004.

[7] CFE, Informe anual 2001, página 43.

[8] http://www.informacionpublica.gob.mx, folio 1816400001503.

[9] Estructura de precios del gas natural http://www.gas.pemex.com/seccion_frame.asp?noticia_id=769&seccion_id=262

[10] César Sánchez, El Norte, Negocios, 30 de enero de 2004. “Concluye CEMEX reconversión.”

[11] César Sánchez, El Norte, Negocios, 23 de marzo de 2004. “Busca Hylsa sustituir gas natural por coque.”

[12] César Sánchez, El Norte, Negocios, 26 de marzo de 2004. “Invierte Vitro Dls. 60 millones”

[13] José Ángel Vela, El Norte, Negocios, 15 de mayo de 2004. “Disparan 16 veces producción de coque.”

[14] Secretaría de Energía, Prospectiva del Mercado de Gas Natural 2003-2012, cuadro 9, página 42.

[15] http://www.pemex.gob.mx/files/dcpe/eimporpetro_esp.xls

[16] North American Energy Working Group, North America – The Energy Picture, June 2002. http://www.eia.doe.gov/emeu/northamerica/engindex.htm#_VPID_1

[17] Energy information Administration, Annual Energy Outlook 2004 with Projections to 2025 Market Trends – Electricity. http://www.eia.doe.gov/oiaf/aeo/electricity.html

[18] Reglamento de la Ley del Servicio Público de Energía Eléctrica, Diario Oficial de la Federación de 31 de mayo de 1993, Diario Oficial de la Federación de 25 de julio de 1997.

[19] Comisión Reguladora de Energía, Metodología para la determinación de los cargos por servicios de transmisión de energía eléctrica. Resolución Núm. RES/146/2001

[20] Margarita Palma Gutiérrez, “Tractebel, campo de batalla de dos grandes sindicatos,” sección Negocios de El Financiero, Jueves 3 de abril de 2003.

[21] Edward Kelly, Horizons 13, Wood Mackenzie, September 2003.

[22] Comisión Reguladora de Energía, Modelo de Convenio de compraventa de excedentes de energía eléctrica (energía económica), RESOLUCION Núm. RES/147/2001

[23] Lisa Kosavic, How clean is coal?, Energy User News http://www.energyusernews.com/eun/cda/articleinformation/features/bnp_features_item/0,,77769,00+en-uss_01dbc.html

[24] Manuel Treviño Coca, Tecnología de Gasificación Integrada al Ciclo Combinado – Aplicación Real en España, ELCOGAS Puertollano. http://www.elcogas.es/shared/GICC%20tecnologia%20limpia%20del%20carbon.pdf

[25] CFE, Subdirección de Programación, COPAR 2003, cuadro 4.4, http://www.informacionpublica.gob.mx folio 1816400018804.

[26] Energy information administration, Fuel and Energy Source Codes and Emission Coefficients http://www.eia.doe.gov/oiaf/1605/factors.html

---

ABOUT THE AUTHORS

Armando Llamas Terrés received his BS (1983) and his MS (1985) from Instituto Tecnológico y de Estudios Superiores de Monterrey, Monterrey Tech. He holds a Ph.D. from Virginia Polytechnic Institute and State University. Currently, he is the Director of the Center for Energy Studies, at Monterrey. He is also the responsible of the Endowed Research Chair in Energy - Modernization of the Mexican Energy Sector, a sustainable approach. Dr. Llamas is member of IEEE, Certified Energy Manager and life member of AEE. He may be contacted at allamas@itesm.mx.

Federico A. Viramontes Brown is an Electrical Mechanical Engineer from the Monterrey Tech, and holds an MS and a Ph.D. from the University of Pittsburgh. He is currently the Director of Graduate Studies of the Engineering Division at Monterrey Tech. Dr. Viramontes is a senior member of IEEE.

Oliver Probst earned his physics diploma at the University of Heidelberg, Germany, in 1990 after studying in Hannover and Heidelberg. He obtained a Ph.D. degree in physics from the University of

Heidelberg in 1994. He is the head of the Physics Department at Monterrey Tech since 1999. Since his arrival in Monterrey he has been collaborating with a number of research centers at the same institution, particularly the Center for Energy Studies.

Ruth Elizabeth Reyna Caamaño received her BS from the Monterrey Tech. Recibió el grado. She earned her MS and Ph.D. degrees from Carnegie Mellon, Pittsburgh. She is currently a researcher at the Environmental Quality Center of Monterrey Tech.

Aníbal Morones Ruelas is an Electrical Mechanical Engineer from the Monterrey Tech. He is currently under an MS program in Energetic Engineering, works at the Center for Energy Studies, at Monterrey Tech as a research assistant.

Manuel Ángel González Chapa received his BS from the Universidad Autónoma de Nuevo León. He holds an MS from the Monterrey Tech.