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The First Edition of *Guide to Electric Power in Mexico* was prepared to provide a comprehensive and balanced educational resource for a wide range of electricity customer groups, from interested residential consumers to large commercial and industrial organizations. It was modeled on the *Guide to Electric Power in Texas*, conceived of and prepared in 1997 by the Houston Advanced Research Center (HARC) and the Center for Energy Economics (CEE) now based in the Bureau of Economic Geology at the Jackson School of Geosciences, the University of Texas at Austin (then at the University of Houston).

The First Edition of the Mexico guide was based largely on work undertaken since 1991 by Dr. Francisco García independently and jointly with Dr. Michelle Michot Foss of CEE to explore issues in Mexico’s energy sector. Dr. García, an emeritus professor at the Instituto Tecnológico y de Estudios Superiores de Monterrey (ITESM), now retired, enjoyed a long career teaching and conducting research on energy and resource economics. The ITESM is one of the most prominent universities in Mexico and an international partner with the University of Texas-Austin. The ITESM is a campus-wide higher education system with campus locations throughout México. Dr. García and Dr. Foss published joint research on Mexico’s natural gas, LPG and electricity sectors. These older studies are still available through CEE, www.beg.utexas.edu/energyecon or contact energyecon@beg.utexas.edu. Ms. Miranda Wainberg, senior advisor at CEE, has been a major co-author of the Mexico guide. Ms. Wainberg collaborates with Dr. Michot Foss and undertakes separately exploration of energy issues in the Americas, with special interests in national oil companies helping to lead CEE’s work in this arena. Ms. Wainberg also helps to develop upstream and midstream components of CEE’s ongoing research.

This updated Second Edition included assistance from and collaboration with researchers and students at Mexico’s Instituto Tecnológico Autónomo de México (ITAM) through a joint grant to UT and ITAM through the Higher Education for Development (HED) TIES (Training, Internships, Exchanges, and Scholarships) program. From 2007-2011 the HED TIES grant facilitated research and programmatic exchanges between UT and ITAM and, with extensive matching support from UT, four graduate scholar positions in the UT Jackson School of Geosciences Energy and Earth Resources master’s program. Mr. Andrés Gallardo, a TIES scholar, provided assistance with this updated edition. Ms. Hazel Blackmore, then director of ITAM’s Department of International Studies-Center on InterAmerican Studies and Programs, provided crucial assistance and support with both the guide update and the UT-ITAM grant. Mr. Severo López also participated in the guide update as an ITAM alumnus. Ms. Kristin Batres, administrative assistant at CEE, provided research support and final translation; Ms. Elizabeth Paris, MultiFuels, provided an initial translation; and Ms. Jamie Coggin, senior graphics designer, designed and updated the Guide layout. This edition includes data through 2011. Up-to-date information for some indicators is available from SENER, http://www.sener.gob.mx/webSener/Default.aspx, and CFE, http://www.cfe.gob.mx/paginas/home.aspx.

The Bureau of Economic Geology’s CEE is a university-based center of excellence on energy value chain economics. Our main focus is on the frameworks that best support sustainable, commercially successful energy resource and infrastructure investments worldwide. The CEE team specializes in interdisciplinary approaches (economic, business, technology and policy/regulatory) that best optimize energy value chains, from energy resource exploration and production, to transportation and distribution, and conversion and delivery for end use. Research, training (largely in conjunction with the Red McCombs School of Business), and outreach projects have been undertaken by the CEE team in North America and worldwide. The CEE is supported by both private and public sector donors. More information about the CEE can be obtained from www.beg.utexas.edu/energyecon.
Mexico’s Secretaría de Energía (SENER) reports internal Mexican electricity consumption as follows:

- SEN (Sistema Eléctrico Nacional) electricity sales which consist of sales made by the two large state owned electric companies, Comisión Federal de Electricidad (CFE) and Luz y Fuerza del Centro (LFC). In October 2009 the government closed LFC and CFE took over its operations. SEN sales include electricity sales made by independent power producers (IPPs) to CFE which CFE then resells to final customers. SEN sales exclude electricity generated by end-users, largely industrial companies, for their own use.

- Total internal Mexican electricity consumption includes SEN electricity sales as well as electricity generated by self-suppliers.

**Total Internal Electricity Consumption**

During the period 1999-2011, total sales of electricity in Mexico grew at an average rate of 2.4 percent per year. This growth has been driven by increases in residential and industrial electricity consumption, including sharp increases in electricity generated by end-users for their own use (self-supply). (An example of the latter is an industrial facility that generates electricity for its own consumption, termed “self-generation” or “generation for self-consumption.”) Self supply of electricity grew at an average rate of 8.5 percent per year over the same period. Lower growth rates after 2007 reflect the impact of the global economic recession beginning in 2008.

**SEN Electricity Sales**

SEN sales of electricity in Mexico grew at an average rate of 2.4 percent during the period 1999–2011. Electricity sales declined 1.3% from 2008 to 2009 due to the economic recession experienced by industries during that period.

CFE generates, transmits and distributes electricity across all of Mexico. Until October 2009 LFC was mainly responsible for transmission and distribution of electricity in Mexico City (Distrito Federal, DF or Federal District). LFC bought approximately 95 percent of its electricity supply from CFE. IPPs sell almost all of their output to CFE which then re-sells the electricity to its customers. (IPPs, self-generation and cogeneration will be discussed in more detail in later sections of this chapter).

Most of Mexico’s electricity sold by SEN is consumed by industrial and residential customers (58 percent and 26 percent, respectively, in 2011). Growth in these two important sectors, especially residential and medium size industries, has propelled the overall growth in national consumption over the period 1999–2011. Sales of electricity to industries decreased between 2008 and 2009 due to a global economic recession. However, in 2011 SEN sales of electricity to medium size and large industrial customers grew 4.9 percent and 11.6 percent, respectively.

Electricity consumption and economic growth (as measured by gross domestic product or GDP) are closely intertwined as indicated in Figure 1. The growth rates in both GDP and electricity consumption declined in 2008 and 2009.

Electricity use per person or per capita tends to be higher in more advanced economies and lower in countries with less developed economies. Despite the growth in electric consumption in Mexico over the period 1997–2007, per capita consumption in 2009 (KWh/resident) remains low at 1,943 KWh/resident compared to more than 8,000 KWh/resident on average for industrialized countries.

Although richer countries consume more electricity per capita than poorer ones, the electric energy intensity of their economies is lower. Richer countries use less electricity to generate an additional dollar of GDP. In Mexico, energy intensity remains relatively high at 1,943 KWh/resident compared to 4.9 percent and 11.6 percent, respectively.

*Source: SENER: Electricity Sector Outlook.*

**Table 1. Total Domestic Mexican Electricity Consumption, 1999-2011 (GWh).**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sales (SEN)</td>
<td>144,996</td>
<td>155,349</td>
<td>157,204</td>
<td>160,203</td>
<td>160,384</td>
<td>163,509</td>
<td>169,757</td>
<td>175,371</td>
<td>180,469</td>
<td>183,913</td>
<td>182,549</td>
<td>187,814</td>
<td>202,226</td>
<td>2.4%</td>
</tr>
<tr>
<td>Variation %</td>
<td>5.7</td>
<td>7.1</td>
<td>1.2</td>
<td>1.9</td>
<td>0.1</td>
<td>1.9</td>
<td>3.8</td>
<td>3.3</td>
<td>2.9</td>
<td>1.9</td>
<td>-0.8</td>
<td>2.9</td>
<td>7.7</td>
<td></td>
</tr>
<tr>
<td>Self-sufficient</td>
<td>10,864</td>
<td>11,027</td>
<td>12,066</td>
<td>12,363</td>
<td>16,608</td>
<td>20,4673</td>
<td>21,582</td>
<td>22,064</td>
<td>23,160</td>
<td>23,946</td>
<td>23,745</td>
<td>21,582</td>
<td>26,155</td>
<td>27,092</td>
</tr>
<tr>
<td>Variation %</td>
<td>19.7</td>
<td>1.5</td>
<td>9.4</td>
<td>2.5</td>
<td>34.3</td>
<td>23.2</td>
<td>5.5</td>
<td>2.2</td>
<td>5.0</td>
<td>3.4</td>
<td>-0.8</td>
<td>10.1</td>
<td>3.6</td>
<td></td>
</tr>
<tr>
<td>Total Sales</td>
<td>155,860</td>
<td>166,376</td>
<td>169,270</td>
<td>172,566</td>
<td>176,992</td>
<td>183,972</td>
<td>191,339</td>
<td>197,435</td>
<td>203,638</td>
<td>207,859</td>
<td>206,263</td>
<td>213,970</td>
<td>229,318</td>
<td>3.0%</td>
</tr>
<tr>
<td>Variation %</td>
<td>6.5</td>
<td>6.7</td>
<td>1.7</td>
<td>1.9</td>
<td>2.6</td>
<td>3.9</td>
<td>4.0</td>
<td>3.2</td>
<td>3.1</td>
<td>2.1</td>
<td>-0.8</td>
<td>3.7</td>
<td>7.2</td>
<td></td>
</tr>
</tbody>
</table>
To generate an additional dollar of GDP, in terms of energy, it costs less in richer countries. Richer countries use less electricity per dollar of GDP, which is lower. Richer countries consume more electricity per person or per capita than poorer countries. Although richer countries consume more electricity per person or per capita, their economic growth is still considerably lower, as measured by GDP per capita.

Electricity consumption in 2009 (kWh/resident) remains unaltered for all industries. Total electricity consumption in Mexico grew more than 8,000 KWh/resident on average for industrialized countries. However, Mexico’s electric consumption in 2009 (KWh/resident) remains low at 1,943 KWh/resident compared to 8,012 kwh of OECD electricity to generate $24,190 of OECD GDP. If Mexico begins to manifest the declining energy intensity typical of other industrial countries in all electricity consuming sectors, the overall growth rate of total electric consumption could decrease.

Who Uses Electricity in Mexico?

More than 35 million customers (representing over 100 million inhabitants) bought electricity from CFE in 2011. Electric service was provided to approximately 95 percent of Mexico’s population. About 88 percent of these customers are residential. There are over three million commercial customers and about 257,900 industrial customers of which 900 are considered “large industries.” In 2011, CFE received most of its revenue from industrial customers who spent over $12 billion on electricity, $8 billion of which was from medium size industries. In this same year, residential customers spent $4.4 billion and commercial users $2.7 billion1. Services and agricultural customers paid $1.15 billion and $439 million, respectively.

In most countries, large volume industrial customers pay lower tariffs (the final price for delivered electricity) than low volume commercial, residential and agricultural users. This lower tariff for large volume

1 The average actual exchange rate between U.S. dollars and Mexican pesos for the year cited is used in this guide to convert Mexican pesos to US dollars and vice versa.

2 The tariff for electric power includes all costs associated with generating, transmitting, and distributing electricity, including operating and maintenance costs and depreciation of the electricity systems and including a rate of return that allows for reinvestment in the electricity systems. Costs for electric power are generally apportioned across classes or categories of customers that reflect amount of usage and the cost to serve particular customer classes. See section on Evolution of Electricity Prices in Mexico.

Table 2. SEN Electricity Sales by Consumer Category (GWh)

<table>
<thead>
<tr>
<th>Year</th>
<th>Residential</th>
<th>Commercial</th>
<th>Services</th>
<th>Agriculture</th>
<th>Medium size industry</th>
<th>Large Industries</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>33,370</td>
<td>10,964</td>
<td>5,432</td>
<td>7,997</td>
<td>49,446</td>
<td>37,788</td>
</tr>
<tr>
<td>2001</td>
<td>33,370</td>
<td>10,964</td>
<td>5,432</td>
<td>7,997</td>
<td>49,446</td>
<td>37,788</td>
</tr>
<tr>
<td>2002</td>
<td>33,370</td>
<td>10,964</td>
<td>5,432</td>
<td>7,997</td>
<td>49,446</td>
<td>37,788</td>
</tr>
<tr>
<td>2003</td>
<td>33,370</td>
<td>10,964</td>
<td>5,432</td>
<td>7,997</td>
<td>49,446</td>
<td>37,788</td>
</tr>
<tr>
<td>2004</td>
<td>33,370</td>
<td>10,964</td>
<td>5,432</td>
<td>7,997</td>
<td>49,446</td>
<td>37,788</td>
</tr>
<tr>
<td>2005</td>
<td>33,370</td>
<td>10,964</td>
<td>5,432</td>
<td>7,997</td>
<td>49,446</td>
<td>37,788</td>
</tr>
<tr>
<td>2006</td>
<td>33,370</td>
<td>10,964</td>
<td>5,432</td>
<td>7,997</td>
<td>49,446</td>
<td>37,788</td>
</tr>
<tr>
<td>2007</td>
<td>33,370</td>
<td>10,964</td>
<td>5,432</td>
<td>7,997</td>
<td>49,446</td>
<td>37,788</td>
</tr>
<tr>
<td>2008</td>
<td>33,370</td>
<td>10,964</td>
<td>5,432</td>
<td>7,997</td>
<td>49,446</td>
<td>37,788</td>
</tr>
<tr>
<td>2009</td>
<td>33,370</td>
<td>10,964</td>
<td>5,432</td>
<td>7,997</td>
<td>49,446</td>
<td>37,788</td>
</tr>
<tr>
<td>2010</td>
<td>33,370</td>
<td>10,964</td>
<td>5,432</td>
<td>7,997</td>
<td>49,446</td>
<td>37,788</td>
</tr>
<tr>
<td>TOTAL</td>
<td>144,996</td>
<td>100</td>
<td>183,913</td>
<td>100</td>
<td>181,465</td>
<td>186,639</td>
</tr>
</tbody>
</table>

Source: SENER: Electricity Statistics

Table 3. SEN Electricity Sales by Consumer Category

<table>
<thead>
<tr>
<th>Year</th>
<th>Residential</th>
<th>Commercial</th>
<th>Services</th>
<th>Agriculture</th>
<th>Medium size industry</th>
<th>Large Industries</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>8.3</td>
<td>6.6</td>
<td>8.1</td>
<td>(1.2)</td>
<td>8.1</td>
<td>6.7</td>
</tr>
<tr>
<td>2001</td>
<td>6.1</td>
<td>4.2</td>
<td>1.4</td>
<td>(5.5)</td>
<td>2.4</td>
<td>(4.4)</td>
</tr>
<tr>
<td>2002</td>
<td>1.8</td>
<td>2.8</td>
<td>1.7</td>
<td>2.4</td>
<td>1.9</td>
<td>1.6</td>
</tr>
<tr>
<td>2003</td>
<td>2.1</td>
<td>2.4</td>
<td>1.2</td>
<td>(4.0)</td>
<td>2.0</td>
<td>(4.6)</td>
</tr>
<tr>
<td>2004</td>
<td>2.2</td>
<td>0.8</td>
<td>2.3</td>
<td>(5.0)</td>
<td>4.0</td>
<td>0.3</td>
</tr>
<tr>
<td>2005</td>
<td>4.4</td>
<td>0.6</td>
<td>2.5</td>
<td>15.8</td>
<td>4.7</td>
<td>0.9</td>
</tr>
<tr>
<td>2006</td>
<td>4.5</td>
<td>1.7</td>
<td>2.3</td>
<td>(1.3)</td>
<td>5.4</td>
<td>0.2</td>
</tr>
<tr>
<td>2007</td>
<td>3.1</td>
<td>1.4</td>
<td>3.2</td>
<td>(2.0)</td>
<td>3.9</td>
<td>2.5</td>
</tr>
<tr>
<td>2008</td>
<td>3.5</td>
<td>1.8</td>
<td>3.9</td>
<td>3.9</td>
<td>1.9</td>
<td>(0.7)</td>
</tr>
<tr>
<td>2009</td>
<td>2.3</td>
<td>(1.7)</td>
<td>10.3</td>
<td>14.7</td>
<td>(2.1)</td>
<td>(9.7)</td>
</tr>
<tr>
<td>2010</td>
<td>0.3</td>
<td>(3.2)</td>
<td>(1.0)</td>
<td>(7.5)</td>
<td>3.5</td>
<td>11.0</td>
</tr>
<tr>
<td>2011</td>
<td>6.3</td>
<td>4.6</td>
<td>4.7</td>
<td>27.6</td>
<td>4.9</td>
<td>11.6</td>
</tr>
<tr>
<td>2000-2111</td>
<td>3.7</td>
<td>1.8</td>
<td>3.4</td>
<td>3.2</td>
<td>3.4</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Source: SENER: Electricity Statistics
customers reflects lower delivery costs and more stable demand. (Low voltage, dense distribution systems required to serve residential and small commercial “load” or demand are relatively expensive to install and maintain, and some locations, residential and commercial load can be highly seasonal.)

In Mexico, however, residential customers pay only slightly less than large industrial customers and agricultural customers pay the lowest price of all. In 2011, SEN’s average rates for different customer classes were 8.5¢/kWh for residential customers; 11.4–8.8¢/kWh for medium and large size industrial customers respectively; 4.0¢/kWh for agricultural customers; and 14.2–19.8¢/kWh for public service and commercial customers respectively.

In Mexico electricity prices are set below costs of production as can be seen in Table 6 (facing page). In 2006 electricity subsidies in Mexico totaled $9 billion and were among the largest in the world. Two-thirds of the subsidies go to residential customers and those subsidies increased by 46% between 2002 and 2006 in real terms. Industrial customers, especially large industrials, come closest to covering the costs of serving them.41

As a consequence of receiving the larger proportion of the total net subsidy, residential consumers in Mexico receive a tariff that is among the lowest in the world. These subsidies distort price signals and increases demand above what it would be if electricity prices reflected actual costs of production. Finally, the bulk of the subsidies go to the non-poor. As a result, SENER is working with the World Bank, among others, to assess alternatives to the current subsidy system.42

**Regional Patterns of SEN Electricity Consumption**

Electricity consumption across the SEN Mexican regions reflects varying patterns. These regional variations are related to differences in climate and urbanization as well as the different compositions of and concentrations of industrial activity. In 2011 the states with the largest electricity consumption in descending order of magnitude were Nuevo Leon, Estado de Mexico, Jalisco, Veracruz, and Sonora.61

The pattern of electricity consumption in Mexico has been relatively stable over the period 1999–2011: the Northeast, Central West and Central regions consume about equal amounts of electricity representing about 71% of total consumption with the Northwest and Southeast regions representing about 14–15% of total electricity consumption each. The Northeast, Central West and Central regions account for about 70% of the total population.

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**Table 4. Facts on Mexico Electricity**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of CFE Generation Units (2011)</td>
<td>627</td>
</tr>
<tr>
<td>Total CFE Generating Capacity 2011</td>
<td>41 GW</td>
</tr>
<tr>
<td>Total IPP Generating Capacity 2011</td>
<td>12 GW</td>
</tr>
<tr>
<td>Total Self-Supply Generating Capacity 2011</td>
<td>7 GW</td>
</tr>
<tr>
<td>Total SEN Gross Generation 2011</td>
<td>257,884 GWh</td>
</tr>
<tr>
<td>Total Self-Supply/Cogen/Own Use Generation 2011</td>
<td>27,845 GWh</td>
</tr>
<tr>
<td>Number of Residential Customers 2011</td>
<td>31.3 million</td>
</tr>
<tr>
<td>Number of Commercial Customers 2011</td>
<td>3.5 million</td>
</tr>
<tr>
<td>Number of Industrial Customers 2011</td>
<td>257,900</td>
</tr>
<tr>
<td>Number of Agricultural Customers 2011</td>
<td>121,000</td>
</tr>
<tr>
<td>Number of Services Customers 2011</td>
<td>186,000</td>
</tr>
<tr>
<td>Average Residential Rate 2011</td>
<td>8.5¢/kWh</td>
</tr>
<tr>
<td>Average Commercial Rate 2011</td>
<td>19.8¢/kWh</td>
</tr>
<tr>
<td>Average Industrial Rate 2011</td>
<td>8.8-11.4¢/kWh</td>
</tr>
<tr>
<td>Average Agricultural Rate 2011</td>
<td>4.0¢/kWh</td>
</tr>
<tr>
<td>Average Services Rate 2011</td>
<td>14.3¢/kWh</td>
</tr>
<tr>
<td>Number of State Owned Companies 2011</td>
<td>1 (CFE)</td>
</tr>
<tr>
<td>SEN Generation by State-Owned Cos. 2011</td>
<td>67 %</td>
</tr>
<tr>
<td>SEN Generation by IPPs 2011</td>
<td>33 %</td>
</tr>
</tbody>
</table>

Source: SENER: Electricity Statistics63 and Electricity Sector Outlook61

**Figure 3. Domestic Electric Power Regions**

Source: SENER: Electricity Sector Outlook61
Table 5. Electricity Subsidies as a Percent of GDP and Gross National Expenditure (GNE), 2005

<table>
<thead>
<tr>
<th>Country</th>
<th>Electricity Subsidy 2005 (Current US$ MM)</th>
<th>Subsidy as a Percent of GDP</th>
<th>Subsidy as a Percent of GNE</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>6,000</td>
<td>0.3%</td>
<td>0.3%</td>
</tr>
<tr>
<td>Indonesia</td>
<td>1,500</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>México</td>
<td>8,876</td>
<td>1.1</td>
<td>.8</td>
</tr>
<tr>
<td>India</td>
<td>10,000</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>South Africa</td>
<td>4,000</td>
<td>1.7</td>
<td>1.6</td>
</tr>
<tr>
<td>Saudi Arabia</td>
<td>5,500</td>
<td>1.8</td>
<td>2.7</td>
</tr>
<tr>
<td>Russian Federation</td>
<td>14,000</td>
<td>1.8</td>
<td>2.1</td>
</tr>
<tr>
<td>Iran</td>
<td>3,500</td>
<td>1.8</td>
<td>2.0</td>
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<tr>
<td>Egypt</td>
<td>2,500</td>
<td>2.8</td>
<td>2.7</td>
</tr>
<tr>
<td>Ukraine</td>
<td>3,500</td>
<td>4.2</td>
<td>4.3</td>
</tr>
</tbody>
</table>


Table 6. Distribution of Mexican Electricity Subsidies by Customer Class, 2006

<table>
<thead>
<tr>
<th>Sector</th>
<th>Sales (GWh)</th>
<th>Subsidies (2006 MM Pesos)</th>
<th>Price/Cost Ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>44.5</td>
<td>63,369</td>
<td>.41</td>
</tr>
<tr>
<td>Commercial</td>
<td>13.2</td>
<td>5,476</td>
<td>.92</td>
</tr>
<tr>
<td>Services</td>
<td>6.6</td>
<td>2,887</td>
<td>.77</td>
</tr>
<tr>
<td>Agriculture</td>
<td>8.0</td>
<td>9,211</td>
<td>.30</td>
</tr>
<tr>
<td>Medium Size Industries</td>
<td>65.3</td>
<td>12,478</td>
<td>.83</td>
</tr>
<tr>
<td>Large Industries</td>
<td>37.9</td>
<td>4,213</td>
<td>.97</td>
</tr>
<tr>
<td>TOTAL</td>
<td>175.4</td>
<td>97,633</td>
<td>.68</td>
</tr>
</tbody>
</table>


Table 7. SEN Electricity Sales by Region (GWh)

<table>
<thead>
<tr>
<th>Region</th>
<th>1999</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northwest</td>
<td>18,505</td>
<td>13</td>
<td>25,567</td>
<td>14</td>
<td>25,566</td>
</tr>
<tr>
<td>Northeast</td>
<td>36,404</td>
<td>25</td>
<td>44,160</td>
<td>24</td>
<td>44,198</td>
</tr>
<tr>
<td>Central West</td>
<td>32,801</td>
<td>23</td>
<td>42,555</td>
<td>23</td>
<td>41,424</td>
</tr>
<tr>
<td>Central</td>
<td>38,239</td>
<td>26</td>
<td>43,995</td>
<td>24</td>
<td>43,131</td>
</tr>
<tr>
<td>Southeast</td>
<td>18,970</td>
<td>13</td>
<td>27,518</td>
<td>15</td>
<td>28,080</td>
</tr>
<tr>
<td>Small Systems</td>
<td>77</td>
<td>NM</td>
<td>118</td>
<td>NM</td>
<td>120</td>
</tr>
<tr>
<td>Total</td>
<td>144,996</td>
<td>100</td>
<td>183,913</td>
<td>100</td>
<td>182,518</td>
</tr>
</tbody>
</table>

Source: SENER Electricity Sector Outlook(61) Numbers may not add due to rounding.

Table 8. SEN Regional Electricity Sales Growth Rates (percent over previous year)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Northwest</td>
<td>7.4</td>
<td>1.7</td>
<td>0.0</td>
<td>0.1</td>
<td>8.7</td>
<td>3.2</td>
</tr>
<tr>
<td>Northeast</td>
<td>7.2</td>
<td>1.2</td>
<td>0.1</td>
<td>3.8</td>
<td>9.3</td>
<td>2.2</td>
</tr>
<tr>
<td>Central West</td>
<td>6.6</td>
<td>2.0</td>
<td>-2.7</td>
<td>6.8</td>
<td>8.8</td>
<td>2.7</td>
</tr>
<tr>
<td>Central</td>
<td>4.4</td>
<td>1.5</td>
<td>-2.0</td>
<td>1.5</td>
<td>4.8</td>
<td>1.1</td>
</tr>
<tr>
<td>Southeast</td>
<td>2.1</td>
<td>3.8</td>
<td>2.0</td>
<td>0.5</td>
<td>6.7</td>
<td>3.9</td>
</tr>
<tr>
<td>Total</td>
<td>5.7</td>
<td>1.9</td>
<td>-0.8</td>
<td>2.9</td>
<td>7.7</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Source: SENER: Electricity Sector Outlook(61) Numbers may not add due to rounding.

In the Northwest, the states of Sonora and Baja California account for about 70% of electricity consumption in the region due to industrial and population growth in cities like Tijuana and Mexicali. Electricity consumption in Baja California Sur grew 5.8% from 1999 to 2011 due to the growth of tourism and related real estate development.

In the Central West region, 62% of regional electricity is consumed in the states of Jalisco, Guanajuato, Michoacan and San Luis Potosi. Intensive industrial consumption of electricity occurs in the zones of Guadalajara, Lazaro Cardenas, Queretaro and Leon.

In the heavily populated Central region, the Federal District and Mexico state account for 67% of the region’s electricity consumption. The water pumping system of Cutzamala is a large electricity consumer. The economic recession of 2008–2009 saw consumption contract in Tlaxcala, Puebla, Hidalgo and Morelos. Due to the population density of this region, most of the electric transmission system is medium and low tension lines.

Electricity consumption in the Southeast region has grown faster than any other region in Mexico from and 84% of the total manufacturing industry in 2007. Electric power in Mexico grew at a faster rate than that of the other three regions from 1999 to 2011.

The state of Nuevo Leon is the largest electricity consumer (34.5% of the total) in the Northeast region. Nuevo Leon is a large industrial and manufacturing center with industries such as iron and steel, glass, cement and chemicals, among others.

In the Central West region, 62% of regional electricity is consumed in the states of Jalisco, Guanajuato, Michoacan and San Luis Potosi. Intensive industrial consumption of electricity occurs in the zones of Guadalajara, Lazaro Cardenas, Queretaro and Leon.

In the heavily populated Central region, the Federal District and Mexico state account for 67% of the region's electricity consumption. The water pumping system of Cutzamala is a large electricity consumer. The economic recession of 2008–2009 saw consumption contract in Tlaxcala, Puebla, Hidalgo and Morelos. Due to the population density of this region, most of the electric transmission system is medium and low tension lines.

Electricity consumption in the Southeast region has grown faster than any other region in Mexico from
1999 to 2011. Veracruz accounts for 36.2% of electricity consumption and in Quintana Roo consumption has grown 12.5% over the period. Industries such as iron and steel, cement, paper, glass, beer breweries and Pemex Petrochemical are important electricity consumers in the region.

**Evolution of Electricity Prices in Mexico**

The price of electricity in Mexico is a function of volume demanded, voltage, user type, and service (interruptible versus firm or guaranteed deliveries). There are currently over 30 tariff categories. The tariff structure is gradually being adapted to reflect the variety of services desired and consumer preferences. Although electricity prices have risen between 1993 and 2011, prices are thought to cover about only 68% of production costs. The relationship between costs of production and electricity prices and tariffs continues to be debated in Mexico.

Electric tariffs in Mexico are set by the Secretaría de Hacienda (Ministry of Finance) and are thus linked to the government’s economic and development strategy for the country as a whole. Unlike practices in most industrially advanced countries, Mexico’s independent electric sector regulator, the Comisión Reguladora de Energía (CRE) is not responsible for setting electric tariffs. As a result, electric tariffs frequently have not been compatible with the needs of a financially self-sustaining power sector. Tariffs have tended to lag production costs for all consumer types. On the assumption that industry could pay a stiffer rate, there continues to be a cross-subsidy from industrial and commercial users to residential and agricultural users. Industries complain that their electricity rates hamper their ability to compete in global markets. And with artificially low tariffs, residential and agricultural customers have little price incentive to moderate demand.

**Making and Moving Electricity**

The main function of an electrical power system is to transmit all electricity demanded reliably, and in the exact amount, where it is needed. In addition, it should provide for unforeseen contingencies arising from larger than expected demand or system outages. The industry structure has three main segments—generation, transmission and distribution.

Generation involves the process of producing electric energy by utilizing other primary forms of energy such as fossil fuels (coal, natural gas or oil), uranium (nuclear), or renewable energy sources (solar, wind) into electricity. Transmission is the movement or transfer of electric energy over an interconnected group of high voltage lines between points of supply and points at which it is transformed to lower voltage. At lower voltage, electricity is delivered to final consumers such as factories or across low voltage local distribution systems to smaller end users such as homes or businesses.

In Mexico, electric generation is provided by the state-owned companies CFE and LFC.
(until October 2009), independent power producers and industries for their own consumption. Transmission and distribution services are provided exclusively by state-owned CFE and LFC (until October 2009).

**Generation**

Electric power plants use coal, lignite, natural gas, fuel oil, and uranium to make electricity. Renewable fuels such as moving water, solar, wind, geothermal sources and biomass are also used.

The type of fuel, its cost, and generating plant efficiency can determine the way a generator is used. For example, a natural gas generator with steam turbines has a high marginal cost but can be brought on line quickly, making it useful for peak periods of demand. Coal, lignite, and nuclear units have lower marginal costs but cannot be brought on line quickly. They are used primarily to provide the base load of electricity (e.g., the constant requirement of the power system which is demanded continuously).

Costs for fuel, construction and operations and maintenance vary greatly among types of power plants. For example, renewable generation plants, such as solar or wind, have virtually no fuel costs but are expensive to manufacture and install and can be expensive to maintain. Nuclear and coal-fueled plants have low fuel costs but are more expensive to build and maintain. Coal units also incur additional costs for meeting air quality standards. Natural gas plants have higher fuel costs than coal or nuclear, but have lower initial construction costs.

**Generation Providers**

Mexicans view energy, including electricity, as a sovereign activity and as such it is the exclusive responsibility of the federal government. By constitutional law, electricity for public service consumption must be provided by state owned CFE and LFC (until October 2009). CFE is a large public enterprise with total assets at year end 2011 of about $66 billion. Prior to October 2009 LFC served Mexico City and the surrounding areas and CFE served the rest of the country. LFC bought approximately 95 percent of its marketed electricity from CFE. In October 2009 CFE took over LFC’s operations.

Reforms to the Law of Public Service of Electricity (Ley del Servicio Público de Energía Eléctrica) passed in 1992 and implemented in 1993 permits cogeneration1 and generation for self-consumption by private entities (principally industries) as well as generation by IPPs with the requirement that essentially all IPP output is sold to CFE. In 2011, CFE accounted for about 67 percent of effective installed generation capacity in Mexico and private generators accounted for 33 percent of capacity.

**Installed Generation Capacity**

At the end of 2011, Mexico had installed generation capacity of 61,570 MW, an increase of 677 MW over 2010. About 66 percent of this capacity is controlled by CFE; 19 percent is controlled by IPPs; 5 percent by cogenerators; and the remaining 7 percent by self-suppliers. The installed generation capacity of SEN at the end of 2011 was 52,512 MW or 85 percent of total installed capacity. The SEN capacity consists of CFE and LFC capacity and the IPP capacity under contract to CFE and represents 85 percent of installed generation capacity. SEN installed generation capacity between 1999 and 2011 has grown at an average annual rate of 3.1 percent compared to average annual sales growth of 2.4 percent over the same period. The regional distribution of SEN generation capacity can be seen in Table 9.

The Northeast and Southeast regions account for 61 percent of SEN’s installed generation capacity. The Southeast region has the most hydroelectric generation of any region and also has the sole nuclear generation facility (Laguna Verde near Veracruz). The Northeast region has registered the most growth in its generation capacity at 4.9 percent annually from 1999 to 2011. The Northeast also has the greatest amount of natural gas combined cycle generation capacity (8,465 MW) followed by the Southeast region (3,906 MW).

Of the 52,512 MW of SEN installed generation capacity, approximately 22 percent is hydroelectric; 2.5 percent is nuclear; 3 percent is geothermal and wind; and 72.5 percent requires the fossil fuels of oil, natural gas and coal.

**Total Actual Generation**

In 2011 total generation (SEN and generation for self-use) was 292,018 GWh, of which non-state-owned generators provided 40.3 percent of total generation.

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1 Cogeneration refers to a generating facility that produces electricity and another form of useful thermal energy (such as heat or steam) that is used for industrial, commercial, heating or cooling purposes.

---

Table 9. SEN Generation Capacity By Region (MW)

<table>
<thead>
<tr>
<th>Region/Year</th>
<th>1999</th>
<th>% Total</th>
<th>2009</th>
<th>% Total</th>
<th>2010</th>
<th>% Total</th>
<th>2011</th>
<th>% Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northwest</td>
<td>5,211</td>
<td>14.6</td>
<td>7,025</td>
<td>13.6</td>
<td>7,023</td>
<td>13.3</td>
<td>6,945</td>
<td>13.2</td>
</tr>
<tr>
<td>Northeast</td>
<td>7,322</td>
<td>20.5</td>
<td>13,222</td>
<td>25.6</td>
<td>13,672</td>
<td>25.8</td>
<td>13,672</td>
<td>26.0</td>
</tr>
<tr>
<td>Central West</td>
<td>5,776</td>
<td>16.2</td>
<td>8,553</td>
<td>16.5</td>
<td>8,553</td>
<td>16.1</td>
<td>8,213</td>
<td>15.6</td>
</tr>
<tr>
<td>Central</td>
<td>4,067</td>
<td>11.4</td>
<td>5,229</td>
<td>10.1</td>
<td>5,291</td>
<td>10.0</td>
<td>5,291</td>
<td>10.1</td>
</tr>
<tr>
<td>Southeast</td>
<td>13,142</td>
<td>36.8</td>
<td>17,654</td>
<td>34.1</td>
<td>18,403</td>
<td>34.8</td>
<td>18,387</td>
<td>35.0</td>
</tr>
<tr>
<td>Total</td>
<td>35,666</td>
<td>100</td>
<td>51,686</td>
<td>100</td>
<td>52,945</td>
<td>100</td>
<td>52,512</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: SENER: Electricity Sector Outlook

Table 10. Total Mexico Generation 2011 (GWh)

<table>
<thead>
<tr>
<th>Generation Provider</th>
<th>Generation (GWh)</th>
<th>% Total Generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFE &amp; LFC</td>
<td>174,335</td>
<td>59.7</td>
</tr>
<tr>
<td>IPPs</td>
<td>84,977</td>
<td>29.1</td>
</tr>
<tr>
<td>SEN (Sub-Total)</td>
<td>259,155</td>
<td>88.7</td>
</tr>
<tr>
<td>Self-supply/Cogeneration</td>
<td>27,845</td>
<td>9.5</td>
</tr>
<tr>
<td>Export</td>
<td>5,017</td>
<td>1.7</td>
</tr>
<tr>
<td>TOTAL</td>
<td>292,018</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Source: SENER: Electricity Sector Outlook
Actual Generation SEN

In 2011 SEN electric generation was 259,155 GWh, an increase of 6.9 percent from 2010. The amount of SEN generation provided by IPPs increased from about 4,605 MW in 2001 to 84,944 MW in 2011. Gross SEN generation by type of fossil fuel can be seen in Table 11.

Between 1999 and 2011, fuel oil has lost 32 percent of its market share as a result of environmental restrictions and the adoption of natural gas-fired combined cycle technology (combined cycle gas turbine or CCGT), primarily by IPPs. In contrast, natural gas has more than tripled its market share over the same time period. Fuel oil, natural gas and diesel (67 percent of total generation fuels in 2011) were supplied by state-owned oil and gas company Petróleos Mexicanos (PEMEX).

The majority of Mexico’s coal reserves, which are low quality due to their high ash content, are located in Coahuila. The major coal producers are Mission Energy, a U.S. company, and Minerales Monclova, a subsidiary of Mexican steel company Grupo Acerero del Norte. Small volumes of coal are imported from the United States, Canada and Colombia.

Actual Generation Private

Figure 6 shows the increase in electricity produced by non-IPP private entities (self-generation, cogeneration etc.) since 2000. IPP generation in 2011 was 84,944 GWh. When total private generation, including exports, is added to SEN generation of 259,155 GWh, total generation in Mexico in 2011 was 292,018 GWh.

Storing Electricity

Unlike water and natural gas, electricity cannot be easily stored. This presents a fundamental challenge to the electric power system. There is no container or large "battery" that can store electricity for indefinite periods. Energy is stored in the fuel itself before it is converted to electricity. Once converted, it has to go out on the power lines.

Worldwide, research and development on possible electricity storage technologies have been underway for some time. Compressed air, pumped hydroelectric, advanced batteries and superconducting magnetic energy storage are the four main technologies being studied for possible electricity storage.

Transmission and Distribution Systems

In general, power plants are located at points which allow access to the fuel source. The most desirable fuel sources are generally far away from population centers, and electricity must be moved from the point at which it is generated to consumers. The transmission system accomplishes much of this task with an interconnected system of lines, distribution centers, and control systems. Electricity is transported at high voltages (69 KV or greater) over a multi-path powerline network that provides alternative ways for electricity to flow.

Most homes and businesses in most countries use low voltage electrical power while industries can often use higher voltages. Some large commercial and industrial customers may receive electricity at high voltages directly from the transmission system.

---

4 Combined cycle is an electric generating technology in which electricity is produced from waste heat that would otherwise be lost as it exits from one or more natural gas combustion turbines. The exiting heat is routed to a conventional boiler or to a heat recovery steam generator for utilization by a steam turbine in the production of electricity. This process increases the efficiency of the electric generating plant. Combined cycle plants can achieve efficiencies ranging from 50 to 80 percent as opposed to efficiencies of 35 to 40 percent for conventional thermal plants. Construction time is shorter and operating costs are lower. Natural gas-fired combined cycle plants produce no sulfur dioxide and only half as much carbon dioxide as conventional coal-fired thermal plants for the same energy output.
Substations on the transmission system receive power at higher voltages and lower them to feed local distribution systems. The local distribution system consists of the poles and wires commonly seen in neighborhoods and can also include below ground lines. At key locations, voltage is again lowered or “stepped down” by transformers to meet customer needs.

Customers on the local distribution system are categorized as industrial, commercial/public sector, and residential/agricultural. Industrial use is fairly constant, both during the day and across seasons. Commercial/public sector and agricultural use is less constant and can vary across seasons. Residential and commercial use may change rapidly during the day in response to customer needs, appliance use and weather events.

Mexico’s national electric grid, SEN, is owned and operated by CFE and serves 97 percent of the population. The transmission and distribution systems of Baja California are not connected with the national interconnected system and neither are some small systems in the Northeast.

In Mexico, transmission lines are those lines of high tension (230–400 kV) that transport electricity over large distances. These transmission lines supply the networks of subtransmission (69–161 kV) which cover much shorter distances. These subtransmission lines supply distribution lines (2.4–34.5 kV) which cover small geographic zones. Finally, low tension lines (220–240 volts) are used to supply low volume consumers.

Over the period 1999–2011, the greatest growth occurred in 13.8 kV CFE distribution lines and the LFC system. Overall, a major effort has been made to increase long distance transmission capacity as well as distribution capacity in Mexico.

As mentioned above, the transmission and distribution network is complemented by transmission substations, distribution substations and distribution transformers. In 2011, substation capacities can be seen in Table 13.

### Transmission and Distribution System Losses

Two types of losses are typically experienced by electricity systems: technical and non-technical losses. Technical or line losses occur because electricity dissipates in the form of heat to the atmosphere along transmission lines.
and distribution lines. Modern power grids have small technical losses. Excessive line losses are due to inefficient and/or non-optimal operation of the system and as such are the responsibility of the system operator, CFE. Non-technical losses are the result of informal connections to electric power lines without payment for electric power. Non-technical losses, on the other hand, usually occur as illegal taps along a local distribution network. Non-technical losses impose costs to electricity systems that are not recovered in payments. Theft degrades system reliability and presents serious hazards both to those making the illegal taps as well as to people and property in the vicinity of illegal taps. In Mexico, technical and non-technical losses are aggregated; losses are higher in some parts of the country than others. These losses are calculated as a percentage of net generation, are significant, and have increased as can be seen in Table 14.

### Imports/Exports

Mexico has 1,591 MW of electrical interconnections with the United States, 40 MW with Belize and 120–200 MW under construction with Guatemala. The interconnections between Mexico and the US are relatively weak, with only 12 high voltage operating interconnections.\(^{[61]}\) The interconnections between Baja California and the US and between Mexico and Belize

### Table 14. System Losses

<table>
<thead>
<tr>
<th>Year</th>
<th>1999</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Losses (% of total generation)</td>
<td>15.0</td>
<td>16.0</td>
<td>16.4</td>
<td>16.8</td>
<td>16.6</td>
<td>16.7</td>
<td>17.2</td>
<td>17.2</td>
<td>16.7</td>
</tr>
</tbody>
</table>

Source: SENER: Electricity Sector Outlook\(^{[62]}\)
and Mexico and Guatemala operate as “permanent” connections which are used for normal system operations. The Baja California interconnection has been a consistent exporter of electricity to the US during the period 1999–2011 and in 2011 accounted for 46% of total Mexican electricity exports.

With the exception of the Eagle Pass-Piedras Negras interconnection, the Texas-Mexico interconnections are for emergency support only due to technical constraints and the potential for system instability. The Eagle Pass-Piedras Negras interconnection uses new technology which allows it to be operated in a “permanent” manner for normal operations.

Since 2003, Mexico has been a net exporter of electricity to the United States. Between 2003 and 2011 electricity exports to the US ranged from a low of 953 GWh to a high of 1,452 GWh with 1,292 GWh exported in 2011.

**Energy Savings and Efficiency**

Energy savings and efficiency plans are implemented mainly by government agencies such as the Comisión para el Uso Eficiente de la Energía (CONUEE)\(^6\), the Fidecomiso para el Ahorro de Energía Eléctrica (FIDE), the Programa de Ahorro de Energía del Sector Eléctrico (CFE-PAESE) and the Programa de Ahorro Sistemático Integral (ASI) with the goal of postponing new electric generation capacity creation. CONUEE has published 16 Normas Oficiales Mexicanas (NOMs) requiring implementation of various energy efficiency/conservation measures.

**Environmental Regulations**

Three NOMs regulate emission of air and water pollutants by electric generators and the environmental impacts of electricity transmission systems. These regulations vary by geographical zone and type and amount of generation capacity. Nine areas have been defined as “critical zones” in terms of air and water pollution levels.

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\(^6\) Formerly Comisión Nacional para el Ahorro de Energia (CONAE).
Electricity travels fast, cannot be stored easily or cheaply, and cannot be switched from one route to another. These three principles are basic to the operation of an electric power system.

Electricity is almost instantaneous. When a light is turned on, electricity must be readily available. Since it is not stored anywhere on the power grid, electricity must somehow be dispatched immediately. A generator is not simply started up to provide this power. Electric power must be managed so that electricity is always available for all of the lights, appliances, computers and other uses that are required at any particular moment.

Electricity traveling from one point to another follows the path of least resistance rather than the shortest distance. With thousands of kilometers of interconnected wires throughout Mexico, electricity may travel miles out of any direct path to get where it is needed.

As a result of these three principles, designing and operating an electrical system is complex and requires constant management.

**Defining and Measuring Electricity**

Electricity is simply the flow or exchange of electrons between atoms. This exchange of electrons forms a moving stream or current of electricity. The atoms of some metals, such as copper and aluminum, have electrons that move easily. That makes these metals good electrical conductors.

Electricity is created when a coil of metal wire is turned near a magnet as shown in Figure 10. Thus, an electric generator is simply a coil of wire spinning around a magnet. This phenomenon enables us to build generators that produce electricity in power plants.

The push, or pressure, forcing electricity from a generator is expressed as volts. The flow of electricity is called current. Current is measured in amperes (amps).

Watts are a measure of the amount of work done by electricity. Watts are calculated by multiplying amps times volts. Electrical appliances, light bulbs and motors have certain wattage requirements that depend on the tasks they are expected to perform. One kilowatt (1,000 watts) equals 1.34 horsepower. One megawatt is equal to 1,000,000 watts.

Kilowatts are used in measuring electrical use. Electricity is sold in units of kilowatt-hours (kWh). A 100-watt light bulb left on for ten hours uses one kilowatt-hour of electricity (100 watts x 10 hours = 1,000 watt hours = 1 kWh).

Electricity is generated and usually transmitted as alternating current (AC). The direction of current flow is reversed 60 times per second, called 60 hertz (Hz). Operators want the same frequency throughout the interconnected power grid and strive to maintain it 60 Hz.

Higher voltages in many instances can be transmitted more easily by direct current (DC). High voltage direct current (HVDC) lines are used to move electricity long distances.

**Generating Electricity**

There are many fuels and technologies that can generate electricity. Usually a fuel like coal, natural gas, or fuel oil is ignited in the furnace section of a boiler. Water piped through the boiler in large tubes is superheated to produce heat and steam. The steam turns turbine blades which are connected by a shaft to a generator. Nuclear power plants use nuclear reactions to produce heat while wind turbines use the wind to turn the generator.

A generator is a huge electromagnet surrounded by coils of wire which produces electricity when the shaft is rotated. Electricity generation ranges from 13,000 to 24,000 volts. Transformers increase the voltage to hundreds of thousand of volts for transmission. High voltages provide an economical way of moving large amounts of electricity over the transmission system.

**Types of Generators**

Steam turbines use either fossil fuel or nuclear fuel to generate heat to produce steam that passes through a turbine to drive the generator. These generators are used primarily for base loads but some gas-fired plants are also used for peak loads. Sizes range from 1 to 1,250 megawatts.

In combustion turbines hot gases are produced by combustion of natural gas or fuel...
oil in a high pressure combustion chamber. These gases pass directly through a turbine which spins the generator. These generators are used primarily for peak loads but combined cycle combustion turbines are used for base loads. Simple combustion turbines are generally less than 100 megawatts and allow quick startup suitable for peaking, emergency and reserve power.

In hydroelectric generating units flowing water is used to spin a turbine connected to a generator. Sizes range from 1 to 700 mega-watts. These units can start quickly and respond to rapid changes in power output. They are used for base loads, peak loads and spinning reserve.8

Internal combustion engines are usually diesel engines connected to the shaft of a generator and are usually 5 megawatts or less. There is no startup time and these units are typically operated in periods of high demand.

Other types of generators include geothermal, solar, wind and biomass which utilize many different technologies and range widely in size and capabilities. These are discussed in more detail in the Fuels for Electric Generation chapter.

Transmission and Distribution

Once electricity is given enough push (voltage) to travel long distances, it can be moved onto the wires or cables of the transmission system. Electricity is stepped up from lower voltages to higher voltages for transmission. The transmission system moves large quantities of electricity from the power plant through an interconnected network of transmission lines to many distribution centers called substations. These substations are generally located long distances from the power plant.

High voltage transmission lines are interconnected to form an extensive and multi-path network. Redundancy means that electricity can travel over various different lines to get where it needs to go. If one line fails, another will take over the load. Most transmission systems use overhead lines that carry alternating current (AC). There are also overhead direct current (DC) lines, underground lines and underwater lines.

All AC transmission lines carry three-phase current—three separate streams of electricity traveling along three separate conductors. Lines are designated by the voltage that they can carry. Power lines operated at 60 kilovolt (kV) or above are considered transmission and subtransmission lines.

Even though higher voltages help push along the current, electricity dissipates in the form of heat to the atmosphere along transmission and distribution lines. This loss of electricity is called line loss.

Switching stations and substations are used to (1) change the voltage, (2) transfer from one line to another, and (3) redirect power when a fault occurs on a transmission line or other equipment. Circuit breakers are used to disconnect power to prevent damage from overloads.

Control centers coordinate the operation of all power system components. To do its job, the control center receives continuous information on power plant output, transmission lines, interconnections and other system conditions.

Transmission Constraints

There are some important constraints that affect the transmission system. These include thermal limits, voltage limits, and system operation factors.

Thermal/Current limits refer to the maximum amount of electrical current that a transmission line or electricity facility can conduct over a specified time period before it sustains permanent damage by overheating or violating public safety requirements. Electrical lines resist the flow of electricity and this produces heat. If the current flow is too high for too long, the line can heat up and lose strength. Over time the line can expand and sag between supporting towers. This can lead to power disruptions. Transmission lines are rated according to thermal limits as are transformers and other equipment.

Voltage limits refer to the maximum voltage that can be handled without causing damage to the electric system or customer facilities. Voltage tends to drop from the power plant through an interconnected network of transmission lines to many distribution centers called substations. These substations are generally located long distances from the power plant.

...and is converted back to boiler water for another cycle

Figure 12. Steam Turbine Electric Power Plant.

8 Spinning reserve is that reserve generating capacity running at zero load and synchronized to the electric system.
**Power flows:** Electricity flows over the path of least resistance. Consequently, power flows into other systems' networks when transmission systems are interconnected. This creates what are known as loop flows. Power also flows over parallel lines rather than the lines directly connecting two points—called parallel flows. Both of these flows can limit the ability to make other transmissions or cause too much electricity to flow along transmission lines, thus affecting reliability.

**Preventive operations** refer to standards and procedures designed to prevent service failures. These operating requirements include (1) having a sufficient amount of generating capacity available to provide reserves for unanticipated demand and (2) limiting the power transfers on the transmission system. Operations should be able to handle any single contingency and to provide for multiple contingencies when practical. Contingencies are identified in the design and analysis of the power system.

**Stability limits:** An interconnected system must be capable of surviving disturbances through time periods varying from milliseconds to several minutes. With an electrical disturbance, generators can begin to spin at slightly differing speeds causing differences in frequency, current and system voltages. These oscillations must diminish as the electric system attains a new stable operating point. If a new point is not quickly established, generators can lose synchronism and all or a portion of the interconnected system may become unstable, causing damage to equipment and, left unchecked, widespread service interruption.

The two types of stability problems are maintaining the synchronization of generators and preventing voltage collapse. Generators operate in unison at a constant frequency of 60 Hz. When this is disturbed by a fault in the transmission system, a generator may accelerate or slow down. Unless returned to normal conditions, the system can become unstable and fail.

Voltage instability occurs when the transmission system is not adequate to handle reactive power flows. "Reactive power" is needed to sustain the electric and magnetic fields in equipment such as motors and transformers, and for voltage control on the transmission network.

**Distribution**

The distribution system is made up of poles and wire seen in neighborhoods and underground circuits. Distribution substations monitor and adjust circuits within the system. The distribution substations lower the transmission line voltages.

**Substations** are fenced yards with switches, transformers and other electrical equipment. Once the voltage has been lowered at the substation, the electricity flows to homes and businesses through the distribution system.

Conductors called feeders reach out from the substation to carry electricity to customers. At key locations along the distribution system, voltage is lowered by distribution transformers to the voltage needed by customers.

**Customers at the End of the Line**

The ultimate customers who consume electricity are generally divided into three categories: industrial, commercial, and residential. The cost to serve customers depends upon a number of factors including the type of service (for example, high or low voltage) and the customer’s location with respect to generating and delivery facilities.

**Industrial** customers generally use electricity in amounts that are relatively constant throughout the day. They often consume many times more electricity than residential consumers and most industrial demand is considered base load (e.g., the load remains within certain limits over time with relatively little variation). As such it is the least expensive load to serve. Major industrial customers may receive electricity directly from the transmission system rather than from the distribution network. Some industrial plants have their own generators. Their excess electricity can be sold to CFE.

**Commercial** loads are similar to industrial loads in that they remain with certain levels over intermediate periods of time. Examples of commercial customers are office buildings, warehouses, and shopping centers.

**Residential** electric use is the most difficult to provide because households use much of their electricity in the morning and evening and less at other times of the day. This is less efficient to provide and is therefore a more expensive use of generating facilities.

Over time, as homeowners buy new appliances and change life-styles, their electricity loads also change. Examples of residential loads are individual households.

---

1 Reactive power is the product of voltage and the out-of-phase component of alternating current. Usually measured in megavolt-amperes reactive, reactive power is produced by capacitors, overexcited generators and capacitive devices and is absorbed by reactors, underexcited generators and other inductive devices.
The history of Mexico's electric industry can be divided into seven phases as follows:

- **1879–1910**: Mexican-owned companies dominated the landscape with foreign capital as an adjunct;  
- **1910–1934**: Domination of the electric industry by foreign capital, primarily from the US, Canada and Germany;  
- **1934–1960**: The creation and growth of CFE;  
- **1960–1992**: Nationalization of the electric industry and expansion of the CFE system;  
- **1992–Present**: Initiation of reforms to permit private sector participation in the electric industry.  
- **2008**: Enactment of the Law for the Development of Renewable Energy, and  
- **2009**: The closure of LFC.

### 1879–1910: Mexican Companies Dominate

In the last quarter of the nineteenth century Mexicans were beginning to use electric-powered engines in the industry, especially mining, and to a lesser extent for public lighting. The first electric generation plant (coal-fired) was installed in 1879 in León, Guanajuato for the use of the textile factory "La Americana." In 1889, the first hydroelectric plant began operation in Batopilas, Chihuahua for the mining industry. At the same time, the Mexican government sold lucrative concessions for electrification of cities; the first of these, in 1881, was sold to Mexicanas de Gas y Luz Eléctrica for electric service in Mexico City. **Surplus power not needed by the industry was sold in surrounding areas for commercial and residential use.** By 1899, Mexico had a generation capacity of 31 MW, of which, 39 percent was hydroelectric and 61 percent thermoelectric. [3]

In the beginning, electric generation, transmission and distribution were controlled entirely by vertically integrated private companies. From 1890 to 1905, almost all electric companies were Mexican-owned. [13] At first, these companies were very small and highly dispersed and were drawn to the wealthiest and most industrialized areas, leaving rural areas unserved. [14] Between 1887 and 1910, more than one hundred Mexican light and power companies were established, almost all in central Mexico. [3]

### 1910–1934: Foreign Companies Dominate

Despite the Mexican revolution, the years from 1910 on saw a gradual and sustained influx of foreign capital, primarily from Canada, the US and Germany, which would almost completely displace Mexican capital by the 1930s. By 1935, Canadian capital represented more than 50 percent of total investment in the sector (about $175 million), followed by the US with $90 million while German investment focused on electrical equipment. [3]

By 1910, Mexico's generation capacity was 50 MW and 80 percent of that capacity was owned by Mexican Light and Power Company (MLP), headquartered in Toronto, Canada. This growth in generation capacity was primarily due to MLP's construction of Mexico's first major hydroelectric project – the Necaxa plant in the state of Puebla. [3]

From 1902 until 1933, Mexican generation, transmission and distribution were dominated by three large foreign companies with a "strong tendency to monopoly": MLP, Impulsora de Empresas Eléctricas (Impulsora), and the Compañía Eléctrica de Chapala (CEC) headquartered in Guadalajara. [11] MLP had practically an absolute monopoly on electric generation in the central zone of the country around Mexico City; Impulsora controlled three interconnected electric systems in the north, and CEC controlled the western electric system. These three companies acquired the assets of the small, dispersed private companies and extended their transmission and distribution networks into the most economically attractive markets in the cities in which they operated. The Constitution of 1917, promulgated at the end of the Mexican Revolution, opened the possibility of state intervention in and regulation of the economy, including the electric sector. However, state regulation of the electric sector grew very slowly. The period 1920–1938 was characterized by the consolidation of the monopolies (e.g., the most important firms became holding companies by absorbing the many small retail companies) and increases in tariffs to consumers.

The first effort at regulating the electric industry was the creation in 1922 of the Comisión Nacional para el Fomento y Control de la Industria de Generación. This first regulatory attempt was in response to consumer pressure protesting the arbitrary monopoly tariffs of the companies. In 1926 this commission was restructured as the Comisión Nacional de Fuerza Motriz which tried to prevent the worst monopolistic abuses while continuing to attract private investment. [14]

Also in 1926, the enactment of the Código Nacional Eléctrico declared electricity to be a public service and conferred to Congress the rights to legislate in related matters. Initially, this code had little impact due to the weakness of the federal government whereas regulation of local electrical monopolies was controlled by local governments and large industrial electricity consumers. [14]

Local governance of the monopolies was unpredictable. In some areas such as Mexico City, arbitrary tariff rules set the stage for perpetual under-investment in the electric sector. [12] In other areas, local arbitrariness and corruption resulted in practices that favored the monopolies. [14]

### 1934–1960: The Creation and Growth of CFE

By the early 1930's, MLP, CEC and Impulsora supplied power to only 38 percent of the population; the rural areas, where 67 percent of the population resided, were largely neglected. "Supply did not fulfill demand, power outages were constant and rates were too high; these conditions hindered the country's economic development," according to CFE (www.cfe.gob.mx).

As a result, the Mexican government assumed the function of supplying electricity itself through the creation of the CFE in 1934–1937. The nascent CFE had two main objectives: (1) to operate as a regulatory agency and liaison between the foreign private companies and the government,
and (2) to supply electric service to those areas considered unprofitable by the foreign private companies. CFE’s pioneer generation projects were in the states of Guerrero, Michoacán, Oaxaca and Sonora; the power generated was sold to the private companies for resale.

At the same time, President Lázaro Cárdenas consolidated power around his party, the Partido Revolucionario Institucional (PRI). One of the key supports for the PRI came from the labor unions, and the best organized ones were those in the largest industries – mining and electricity. The oldest and strongest labor union in Mexico, the Sindicato Mexicano de Electricistas (SME) founded in 1914, was a critical piece in Cárdenas’ "corporatist" political structure, e.g. strong central government in collaboration with other important sectors such as organized labor.

In 1936, the SME struck against Impulsora and its seven subsidiaries. Labor unrest coupled with low mandated tariffs in key areas led the foreign private companies to reduce new investment in Mexico. From 1937 to 1943 private investment grew less than 1 percent due to the uncertainty surrounding the role of CFE and the vitality of the trade unions.

In 1938, the Congress enacted the Electricity Public Service Act which required strong federal regulation of the electric sector. In response to underinvestment in the electric sector, a "rolling process of nationalization" was begun: CFE was instructed to buy (at depressed prices) existing electric assets and to construct new generation, transmission and distribution assets funded by public resources. In 1944, CFE acquired CEC, the third largest of the foreign private companies and built its first large-scale generating plant Ixtapantongo. During the 1940’s and 1950’s, CFE acquired and consolidated hundreds of regional electricity monopolies into a single firm with common technical standards. From 1939 to 1950, 82 percent of the total investment in the electric power system came from public resources and was dedicated to expanding the CFE system; only 18 percent of the total investment came from private firms during this same period.

**1960–1992:**
**Nationalization and Development of the CFE System**

In 1960, Mexico’s rated capacity was 2,308 MW: 54 percent owned by CFE, 25 percent by MLP, 12 percent by Impulsora and 9 percent by remaining private companies. The consolidation of the electric sector continued in that year when the Mexican government acquired a majority stake in MLP and 95 percent of the common shares of Impulsora. At the same time, a new state-owned enterprise, Compañía de Luz y Fuerza del Centro (LFC), was created out of the remnants of MLP which would provide electric service to the central states of Mexico, Morelos, Puebla, Hidalgo and Distrito Federal.

Having completed the nationalization of the electric sector in fact, the government made the arrangement official in 1960 by amending the Mexican constitution (Article 27, paragraph 6) to state: “It is the exclusive responsibility of the Nation to generate, transmit, transform, distribute and supply electric power that is intended for public service use. Therefore, concessions will not be given to private individuals and the Nation shall utilize its natural resources and assets required for such purposes”.

During the 1960’s, more than 50 percent of total public investment was dedicated to infrastructure projects. Major generating plants were built from these proceeds, including Infiermillo and Temascal. Installed generation capacity reached 17,360 MW by 1980 and 26,797 MW by 1991.

In addition to greatly expanding the country’s generation capacity, the CFE standardized technical and economic criteria for the power system. It standardized operating voltages and interconnected the separated transmission systems. During the 1970’s all the transmission systems were interconnected except the electric systems of Baja California and the Yucatan peninsula. In 1990, the Yucatan was incorporated into the Sistema Eléctrico Nacional (SEN).

In 1976 the 60 hertz electrical frequency was unified throughout the country. This was done despite technical, social and labor union obstacles that opposed the conversion of existing electric equipment operating at 50 hertz.

During this period, the CFE adhered to two basic principles: (1) satisfy the growing demand for electricity, and (2) keep electricity prices low to promote competitiveness of Mexican manufactured goods in international trade. The remarkable success of the CFE in connecting millions of people to the electric grid, achieving nearly universal coverage, is one of the reasons why many people in Mexico support state control of electric utilities. In addition, the idea of social justice was expanded to include a wide array of electricity price subsidies for residential and agricultural consumers which ultimately led to a system characterized by mounting financial losses.

In 1975 this process of nationalization and consolidation of state control of the electric industry was formalized legally with the Ley del Servicio Público de Energía Eléctrica (LSPEE) which declared CFE and LFC as public suppliers of electricity. "State-controlled monopoly, it was thought, was essential for ensuring the real-time management of electric power. Only a state enterprise could be trusted with a technology that had large economies of scale and thus natural tendencies to monopoly. Furthermore, private generators sought only profitable markets, leaving a large part of the population without electricity, and it was assumed that only a state-owned enterprise could deliver electric service more equitably,\[15]\)

This system performed well throughout the 1970’s. Demand grew rapidly, but so did installed capacity. In fact, over-building of generation capacity was commonplace with reserve margins greater than 30 percent throughout the period.\[15]\)

During the 1970’s and 1980’s, fuel oil became the primary generation fuel. Water resources in the north are scarce and the load factors on hydroelectric plants were fairly low. As

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14 Ibid.

15 Nationalism has always been invoked by both the government and the unions as a motivation for the consolidation of the electricity sector. Mexican society as a whole has a positive impression of CFE and its accomplishments although specific operational and management criticisms exist.
Mexico became one of the world's top ten oil producers, oil-fired generation facilities, constructed mainly with local equipment in contrast to coal and gas plants, made sense for an oil-rich nation. Importantly, however, PEMEX sold fuel oil to the power sector at 30 percent of its opportunity cost during the 1970's and 1980's. This under-pricing of fuel oil amounted to a massive implicit subsidy to the power sector that averaged about $1.5 billion dollars per year for the period 1974–1989 at 2001 constant dollars.\footnote{Carreón-Rodríguez, Victor G., Armando Jiménez San Vicente and Juan Rosellón, “The Mexican Electricity Sector: Economic, Legal and Political Issues,” Working Paper #5, Program on Energy and Sustainable Development, Stanford University, Stanford, California, November 2003.}

Artificially low fuel oil prices for electric generation permitted electric tariffs that did not fully cover costs. Overall, the Mexican power sector's tariff policy seems to have been broadly reflecting costs until 1973. After that time, tariffs were lowered with the help of oil revenues.\footnote{Ibid.}

Beginning in the early 1980's, Mexico entered into an economic period characterized by financial crises, increasing public debt and hyperinflation. The price for fuel oil for electric generation was increased as well as the electric tariffs for commercial and industrial users. However, the tariffs for the more politically sensitive residential and agricultural consumers were kept flat. On the assumption that industry could pay a higher price for electricity, the cross-subsidy from industrial and consumer users to the other customer classes grew over the following years.

Importantly each financial crisis since 1982 has brought strict limits on public debt. In fact, the financial crisis of 1994–1995 resulted in a negotiated settlement with Mexico's creditors that included a prohibition against state-owned enterprises incurring additional debt. These financial crises and their consequences limited the ability of CFE to raise the capital needed to build new plants to keep pace with rising demand. In contrast with the 1970's, from 1982 to the present, the growth in electricity supply and demand was more unpredictable and reserve margins varied widely because of lack of investment in capacity as demand was growing. In addition, the NAFTA treaty fueled economic growth in Mexico and led to power demand that rose at a much higher rate than expected.

1992–2009: Reforms to Permit Private Participation in the Electric Sector

As a result of these factors, reforms to the LSPEE were undertaken in 1992 to permit limited private participation in the electric generation sector in order to alleviate the looming crisis in power supply caused by CFE's inability to fund the required investment. Under current conditions, private entities can only participate in the sector as a generator; the resulting power can only be used for its own consumption, for export, or for sale to a single buyer, the CFE.\footnote{Ibid.} This reform of 1992 and attempted further reforms in 1999 and post-2000 are discussed in more detail in the chapter Regulations and Policies.

In addition, measures were taken to raise tariffs and reduce CFE operating costs with the aim of restoring some sustainability to the sector. However, it has proved to be politically very difficult to raise residential and agricultural tariffs. Similarly, it is politically difficult to reduce CFE's costs because it requires confronting the powerful labor unions embedded in both CFE and LFC. These labor unions have led a broad coalition to block private investment in the sector and tariff reforms. If both consumers and labor unions oppose meaningful reforms, it becomes politically very risky to support further electric sector reforms.


The Mexican Congress enacted the Renewable Energies Law (REL) in late 2008 with the goal of reducing the country's dependence on fossil fuels by (1) fostering renewable energy development; (2) providing financing tools for such development and (3) replacing fossil fuel electric generation with renewable fuels generation.\footnote{In 2008 LFC accounted for 19% of total SEN customers and 17% of total SEN electricity sales.} The REL also complements Mexico's Special Program for Climate Change which envisions reducing greenhouse gas emissions from 2000 levels by 50% by 2050.\footnote{In addition the SME claimed that the closure was a direct political attack on the union which supported leftist politician Andrés Manuel Lopez Obrador for president in 2006.}

In compliance with this legislation, SENER, together with other executive branch participants, developed in 2010 the National Strategy for the Energy Transition and the Sustainable Use of Energy (National Energy Strategy or NES). Goals include increasing electric generation capacity from non-hydro renewable fuels from about 3 percent to 7.6 percent (4,500 MW) by 2012. Electric generation capacity from all “clean” fuels (all renewables plus nuclear and projects with carbon capture/sequestration) is expected to reach 35% by 2025.

A Renewable Energy Fund, funded at $220 million for the period 2009 to 2011, was created to provide financing guarantees and direct support to promote energy efficiency and renewable fuels. New regulations were created in 2010 including reductions in the transmission charges for private renewable energy developers. New models of interconnection contracts and agreements for small scale renewable energy projects are being developed.

2009: The Closure of LFC

On October 11, 2009 President Felipe Calderon issued a decree ordering the liquidation of LFC and ordering CFE to take over its operations.\footnote{According to the government, LFC was closed because it was financially unsustainable and operationally inefficient. Between 2003 and 2008, LFC produced financial losses of about $21 billion. If left in operation, the federal government expected it would have to transfer over $18 billion in additional funds to LFC by 2012. The federal government absorbed the pension liabilities of LFC. The electricians' union, SME, protested the closure as the government only guaranteed jobs to 10,000 of the 55,000 LFC workforce. In addition the SME claimed that the closure was a direct political attack on the union which supported leftist politician Andrés Manuel Lopez Obrador for president in 2006.} In 2008 LFC accounted for 19% of total SEN customers and 17% of total SEN electricity sales.\footnote{In 2008 LFC reported operating system losses of electricity of about 33 percent.} LFC also reported operating system losses of electricity of about 33 percent.

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Table 15 shows that the SEN’s installed generation capacity of 52,512 MW is fueled primarily by water (22 percent) and the fossil fuels\(^*\) oil and natural gas (68 percent). Other fuels such as geothermal, wind, uranium for nuclear and coal play a relatively small role at present.

The use of natural gas as a fuel for electric generation has grown dramatically increasing from 15 percent of the total to 50.4 percent of the total. Oil-fueled electric generation has dropped significantly in both absolute and percentage terms.

### NON-RENEWABLE FUELS

#### Fuel Oil

Fuel oils are the heavier oils in a barrel of crude oil, comprised of complex hydrocarbon molecules that remain after the lighter oils have been distilled off during the refining process. Fuel oils are classified according to specific gravity and the amount of sulfur and other substances they contain. Virtually all petroleum used in steam electric plants is heavy fuel oil.

In 2011 fuel oil fired only 15.9 percent of Mexico’s SEN generation. It comes primarily from heavy high sulfur crude oil (Maya-22) and PEMEX is the sole supplier. Historically, years of neglected capital investment in refining meant that PEMEX had large volumes of this high sulfur fuel oil for which CFE was a steady customer. On the positive side, Mexico had abundant reserves of Maya-22; on the negative side, fuel oil-fired electric generation contributed to extensive air quality degradation in the major metropolitan areas. As a result of stricter environmental regulations and the increase in the construction of gas-fired power plants, fuel oil’s percentage of total SEN generation has declined 32 percent over the period 1999 to 2011.

SENER expects that the use of fuel oil for SEN electric generation will continue to decline from 15.9 percent in 2011 to 4.0 percent in 2026. It will be replaced by natural gas and, to a lesser extent, renewable fuels.

#### Natural Gas

Natural gas is a mixture of hydrocarbons (principally methane, a molecule of one carbon and four hydrogen atoms) and small quantities of various non-hydrocarbons in a gaseous phase or in solution with crude oil in underground reservoirs.

Natural gas consumption for electric generation in Mexico grew dramatically over the period of 1999 to 2011. This growth is due to the increased construction of combined cycle gas-fired generation plants, most of which was undertaken by IPPs, cogenerators and self-suppliers. SENER expects natural gas-fired generation to increase to 67 percent of total SEN generation in 2025.

Because natural gas has been and is expected to be such an important fuel for electric power generation in Mexico, additional detail is provided on natural gas supply and demand.

### Who Uses Natural Gas in Mexico?

Consumption of natural gas in Mexico is heavily concentrated in the oil, industrial and electric sectors representing 95 percent and 98 percent of gas consumption in 1999 and 2011, respectively. This has been the pattern of consumption historically in Mexico with dropping percentage shares in the industrial sector being offset by growing consumption in the oil and electric sectors. The residential and commercial sectors are relatively small in part due to underdevelopment of the distribution network until recent years.

The oil sector uses natural gas for gas lift in oil fields, for nitrogen injection in the Cantarell oil field offshore, for fuel in refineries and to generate electric power. In the oil sector in 2011, PEMEX Petroquímica (PPQ) accounted for 8 percent of total oil sector consumption, down from 22 percent in 1999. PPQ uses natural gas both as a fuel

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**Table 15. 2011 SEN Installed Capacity by Fuel (MW and percent)**

<table>
<thead>
<tr>
<th>Type</th>
<th>Hydro</th>
<th>Thermo*</th>
<th>Geothermal</th>
<th>Wind</th>
<th>Nuclear</th>
<th>Coal</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>MW</td>
<td>11,499</td>
<td>35,395</td>
<td>887</td>
<td>87</td>
<td>1,365</td>
<td>3,278</td>
<td>52,512</td>
</tr>
<tr>
<td>Percent of Installed Capacity</td>
<td>21.9%</td>
<td>67.4%</td>
<td>1.7%</td>
<td>0.2%</td>
<td>2.6%</td>
<td>6.2%</td>
<td>100%</td>
</tr>
</tbody>
</table>

*Source: SENER: Electricity Sector Outlook. *Oil and Natural Gas

**Table 16. SEN Gross Generation by Fuel (GWh)**

<table>
<thead>
<tr>
<th>Year/Type</th>
<th>1999</th>
<th>% of Total</th>
<th>2009</th>
<th>% of Total</th>
<th>2011</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro (Water)</td>
<td>32,746</td>
<td>18.1</td>
<td>26,332</td>
<td>11.2</td>
<td>35,763</td>
<td>13.8</td>
</tr>
<tr>
<td>Oil</td>
<td>86,116</td>
<td>47.6</td>
<td>39,263</td>
<td>16.7</td>
<td>41,206</td>
<td>15.9</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>27,138</td>
<td>15.0</td>
<td>121,785</td>
<td>51.8</td>
<td>130,614</td>
<td>50.4</td>
</tr>
<tr>
<td>Wind &amp; Geothermal</td>
<td>5,608</td>
<td>3.1</td>
<td>7,053</td>
<td>3.0</td>
<td>6,583</td>
<td>2.54</td>
</tr>
<tr>
<td>Coal</td>
<td>18,092</td>
<td>10.0</td>
<td>29,153</td>
<td>12.4</td>
<td>33,431</td>
<td>12.9</td>
</tr>
<tr>
<td>Diesel</td>
<td>1,266</td>
<td>0.7</td>
<td>1,176</td>
<td>0.5</td>
<td>1,296</td>
<td>0.5</td>
</tr>
<tr>
<td>Nuclear (Uranium)</td>
<td>9,950</td>
<td>5.5</td>
<td>10,580</td>
<td>4.5</td>
<td>10,107</td>
<td>3.9</td>
</tr>
<tr>
<td>Total</td>
<td>180,917</td>
<td>100.0</td>
<td>235,107</td>
<td>100.0</td>
<td>259,155</td>
<td>100.0</td>
</tr>
</tbody>
</table>

*Source: SENER: Electricity Sector Outlook.

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\(^*\) Fossil fuels are derived from decaying vegetation over many thousands or millions of years. Coal, lignite, oil (petroleum) and natural gas are all fossil fuels. Fossil fuels are non-renewable, meaning that we extract and use them faster than they can be replaced. A concern is that fossil fuels, when combusted, may emit gases into the atmosphere that contribute to climate change. Considerable effort is underway to devise clean technologies that will allow fossil fuel use with few or no emissions.
and as a raw material in the production of secondary petrochemicals. The decrease in gas consumption by PPQ reflects its reduced petrochemical output. PPQ’s output has been displaced by cheaper imported petrochemicals since the mid-1990’s.

The industrial consumption is concentrated in the industries highlighted in Table 18. Basic metals and chemicals accounted for 26 percent of total industrial gas consumption with food and glass at 22 percent of the total. Electric sector consumption of natural gas represented 20 percent of total gas consumption in 1999, increasing to 39 percent in 2011. The most striking change is the growth in natural gas consumption by private generators. In 1999, gas demand by CFE and LFC accounted for 86 percent of total gas consumption for electric generation; this dropped to 35 percent in 2011. On the other hand, gas consumed by private generators was 14 percent of total gas consumption for electric generation in 1999 and now represents 65 percent of the total consumed in the sector. This is due to the fact that all the IPP projects are gas-fired combined cycle generation plants.

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### Table 17. Natural Gas Demand by Sector (million cubic feet per day, or MMcf/day)

<table>
<thead>
<tr>
<th>Year</th>
<th>1999</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>AAGR,* %</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEMEX (Oil)</td>
<td>2,072</td>
<td>3,269</td>
<td>3,422</td>
<td>3,673</td>
<td>3,597</td>
<td>4.5%</td>
</tr>
<tr>
<td>Industrial</td>
<td>1,023</td>
<td>1,027</td>
<td>913</td>
<td>1,054</td>
<td>1,129</td>
<td>0.9%</td>
</tr>
<tr>
<td>Electric, of which:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CFE &amp; LFC</td>
<td>821</td>
<td>2,794</td>
<td>2,933</td>
<td>2,936</td>
<td>3,088</td>
<td>10.7%</td>
</tr>
<tr>
<td>IPPs</td>
<td>705</td>
<td>946</td>
<td>1,051</td>
<td>1,033</td>
<td>1,077</td>
<td>3.7%</td>
</tr>
<tr>
<td>Self-generation</td>
<td>0</td>
<td>1,458</td>
<td>1,500</td>
<td>1,537</td>
<td>1,641</td>
<td>NM</td>
</tr>
<tr>
<td>Export</td>
<td>116</td>
<td>244</td>
<td>247</td>
<td>266</td>
<td>266</td>
<td>7.9%</td>
</tr>
<tr>
<td>Residential</td>
<td>0</td>
<td>145</td>
<td>135</td>
<td>101</td>
<td>105</td>
<td>NM</td>
</tr>
<tr>
<td>Services</td>
<td>57</td>
<td>87</td>
<td>83</td>
<td>86</td>
<td>82</td>
<td>3.9%</td>
</tr>
<tr>
<td>Transport</td>
<td>20</td>
<td>25</td>
<td>25</td>
<td>27</td>
<td>25</td>
<td>2.1%</td>
</tr>
<tr>
<td>Export</td>
<td>136</td>
<td>107</td>
<td>67</td>
<td>83</td>
<td>24</td>
<td>0.2%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>4,129</td>
<td>7,311</td>
<td>7,444</td>
<td>7,860</td>
<td>7,947</td>
<td>5.6%</td>
</tr>
</tbody>
</table>

Source: SENER: Natural Gas Outlook[^62]. *AAGR is annual average growth rate.

### Table 18. Natural Gas Consumption by Industry Type 2011

<table>
<thead>
<tr>
<th>Industry Type</th>
<th>MMcf/Day</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Metals</td>
<td>298</td>
<td>26%</td>
</tr>
<tr>
<td>Chemicals</td>
<td>159</td>
<td>14%</td>
</tr>
<tr>
<td>Food, Drink, Tobacco</td>
<td>117</td>
<td>10%</td>
</tr>
<tr>
<td>Glass</td>
<td>131</td>
<td>12%</td>
</tr>
<tr>
<td>Non-Metal Mineral Products</td>
<td>72</td>
<td>6%</td>
</tr>
<tr>
<td>Pulp and Paper</td>
<td>67</td>
<td>6%</td>
</tr>
<tr>
<td>Cement</td>
<td>12</td>
<td>1%</td>
</tr>
<tr>
<td>Other</td>
<td>73</td>
<td>6%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1,129</td>
<td>100%</td>
</tr>
</tbody>
</table>

Source: SENER: Natural Gas Outlook[^63]

### Table 19. Electric Sector Natural Gas Consumption (MMcf/day)

<table>
<thead>
<tr>
<th>Year</th>
<th>1999</th>
<th>%</th>
<th>2009</th>
<th>%</th>
<th>2010</th>
<th>%</th>
<th>2011</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFE</td>
<td>665</td>
<td>81</td>
<td>991</td>
<td>34</td>
<td>982</td>
<td>33</td>
<td>1,013</td>
<td>33</td>
</tr>
<tr>
<td>LFC</td>
<td>40</td>
<td>5</td>
<td>60</td>
<td>2</td>
<td>51</td>
<td>2</td>
<td>64</td>
<td>2</td>
</tr>
<tr>
<td>Public Sector Sub-Total</td>
<td>705</td>
<td>86</td>
<td>1,051</td>
<td>36</td>
<td>1,033</td>
<td>35</td>
<td>1,077</td>
<td>35</td>
</tr>
<tr>
<td>IPPs</td>
<td>0</td>
<td>0</td>
<td>1,500</td>
<td>51</td>
<td>1,537</td>
<td>52</td>
<td>1,641</td>
<td>53</td>
</tr>
<tr>
<td>Self-generation</td>
<td>116</td>
<td>14</td>
<td>247</td>
<td>8</td>
<td>266</td>
<td>9</td>
<td>266</td>
<td>9</td>
</tr>
<tr>
<td>Export</td>
<td>0</td>
<td>0</td>
<td>135</td>
<td>5</td>
<td>101</td>
<td>4</td>
<td>105</td>
<td>3</td>
</tr>
<tr>
<td>Sub-Total Private Generation</td>
<td>116</td>
<td>14</td>
<td>382</td>
<td>64</td>
<td>366</td>
<td>65</td>
<td>371</td>
<td>65</td>
</tr>
<tr>
<td>TOTAL</td>
<td>821</td>
<td>100</td>
<td>2,933</td>
<td>100</td>
<td>2,936</td>
<td>100</td>
<td>3,088</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: SENER: Natural Gas Outlook[^62]
Who Supplies Natural Gas in Mexico?

There are two primary sources of natural gas supply in Mexico: PEMEX and imports. In recent years, PEMEX’s gas production has not kept up with the growth in demand and as a result imports increased to 22 percent of total natural gas supply in 2011 (see Table 20).

Going forward SENER forecasts that natural gas supplied by Pemex will increase at an average annual rate of 3.4 percent between 2009 and 2025. Natural gas supplies imported by pipeline are expected to increase at an average annual rate of 1.8 percent and imports of liquefied natural gas are expected to increase at an average annual rate of 5.3 percent.

**PEMEX**

In 1938, Mexico’s President Lázaro Cárdenas del Río nationalized the foreign-owned oil companies then operating in Mexico and consolidated their assets under the control of state-owned PEMEX. It is a decentralized public entity, 100 percent owned by the Mexican government, and is responsible for the central planning and strategic management of Mexico’s hydrocarbon industry. The hydrocarbon reserves themselves are owned by the Mexican nation and not by PEMEX. In 1992, the operational management was split into four subsidiaries: PEMEX-Refinación (PEMEX Refining), PEMEX-Gas y Petroquímica Básica (PEMEX Gas and Basic Petrochemicals or PGBP), PEMEX-Petroquímica (PPQ) and PEMEX-Exploración y Producción (PEMEX Exploration and Production or PEP). Each subsidiary operates as a separate entity of the Mexican government and has the legal authority to own assets and operate its businesses under its own name.19

With respect to production of natural gas, PEP is responsible for the exploration, development, production and first hand sales of oil and natural gas. These activities are reserved exclusively to PEMEX by the Mexican Constitution. Natural gas processing, transportation and distribution are done by PGBP. In 1995, the Mexican Congress amended the law to allow domestic and foreign private companies to participate, with the Mexican government’s approval, in the storage, distribution and transportation of natural gas.

**Imports**

Until 2006 all natural gas imports came from the United States and were delivered via natural gas pipeline. Beginning in 2005 Mexico began to import liquefied natural gas (LNG) which was regasified at terminals in Altamira and Ensenada. LNG accounted for 8 percent of total imports in 2006, growing to 27 percent of total imports in 2009.

Natural gas infrastructure capacity between Mexico and the US amounts to 3.3 billion cubic feet per day (or Bcf/day) across 17 cross-border interconnections. The pipeline interconnections between Mexico and the United States can be seen in Figure 13.

In 2009 gas imports from the United States decreased 7 percent over import volumes in 2008. The 2009 imports were received in the states of Baja California, Tamaulipas, Chihuahua, Sonora and Coahuila.

**Liquefied Natural Gas (LNG) Imports**

LNG is natural gas that has been cooled to the point that it condenses to a liquid, which occurs at a temperature of approximately -256 degrees F (-161 degrees C) and at atmospheric pressure. Liquefaction reduces the volume by approximately 600 times thus making it more economical to transport between continents in specially designed ocean vessels, whereas traditional pipeline transportation systems would be less economically attractive and could be technically or politically infeasible. Thus, LNG technology makes natural gas available throughout the world.20

During 2003, the CRE granted four LNG regasification permits; however, only two have been developed. One project is the construction of a 500 MMcf/d regasification terminal on the east coast at Altamira by

---

**Table 20. Sources of Natural Gas Supplies (MMcf/day)**

<table>
<thead>
<tr>
<th>Year</th>
<th>1999</th>
<th>%</th>
<th>2008</th>
<th>%</th>
<th>2009</th>
<th>%</th>
<th>2010</th>
<th>%</th>
<th>2011</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEEX</td>
<td>4,039</td>
<td>96</td>
<td>6,014</td>
<td>82</td>
<td>6,244</td>
<td>83</td>
<td>6,440</td>
<td>82</td>
<td>6,224</td>
<td>78</td>
</tr>
<tr>
<td>Imports</td>
<td>168</td>
<td>4</td>
<td>1,336</td>
<td>18</td>
<td>1,258</td>
<td>17</td>
<td>1,459</td>
<td>18</td>
<td>1,749</td>
<td>22</td>
</tr>
<tr>
<td>Total</td>
<td>4,207</td>
<td>100</td>
<td>7,350</td>
<td>100</td>
<td>7,502</td>
<td>100</td>
<td>7,899</td>
<td>100</td>
<td>7,973</td>
<td>100</td>
</tr>
</tbody>
</table>

*Source: SENER: Natural Gas Outlook21*

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**Figure 13. Mexico-United States Gas Pipeline Interconnections**

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**Notes:***

Nuclear plants have been by far the most expensive to construct, although uranium is the least expensive fuel to use (apart from questions about disposal costs). In recent years, nuclear facilities have proved to be reliable generators. Nuclear generation produces no greenhouse gas emissions.

Mexico has one nuclear power plant (1,365 MW) located in Veracruz state which was built 1990–1995 by Ebasco Services Inc. SENER expects nuclear capacity to increase slightly to 1,561 MW by 2025.

### Coal

Coal is a black or brownish black solid combustible fossil fuel typically obtained from surface or underground mines. Coal is classified according to carbon content, volatile matter and heating value. Lignite coal generally contains 5.9 to 13.1 million Btus per ton. Sub-bituminous coals range from 16 to 24 million Btu per ton; bituminous coals range from 19 to 30 million Btu per ton; and anthracite, the hardest type of coal, from 22 to 28 million Btu per ton.

Coal fired generation represented about 12 percent of Mexico’s total generation in 2011. Most of the country’s coal reserves and all of its coal fired generation are in the northeastern state of Coahuila. The coal is low quality due to its high ash content. Mission Energy, a US company, is the largest coal producer followed by Mexican company Minerales Monclova, a subsidiary of steel company Grupo Accero del Norte. Due to an explosion at the Pasta de Conchos coal mine in February 2006, the Mexican Congress passed a measure permitting non-PEMEX entities to develop and produce coalbed methane gas for self-use or sale to PEMEX.

Domestic coal supplies are supplemented by imports from the United States, Canada and Colombia. Hard coal and brown coal are consumed in Mexico: hard coal is used by coke ovens in oil operations and brown coal is used for electric generation.

### Renewable Fuels

#### Hydroelectric

Electricity can be created as turbine generators are driven by moving water. While hydroelectricity is considered a renewable fuel, management of flowing rivers and cycles of rain and drought can impact hydroelectric capacity greatly as well as contribute to other environmental effects.

There are no major river systems in Mexico. The Sierra Madre mountains separate the country into Pacific and Atlantic watersheds resulting in short-length rivers that flow west to the Pacific Ocean or east to the Gulf of Mexico. The longest river in Mexico is the Rio Grande (called Rio Bravo in Mexico) which forms part of Mexico’s northern border with the United States. The longest river within Mexico is the Lerma-Santiago in south-central Mexico which flows northward and westward to the Pacific.

Historically Mexico has derived much of its power from hydroelectric facilities some of which date back to the 1920’s in remote areas. Although expensive to construct, hydroelectric facilities typically generate the least cost electricity on an operating basis. If water resources are abundant, countries will typically develop extensive hydroelectric capacity. Hydroelectric power is produced as water moves from a higher to lower level and pushes a turbine. Most of Mexico’s hydroelectric facilities are located in the south south-east part of the country.

CFE owns and operates all of Mexico’s hydroelectric generation except for one small 6 MW facility. CFE estimates that the country’s total hydroelectric potential is about 42,000 MW compared with 11,028 MW currently. However, because of the arid conditions over much of the northern part of the country, there are relatively few sites for new hydroelectric facilities. Environmental concerns and the need to relocate rural communities also hinder the development of new hydroelectric facilities. SENER forecasts that SEN hydroelectric generation capacity will increase from 11,499 MW to 16,297 MW in 2026.

#### Geothermal

Electricity can be created when steam produced deep in the earth is used to run turbines in a generator. Geothermal steam can be a renewable fuel if the associated geology and subsurface heat conditions are favorable.
Mexico's geothermal electricity potential is estimated at 8,000 MW, second in the world only to Indonesia. The majority of this potential is located in a band of geothermal fields across the middle of Mexico in the volcano region. Potential geothermal energy sites are in close proximity to volcanos.

Currently most of Mexico's geothermal fired generation is in Baja California with very small amounts in the center regions. SENER forecasts a slight increase in SEN geothermal generation capacity from 887 MW in 2011 to 1,029 in 2026.

**Wind and Solar Energy**

Electricity can be created when the kinetic energy of wind is converted into mechanical energy by wind turbines (blades rotating from a hub), that drive generators. Wind energy technology (advanced wind turbines) is available today at competitive prices. However, wind resources are fairly site specific and tend to be distant from major demand areas. As a result, the feasibility of wind energy is dependent on access to economic transmission which often is unavailable. In addition, wind energy is intermittent and thus is not always available to meet demand.

SENER reported 87 MW of SEN wind generation capacity in Mexico in 2011 and expects it to increase to 1,800 MW by 2026. Radiant energy from the sun can be converted to electricity by using thermal collecting equipment to concentrate heat, which is then used to convert water to steam to drive an electric generator (thermosolar) or can be converted to electricity directly through silica cells (photovoltaic). Solar energy depends on available sunlight and is reliant on storage or supplementary power sources. Costs for solar energy applications have declined substantially and in some applications, solar electricity is economically competitive. Like wind resources, the best sites especially for large scale projects often are not near major populated areas and thus also are constrained by transmission access. Like wind, solar is intermittent, and backup power must be available for periods when radiant energy is too low or not available. In addition, solar panels and large solar arrays face environmental and community opposition similar to placement of other large electric power projects.

Solar electric generation capacity is currently very small in Mexico. SENER forecasts that 6 MW of SEN solar generation capacity will be added between 2012 and 2019.

**Biomass**

Electricity can be created when various materials (like wood products, agricultural and urban waste) are combusted. Heat from combustion is used to convert water to steam for power generation. Biomass resources from urban waste are most available in heavily populated areas, while agricultural-based fuels are strongly associated with rainfall distribution as well as agricultural production.

The Institute of Electric Research (IIE) estimates that Mexico produces 90,000 tons of municipal waste annually which could support about 150 MW of generation capacity. As of 2010, there was 24 MW of capacity in operation for self-supply and cogeneration. SENER expects an additional 300 MW of biomass generation to be added by 2025, all for self-supply and cogeneration.

**NON-SEN Electric Generation Fuels**

Self-generation and cogeneration capacity is expected to increase by 2,480 MW from 7,228 MW in 2009 to 9,716 MW in 2020. Most of this capacity should be installed between 2010 and 2014 and is fueled primarily by renewables as can be seen in Figure 15.
Greenhouse Gas Emissions

Global warming, or the “greenhouse effect” is an environmental issue that involves the potential for global climate change due to increased levels of atmospheric greenhouse gases. Certain components in our atmosphere serve to regulate the amount of heat that is kept close to the Earth’s surface. Scientists theorize that an increase in greenhouse gases from human activities could induce climate change, which could result in many environmental impacts, both positive and negative.

The principle greenhouse gases (GHG) include water vapor (the most abundant), carbon dioxide (the most prominent of human produced gases), methane (the most potent), nitrogen oxides, and some engineered chemicals such as chlorofluorocarbons (which have been banned worldwide). While most of these gases occur in the atmosphere naturally, debate centers on the extent to which levels have been elevated due to a number of human activities ranging from agricultural practices and deforestation to the combustion of fossil fuels for energy production.

Among the GHG, carbon dioxide (CO₂) commands the greatest and most widespread attention. Although carbon dioxide does not trap heat as effectively as other greenhouse gases (making it a less potent greenhouse gas), and although the concentration of CO₂ in the atmosphere is very low relative to other time periods in the earth’s history, measures of CO₂ associated with growing human populations and increased industrialization in recent decades suggest that concentrations have been rising rapidly.

A number of policy and regulatory issues flow from the debate about CO₂. These include the potential for eliminating fossil fuel use altogether (an option that is widely regarded to be impractical because of tradeoffs associated with potential substitutes for electric power production, like nuclear power, and the lack of compelling and cost effective alternatives for fossil energy based vehicle transportation fuels); capturing CO₂ from power plant and other industrial fuel gases and storing CO₂ long term in underground brine aquifers or through practical applications such as enhanced oil recovery (with CO₂ recaptured during oil conversion at refineries and petrochemical facilities); reducing CO₂ emissions through alternative technologies; and so on.

In addition to technology development, a number of policy and regulatory approaches are either under consideration or in experimental use to provide market and economic incentives for CO₂ reductions. The most common approach is creation of CO₂ credits, produced when measurable quantities of CO₂ emissions are reduced or eliminated, that can be traded and thus be used to transfer value of CO₂ emissions mitigation to those undertaking the cost of making the reductions. A variety of CO₂ emissions credit markets are operating around the world, including the European carbon credit market (the European Union Emissions Trading Scheme), the Chicago Climate Exchange in the US (a voluntary private market), and a variety of “over the counter” transactions in the US and Australia in which credits are derived and traded without formal trading schemes or market structures (exchanges).

Smog

Smog and poor air quality is a pressing environmental problem, particularly for large metropolitan areas. Smog, the primary constituent of ground level ozone, is formed by a chemical reaction of carbon monoxide, nitrogen oxides, volatile organic compounds, and heat from sunlight. As well as creating that familiar smoggy haze commonly found surrounding large cities, particularly in the summer time, smog and ground level ozone can contribute to respiratory problems ranging from temporary discomfort to long-lasting, permanent lung damage. Pollutants contributing to smog come from a variety of sources, including vehicle emissions, smokestack emissions like power plant fuel gases, paints, and solvents. Because the reaction to create smog requires heat, smog problems are the worst in the summertime.

Acid Rain

Acid rain damages crops, forests, wildlife populations, and causes respiratory and other illnesses in humans. Acid rain is formed when sulfur dioxide and nitrogen oxides
react with water vapor and other chemicals in the presence of sunlight to form various acidic compounds in the air. The principle source of acid rain causing pollutants, sulfur dioxide (SO₂) and nitrogen oxides (NOₓ), are coal fired power plants. Particulate emissions also cause the degradation of air quality. These particulates can include soot, ash, metals, and other airborne particles.

Experimentation with tradable emissions credits was first undertaken with SO₂ in the US in response to concerns about acid rain deposition. SO₂ credits generated by power plants and other emitters are traded on the New York Mercantile Exchange (NYMEX). The success of that program in supporting SO₂ reductions is often cited as a main factor underlying development of tradable credit schemes for CO₂.

### Fossil Fuels and Pollutants

Natural gas is the cleanest of all the fossil fuels. Composed primarily of methane, the main combustion products of natural gas are carbon dioxide and water vapor, the same compounds we exhale when we breathe. Coal and oil are composed of much more complex molecules, with a higher carbon ratio and higher nitrogen and sulfur contents. This means that when combusted, coal and oil release higher levels of harmful emissions, including a higher ratio of carbon emissions, NOₓ, and SO₂. Coal and fuel oil also release ash particles into the environment, substances that do not burn but instead are carried into the atmosphere and contribute to pollution. The combustion of natural gas, on the other hand, releases very small amounts of sulfur dioxide and nitrogen oxides, virtually no ash or particulate matter, and lower levels of carbon dioxide, carbon monoxide, and other reactive hydrocarbons.

With respect to greenhouse gases, the combustion of natural gas emits almost 30 percent less carbon dioxide than oil, and just under 45 percent less carbon dioxide than coal. In addition, natural gas contributes less to smog formation, as it emits lower levels of nitrogen oxides, and virtually no particulate matter.

In congested urban areas where NOₓ and smog are specific problems, some natural gas power plants may be subjected to air quality rules that restrict the amount of emissions they can produce and thus the amount of time these plants can operate. During peak periods of demand, these rules can impact the amount of electric power available and limit the effective use of natural gas peaking units. In these cases, efforts are usually underway to balance NOₓ emissions from natural gas electricity generators with emissions reductions from other sources in order to reduce production of ground level ozone and smog.

Since natural gas emits virtually no sulfur dioxide, and up to 80 percent less nitrogen oxides than the combustion of coal, it produces fewer acid rain causing emissions. Natural gas emits virtually no particulates into the atmosphere. In fact, emissions of particulates from natural gas combustion are 90 percent lower than from the combustion of oil, and 99 percent lower than burning coal.

### Environmental Mitigation Associated with Electric Power in Mexico

Mexico is the largest carbon dioxide emitter from fossil fuel burning in Latin America and may be relatively vulnerable to climate change. As such, Mexico was the first country in the Western Hemisphere to sign the Kyoto accord. Mexico is estimated to be responsible for 1.5 percent of global greenhouse gas emissions: of these Mexican emissions, the energy sector is responsible for 60 percent of the total.

In the 1990s, Mexico implemented a fuel substitution policy that called for reduced use of fuel oil and increased use of natural gas in electric generation. As mentioned previously, the Mexican Congress enacted the Renewable Energies Law (REL) in late 2008 with the goal of reducing the country’s dependence on fossil fuels by (1) fostering renewable energy development; (2) providing financing tools for such development and (3) replacing fossil fuel electric generation with renewable fuels generation. The REL also complements Mexico’s Special Program for Climate Change which envisions reducing greenhouse gas emissions from 2000 levels by 50% by 2050.

Of course, the use of renewable fuels such as water for hydroelectricity, solar, wind, geothermal and biomass fuels in place of fossil fuels for electric generation produces little or no direct emissions. However, generation from renewable fuels is generally more costly; still requires raw materials, land and water; and also has issues of availability, transmission access and reliability as discussed above. In 1996, CONAE and ANES established a consultative forum to identify actions necessary to promote the use of solar power. This forum was expanded into the COFER, composed of representatives from the industrial, commercial, academic, government and development bank sectors to promote the use of renewable fuels.

COFER identifies specific projects and develops programs and policies to support them. The marginal generation cost, about 3.2 cents per Kwh, in Mexico is based on gas-fired combined cycle units. Generation costs using most renewable fuel sources are higher. Programs to promote renewable energy provide incentives to offset the higher marginal generation costs including green funds and carbon credits. According to CRE, it had granted 117 permits for self-supply generation and cogeneration with renewable fuels as of April 2011. The renewable fuels generation capacity authorized by CRE totaled 3,640 MW of which 1,040 MW (29 percent) was in operation.

<table>
<thead>
<tr>
<th>Contaminants</th>
<th>Natural Gas</th>
<th>Fuel Oil</th>
<th>Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Dioxide</td>
<td>117,000</td>
<td>164,000</td>
<td>208,000</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>40</td>
<td>33</td>
<td>208</td>
</tr>
<tr>
<td>Nitrogen Oxides</td>
<td>92</td>
<td>448</td>
<td>457</td>
</tr>
<tr>
<td>Sulfur Dioxide</td>
<td>1</td>
<td>1,122</td>
<td>2,591</td>
</tr>
<tr>
<td>Particulates</td>
<td>7</td>
<td>84</td>
<td>2,744</td>
</tr>
<tr>
<td>Mercury</td>
<td>0.000</td>
<td>0.007</td>
<td>0.016</td>
</tr>
</tbody>
</table>

Source: USEIA, Natural Gas Issues and Trends, 1998 (www.eia.doe.gov)

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22 A three to five degree temperature increase without commensurate rainfall could cause drought in 50 percent of all arable land and significant damage to the inhabited Gulf of Mexico coasts.
24 National Association for Solar Energy.
25 Forum to Promote Renewable Fuels.
26 CRE totaled 3,640 MW of which 1,040 MW (29 percent) was in operation.
The legal framework for the Mexican electric sector is set out in the Mexican Constitution Articles 27 and 28 and the Public Electricity Utility Law (Ley del Servicio Público de Energía Eléctrica). This law makes providing energy for public service, e.g., selling electricity to consumers, the exclusive domain of the SEN companies CFE and LFC.

Prior to 1992, CFE and LFC controlled all electric generation, transmission, distribution and marketing activities with the exception of generation for self-use. In 1992 the government initiated changes to permit entry of private participants in electric power generation. Further attempts to modify the legal and regulatory structure of the industry were made in 1999 and during the Fox administration but were not successful.

Given the importance of fuel oil and natural gas supplies for electric generation, it is also necessary to address the legal and regulatory structure of the hydrocarbon sector in Mexico. As with the electric sector, the Mexican Constitution reserves oil and gas exploration and production, transportation, distribution and marketing to the state whose rights are exercised by PEMEX. In 1995 reforms were made to permit private participants in non-exploration and production related gas transmission, distribution and storage. In 2003, PEMEX implemented a contracting structure (Multiple Services Contracts) to attract private investment in designated non-associated[25] natural gas areas in order to increase natural gas production.

In 2008 the Mexican government enacted reforms of PEMEX and the hydrocarbon sector. The 2008 reform package consisted of a number of laws and revisions to laws,[26] geared toward facilitating Pemex efficiency and effectiveness through improved corporate governance; enabling increased Pemex investment through tax regime reductions in certain areas; gradually integrating some modicum of upstream competition through a restructured exploration, development and production service contract to reduce Pemex’s upstream isolation and provide third party funds for investment; providing Pemex with some market discipline through the issuance of “citizen bonds” and improving upstream governance through the establishment of the new National Hydrocarbons Commission (CNH).

The reforms also created avenues for alternative energy investment and a national planning commission (whose functions are still evolving).

The reform initiatives, successful and unsuccessful, as well as the current legal and regulatory structures of the energy industries are discussed below.

**Energy Sector and Electricity Governance in Mexico**

**Secretaría de Energía (SENER, Ministry of Energy)**

SENER is responsible for Mexico’s energy policies (electricity and hydrocarbons) which should ensure competitive, sufficient, high quality, economically feasible and environmentally sustainable energy supplies as required by the nation. Since 2008 SENER is responsible for the development of the National Energy Strategy which is then presented to and ratified by the Mexican Congress.

The Energy Minister is appointed by the President of Mexico. The Energy Minister is also the Chairman of the Boards of CFE and PEMEX. SENER also coordinates with and supports the CRE and CNH in their activities. The multiple roles of the Energy Minister which involve interaction with the regulatory bodies (CRE and CNH) and those it regulates (PEMEX and CFE) could lead to conflicts of interest. The Energy Minister is responsible for the financial and operating well-being of the state-owned companies while simultaneously promoting a fair and competitive business environment which policies may be to the detriment of the state-owned companies.

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The main functions of the CRE are to grant permits, authorize transportation, transmission and distribution prices and rates, approve terms and conditions for the provision of services, issue directives, and regulate the state-owned electricity companies CFE and LFC.

Since 1975 the private sector has been allowed to generate power for its own use. Non-associated natural gas is mainly methane that is produced alone (dry gas) or with condensates (natural gas liquids). Non-associated gas is distinct from associated gas which is produced with crude oil.

The seven pieces of legislation that form the 2008 reform package include: The Pemex Administration Act, Amendments to the Regulatory Law of Article 27 of the Constitution; Amendments to the Law of Public Works and to the Acquisitions Law, to carve out PEMEX from these statutes; Petroleum Commission Act to create Comisión Nacional de Hidrocarburos (CNH) and outline its functions; Amendments to the Law of the CRE; Law for the Use of Renewable Energies and the Financing of the Energy Transition; and Law for the Sustainable Use of Energy.

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resolve disputes, request information and impose sanctions, among others. Although the CRE approves the methodologies for calculating payments for electricity and natural gas transmission and distribution, it does not have the authority to actually establish tariffs and end-use prices of electricity and natural gas. It “participates” in tariff setting with the Ministry of Finance.

The CRE also grants permits for the installation of regasification terminals in Mexico. These permits along with other guidelines regulate the operating, technical and safety standards of the facility. LNG storage and regasification facilities may be 100 percent privately owned and operated. Plant owners have a five year grace period from start-up before open access to the plant is required. The price of gas at the tail gate of the plant is set by market forces. Regasification tariff rates are regulated and approved by the CRE.

There does not appear to be a clear set of rules or procedures for appointment of the five CRE commissioners. It appears that commissioners are nominated by the Energy Minister appointed by the President of Mexico for renewable, staggered five year terms without public scrutiny or the approval of Congress.\[26\]

**Comision Nacional de Hidrocarburos (National Hydrocarbons Commission, CNH)**

The CNH was created in 2008 as a decentralized agency with “technical and operational autonomy” to oversee and regulate oil and natural gas exploration, development and production as well as the technical assessment and quantification of Mexico’s oil and natural gas resources.

Although SENER continues to issue oil and gas exploration, development and production operating licenses to PEMEX, it does so after taking into account CNH’s technical assessment of proposed PEMEX projects. The CNH’s assessment considers the technologies proposed by PEMEX and can suggest alternative technologies. The CNH seeks to ensure that oil and gas exploration, development and production projects attain the maximum possible reserve recovery rates under viable economic conditions while minimizing risks to safety and the environment. The CNH has the potential to support PEMEX under the best international practices with regards to technology, safety, and the environment. It has yet to be seen whether CNH will have the resources and authority to play an important role while maintaining itself as an advisor to SENER.

**Secretaria de Hacienda (Ministry of Finance)**

The Finance Ministry plays a critical role in both the electric and hydrocarbons sectors. The Finance Minister is a Presidential appointee. The Ministry administers end-use electricity and hydrocarbons prices and is thus responsible for subsidy policies. Prior to 2008, the approvals of the Finance Ministry and Mexican Congress were required for the financing of PEMEX projects. The 2008 reforms removed the Finance Ministry and the Mexican Congress from the specific PEMEX project approval process and debt approval process which greatly simplifies and expedites the decision-making and financing processes as well as strengthening PEMEX autonomy.\[29\]

**Secretaria del Medio Ambiente y Recursos Naturales (Semarnat, Ministry of the Environment and Natural Resources)**

All electric industry activities must obey the applicable legal provisions on environmental protection, chief among them the Ley General del Equilibrio Ecológico y la Protección al Ambiente-LGEEPA (General Law on Ecological Balance and Environmental Protection) and the Mexican official standards (NOM) on environmental protection. A summary of Mexico’s NOMs is contained in SENER’s annual Prospectiva del Sector Eléctrico, www.sener.gob.mx.

**Mexican Congress**

The Mexican Congress approves the annual operating and investment budgets of CFE and PEMEX. It also establishes the tax regimes for these companies. As a result, the Congress clearly influences the availability of capital for electric and hydrocarbons infrastructure and supplies.

**Mexican Presidency**

Substantial progress in political liberalization has been accomplished in Mexico including increased transparency in elections and voting in general, and for presidential elections in particular; a more open, free, and transparent press; increased public access to the political process; more competitive elections and greater transparency with respect to campaign finance. Mexico’s president, with a six year term and life time ban on re-election, remains the nation’s most important office for national policy making. The office of the president is also engaged in day-to-day energy sector operations through the process of establishing energy prices, as described earlier, as well as through key appointments to lead Mexico’s energy companies and energy sector governance institutions.

**Petróleos Mexicanos (PEMEX)**

The corporate governance of PEMEX was substantially reformed in 2008. PEMEX’S main objective was clarified and redefined to "create economic value for the benefit of the Mexican people."

**“Mission”**

Maximize the value of the oil assets and hydrocarbons in the nation, satisfy the national demand for petroleum products with the required quality, safe, reliable, cost-effective and sustainable way.

**“Value”**

Be recognized by the people as a socially responsible organization that permanently increases the value of your assets and hydrocarbons of the nation, agile, transparent, and with a high level of innovation in its strategy and operation.

The PEMEX Board of Directors (BoD) was expanded from eleven to fifteen members and now 25 percent of the directors must be independent professional directors with relevant experience. The role of the BoD was strengthened through the establishment of seven new BoD committees with meaningful duties provided by law and the close involvement of the independent professional directors.\[30\]

The Finance Ministry and the Mexican Congress have been removed from the specific PEMEX project approval process and debt approval process. PEMEX activities and performance will be evaluated using oil and gas industry standards rather than government agency standards. Exploration and production procurement activities are no longer subject to cumbersome and industry inappropriate government procurement procedures.\[49\] The reforms proposed the creation of “citizen bonds” to be issued by PEMEX to the Mexican people. The bonds would be publicly traded in the Mexican financial markets with a yield component.

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26 The Finance Ministry will now only approve specific rules with respect to debt. As long as PEMEX fulfills its productivity goals, it will be able to contract financing in the credit markets.

30 Audit and Performance-Evaluation Committee—verifies the achievement of goals, objectives, plans and programs; evaluates the financial and operational performance; appoints, supervises and evaluates the external auditor; and informs the Board about the system of internal controls and proposes improvements to it. It consists of three professional Board members and a representative from the Ministry of Public
linked to the actual performance of PEMEX. The goal of the bonds is to provide PEMEX with market feedback on its performance.

These corporate governance reforms are generally expected to increase PEMEX's efficiency, flexibility, autonomy and transparency. However, the BoD structure is complex and potentially unwieldy and the Mexican government continues to be inextricably involved in PEMEX matters. Of the fifteen BoD members, ten continue to be appointed by the President of Mexico (including the independent directors) and six continue to be Cabinet level representatives of the state. The Mexican Congress must continue to approve PEMEX's annual budget. The Secretary of Energy (SENER) continues as Chairman of the BoD and exercises the tie-breaking vote.

The cumbersome management structure of the four PEMEX subsidiaries continues as is. The President continues to appoint the Director Generals of PEMEX and its subsidiaries. As a result, the PEMEX Director General has little authority over the actions of the operating company appointees. Each PEMEX subsidiary is governed by an eight member board consisting of the Director General of PEMEX, the Director Generals of the three other subsidiaries and four members appointed by the President of Mexico. These board members are not appointed for a specific term and serve subject to the discretion of the President of Mexico. Finally, outside of the international debt markets and the "citizen bonds," Pemex continues to be shielded from meaningful "market discipline." At the time of this writing, the citizen bonds have not yet been created.

**Comisión Federal de Electricidad (CFE)**

The CFE is governed by a government appointed Board of Directors as follows: the Energy Minister is the Chairman of the Board and other members include the Director General of PEMEX, the Secretaría de Hacienda y Crédito Público (Finance and Public Credit), the Secretaría de Desarrollo Social (Social Development), the Secretaría de Medio Ambiente y Recursos Naturales (Environment and Natural Resources) the Secretaría de Economía and three workers from the electrical workers' union. This board meets four times per year in regular session and also in extraordinary session when necessary. Decisions are taken by majority vote; in the case of a tie, the President of Mexico makes the decision. The mission and goals of the CFE are as follows.

**Mission**

- To ensure, within a technologically updated framework, supply of electricity with acceptable quality, quantity and price, with appropriate diversification of power sources;
- To optimize the use of physical, commercial and human resource infrastructures;
- To provide outstanding customer service, and
- To protect the environment, promote social development and respect the values of populations where electrical power is provided.

**Goals**

- To remain as the leading domestic electric power corporation;
- To operate according to international benchmarks in terms of productivity, competitiveness and technology;
- To be known to our customers as a corporation of excellence, concerned about the environment and customer service-oriented, and
- To promote high qualifications and professional development of CFE workers and managers.

**Electric Power Reform Initiatives**

**1992 Electric Generation Reform**

In an attempt to stimulate investment in Mexico's electric power industry, the Law of Public Service of Electricity was reformed during the Presidency of Carlos Salinas. This law is associated with Article 28 of the Mexican Constitution which addresses the sovereign control and public service responsibilities of the CFE. This reform allowed the private sector to participate in cogeneration and self-use production, in BLT (build, lease and transfer) and as independent power producers (IPPs). The main characteristics of each one of these categories can be described as follows:

- In the case of cogeneration and self-use production, any surplus production has to be sold to the CFE at a price fixed by an energy regulator.
- For BLT projects, building and financing are the responsibility of the private investor. The CFE supervises the project and sets the technical specifications. When construction is complete, the plant is operated by the CFE. Once in operation, the plant is leased to the CFE for a period of 20–25 years at the end of which ownership passes to the CFE. The project costs are registered as direct private investment (regardless of whether it is domestic or foreign), and after two years it is converted to public debt (again, regardless of whether the generator is domestic or foreign).
- In the case of IPPs, the project developer designs, finances, builds and operates the plant and delivers the electricity generated to the CFE for a period of 20–25 years. Through a bidding process the CFE guarantees the price and the market (total or partial) to the project developers.
- The 1992 reform was a stopgap measure that resulted in almost no change in the architecture of the sector. It is also complex in practice, due to the cumbersome bureaucracy it entails. In addition, the level of electricity production engendered under the reform appears insufficient in light of projected electricity demand.

**1995 Natural Gas Transportation, Storage and Distribution Reforms**

In Mexico, the hydrocarbons (oil and natural gas) sector and the electricity sector are intertwined due to the importance of hydrocarbons as fuels for electric generation. Prior to 1995, oil and natural gas transportation, storage and distribution were controlled exclusively by PEMEX.
In 1995, reforms were implemented to allow public and private companies, domestic and foreign, to own and operate natural gas transportation, storage and distribution systems subject to regulation by the CRE.\textsuperscript{31} These natural gas reforms were related to the 1992 electric sector reforms: public and private natural gas-fired generators required access to an open and competitive market for natural gas, including transportation, distribution and storage. As natural gas production continued to be in the sole domain of PEMEX, these reforms partially “opened” the natural gas sector.

In 1995, in conjunction with the natural gas reforms, a separate regulatory commission, CRE, was established to oversee natural gas and power activities. In addition to the duties outlined previously, the CRE also bids and licenses new IPP projects under the 1992 electricity law.

Through September 30, 2011, CRE had authorized 28,546 MW of capacity owned by private generators. Fifty percent is in IPP capacity and the remainder is primarily in self-supply and cogeneration.\textsuperscript{32}

With respect to transportation and storage, both PEMEX and private companies are required to obtain permits. Transportation and storage permits are issued for 30 years and are renewable. These permits require the investor to assume the market risk for there is no exclusivity with respect to specific capacities or defined routes. Permits are assigned to technically sound proposals and the market decides which permitted project is finally carried out. For transportation promoted by the government, permits are issued through public bidding. For example, the CFE bid independent power projects together with the pipeline that connects the generation plant to the natural gas system.

Between 1996 and 2009, the CRE issued 23 permits covering 12,480 kilometers of gas pipelines and requiring an investment of US $2.5 billion: about 28 percent of this investment is for private sector open access\textsuperscript{33} pipeline projects and the other 72 percent is for PEMEX’s expenditures on its own trunkline.\textsuperscript{34}

Despite the introduction of competition into the gas transportation sector, PEMEX continues to control about 85 percent of installed capacity. It also controls all domestic natural gas production and the marketing of that production. In 2000, the CRE recognized that the vertical integration of PEMEX in natural gas production, transportation and marketing was hindering competition in gas marketing. The CRE issued a directive requiring PEMEX to “unbundle” or separate its production, transportation and marketing activities and to eliminate cross subsidies between marketing and first hand gas sales. Similarly, private transporters, distributors and storage operators can buy and sell natural gas but the services must be unbundled, with separate accounting systems for each service and without cross subsidies among services.

Also in 1995, private and public companies were permitted to own and operate gas distribution facilities in Mexico subject to government approval and regulation. PEMEX had to divest its distribution assets and provide open access to its transportation system for distributors. Through 2009 the CRE had granted 22 permits to private companies to operate gas distribution systems serving over 2 million customers with an average total volume of 875 MMCF/day and a total investment of $346 million.\textsuperscript{35}

One factor impeding growth in gas-fired generation is the continued dominance of PEMEX in gas production and transportation. This issue is discussed more fully in the Major Issues chapter.

Proposed 1999 Electric Sector Reforms

Concern began to grow that electric demand would continue to outstrip supply despite the 1992 electricity law reforms. Electric price subsidies continued to stimulate demand growth. As well, a number of factors discouraged potential IPP investors: the lack of flexibility for wholesale transactions outside of CFE; restrictions on how much surplus generation capacity could be developed for sale outside of CFE (no more than 5 percent); lack of clarity with regard to contracts for the purchase of natural gas from PEMEX for both new and existing facilities.\textsuperscript{36}

As a result of these concerns, a second, broader phase of electric reform was contemplated by the government of President Ernesto Zedillo in 1999. In late 1999, President Zedillo’s energy minister, Luis Tellez, proposed a full restructuring of the electric power sector as follows.

- A wholesale market would be created with an independent system operator that would mimic the functions of similar organizations being created in the U.S.
- Generation would become fully competitive with generation companies or “Gencos” that could be privately owned.
- The sovereign electric companies would not be privatized, an important difference between Mexico’s strategy and other nations. However, opinion hewed strongly to the notion that the Tellez proposals would pave the way for an eventual sale of CFE and LFC and it was clear that, privately, Tellez held out that possibility. Rather, CFE would maintain control and operation of transmission and local distribution (as would LFC). Mechanisms would be provided for private investment in new transmission facilities. A goal was to make Mexico’s grid more compatible with that of the US in order to facilitate cross-border exchanges.\textsuperscript{37}

Tellez’s initiative was an unusual gambit to roll out a major policy change late in a presidential term. By summer 2000, Tellez’s proposed reforms had failed in the Mexican Congress.

Proposed Fox Administration Electric Reforms

The government of President Vicente Fox attempted to amend the restriction on sales of surplus generation to non-CFE entities by increasing it from 5 percent to 10 percent but the attempt failed. A group of Congressmen filed a constitutional challenge before the Mexican Supreme Court, accusing Fox of exceeding his presidential authority. The Supreme Court, in an unprecedented decision, ruled that Fox’s amendments were unconstitutional. Moreover, the Supreme Court, in its discussions and deliberations, considered that power generation by private parties could be against the Constitution, without making a final ruling on this issue since it was not the subject matter of the case.\textsuperscript{38}

In 2001 President Fox introduced a recast version of the 1999 Tellez proposal to the Mexican Congress which also failed. It was opposed by an alliance made up of Senators and Deputies from the PRI, the Democratic Revolution Party (PRD), the National Workers Union (UNT), and the Mexican Trade Union, made up primarily of electric companies. Key components of the Fox proposal were:
• Generation, transmission and distribution activities would be separated. Constitution articles 27 and 28 would be amended to permit private investment in generation and distribution. Transmission and nuclear generation would remain reserved to the state and regulated.

• CFE and LFC would not be privatized; they would be strengthened financially.

• The CRE would have new and increased responsibilities including the power to fix electricity prices, provide technical and economic regulation and deter anti-competitive behavior from market participants, including CFE and LFC.

• Redefinition of electricity price subsidies in a transparent way.

Rather than implement the proposed reform, the alliance advocated granting technical, administrative and financial autonomy to the CFE and LFC so that they can expand capacity and leaving the system vertically integrated and organized much as it is today. Private generation (IPPs selling to CFE, self-supply and cogeneration) would be permitted as secondary and complementary activities to the public provision of electricity which would remain the responsibility of CFE and LFC.

With respect to electricity prices, the PRI advocated that tariffs be set by the CRE with the input of the secretariats of Hacienda and Economy. The PRD advocated that tariffs be proposed by CFE and approved by CRE.  


The Mexican Congress enacted the Renewable Energies Law (REL) in late 2008 with the goal of reducing the country’s dependence on fossil fuels by (1) fostering renewable energy development; (2) providing financing tools for such development and (3) replacing fossil fuel electric generation with renewable fuels generation. The REL also complements Mexico’s Special Program for Climate Change which envisions reducing greenhouse gas emissions from 2000 levels by 50% by 2050.

In compliance with this legislation, SENER, together with other executive branch participants, developed in 2010 the National Strategy for the Energy Transition and the Sustainable Use of Energy (National Energy Strategy or NES). Goals include increasing electric generation capacity from non-hydro renewable fuels from about 3 percent to 7.6 percent (4,500 MW) by 2012. Electric generation capacity from all “clean” fuels (all renewables plus nuclear and projects with carbon capture/sequestration) is expected to reach 35% by 2025.

A Renewable Energy Fund, funded at $220 million for the period 2009 to 2011, was created to provide financing guarantees and direct support to promote energy efficiency and renewable fuels. New regulations were created in 2010 including reductions in the transmission charges for private renewable energy developers. New models of interconnection contracts and agreements for small scale renewable energy projects are being developed.

2009: The Closure of LFC

On October 11, 2009 President Felipe Calderon issued a decree ordering the liquidation of LFC and ordering CFE to take over its operations. In 2008, LFC accounted for 19% of total SEN customers and 17% of total SEN electricity sales. LFC also reported operating system losses of electricity of about 33 percent.

According to the government, LFC was closed because it was financially unsustainable and operationally inefficient. Between 2003 and 2008 LFC produced financial losses of about $21 billion. If left in operation, the federal government expected it would have to transfer over $18 billion in additional funds to LFC by 2012. The federal government absorbed the pension liabilities of LFC. The electricians’ union, SME, protested the closure as the government only guaranteed jobs to 10,000 of the 55,000 LFC workforce. In addition, the SME claimed that the closure was a direct political attack on the union which supported leftist politician Andres Manuel Lopez Obrador for president in 2008.
A number of key issues impact Mexico's electricity sector, now and into the future (with ramifications into the future).

Political Fragmentation

Mexico is in the midst of both a political and an economic transition. The election of President Vicente Fox in 2000 marked an important shift towards democracy, increased political pluralism and resulted in more checks and balances to the power vested in the President. Seven decades of dominance by the Partido Revolucionario Institucional (PRI) resulted in an elite-driven policy-making process that was relatively straightforward. Today policy-making is much more complex, with the rise of a multi-party system, the decline of Presidentialism, and the rising importance of local governments for social and economic development. Mexico's Congress and legal system are Napoleonic in origin and administrative in practice, yielding few opportunities for and no experience with effective political coalition building.[26]

Regulatory Independence

The CRE and CNH are not completely independent of political control by SENER, although CRE commissioners have attempted to assert their independence on crucial decisions and controversial decisions on bids and licenses.[26] More problematic is the conflict of interest inherent in the position of the Secretary of Energy as chairman of the boards of PEMEX and CFE while also providing support for CRE's and CNH's reforms when they threaten the competitive interests of the sovereign companies. In addition, other government entities, particularly the Secretariats of Hacienda and Economy, have significant input on electricity price regulation which, in most industrialized nations, is reserved to the independent regulator.

Infrastructure Investment

Substantial investment is required in Mexico's SEN electric sector infrastructure. Between 2011 and 2025 SENER expects that about $98 billion of investment is required for generation (51 percent), transmission (16 percent), distribution (20 percent) and maintenance and other investments (13 percent).[41]

Of the expected investment of $98 billion, about 41 percent is expected to come from CFE and 59 percent from private investors and “financing schemes to be defined.” The private sector investment is uncertain given the policy and regulatory concerns discussed previously. The $40 billion in investment to come from CFE is also problematic due to its financial condition which is discussed in more detail below.

Subsidies of Electricity Prices

Mexico has long had "administered" prices for electric power: electricity prices have traditionally been established via a committee including the office of the president, Mexico's treasury ("Hacienda"), the energy ministry, the sovereign companies and the ministry of commerce. As a result of this pricing scheme, the clearing of supply-demand imbalances is done through quantity. Thus, even during the worst of economic times, electric power consumption is resilient and even increases. Concerns about the maintenance of social and political stability have led Mexican governments to subsidize the electricity consumption of a very large proportion of the population in an effort to maintain their purchasing power. Tariffs have been held below the cost of service, preventing the sector from recovering costs of operations and investment. The average tariff charged to all customers covered only 68 percent of costs in 2006.[42] While the electric sector has been generally successful in providing electricity to meet current needs, its ability to make adequate provision for investment levels in the future could be impaired by the price subsidies. The Mexican government reimburses the CFE for its subsidies by discounting the taxes and dividends (aprovechamiento) that CFE has to pay the government. However, since 2002, the subsidy amounts have exceeded the aprovechamiento, eroding the CFE's capital base. Subsidies were a key consideration in the decision to close LFC: its financial situation was so dire that the government had to cover its subsidies in cash which was an unacceptable drain on the government's revenues.[42]

If this situation continues, the capacity of CFE to "pay its way" will continue to deteriorate, placing a growing burden on the public purse, as well as on PEMEX reinvestment. This is because PEMEX is the single largest generator of hard currency through petroleum exports and the single largest contributor to Hacienda finances. As a consequence, management of the electric power system in Mexico bears implications for the overall health and welfare of the energy sector in general. In addition, the market distortions resulting from subsidized electricity prices make it difficult to attract private investment and competition into the sector. If CFE buys power from private generators at market prices, they incur losses when they resell the power in the retail markets. These losses further erode its creditworthiness, making it more difficult for private generators to obtain financing based on long-term sales contracts with CFE. Even if it were to be allowed, private generators could not compete directly with CFE in the retail markets because their prices are at a competitive disadvantage with respect to the subsidized prices. The lack of predictability and transparency in electric price setting is a major concern to current and potential private investors in the sector. The electricity business, like other subsectors that comprise the energy sector, is characterized by large sunk investments with long payback periods. As a result, financing for these investments requires a high degree of predictability with respect to future revenues.

Labor Unions

The electric sector hosts two of Mexico's strongest unions which historically have been key elements of the PRI's power base. The CFE-related union is the Sindicato Único de Trabajadores Eléctricos de la República Mexicana (SUTERM); the LFC-related union is the Sindicato Mexicano de Electricistas (SME). These unions have contributed to the debate surrounding the electric sector and electric tariffs reforms. The employment status of electric sector workers was an issue in Zedillo's proposed 1999 reforms. Although the SUTERM supported the 1999 initiatives, the sharpest protests against them were led by the SME which succeeded in rallying a large number of intellectuals, academics and opinion leaders, as well as a sizeable segment of the PRD, around the rejection of the proposal. The SME feared that electric sector restructuring would lead to massive layoffs as had occurred in other countries like Argentina. However, in July 2000, the government and SUTERM signed an employment security and stability agreement which asserted that if control of the CFE or LFC changed, labor rights would not be affected. Nevertheless, despite widespread protests by the SME, the Calderon government proceeded with closure of LFC in 2008 and an accompanying work force reduction.

With respect to electric tariff reform, especially increasing residential and agricultural tariffs, the SME and SUTERM created alliances with the PRD, the leftist
wing of the PRI and some other social organizations to block modification of the electricity subsidy policies. Since the SME and SUTERM are well-organized groups with the capacity to mobilize votes, electric tariff reform remains politically risky.\textsuperscript{31}

**PEMEX Dominance in Natural Gas Transmission and Marketing**

On February 23, 2000 the CRE issued the Directive on First Hand Sales of Natural Gas because the vertical integration of PEMEX in natural gas production, transmission and marketing was hindering competition in gas marketing.\textsuperscript{\textsuperscript{30}} Basically this directive posits that PEMEX retains a de facto monopoly in gas marketing and thus, this activity must be regulated.

The directive requires PEMEX to unbundle its production, transmission and marketing activities. PEMEX may negotiate long-term contracts at prices below the maximum allowed by regulation provided there are no cross-subsidies between marketing and first hand sales. However, regulation of PEMEX’s discretionary discounts on domestic gas and transport services is easier said than done given the company’s monopoly in gas production, its dominant position in gas transmission and asymmetry of information between PEMEX and CRE. This lack of clarity with regard to contracts for the purchase of natural gas from PEMEX is a concern of private investors developing natural gas-fired generation projects.

**Future Domestic Natural Gas Supplies**

Natural gas consumption in Mexico grew at an average annual rate of 6.3 percent between 1999 and 2009. SENER expects natural gas consumption to increase by 17 percent from 2009 to 2015. The primary drivers for this growth in natural gas consumption are consumption by the electric power and petroleum sectors. As of this writing, demand for natural gas exceeds available supply in Mexico.

From 1999 to 2009, PEMEX’s natural gas production grew at an average annual rate of 4.5 percent compared to a 6.3 percent average annual rate of growth in natural gas demand. The gap between demand and supply was made up by imports which grew at an average annual rate of 22.3 percent. However, dry gas proven reserves in Mexico have declined steadily in all production regions since 1999, decreasing from 30 trillion cubic feet (Tcf) in 1999 to 12Tcf at year end 2009.

SENER expects PEMEX natural gas production to grow at an average annual rate of 2.1 percent between 2009 and 2025 and national gas demand to grow at an average annual rate of 2.4 percent. Much of this expected PEMEX production growth is forecast to come from future exploratory successes. Mexico continues to be a net natural gas importer over this period.

Another issue associated with future natural gas supplies is PEMEX’s ability to fund the investment required to generate the gas production growth forecast by SENER for the period 2009–2025. An estimated $24 billion per year is the required investment in exploration and production (PEP). There is also substantial investment required by PGBP over the projection period for gas transmission and associated infrastructure.

PEMEX’s annual capital budget is part of the federal budget and as such must be approved by the Mexican Congress. As a result, PEMEX faces competition from other government programs for capital and the capital allocation is subject to politics. In other words, it is not certain that PEMEX will be able to obtain the capital it needs to implement the investment program embodied in these gas production forecasts.

In December 2001 PEMEX attempted to improve its investment dilemma by announcing the Multiple Services Contracts (MSC) scheme which was designed to attract private companies to develop non-associated natural gas fields, primarily in the Burgos basin in northeastern Mexico, pursuant to a contractual fee-based arrangement in which PEMEX retains the rights to all extracted hydrocarbons. Exploitation activities pursuant to the MSCs began in 2004 and gas production from the nine awarded MSCs grew at an average annual rate of 6.7 percent between 2004 and 2009. Eight MSC contracts continued to be in effect at the end of 2009.\textsuperscript{32}

Pursuant to the 2008 reforms, PEMEX developed new "integrated service contracts" with the following goals: (1) to increase PEMEX’s operational and managerial capabilities through the transfer of technology and international best practices and (2) increase oil and gas exploration and production investment to reverse declines in Mexican reserves and production. These contracts would first be applied to mature oil fields redevelopment, later to Chicontepec development and finally to deepwater (oil and gas) Gulf of Mexico exploration and development. The contractor would undertake all work for PEMEX at their expense and would be remunerated by a cash fee per barrel of production and recovery of a defined percentage of costs. The PEMEX Law of 2008 explicitly prohibits PEMEX contractors from booking hydrocarbon reserves as assets of their own which is typically a disincentive to investors, particularly in exploration projects. Service contracts are seldom used for upstream exploration, for the obvious reason that fee-based exploration is difficult to reward given the inability to book reserves. Fee-based service contracts for development to date have been restricted to areas like Iraq where the reserve and production potential is orders of magnitudes greater than Mexico’s. To enable increased PEMEX investment in oil and gas exploration and production, the 2008 reforms also proposed special tax regimes for PEMEX activities in Chicontepec and deepwater Gulf of Mexico projects with lower tax rates and higher limits on permitted deductions. Although positive, these limited reductions, similar to those implemented between 2005 and 2008, do not meaningfully reduce the disproportionately high tax burden borne by PEMEX in the Mexican economy. Consequently its investment capacity is not materially increased.

The first new integrated service contracts covered mature oil fields in PEMEX’s Southern Area and were awarded in August 2011 to UK oil services company Petrofac and Mexican company Administradora de Proyectos de Campo.\textsuperscript{33} However, it remains to be seen if the new integrated service contracts will attract the level of investment and the investors desired by PEMEX, allowing it to meet its goals as specified above.

In 2011, interest in the potential development of shale gas in Mexico began to grow. Shale gas refers to natural gas that is trapped within fine-grained sedimentary rocks called shales. Until there were advances in horizontal drilling and hydraulic fracturing technologies shale gas production was often uneconomic because the natural gas could not flow from the formation at high enough rates to justify the cost of drilling.\textsuperscript{34}

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\textsuperscript{32} Ibid.

\textsuperscript{33} The Mexican Petroleum Law of 2008.

\textsuperscript{34} Carreón-Rodríguez et al. (2003).
Horizontal drilling enables lateral as well as vertical penetration of the shale formation thereby exposing more of the surface area of the formation to extraction which increases gas production. In addition, multiple wells can be drilled from one drill pad which reduces costs. Hydraulic fracturing (“fracking”) involves pumping a combination of water, chemicals and sand into the well to open cracks (fractures) in the rock to allow natural gas to flow from the shale into the well increasing gas production. Most shale gas production to date has been in the United States. Shale gas accounted for 14 percent of US natural gas supplies in 2009 and the EIA projects that it will account for 46 percent of total natural gas supplies in 2035. [22]

In 2011 the CNH announced estimates of technically recoverable shale gas resources in Mexico ranging from a low of 150 Tcf (PEMEX) to a high of 681 Tcf (US EIA), primarily in Burgos, Sabinas, Tampico, Veracruz and Tuxpan. [24] PEMEX has drilled one shale gas well in Coahuila and, according to the CNH, plans to invest 200 million pesos (about $17 million) in studies and three more wells before 2013. [24] The CNH advocates the development of these shale gas resources together with conventional gas resources and coal bed methane. [24]

The true production potential of shale gas is uncertain due to quality variability across shale basins and continued evolution of production decline rates. Development of the shale basins is still in early stages and knowledge continues to evolve. In one shale basin, some wells have high gas production rates and recoveries (“sweet spots”) due to geological factors while others can be non-commercial. Depending upon well location and the nature of the particular shale, production decline rates can be very steep thereby requiring “refracking” which increases costs.

There are also environmental issues associated with shale gas production. Well fracturing requires large quantities of water which can be problematic in water short areas. The fracturing fluids contain chemicals that could contaminate surrounding areas if the fracturing processes are not managed properly. Fracturing also produces large amounts of wastewater which may contain dissolved chemicals thereby requiring treatment before disposal or reuse.

Finally, Mexico can, and does, import natural gas supplies from the United States. In 2010, U.S. natural gas sales constituted roughly 13 percent of total Mexican natural gas consumption. Work is underway to add and expand cross-border pipeline capacity from South Texas to Northeast Mexico and Arizona to Sonora. These and other projects could provide an additional 2 to 3 Bcf/day to help balance Mexico’s market.

Renewable/Alternative Fuels

As described earlier, alternatives for power generation include hydroelectric power, solar electricity, wind energy, biomass energy and geothermal power. The fuels for each of these are available at little or no cost; they are often renewable fuels; and they may produce little if any direct emissions. There is little to no price volatility associated with renewable fuels while fossil fuels, particularly oil and natural gas, have relatively high price volatility.

However, in many cases renewable-fueled electric generation is not cost competitive with fossil fueled generation on a total cost basis, particularly with respect to natural gas, as can be seen in Table 24 (facing page). Since much renewable-fueled electric generation is not cost competitive, many countries are providing taxpayer funded subsidies to renewable-fueled generation to encourage investment in these technologies. In the United States, for example, federal government subsidies for renewable fuels, primarily wind and solar energy, in 2010 exceeded $7 billion compared with about $2.5 billion in federal incentives for fossil fuels. [68] These amounts do not include state subsidies for renewable fuels which can be substantial.

There are costs and benefits associated with the incorporation of renewable technologies into the generation mix. Although costs increase as the use of renewable technologies in the generation portfolio increases, risk, defined as fuel price volatility, decreases. The application of financial tools such as modern portfolio theory analysis can help generation planners determine an acceptable allocation of generation technologies given a set of policy objectives.

While the benefits of cleaner, alternative energy sources for electricity are appealing, they do pose operational considerations for the management of electricity services. For one thing, they are “intermittent” power sources (the sun does not shine at night, the wind is variable), and peak availability of alternative energy sources does not always coincide with peak demand. Options like solar and wind cannot provide consistent power production, in contrast to the coal and nuclear facilities that are usually used for “base load” (the units operate continuously providing a consistent power base). Many solar technologies tend to be implemented in conjunction with natural gas turbines. In addition, both solar and wind require large amounts of acreage when deployed for large-scale power generation and extensive use of materials (steel and other products) that require considerable energy to produce.

Technological advances are such that some success in integrating wind-generated electricity has been achieved. Likewise, hydro facilities provide a readily available power reserve (interrupted only by periods of extreme drought). Solar poses more of a problem, because some form of storage is required. Scientists are experimenting with a variety of storage solutions, like letting daytime heat accumulate in fluids like molten salt so that turbines can continue to operate after sunset. However, it will be some time before the economics of utility-scale renewable technologies become favorable.

What many renewable technologies (and some small scale technologies like natural gas microturbines and fuel cells) do offer are options for users in remote locations or localized solutions for energy demand. An isolated community can distribute electricity to its residents “off-grid” (meaning that there does not have to be a connection to a transmission system). Or, excess power from location-specific generation, including cogeneration, can be distributed “on-grid.” Distributed and off-grid generation bear significant implications for the future, particularly for rural Mexican populations without reliable electricity service.

Cross-Border Electricity Trade

Cross-border electricity trade can offer a number of options for meeting both demand for electricity in North America and flexible and reliable management of North American electric power transmission grids. Mexico’s electricity grid connects to the United States on its northern border in several places. There are two connections between Baja California and California which were used for exports from CFE to San Diego Gas and Electric and Southern California Edison in the 1980’s. There are seven connections between Mexico and the Electric Reliability Council of Texas (ERCOT) which are used exclusively for emergency purposes.
Table 24. EIA Estimates of Power Plant Capital and Operating Costs November 2010 (US $)\(^{(2)}\)

<table>
<thead>
<tr>
<th>POWER PLANT CHARACTERISTICS</th>
<th>OPERATING COSTS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nominal Capacity (kW)</td>
</tr>
<tr>
<td>Coal</td>
<td></td>
</tr>
<tr>
<td>One Unit: Advanced Pulverized Coal</td>
<td>650,000</td>
</tr>
<tr>
<td>Dual Unit: Advanced Pulverized Coal</td>
<td>1,300,000</td>
</tr>
<tr>
<td>Single Unit Advanced Pulverized Coal with Carbon dioxide capture and sequestration (CCS)</td>
<td>650,000</td>
</tr>
<tr>
<td>Dual Unit Advanced Pulverized Coal with CCS</td>
<td>1,300,000</td>
</tr>
<tr>
<td>Single Unit Integrated gasification combined cycle (IGCC)</td>
<td>600,000</td>
</tr>
<tr>
<td>Dual Unit IGCC</td>
<td>1,200,000</td>
</tr>
<tr>
<td>Single Unit IGCC with CCS</td>
<td>520,000</td>
</tr>
<tr>
<td>Natural Gas</td>
<td></td>
</tr>
<tr>
<td>Advanced NGCC</td>
<td>400,000</td>
</tr>
<tr>
<td>Advanced NGCC with CCS</td>
<td>340,000</td>
</tr>
<tr>
<td>Conventional Combustion Turbine (CT)</td>
<td>85,000</td>
</tr>
<tr>
<td>Advanced Combustion Turbine (CT)</td>
<td>210,000</td>
</tr>
<tr>
<td>Fuel Cells</td>
<td>10,000</td>
</tr>
<tr>
<td>Uranium</td>
<td></td>
</tr>
<tr>
<td>Dual Unit Nuclear</td>
<td>2,236,000</td>
</tr>
<tr>
<td>Biomass</td>
<td></td>
</tr>
<tr>
<td>Biomass Combined Cycle</td>
<td>20,000</td>
</tr>
<tr>
<td>Biomass Bubbling Fluized Bed (BFB)</td>
<td>50,000</td>
</tr>
<tr>
<td>Wind</td>
<td></td>
</tr>
<tr>
<td>Onshore Wind</td>
<td>100,000</td>
</tr>
<tr>
<td>Offshore Wind</td>
<td>400,000</td>
</tr>
<tr>
<td>Solar</td>
<td></td>
</tr>
<tr>
<td>Solar Thermal</td>
<td>100,000</td>
</tr>
<tr>
<td>Small Photovoltaic</td>
<td>7,000</td>
</tr>
<tr>
<td>Large Photovoltaic</td>
<td>150,000</td>
</tr>
<tr>
<td>Geothermal</td>
<td></td>
</tr>
<tr>
<td>Geotherman – Dual Flash</td>
<td>50,000</td>
</tr>
<tr>
<td>Geotherman- Binary</td>
<td>50,000</td>
</tr>
<tr>
<td>Municipal Solid Waste</td>
<td></td>
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<tr>
<td>Municipal Solid Waste</td>
<td>50,000</td>
</tr>
<tr>
<td>Hydro</td>
<td></td>
</tr>
<tr>
<td>Hydro-electric</td>
<td>500,000</td>
</tr>
<tr>
<td>Pumped Storage</td>
<td>250,000</td>
</tr>
</tbody>
</table>
Currently, ERCOT has worked closely with CFE in an attempt to increase the interconnectedness of their grids, both for economic and reliability reasons. With the technology currently available, interconnections between the close geographic regions yet isolated transmission systems of CFE and ERCOT can uniquely and cost effectively displace inefficient units and provide economic reliability enhancements to meet local load growth needs. Asynchronous interconnections between CFE and ERCOT could reduce generation costs, provide mutual emergency support and allow for economic transactions. By the end of 2005, new open-access asynchronous interconnections between ERCOT and CFE with an aggregate capacity of 250 MW were under construction. CFE and ERCOT are also studying the necessary transmission reinforcements to facilitate large scale electric trade.\[29\]

The North American Free Trade Agreement (NAFTA) instituted specific concessions for electricity services as well as other energy services. However, it did not provide any resolution on government monopolies, formalize arrangements for energy regulatory harmonization or extend the energy crisis provisions from the Canada-US Free Trade Agreement to Mexico. As a result, the NAFTA provides only a weak framework for North American electricity integration.\[29\]

For a robust border electricity trade to take hold and flourish, harmonization of energy policies and regulatory frameworks between the United States and Mexico needs to take place. This is difficult to achieve because it requires resolution of fundamental differences of opinion between the two countries, and their sub-jurisdictions, regarding reliance on markets and the role of government. At any point in time, commitment to either philosophy can be influenced by economic, political and social conditions outside of the control of policy makers, regulators, firms or consumers, and long-term patterns can revert or become cyclical.\[9\]

In recognition of the need to harmonize energy policies and regulatory frameworks, the North American Energy Working Group (NAEWG) was established in the spring of 2001 by the Canadian Minister of Natural Resources, the Mexican Secretary of Energy and the US Secretary of Energy, to enhance North American energy cooperation.

The goals of the NAEWG are to foster communication and cooperation among the governments and energy sectors of the three countries on energy-related matters of common interest, and to enhance North American energy trade and interconnections consistent with the goal of sustainable development, for the benefit of all. This cooperative process fully respects the domestic policies, divisions of jurisdictional authority and existing trade obligations of each country.

In June, 2002, NAEWG released North America-The Energy Picture. This report presents a range of energy information for the three countries, including an economic overview, energy data, supply and demand trends, energy projections and descriptions of infrastructure, laws and regulations.\[24\] NAEWG also has issued two working papers: “Regulation of International Electricity Trade” (which deals with exports and imports as well as interconnection transmission lines) and “Energy Efficiency.”

In addition to NAEWG, the regulatory commissions of the US, Canada and Mexico meet at least three times annually to review their regulatory agendas, strengthen relationships and exchange information. Some of the topics covered include: Electricity interconnection projects, LNG projects, possible natural gas interconnections, regional supply/demand topics and regulatory coordination.\[32\]

In May 2010, Mexican President Calderon and US President Obama created a Cross-Border Electricity Task Force between the United States and Mexico to promote regional renewable energy markets between the two countries as well as increasing electricity grid reliability and resiliency.\[35\]

Since 1994, the Texas General Land Office has worked with a wide variety of partner agencies in the United States and Mexico, including representatives of local, state and federal governments, the private sector, universities and non-governmental organizations, to organize the annual Border Energy Forum. Composed of about 200 participants annually, the Forum is a conference designed to improve the exchange of information regarding energy, including electricity, and its relationship to the environment throughout the border region.

\[24\] The NAEWG report is available at http://www.eia.doe.gov/emeu/northamerica/index.htm.
New Generation Technologies

In addition to the advances in natural gas turbine design, there are new ways to achieve clean combustion of coal and fuel oil and improvements in alternative energy technologies. In Mexico, the Centro de Investigación en Energía (CIE) at the Universidad Nacional Autónoma de México (UNAM) is actively involved in researching and developing new generation technologies.

Integrated gasification combined cycle (IGCC) is a power generation process that integrates a gasification system with a conventional combustion turbine combined cycle power block. The gasification system converts coal (or other solid or liquid feedstocks such as petroleum coke, biomass or heavy oils) into a gaseous synthetic gas ("syngas") made predominantly of hydrogen and carbon monoxide.

The syngas is used to fuel a combustion turbine to generate electricity. IGCC is an advanced technology that can substantially reduce air emissions, water consumption, and solid waste production from coal and heavy fuel oil-fired power plants. In addition, IGCC technology offers the potential for separating and capturing carbon dioxide emissions (and producing pure hydrogen) by adding water-gas shift reactors to the syngas treatment system and physical absorption processes to remove carbon dioxide. The captured carbon dioxide could then be stored or "sequestered," (depending on the carbon dioxide sequestration technologies discussed below).

However, many experts believe that IGCC power plants have uncertain cost and performance characteristics. In 2010, the US Department of Energy’s Office of Fossil Energy cancelled its original IGCC test project (FutureGen) due to cost considerations. A new project, FutureGen 2.0 was announced which includes retrofitting a closed coal-fired power plant in Illinois to demonstrate oxy-combustion technology as well as carbon dioxide capture and sequestration. FutureGen 2.0 is under consideration by the Department of Energy.

In addition, there are technologies on the horizon that may completely change the industry. Often discussed are fuel cells, which use electrochemical reactions-like automotive batteries-to produce electricity. Most promising are fuel cells that can use natural gas as a feed stock for producing hydrogen. Fuel cells are smaller and modular and could be used to power individual buildings or neighborhoods with none of the noise and unsightliness of traditional generating stations.

Fuel cells, improved solar technologies and other developments may lead to a "decentralizing" of electric power systems, allowing small scale applications and resolving many of the potential reliability problems that customers fear. These types of decentralized power systems could make a significant contribution to the provision of clean, efficient energy delivery systems in rural Mexico where much of the population lives without reliable electricity service.

Further into the future, economic nuclear fusion technologies may finally be achieved. Unlike nuclear fission, fusion is the combination of atoms to produce heat. Fusion is a long sought technology that holds tremendous promise of clean, renewable energy, if it can be achieved. Pebble-bed modular reactor (PBMR) technology (still based on fission), on the other hand, may yield its first commercial reactor by 2007. PBMR reactors are fueled by several hundred thousand tennis-ball-sized spheres, known as pebbles, each of which contains thousands of tiny "kernels" the size of poppy seeds. As compared to pressurized-water reactor (PWR) technology used in more than half of the world’s existing reactors, PBMR reactors are smaller and can be built faster. Proponents also argue that they are safer and cheaper. Both claims are challenged by critics.

Microturbines, solar power (either as large collector farms or photovoltaic cells on buildings), ocean power (using either the tidal currents or waves) are other technologies that are being closely watched by the investor community.

Many of these technologies discussed here are not new. All are being pursued at various universities and research institutes in Mexico including, but not limited to, CIE; Instituto de Investigaciones en Electricas (IIE); UNAM; Instituto Politecnico Nacional and the Consejo Nacional de Ciencia y Tecnologia. All are dependent on favorable economic and market conditions. A benefit of competition is that it will accelerate introduction of new technologies.

Carbon Dioxide Capture and Sequestration

Carbon dioxide capture and sequestration (CCS) refers to technologies being developed to "capture" carbon dioxide from potential emitting sources such as electric generation plants before it is emitted and to "sequester" or store it in a variety of places including: geologic formations such as oil and gas reservoirs, unmineable coal seams, and deep saline reservoirs; the deep ocean, and terrestrial ecosystems through the protection of ecosystems that store carbon so that carbon stores can be maintained or increased, and manipulation of ecosystems to increase carbon sequestration beyond current conditions.
Successful development and commercialization of such technologies could greatly improve the greenhouse gas impact of fossil fuel-fired electric generation plants, especially coal-fired and heavy fuel-oil fired plants. The aim of current research is to provide a science-based assessment of the prospects and costs of CO\(_2\) sequestration.

To be successful, the techniques and practices to sequester carbon must meet the following requirements:

- be effective and cost-competitive,
- provide stable, long term storage, and
- be environmentally benign.

Based on current capture and sequestration technologies, the application of these technologies to electric generation plants would raise the cost of electricity significantly. The application of CCS technologies to a pulverized coal power plant and a natural gas combined cycle power plant would raise electricity costs by 43 to 91 percent and 37 percent to 85 percent, respectively.\(^{[27]}\)

If the carbon dioxide could be sold for enhanced oil recovery projects, the increase in electricity costs would be reduced to 12 to 57 percent for pulverized coal power plants and 19 to 63 percent for natural gas combined cycle power plants.\(^{[27]}\) The least increase in electricity costs would be achieved by application of the CCS technology to IGCC power plants. As CCS technology advances and is applied on a large scale, costs could potentially decline by 20 to 30 percent.\(^{[27]}\)

In the mid-term, sequestration pilot testing will develop options for direct and indirect sequestration. The direct options involve the capture of CO\(_2\) at the power plant before it enters the atmosphere coupled with "value-added" sequestration, such as using CO\(_2\) in enhanced oil recovery (EOR) operation and in methane production from deep unmineable coal seams. "Indirect" sequestration involves research on means of integrating fossil fuel production and use with terrestrial sequestration and enhanced ocean storage of carbon.

In the long term, the technology products will be more revolutionary and rely less on site-specific or application-specific factors to ensure economic viability.\(^{[25]}\)

In addition to technology development, a commercial value chain must be created from capture to end use to make large scale carbon dioxide sequestration feasible. Value chain economics incorporating enhanced oil recovery (EOR) are sensitive to oil prices and prices paid for CO\(_2\). Initial analysis indicates that prices paid by EOR operators for CO\(_2\) may have to exceed prices paid historically or subsidies may be required.\(^{[43]}\) CO\(_2\) value chain development and expansion will require new policies, regulations and market design. Work is underway in this regard at the Bureau of Economic Geology, University of Texas and the Gulf Coast Carbon Center and Center for Energy Economics.\(^{[41]}\) Research linkages between Mexico, the United States, and Canada on capture and sequestration are mainly through the respective energy and natural resource ministries and science foundations (Conacyt in Mexico, National Science Foundation in the U.S., and the collective organizations under Canada’s Science.gc.ca).

### Transmission, Distribution and Storage Technologies

Improving the existing capacity of transmission and distribution grid systems and transmitting electricity more efficiently are key stepping stones to facilitating a transition to alternative sources of energy and small-scale, decentralized distributed energy systems. An improved grid could revolutionize the ways in which we supply and use electricity. In Mexico, new transmission, distribution and storage technologies are being researched and developed by the organizations mentioned in New Generation Technologies above as well as by SENER’s Committee of Technology and Development in association with UNAM.

As electricity travels over the transmission grid, much of it is lost (sometimes upwards of 10 percent). This is because the materials typically used in transmission wires can only withstand a certain amount of heat. New, superconducting materials may change that. At research centers around the world, including the Texas Center for Superconductivity at the University of Houston, scientists are developing new materials that can withstand levels of heat and stress beyond anything achievable with traditional metals. These materials, if they can be economically developed for applications like electricity transmission, will dramatically reduce the amount of electricity that must be generated and allow electricity to be efficiently transported over long distances. Experiments with short-distance high voltage lines that use superconducting materials have produced encouraging results.

For electricity to be more easily managed, new ways of handling electricity are needed that take advantage of superconducting materials and devices. One such technology is the use of superconducting devices for instantaneous management of electric power. Researchers at the Houston Advanced Research Center (HARC) have studied small superconducting switches and much larger superconducting energy storage devices for transmission enhancement applications. HARC (with a private and public sector consortium and the State of Texas) has examined the technical and economic feasibility of applying these technologies to constraints in the Texas transmission system. Such devices would enable various power management services such as stability enhancement, increased transmission capacity, voltage and frequency control and other quality enhancements for transmission.

Programs are also underway to study the implications of nanotechnology for energy. At Rice University in Houston, Texas, methods are being developed which would permit electricity to be carried over long distances economically via high-voltage carbon nanotube wires with little or no loss of supply, and facilitate the access of remote energy sources, such as solar power farms. Coupled with the development of enhanced battery storage, this technology could promote distributed energy.

Electric storage technologies are often viewed as the “holy grail” of all energy technologies. In particular, flywheel technology seems to be the most advanced. A Texas company, Active Power, developed the first commercially viable flywheel energy storage system and has distribution deals with companies such as Caterpillar, GE and Invensys. Other storage technologies include pumped hydropower, compressed air energy storage, superconducting magnetic energy storage, and ultracapacitors.

**Btu (British Thermal Unit):** A standard unit for measuring the quantity of heat energy equal to the quantity of heat required to raise the temperature of 1 pound of water by 1 degree Fahrenheit.

**Capacity:** The amount of electric power delivered or required for which a generator, turbine, transformer, transmission circuit, station, or system is rated by the manufacturer.

**Cogenerator:** A generating facility that produces electricity and another form of useful thermal energy (such as heat or steam) used for industrial, commercial, heating, or cooling purposes.

**Combined Cycle:** An electric generating technology in which electricity is produced from otherwise lost waste heat exiting from one or more gas (combustion) turbines. The exiting heat is routed to a conventional boiler or to a heat recovery steam generator for utilization by a steam turbine in the production of electricity. This process increases the efficiency of the electric generating unit.

**Cf:** Cubic foot of natural gas. We use MMcf to mean million cubic feet; Bcf to mean billion cubic feet; and Tcf to mean trillion cubic feet. We use MMcf/day and Bcf/day to mean flow rates on a daily basis.

**Distribution System:** That portion of an electric delivery system operating at under 60 kilovolts (kV) that provides electric service to customers.

**Futures Market:** Arrangement through a contract for the delivery of a commodity at a future time and at a price specified at the time of purchase. The price is based on an auction or market basis. In the United States, this is a standardized, exchange-traded, and government regulated hedging mechanism.

**Gross Generation:** Electricity produced by generators, measured at the generating plant.

**Independent Power Producers:** Entities that are non-CFE and non-LFC power generators. Independent power producers do not possess transmission or distribution facilities and sell electricity solely to the CFE.

**Load:** The amount of electric power delivered at any specified point or points on a system.

**Load Profile:** A representation of the energy usage of a group of customers, showing the demand variation on an hourly or sub-hourly basis.

**Market-Based Pricing:** Electric service prices determined in an open market system of supply and demand under which the price is set solely by agreement as to what a buyer will pay and a seller will accept. Such prices could recover less or more than full costs, depending upon what the buyer and seller see as their relevant opportunities and risks.

**Net Generation:** The electricity delivered to the SEN transmission grid. Net generation is usually equal to gross generation less the electricity used in the generation operations.

**Open Access:** A regulatory mandate to allow others to use gas transmission and distribution facilities to move gas from one point to another on a nondiscriminatory basis for a cost-based fee.

**Outage:** Removal of a facility from service to perform maintenance, construction or repair on the facility for a specified duration.

**Parallel Path Flow:** Electricity flows over transmission lines according to the laws of physics. As such, the power generated in one region may flow over the transmission lines of another region, inadvertently affecting the ability of the other region to move power.

**Reactive Power:** The product of voltage and the out-of-phase component of alternating current. Reactive power, usually measured in megavolt-amperes reactive, is produced by capacitors, overexcited generators and other capacitive devices and is absorbed by reactors, underexcited generators and other inductive devices.

**Spinning Reserve:** That reserve generating capacity running at zero load and synchronized to the electric system.

**Transmission Losses:** Difference between energy input into the SEN transmission grid and the energy taken out of the SEN transmission grid.
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