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China's Sustainable Energy Future Scenarios and Carbon Emissions Analysis

Subreport 11:

International Trends in

Energy-Efficiency Technologies and Policies

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1. Introduction

This subreport to the final report for the China's Sustainable Energy Futures Scenarios and Carbon Emissions Analysis project is intended to provide international context for the technologies and policies selected for inclusion in the preparation of scenarios and building of end-use models on which to run the scenarios. Section 2 reports on the results of analysis of energy-efficiency policies that have been implemented in a variety of countries. While policies regarding renewable energy and other energy supply are also important in fashioning strategies for low-carbon development paths, we focus on energy efficiency in this subreport, since efficiency is a crucial component of any strategy.

The remaining sections are concerned with developments in the efficiency of energy-using technologies, including past, current, and potential future energy demand and energy-efficiency levels of selected countries and particular technologies. The review focuses on the sectors that were chosen for analysis in the scenarios. Section 3 contains a short discussion of "best practices" in technology. Industrial subsectors are covered in Section 4, transportation in Section 5, buildings in Section 6, and electricity generation in section 7.

2. Energy Efficiency Policies, Implementation, and Outcomes Internationally

2.1. Types of Policies

Virtually all developed countries and many developing countries have experience with policies to promote energy efficiency, renewable energy, and other technologies that may contribute to a low-carbon development path. While it is probably impossible to find an example of any country that has an ideal, "coherent", and comprehensive energy policy that integrates energy supply, energy demand, environmental protection, social development, and other goals, most countries have made at least some effort to align energy policy with other policies. Studies have indicated that policies to promote greater efficiency and decarbonization of energy supply are consistent with achieving other social objectives besides environmental protection, such as increasing employment and raising incomes (Lenzen and Dey, 2002). Unfortunately, few nations have conducted formal policy impact assessments, hindering evaluation of accomplishments, failures, and the reasons behind them.

Many sources in the energy policy literature describe and analyze the efforts of individual countries, but few offer systematic international comparisons. Exceptions include two reports the World Energy Council (WEC) has released summarizing studies of energy-efficiency policies in several dozen countries, drawing a variety of lessons (Moisan, 1995; WEC, 2001), and a volume on industrial energy-efficiency policies prepared by Lawrence Berkeley National Laboratory (LBNL; Martin *et al*., 1998).[1] This last reference provides

[1] The WEC (2001) study examined five types of energy-efficiency policies, including: building energy standards; labeling, efficiency standards, and other regulations concerning household appliances; fiscal measures regarding purchase and use of motor vehicles; energy audits; and financial incentives (investment subsidies and soft loans). The LBNL (1998) report deals with financial instruments, voluntary agreements,

one framework for organizing energy-efficiency policies, dividing them between those with short- and long-term objectives, and those that emphasize economic and non-economic (usually regulatory) approaches (Table 1).

Table 1. Framework for Analyzing Energy-Efficiency Policy Instruments

	Economic Approach	*Non-economic Approach*
Short-Term Objective	• Subsidies (audits, hardware) • Tax schemes, rebates, credits • Market regulation (e.g., standards)	• Voluntary/negotiated agreements • Information (audits, dissemination) • Monitoring
Long-Term Objective	• R&D subsidies • Pricing/taxation • Market regulation (e.g., revisions to standards) • Institutional change (market transformation)	• Education and training • Creation/strengthening of organizations to promote efficiency • Voluntary/negotiated agreements→ transformation • Modifying strategic (corporate) goals • Management schemes (e.g., energy managers)

Source: adapted from Martin *et al*., 1998.

A distinction is often made between policies that embody a regulatory approach and those that feature a market approach (WEC, 2001). The former measures tend to mandate specific changes to energy efficiency levels or adoption of specific technologies, provide information relevant to energy-related decision making, or foster changes in goal-setting. The latter measures, including subsidies, tax measures, market rule-setting through standards, etc., operate through the medium of price signals or setting rules regarding the characteristics of products that are allowable on markets. Of course, some measures, like auditing and informational programs, do not fit neatly into either category. While these could potentially be put in a separate category altogether, one might characterize them as non-market policies intended is to rectify market failures so that rational behavior will be more likely to lead to greater energy-efficiency.

Dividing measures among those with short-term and long-term objectives aids in determining how to evaluate effectiveness. One would not expect, for example, that subsidies for R&D would lead within a year or two to a radical change in average end-use efficiency in a particular application. These are more appropriate for long-term transformations of activities. At the same time, while subsidy and fiscal programs to promote adoption of particular new technologies would be very useful in rapidly achieving short-term goals, they would not continue to be effective beyond a relatively short period.

Another axis on which to arrange policies is degree of integration. There are many individual measures, such as efficiency standards for particular types of equipment, rebate programs, or energy audits, that can be considered as isolated, standalone policies. Other approaches, however, can be considered "umbrella" policies that attempt to tie together a variety of measures that together would be more effective than any of them singly. Voluntary agreements and market transformation strategies would fit under this heading.

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information, monitoring and RD&D programs, demand-side management programs, and technology-oriented policies (combined heat and power, motors).

Some approaches may blend regulatory or non-market measures with market measures to create an integrated set of policies that enhance each other's effectiveness.

Yet another way of categorizing energy-efficiency policies is according to sector. Major efforts are associated with specific sectors, such as fuel economy standards for vehicles. This framework also identifies "cross-cutting" measures, typically those associated with a particular device or system that is widespread in many sectors. Policies aimed at improving motors systems would fall into this category.

In the sections that follow, we first set out some general thoughts on "best practices for policy" and consider the need for government intervention and organizational infrastructure. Then we discuss a variety of sectorally targeted policies that have been tried in many countries. We gradually turn attention to cross-sectoral and integrated approaches.

2.2. "Best Practices" for Policy

One of the major conclusions arising from the studies mentioned above is that no single type of efficiency policy or set of policies is always effective under all circumstances. Best-practice policies must be devised for a particular set of conditions—and revised to reflect changes in those conditions.

"Best practice" is determined by goals and the conditions under which they are pursued. Because of this, there is no easy formula for determining what the most effective policies are and how to achieve them. However, it is possible to note some of the trends in energy-efficiency policies. As experience has been gained with individual measures and packages of measures, awareness has grown regarding the importance of integrating a variety of measures to attain the goal of greater efficiency. Incorporating energy efficiency into all phases of decision making, from planning and design to implementation and operation, is essential to take advantage of direct and indirect opportunities for efficiency (Worrell, *et al*., 2001). Beyond that is the necessity of integrating policies that promote energy efficiency with policies that are aimed at other important social objectives, such as environmental protection, economic development. This has gone along with a recognition that, to take advantage of many opportunities for efficiency, larger system boundaries must be drawn, e.g., aiming to improve the efficiency of entire processes or systems rather than individual pieces of equipment, and including behavioral factors along with hardware. Just as importantly, it has become more widely recognized that long-term solutions are needed.; taking advantages of opportunities for efficiency means more than replacing a few pieces of equipment in the span of a few years, but requires instead a commitment to fundamentally change the way things are done.

Best practice in policy requires learning from past efforts. Program evaluation is therefore important—a neglected topic (in virtually all areas of policy), and one urgently needing attention (Martin *et al*., 1998). Because of the need for long-term solutions, a particular challenge is maintaining continuity of support in the face of changing economic, organizational and political environments (IEA, 1997a). This is an issue in all countries, including developed ones, where changes in administrations and legislatures can lead to great variation in support for energy efficiency and other elements of sustainable

development. With the widening of the scope of policy needed to achieve greater efficiency, greater attention and cooperation across organizational, functional and even national boundaries is required. In casting the net very widely, one can view energy-efficiency policy as just one element of an integrated response to climate change and other regional and global environmental threats. Finally, since hardware is not the only thing that is in need of transformation, policies should be aimed a fostering continual improvements in technical capabilities in both "hard" and "soft" areas. Both types of capabilities are necessary for successful technology transfer, and for developing the domestic research and development infrastructure that is needed in all countries to support steady progress towards the goals of sustainable development.

2.3. Organizational Infrastructure

Markets are important, but governments are too. Experience shows that, even under the best of market circumstances, sustained government attention and effort is essential to providing the long-term public benefits that improved energy technologies provide. The WEC (WEC, 2001) found that most (32 of 51 surveyed) of the governments surveyed had established government organs with responsibility for implementing energy efficiency policy. These were mainly financed with public funds, indicating a broad international consensus that governments have the responsibility to promote public welfare through more-efficient use of energy. Many countries also had regional and local agencies. The agencies functioned as repositories of technical expertise, promoters of energy-efficient technologies, and coordinators of government interventions. Most countries also had formalized energy-efficiency policies into programs, with several of them codifying them into laws. Activities to promote energy efficiency necessarily cross the traditional lines of authority of government agencies, so an important function of these agencies is to motivate and to coordinate the activities of other government agencies (IEA, 1997a).

The need for strong infrastructure extends beyond government. It is important to develop an awareness among all stakeholders, especially those responsible for making the purchasing, investment, and operational decisions, of the importance and role of energy efficiency. An organizational infrastructure that facilitates frequent communication and strong marketing of efficiency goals is essential (Martin *et al*., 1998). For this reason, policies that seek to foster the creation within corporations of structures to promote energy efficiency (such as the requirement in some countries that all large corporate energy users employ a trained energy manager) and the incorporation of efficiency goals (such as by setting specific targets through voluntary agreements) are important to achieving long-term efficiency goals. Rules are not enough; it is imperative to build up a corporate and government culture that values the social and economic benefits that improved energy efficiency can provide.

2.4. Building Standards

Most countries surveyed for the WEC report (WEC, 2001), including most developed and some developing countries, had instituted or were considering energy-efficiency codes for new residential and commercial buildings. Buildings constitute a sector in which there is an especially acute problem of split incentives, whereby, for instance, the first purchaser of an energy-using piece of equipment (like a heating furnace or an entire building) is not also

the end user. Since the first purchaser will not pay for the energy required to run the building, there is little incentive to purchase more-expensive equipment and materials that will benefit the end-user, but only reduce the profit of the first purchaser. Building codes get around this problem—a clear failure of markets—by requiring that new buildings meet minimum energy performance standards.

WEC also found that building energy codes are becoming more complex. As countries gain experience with energy-efficiency codes for buildings, they move from regulating individual building components to developing standards for entire building systems (Table 2). Mixed approaches can be adopted. The energy-performance standard approach can be combined with specific standards for materials and equipment, in order to ensure that retrofitted buildings also receive the most-efficient technologies, without requiring that older building meet the same overall performance standard demanded of new buildings. Codes are also updated periodically, to reflect changes in building practices and technology. Software packages have been developed that can help architects, building operators and others analyze building energy performance to assist in designing and operating building in compliance with standards.

Table 2. Types of Building Codes

	Early Standards		**Currently Most Common**		**Prospective**
Type of Standard	**Envelope Component Approach**	**Overall Envelope Approach**	**Heating/Cooling Demand Standard**	**Energy-Performance Standard**	**Life-Cycle Standard**
Objective	Limitation of heat transfer (losses & gains) through individual building components	Limitation of heat transfer (losses & gains) though building shell	Limitation of annual heating & cooling demand of building	Limitation of annual (final or primary) energy use of building	Limitation of life-cycle (final or primary) energy use of building
Regulated Indicator	k-value (U-value) or R-value of components: W/m^2K	Mean k-value (U-value) or R-value of building shell: W/m^2K	Mean annual heating & cooling demand per m^2 or m^3	Mean annual (final or primary) energy use per m^2 or m^3	Lifecycle (final or primary) energy use per m^2 or m^3
Energy Flows Considered	• Transmission through components	• Transmission through building envelope	• Transmission through building envelope • Ventilation losses or gains • Passive solar gains • Internal heat sources	• All energy use for heating and cooling, incl. HVAC system • Energy use for hot water, incl. Distribution, for ventilation, lighting, motors, pumps, elevators, and other systems • All energy gains from active solar energy, e.g., PV, solar collectors, etc.	• Energy use for production of materials and products, transport, construction of building, maintenance, and decommissioning

Source: adapted from WEC, 2001.

It is very difficult to accurately gauge the impact of building standards, especially because of a lack of field studies that assess impacts of standards, and confounding factors such as the slow turnover of building stock and the rise in demand for comfort (e.g., higher or lower temperatures, better lighting). WEC found that they had contributed to stabilization of building energy demand in many countries. In the EU, buildings constructed according to current standards would be about 60% more efficient than equivalent buildings

constructed in the early 1970s, and proposed revisions would improve efficiency by a further 20-30% (WEC, 2001). The additional costs imposed by standards were estimated to be on the order of several percentage points compared to buildings that did not meet standards.

2.5. Appliance Efficiency Standards and Labels

Minimum energy performance standards for appliances have been found to be highly effective in promoting energy efficiency in many countries, especially when paired with labeling programs that are intended to inform customers and guide their selections (Menanteau, 2000). As WEC (2001) wrote, "[E]xperience has shown that labeling programs and performance standards are effective instruments both for governments (low-cost energy savings) and consumers (lower expenditures)…[L]abeling stimulates technological innovation and the introduction of new, more efficient products, while standards complement this development by enforcing the gradual removal from the market of the least energy efficient appliances."

In most countries, minimum energy performance standards were first developed for the highest energy-consuming appliances, i.e., refrigerators and air conditioners (WEC, 2001). In some countries, the standards are set low, so that only a small fraction of appliances on the market are unable to meet it. Standards can also be set to meet cost-benefit criteria. These efficiency standards are updated periodically to reflect changes in available technology that make further progress in energy efficiency cost-effective. Setting standards can be a contentious process, with manufacturers often opposing the imposition of standards. In some cases, however, manufacturers may welcome national standards as an alternative to multiple, differing local standards. Standards are not necessarily mandatory; those in Japan, for instance are voluntary targets.

Two types of labels have been developed: endorsement labels, which indicate that the labeled product is "efficient" according to some criteria. Information labels, which generally give a quantitative score (such as kWh consumed per year) that can be compared with other appliances in the same class, and can be more effective than endorsement labels at stimulating the purchase of more-efficient devices (WEC, 2001). Participation in endorsement labeling schemes is typically voluntary, while information labels are generally mandatory. Manufacturers tend to be more receptive to labeling programs than performance standards, since labels are perceived to give some advantage in marketing of products. A great deal of experience has been accumulated in labeling, and transfer of this experience between countries can be very rapid.

Standards and labels are often integrated into "market transformation" strategies (see below), and are implemented at the same time as other measures that reinforce each others' effectiveness in raising market penetration. Such measures can include information dissemination, training, financial incentives (such as rebates for purchase of efficient products), and bulk procurement programs.

2.6. Regulations and Standards in Industry[2]

In industry, regulations and standards are typically applied to particular pieces of equipment such as motors or boilers that are used in a variety of industrial processes (Hall, 1997). Although they are not used now, regulations and standards can potentially also be used for equipment specific to an industry, such as electric arc furnaces or rotary kilns. In addition, regulations can require that industrial facilities conduct energy audits, employ an energy manager, or adopt an energy management system. Examples of regulations and standards include Brazil's adoption of minimum efficiency levels for high-efficiency motors (de Oliveira et al., 1997; Geller et al., 1998), Canada's Energy Efficiency Regulations (Whelan, 1997), the U.S. Energy Policy Act Motor Efficiency Standards (Balducci, 1997; Nadel and Elliott, 1997; Schiehing, 1997), the U.S. Federal Energy Management Program that requires federal facilities to purchase energy-efficient equipment (Clinton, 1999), the Mandatory Energy Manager programs in Italy and Japan (Rega and Mebane, 1994), and the mandatory energy audits and energy management systems required in the Danish Agreements on Industrial Energy Efficiency (Togeby et al., 1999).

2.7. Transport Policies

Relatively fewer efficiency programs have been developed for the transportation sector than for commercial and residential building and for industry (IEA, 1997a). Among transport-sector efficiency policies, fuel-economy standards, such as the U.S. CAFÉ standards, appear to have been most effective at reducing growth in transport fuel use (Moisan *et al*., 1995). There is some evidence for a rebound effect, however; since more-efficient vehicles effectively make driving cheaper, consumers tend to drive more, leading to a decline in fuel use that is smaller than the reduction in vehicle fuel economy (Greening *et al*., 2000). However, the rebound effect is limited, and much smaller than the primary effects of fuel-economy standards.

Various countries have introduced fiscal policies aimed at modifying demand for vehicle ownership and use, such as taxes on car purchases, higher annual ownership of registration fees, and fuel taxes. WEC (2001) concluded that, while high taxes on car purchases did lead to lower rates of car ownership, there was no discernable effect on demand for efficient vehicles. One way to improve the impact of vehicle purchase fees, therefore, is to make rates higher on less-efficient vehicles ("gas guzzler taxes"). Taxes on vehicle purchases can have other unfortunate impacts, such as slowing the penetration of new technologies, and restricting car ownership to the wealthy, who may tend to demand larger, higher-performance, and less-efficient vehicles.

Fuel taxes, on the other hand, did seem to be associated with greater demand for more-efficient vehicles, as well as with lower levels of vehicle use. Studies have shown that consumers are very responsive to prices, and that a 10% increase in fuel prices leads to a 1% reduction in vehicle stocks, a 2% reduction in distance driven, and a 4% improvement in efficiency, as well as a 3% decline in travel demand (Johansson-Stenman and Schipper, 1997). Subsidies or rebates for more-efficient or alternative-fuel vehicles also speed the

[2] Adapted from Price and Worrell, 2000.

deployment of such vehicles. Programs to purchase and scrap older vehicles accelerates turnover in vehicle stock, but are subject to free-rider problems. Little is known about how road pricing (tolls) may affect efficiency.

2.8. Financial Instruments

Fiscal measures have been used in other sectors besides transportation. Fiscal policies include imposition of taxes, tax rebates, investment tax credits, and establishing investment bank lending criteria for promotion of energy efficiency. Rebate programs and other credits have been used in demand-side management programs (see below). Some countries, including China, have also used such measures to promote industrial energy efficiency.

Taxation policies are a mandatory means for influencing the introduction of energy efficiency. For example, Denmark has a mandatory CO2 tax where the level of taxation depends on the purpose of the energy use, the type of energy used, and whether an agreement for improving energy efficiency exists between the company and the Danish Energy Agency (Ezban *et al*., 1994; Josefsen, 1999; Togeby *et al*., 1998; Togeby *et al*., 1999). Taxation policies can also influence energy efficiency through the use of tax rebates or investment tax credits. In Denmark, the government provides tax subsidies for energy managers.

Both energy bonus taxes (subsidies to stimulate investments in energy efficient equipment) and investment grants and credits for combined heat and power systems have been used in The Netherlands (Farla and Blok, 1998). A Dutch program that provided a tax credit to industrial facilities that invested in energy efficiency, in which most of the energy savings was associated with projects undertaken early in the program with short payback periods, like insulation (Martin *et al*., 1998). Such projects accounted for about half of the total energy savings in industry over the period of the program (1980-1988). Less cost-effective were projects with longer payback periods, such as combined heat and power (cogeneration) projects. A Danish program imposed varying levels of CO_2 taxes, which made energy for various end uses more expensive. The program demonstrated that industrial end users were very price-sensitive, particularly those in electricity-intensive industries (Martin *et al*., 1998). Finally, tax credits for investments in combined heat and power have been proposed in the U.S. (Geller, 1999).

Investment bank lending criteria can be established to give higher priority for funding projects that improve energy efficiency (Inaba, 1994). Recently, an analysis of this type of program was made that evaluated ways that the Industrial Development Bank of India could improve energy efficiency in ten industrial sectors of the Indian economy (Sathaye *et al*., 1998).

2.9. Reporting/Benchmarking[3]

Programs or policies that promote or require reporting and benchmarking energy consumption have been implemented in some countries (Sun and Williamson, 1999).

[3] This section and the next two are adapted from Price and Worrell, 2000.

Reporting facility energy use has been shown as an effective means of raising management awareness of internal energy consumption trends while benchmarking energy use provides a means to compare the energy use of one company or plant to that of others producing the same products. Reporting and benchmarking programs have been established in Canada (Jago, 1999; Munroe, 1999), Norway (Finden, 1998; Helgerud and Mydski, 1999; Institute for Energy Technology, 1997), the U.K., and the U.S. (Martin *et al*., 1999; U.S. EPA, 1998). In addition to such national programs, specific industrial sectors such as the petroleum refining industry have (voluntary) international benchmarking programs (Solomon Associates, 1999).

2.10. Audits/Assessments

Audits or assessments of industrial facilities provide managers with information regarding current energy use patterns as well as opportunities to reduce energy use through implementation of energy efficiency measures. Such audits can be done through a government program, such as the U.S. Industrial Assessment Centers (Clark and Birkmore, 1999; Muller and Barnish, 1998), the Iowa Energy Center (Haman, 1999); the Danish energy audits (Josefsen, 1999), the TERI Bangalore/GTZ audit program in India, and the Annual Self Audit and Statement of Energy Accounts Scheme in Ireland. Audits and assessments can also be performed by independent energy service companies (ESCOs). ESCOs typically assume the technical, financial, and operational risks associated with implementation of the identified energy efficiency measures and are paid through the realized energy savings (Vine *et al*., 1998).

2.11. Information Dissemination and Demonstration

Information dissemination and demonstration programs provide industries with information on energy efficiency technologies and practices that may be difficult, costly, or time-consuming for individual enterprises to gather. Examples of these programs are the U.S. Industrial Assessment Centers (Muller and Barnish, 1998), Norway's Industrial Network for Energy Conservation (Finden, 1998), and the U.K.'s Energy Efficiency Best Practice Program (Miles, 1994). Case studies of a number of countries have shown that educational and motivational programs for all stakeholder groups are prerequisites to the success of wider programs to promote energy efficiency (IEA, 1997a).

Utility or national demand-side management (DSM) programs (see below) provide information on energy efficiency technologies and measures, design assistance, financial information, technology demonstrations, and many other information-type services. Industrial DSM programs have been established in the U.S., Europe, and some developing countries such as Brazil (de Almeida and Fonseca, 1998; Schaeffer, 1998).

2.12. Technology-specific Policies

A variety of policies have been oriented towards particular technologies that are used in multiple sectors. Motors systems, lighting systems, and combined heat and power generation (cogeneration), for instance, have been the focus of promotional efforts. The US Motor Challenge program is an informational and technical assistance program that has concentrated on assisting end users in the most energy-intensive industries to use motors in pumping, materials processing, and air compression systems (Martin *et al*., 1998). A

number of countries have had Green Lights programs that use a variety of instruments targeted at manufacturers and consumers to raise awareness, promote technological change, and support switching to more-efficient bulbs, ballasts, fixtures, and even control systems. Numerous countries have supported cogeneration development. From the 1970s to the early 1990s, the Netherlands fostered industrial cogeneration, first through a variety of measures including grants and credits for feasibility studies and investments, improving grid access and purchase prices for electricity, and R&D. The most effective measures during this period of high electricity prices were investment grants and raising standby power buyback tariffs (Martin *et al*., 1998). Later measures included subsidies for construction of cogeneration facilities, an information brokering center, voluntary agreements, and joint ventures for project development. Overall, the program is judged to have been responsible for 90% of the increment in cogeneration development over "business as usual".

Technology-focused, cross-sectoral program such as these typically rely on a range of measures, and as such can be seen as forms of integrated policies. When they center on end users, then they can be considered as types of demand-side management programs (described below).

2.13. Promoting research, development and deployment

Many national governments support R&D in energy-efficiency and other low-carbon technologies, and important lessons have been learned and recommendations developed for energy R&D policy (e.g., principles and recommendations for US R&D policy and budget in PCAST, 1997 and PCAST 1999). In a typical offering, the International Energy Agency (IEA, 2000) came to the following general conclusions:

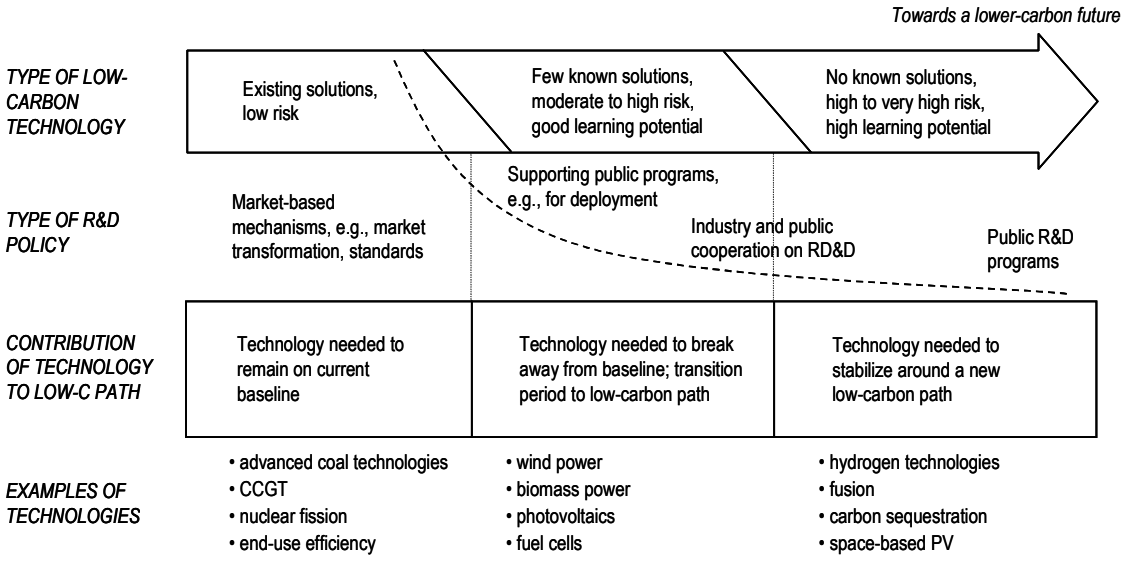
- Significant public support is often needed prior to emergence of self-sustaining markets.
- Continuity of support is crucial—in many cases, public support has been cut off too soon.
- A climate in which innovation is rewarded is key.
- Governments perform poorly in picking winners; support for a variety of contenders needed.

Figure 1 shows a conceptual framework for guiding R&D policy for low-carbon technologies. Technologies can be categorized by their state of development, here divided into existing technologies, those that are currently being developed, and those that are in a conceptual stage. Technologies in the first category tend to be currently entering markets, but still sometimes expensive, such as advanced coal-using technologies. Those in the second category may have some limited market penetration, but remain expensive in most applications, like fuel cells and wind power. In the last category are those with no market penetration but with long-term possibilities, such as hydrogen technologies.

Each of these types of technology offer different contributions to achieving low-carbon development, from remaining on the current path to breaking away to a low-carbon path, and each requires different types of supporting policies. This typology grows out of the

recognition that the market cannot provide sufficient R&D funding to provide the public goods and the mitigation of externalities that societies require (PCAST, 1999). For those technologies already on the market, market-based promotional activities should suffice. Market-transforming activities, like informational programs, standards, and labels, should be enough to foster R&D investment by manufacturers themselves, in order to remain competitive. For technologies just starting to appear on markets, support for deployment (e.g., creation of niche markets through procurement programs) and joint public-private R&D programs would be in order. For those high-risk technologies with no currently available marketable devices, the public sector must bear the majority of the responsibility for R&D funding, since the private sector will not provide the support needed to keep open a wide variety of technological options that may not be available for years or decades. Recent modeling studies support the view that the path-dependence of technological development can lead to the closing off of potentially significant low-carbon technologies if R&D support is too narrowly focused on a few "winning" technologies (Gritsevskyi and Nakićenović, 2000).

Figure 1. Roadmap for public R&D support for low-carbon technology



Source: adapted from IEA, 2000.

An important aspect of R&D for developing countries is that of adaptation of technologies to local conditions. The technical operating environment in these countries is often different from that of industrialized countries, and deployment of low-carbon technologies is affected by institutional factors beyond the realm of strictly economic factors (Jacobsson and Johnson, 2000). For example, different raw material qualities, lower labor costs, poorer power quality, higher environmental dust loads, and higher temperatures and humidity require energy efficiency solutions that differ from successful solutions in industrialized country conditions. More generally, technology transfer is slowed by barriers such as firm-level decision-making processes that do not value energy efficiency, lack of information about and reliable assessment of technologies, limited capital

availability, uncertainty in energy prices, inflexible trade and investment policies, and lack of trained technical personnel (Worrell *et al*., 2001). In practice, adaptation practices vary widely in various countries. For example, Chinese enterprises have spent, on average, only 9 (US) cents on assimilation for every dollar on foreign technology in contrast to countries such as S. Korea and Japan where the amounts spent on assimilation were greater than those spent on technology itself (Suttmeier, 1997).

While it is important for individual countries to invest in R&D, international linkages are key, not only for technology transfer, but also for joint development of technologies. Learning is important not just in the area of discovering and designing new devices, but also in learning how to manufacture new hardware more cheaply and use them more effectively. Unfortunately, the global system of innovation in and transfer of energy technologies is poorly understood; there is a lack of systematic information on investment flows for energy R&D and on the outcomes of those investments (Worrell *et al*., 2001). A better understanding would aid in creating strategies to develop and deploy new technologies, especially the establishment of partnerships within governments, between public, private, and nonprofit sectors, between governments of different countries, and between governments and international organizations (Sagar and Holdren, 2002).

2.14. Energy Prices

It is a generally accepted principle that higher relative energy prices will, other conditions being equal, encourage more-efficient use of energy. Comparison of energy prices and energy intensities in developed and developing countries seems to show a correlation between the two, with energy intensities dropping more rapidly during the oil price rises of the early 1970s and 1979-1980, although there is no apparent consistent quantitative relationship between the relative magnitudes of the changes in the two indicators (Moisan *et al*., 1995). Price elasticities of energy demand vary considerably by sector, by fuel, by country, and over time; the response of energy consumers to changes in energy prices cannot be taken for granted. Energy intensities have fallen in many countries, even while energy prices have declined. How much of the change in intensity may be attributed to deliberate efforts to improve efficiency, and how much may be due to autonomous technological change, shifts in economic structure, and other factors, has proven difficult to analyze.

In many countries, electricity markets have been in the process of being reformed, ostensibly in a way that will reduce costs by creating competition among market players. Reforms tend to include removing subsidies so that consumers face full financial costs of generating and delivering power, allowing greater private ownership of generation and distribution assets, and separating generation and distribution functions. From the limited experience to date, it seems that reform of electricity is not necessarily associated with greater end-use efficiency. A study of Latin American countries showed that reforms had considerably reduced support among utilities for end-use efficiency, so that utility demand-side management programs—in the past, a major factor in promoting efficiency in commercial and residential buildings—tended to be neglected (WEC, 2001). California provides an anomalous case. Utility-sector reforms led to widespread electricity outages in the winter of 2000-2001. As a consequence, the state government and utilities made great

efforts to reduce demand by promoting efficiency. Consumers reacted to this stimulus very well, aiding in the avoidance of outages in the period since then.

The importance of energy prices highlights the condition that the effectiveness of measures to promote energy efficiency and other low-carbon technologies is predicated on "infrastructural" conditions. In particular, measures and policies that employ or mimic market mechanisms assume not only rational prices, but also environmental awareness, availability of financing, well developed legal system, and other prerequisites (Worrell, *et al*., 2001). Clear systems of property ownership, defining rights and responsibilities, are also important (IEA, 1997a). Best-practice energy policy therefore goes far beyond energy into other areas of policy, and coordination between energy and other areas is crucial to achieving low-carbon goals. The next section describes some approaches that attempt to integrate different types of measures and to coordinate policies in traditionally separate sectors.

2.15. Integrated Approaches

2.15.1. Demand-Side Management Programs and Related Measures

Demand-side management (DSM) programs typically have been undertaken by electric utilities, usually with some participation from government, industry and other stakeholders, to promote shifts in energy demand among consumers, both through changing the timing of demand, and through lowering overall demand by making end uses more efficient. For utilities, this provides a way to avoid or defer expensive investments in new generation, transmission and distribution capacity, so long as rules are set that allow the utility to benefit financially from improved efficiency rather than simply losing revenue from foregone sales of power. Many different measures have been incorporated into DSM programs (only a few of which are discussed below) include marketing, technical assistance, financial incentives, audits and informational programs, procurement programs, and standards and labels.[4] Some of the ingredients found to be necessary for successful implementation of DSM programs include:

- good marketing
- tailoring to specific customer needs
- technical assistance,
- simple procedures and materials,
- financial incentives, and
- measures for multiple end uses (Martin *et al*., 1998).

Informational programs have been important on their own and as parts of DSM programs. These range from broadly targeted advertising and information campaigns, to audits of individual sites. Audits of energy-using facilities, usually industrial sites and buildings, have been widely used to provide key information on energy use to end users and to

[4] Integrated Resource Planning (IRP) for utilities involves considering DSM along with supply and other options for a utility to meet demand for energy services within its territory of operation.

identify financially sound improvements to equipment, facilities, and management practices. Audits may be free or provided at low cost to end users (subsidized), or completely paid for by end users. The rationale for public funding is that audits perform a key function in providing information, thereby correcting a market failure and facilitating the adoption of economically attractive energy-efficient technologies.

Audits are often found as standalone measures, as well as parts of DSM and other integrated programs. In audit programs undertaken in developed countries, large fractions (40% to 80%) of the recommended efficiency measures proposed were actually implemented by businesses that underwent audits (WEC, 2001). Audits have been very important in Japan, where they have been linked to setting of standards for energy efficiency in industry. This approach bears some similarity to the voluntary agreements described below, in which targets for energy efficiency and audits to verify performance are key elements. In the US, the network of Industrial Assessment Centers performed nearly 8000 assessments, including audits and investment recommendations, between 1981 and 1997, with 42% of measures implemented (Martin *et al*., 1998). Norway's Industrial Energy Efficiency Network has been directed ad small and medium enterprises, and featured benchmarking and other elements of voluntary agreements, along with informational and auditing measures. In the UK, the Energy Efficiency Best Practice Program has focused mainly on information exchange.

As with standards and labeling programs, considerable experience accumulated in developed (and some developing) countries in auditing can be easily transferred internationally (WEC, 2001). Similarly, auditing programs are most effective when used as one part of an integrated approach. End users are more likely to adopt recommendations that result from audits if fiscal incentives, such as subsidized loans, accelerated depreciation, or reduced taxes, are available.

The availability of performance contracting services through energy service companies (ESCOs) has been important in the US for taking advantage of audit results, since businesses often do not have the time or expertise to implement efficiency measures on their own (Osborn *et al*., 2002). Development of ESCOs in the US, in turn, benefited greatly from legislative, regulatory, and procurement support from state governments and utility commissions, which helped create market opportunities for these providers of demand-side energy services. A variety of economic and fiscal incentives help to create an environment in which the ESCO business model can thrive.

Subsidies, rebates, and tax breaks for investments in energy-efficient devices have been measures associated with many demand-side management programs, or sometimes offered by themselves. While subsidies are a very direct way to encourage adoption of new technologies, they are expensive, suffer from free-ridership, and other problems. WEC (2001) concluded that they "should be viewed as temporary measures to mobilize consumers, to prepared for new regulations," or to develop market demand. Such programs have to be carefully evaluated for cost-effectiveness, and recommended features included restricting availability of purchase subsidies to a relatively small target set of end users, and providing them only for technologies that are relatively expensive or new, i.e.,

technologies that may encounter problems in initial market acceptance. Subsidies may be paid for from tax revenues (government programs), utility fees (utility demand-side management programs), or even private-sector grants and development aid. In some circumstances, simply facilitating access to commercial capital (e.g., bank loans) may be sufficient, since banks are often reluctant to lend for small, technically uncertain efficiency investment projects. In such cases, loan guarantee funds—which are much less expensive than subsidies—may be used to good effect.

2.15.2. Market transformation[5]

Market transformation indicates an approach intended to promote adoption of new energy technologies by influencing activities along the entire chain of the process of technological diffusion through markets. Multiple elements (that may overlap with other programs) can include:

- RD&D,
- incentives for commercialization,
- marketing and consumer education,
- economic and fiscal incentives,
- voluntary commitments,
- bulk procurement policies, and
- standards, codes, and labels.

In the past, many energy-efficiency programs have been aimed at achieving short-term savings, without a long-term objective to transform markets, and, in some cases, with too little understanding of the target markets. In the U.S. and some other OECD countries, the past decade has seen a growing emphasis on "market transformation" programs, which are intended to bring about lasting changes towards higher energy efficiency in target markets. The market transformation approach has been applied in many countries for appliances and electronic equipment, lighting equipment, motors and drive systems, buildings and building components, and transportation equipment. In contrast to traditional energy-efficiency programs, market transformation programs typically:

- take a long-term view of target markets, addressing both demand and supply sides of markets, as well as sustainability of the changes in the market after the end of the program;
- attempt to use a minimum of resources to catalyze a maximum amount of desired change; and
- emphasize partnerships between government, the private sector, and other institutions to achieve common goals.

Market transformation programs aim to rectify particular barriers, which can be classed into six types, i.e., barriers related to:

[5] This section is paraphrased from Meyers (1998) and also draws on Geller and Nadel (1994). These sources describe a number of examples of market transformation programs, or programs that could be part of market transformation programs, in both developing and industrialized countries.

1. macro-economic conditions (e.g., high import duties, uncertain status of firms, weak legal system);
2. energy prices (e.g., subsidized energy product prices, irrational electricity rate structures);
3. international flows of capital, technology, and knowledge;
4. institutional weaknesses (e.g., government, financial institutions, electric utilities);
5. behavior and features of specific markets (e.g., lack of information, misplaced incentives, weakness in product development and marketing); and
6. features of energy-efficient products and services (e.g., performance uncertainties, high first cost).

Among the types of strategies typically considered as part of market transformation programs are:[6]

1. improving information about energy-efficiency opportunities and providing technical assistance;
2. financing of energy-efficiency investments;
3. providing financial incentives for energy-efficiency investments;
4. setting minimum efficiency standards;
5. instituting market aggregation and technology procurement programs; and
6. promoting voluntary commitment and recognition.

All of the above have been implemented as individual programs in various settings, of course, but can provide substantially more benefit when combined in a larger program. While programs vary considerably, in general, they involve multiple market actors, are designed to remove or lower specific market barriers, have long lead times (compared to traditional energy-efficiency programs) before effects are noticeable, and involve significant activity upstream from the end-user (e.g., manufacturers, dealers, and contractors). They attempt to create conditions under which the self-interest of actors (or market forces) are aligned with achieving greater efficiency, and to use momentum already present in the market. Energy efficiency is often linked with other attributes of the target product or service that are desirable.

Market transformation programs in the U.S. and western Europe have mainly focused on changing markets for new products, including refrigerators, clothes washers, air conditioners, lighting equipment, office equipment, and residential furnaces. In general, the experience provides shifts in the markets for targeted products, including increased availability and sales of high-efficiency products, and changes in manufacturer, dealer, and consumer behavior. The market transformation approach has also been applied for new buildings, and, to a lesser extent, for retrofits of existing buildings and industrial facilities.

Although it is difficult to attribute particular market shifts to specific policies or programs, it appears that many of the market transformation programs are having a positive impact.

[6] Meyers (1998) discusses the advantages and problems of measures of these types, with examples from different countries.

Experience to date suggests that a market transformation approach can effectively bring about long-run changes in markets, although it may not be an appropriate approach for all situations or objectives (e.g., meeting short-term objectives to reduce demand in the face of power shortages). Experience has also shown that, while certain programs do not by themselves have a large impact (e.g., consumer education, energy audits), when they are combined with other programs (e.g., standards and labels, targeted financing) the effect can be much greater than the sum of the impacts of the individual programs taken alone.

A variety of experience shows that the preferred market transformation strategy varies from product to product, depending on the characteristics of the technology and the market being served. Some technologies and end-use markets are mature, while others are expanding and innovating. For some products, such as lamps or ballasts, efficiency is a prominent feature and consumers are relatively interested in energy efficiency. For other products, such as refrigerators or personal computers, efficiency is a hidden attribute, and consumers pay little attention to it. Some products are made primarily by large companies that can perform R&D on their own, but others are made by many small companies that conduct little R&D. In some cases, energy-efficiency measures are feasible for all uses, while in other cases measures are specific to the application.

Following from this, it is clear that, for instance, support for R&D and demonstration may be critical for some products, and not necessary for others. Manufacturer-oriented commercialization incentives could be valuable for products that use advanced technologies that are near maturity. Consumer, dealer, or manufacturer incentives, as well as bulk purchases, are important for products such as CFLs or adjustable-speed drive motors, for which first cost is a barrier to adoption. A key objective with all technologies is to establish a significant initial market that is large enough to exhibit economies of scale and support R&D for later generations of products. Geller and Nadel (1994) suggested appropriate combinations of mechanisms that could be applied to market transformation programs aimed at a specific end uses (Table 3). Note that these recommendations were developed in the U.S. context, and that appropriate strategies for the same end uses may differ in other countries.

Table 3. Targets for Market Transformation Strategies

Product	Possible Mechanisms
Adjustable-speed drive motors	Bulk purchases, incentives, purchaser and installer training, voluntary commitments
Heat-pump water heaters	Bulk purchases, financing and incentives, contractor training, standards
Gas heat pumps	R&D, demonstration, incentives, standards (in long term)
Duct sealants	R&D, demonstrations, contractor and consumer education, incentives
Compact fluorescent lamps	Incentives, consumer education, building codes, portable luminaire standards
Clothes washers	R&D, demonstrations, incentives, standards
Incandescent lamps	R&D, “golden carrot” incentives (for R&D), standards
Central air conditioning and heat pumps	Incentives, standards
Windows	Incentives, builder education, building codes, standards
Commercial packaged air conditioning	Demonstrations, incentives, standards
Light vehicles	R&D, commercialization incentives, taxes and rebates, standards

Source: Geller and Nadel, 1994.

Minimum efficiency standards can play a crucial role in market transformation. While not appropriate for all products, standards can by themselves transform markets by removing inefficient products from the marketplace. Standards accelerate the diffusion of new technologies, and can raise levels of penetration. They can also direct manufacturers' attention towards R&D needed to develop and commercialize new technologies.

Market transformation efforts in developing and transitioning countries are likely to take a different form than those in industrialized countries (Meyers, 1998). Strengthening of key institutions requires attention, as does increasing the knowledge and skills of actors on the supply side. As the rise of the market transformation approach is associated with a move in some developed countries away from "command and control" regulatory practices, this approach is most appropriate in a setting that emphasizes market-oriented mechanisms. Minimum efficiency standards for new products and buildings can play an important role in setting a market floor for energy efficiency and encouraging market actors to upgrade their products, but take time and effort to successfully implement. Enlisting voluntary cooperation of market actors is an important strategy, but requires development of outreach skills by program sponsors.

The higher first cost of many energy-efficient products and investment required for retrofits is an even greater barrier in developing countries than in industrialized countries, so development of appropriate financing mechanisms is of great importance. The capacity of financial institutions to implement such strategies needs to be nurtured. Financial incentives to lower the cost of energy-efficient products and services may be necessary to build market demand, especially in the early stages of market evolution. Care must be taken not to create dependency on such incentives, however. Using market aggregation strategies can also build demand for new products and services.

Among the greatest challenges facing market transformation strategies is overcoming a wide variety of intractable barriers that are related to larger forces at work within countries, and working within macro-level changes (e.g., utility deregulation, industrial restructuring) that profoundly change the environment that end users work in. On the plus side, market transformation programs, by working to reduce energy costs, can ameliorate some of the short-term impacts of macro-level reforms.

2.15.3. Voluntary agreements in industry[7]

The voluntary agreement approach is an integrated strategic planning tool, with details that vary considerably among the developed countries that have implemented them. While many countries have used voluntary agreements for pollution reduction, many fewer, have applied them to energy efficiency.

Agreements to meet specific energy use or energy efficiency targets are used widely in the industrial sector (Bertoldi, 1999; Chidiak, 1999; Hansen and Larson, 1999; Mazurek and Lehman, 1999; Newman, 1998). The International Energy Agency has identified two broad categories of Voluntary Agreements: "(1) informal programmes, self-commitments

[7] Portions of this section are drawn from Price and Worrell, 2000.

and declarations, where the parties entering into the action with the government set their own targets and often do their own monitoring and reporting; and (2) more formal voluntary approaches where there is essentially a contract between the government and industry, or negotiated targets with commitments and time schedules on the part of all participating parties" (IEA, 1997b). An agreement can be formulated in various ways; two common methods are those based on specified energy efficiency improvement targets and those based on specific energy use or carbon emissions reduction commitments. Either an individual company or an industrial subsector, as represented by a party such as an industry association, can enter into such agreements.

Examples of industrial sector agreements and target programs include the following:

- Australia: Energy Smart Business Program (Cooper *et al*., 1999), Greenhouse Challenge (Australian Government Office, 2002)
- Canada: Industry Program for Energy Conservation (CIPEC) (Jago, 1999; McKenzie, 1994)
- Denmark: Agreements on Industrial Energy Efficiency (Togeby *et al*., 1998; Togeby *et al*., 1999)
- Finland: Agreements on Industrial Energy Conservation Measures
- Germany: Declaration of German Industry on Global Warming Prevention (Ramesohl and Kristof, 1999)
- Japan: Keidanren Voluntary Action Plan on the Environment (Japan Federation of Economic Organizations, 1998)
- Netherlands: Long-Term Agreements on Energy Efficiency (Ministry of Economic Affairs, 1997; Nuijen, 1998; Rietbergen *et al*., 1998)
- Sweden: EKO-Energy
- U.K.: Climate Change Levy (ETSU - AEA Technology, 2001)
- U.K.: Energy Efficiency Best Practice Program (Miles, 1994)
- U.K.: Energy-Intensive Industry Sector Efficiency Targets (Environmental News Service, 1999)
- U.S.: Voluntary Aluminum Industrial Partnership; PFC Emissions Reduction Partnership for the Semi-Conductor Industry (U.S. Environmental Protection Agency, 2002)

These agreements feature negotiated targets for energy savings, and aim to focus attention of all stakeholders on energy efficiency goals over a relatively long term, with goals typically set five to ten years from the start of the program. These targets raise the visibility of energy efficiency within firms, and encourage incorporation of concern for energy efficiency into organizational culture and into strategic, long-term decision making. Ideally, the more energy efficiency becomes part of organizational culture, the less need there should be for policy measures to promote efficiency. A key feature that is attractive to private-sector partners is that they allow enterprises, which are in the best position to determine what measures are feasible, to determine the particular path they will take to achieve targets (IEA, 1997a). The determination of energy efficiency potential and targets—and the baseline against which progress is measured—is typically arrived at through negotiations between industry and government, and often with involvement by

independent expert groups and other interested parties as well. Supporting programs can include:

- audits and assessments,
- benchmarking,
- monitoring,
- information dissemination, and
- financial assistance.

Voluntary agreements are an increasingly popular approach that has been most successfully used to date in northern Europe. This type of policy is seen as a negotiated approach that is fundamentally different from "command and control" regulations since it allows targeted end users to decide themselves how to achieve a particular target. In practice, it seems that the threat of heavier-handed regulation should end users fail to meet their voluntary targets exerts a powerful incentive to comply. While the terms "carrots" and "sticks" are often applied to the supporting regulations that make voluntary agreements possible, some of the "carrots", e.g., exemption from or reduction of a carbon tax, can be seen as merely the withholding of a "stick". Various supporting policies have been used in voluntary agreements programs, as shown in Table 4.

Table 4. Overview of Supporting Policies and Measures in Selected Voluntary Agreements Programs

		Supporting Policies and Measures				
Country	**VA Scheme**	**Government Facilitation of VA Process**	**Audits and Assessments**	**Financial Assistance and Incentives**	**Government and Public Recognition**	**Exemption from Regulation and Taxes**
Australia	Greenhouse Challenge	X			X	
Canada	Industry Program for Energy Conservation	X			X	
Denmark	Agreements on Industrial Energy Efficiency	X	X	X		X
Germany	Declaration of German Industry on Global Warming Prevention; Agreement on Climate Protection	X				X
Netherlands	Long Term Agreements	X	X	X		X
Sweden	EKO-Energi	X	X		X	
UK	Make a Corporate Commitment, Climate Change Agreements	X			X	X

Source: adapted from Price, 2002.

Some see the process of negotiation of voluntary agreements (and standards for appliances and buildings) as inherently easier and less costly than other types of regulation (WEC, 2001). In this view, such processes are less confrontational, speeding the process of arriving at a consensus and reducing the need for adversarial oversight. On the other hand, monitoring of performance of targeted end users is still a crucial element, since conformance with a voluntarily adopted target or standard must still be independently verified to maintain trust among all partners that the system works as intended. Since measurement of long-term progress is fundamental to this approach, the programs that have been most successful are those that "ere transparent (e.g., with clear targets), credible, and consistently applied over time" (Martin *et al*., 1998).

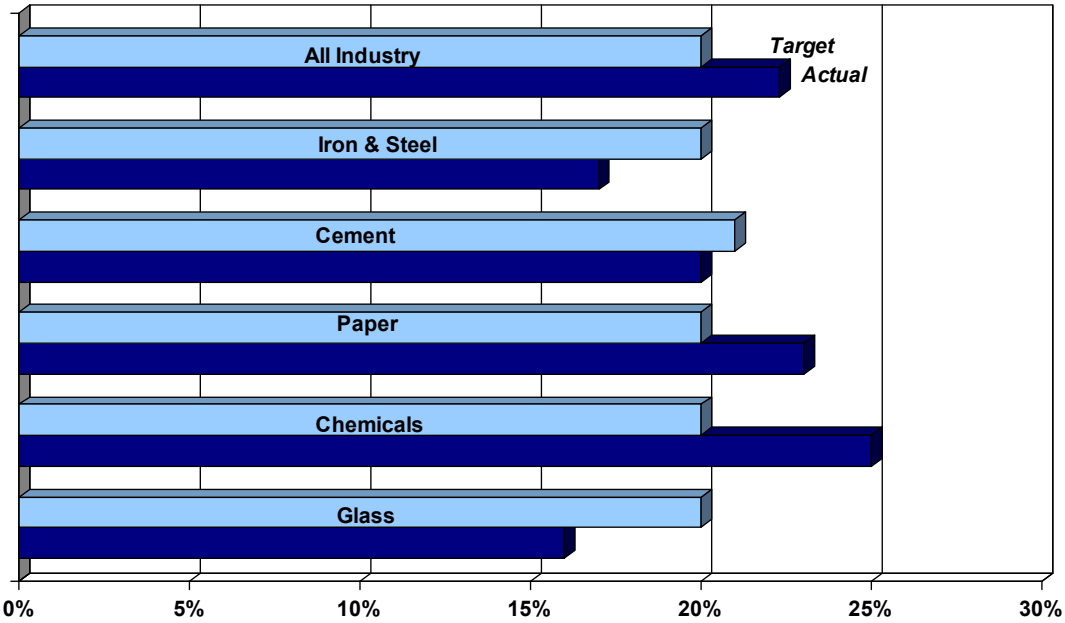
Probably the most successful voluntary agreements program is the one implemented in the Netherlands, which industrial facilities responsible for 90% of industrial energy use from 1989 to 2000 (Martin *et al*., 1998). The Long-Term Agreements on Energy Efficiency in The Netherlands are voluntary, but formal and legally binding agreements between industry associations and the Dutch Ministry of Economic Affairs. This national policy integrates components including:

- fiscal policies: investment tax credit,
- agreements/targets,
- reporting: energy use monitoring and reporting,
- audits/assessments: energy conservation plans and audits, and
- information dissemination and demonstration: demonstration program.

Under the agreements, the companies prepare and implement energy conservation plans. The companies also monitor and report energy consumption data on an annual basis. The Dutch government provides an investment tax credit as an incentive for investments in new energy-efficient equipment as well as a demonstration and auditing program for the companies that have agreements in place. For most sectors, targets were set at about twice the level of autonomous efficiency improvement historically (i.e., with no policy intervention). While some sectors did not meet their targets, most did, and overall the program exceeded targets (

Figure 2). This program was found to be more effective at promoting efficiency improvements than the investment tax credit scheme to promote efficiency that was implemented in the Netherlands in the 1980s. Current efforts in the Netherlands include new investment tax credits, and voluntary agreements that expand the scope of activity beyond energy efficiency to include recycling, dematerialization, and other measures associated with a broader definition of sustainable development.

Figure 2. Targets and Performance of Industrial Subsectors, Dutch Voluntary Agreements Program



Source: International Energy Studies Group, LBNL, 2001.

Due to unanticipated high economic growth (and associated industrial output) in The Netherlands during this period, overall CO2 emissions actually increased during the agreement period despite the significant improvements in energy efficiency (Nuijen, 1998). Following the current Long-Term Agreements on energy efficiency, a new agreement has been developed for the energy-intensive industries. In the new agreements, industry groups agree to strive to be among the world's most energy efficient producers by 2012. The agreement will use benchmarking of regions (with a similar production capacity as in The Netherlands) to monitor and verify the results of the industry efforts.

The Danish Agreements on Industrial Energy Efficiency integrates regulations (mandatory energy audits/energy management systems), fiscal policies (taxation and subsidies), and agreements/targets. Denmark has committed to reduce national CO2 emissions from all sectors by 20% in the year 2005 compared to 1988 emissions (Togeby *et al*., 1999). The industrial sector is expected to contribute to this goal by reducing CO2 emissions by 4.6% in 2005 relative to 1988 emissions (Togeby *et al*., 1998). The Danish Agreements on Industrial Energy Efficiency are based on the imposition of a mandatory CO_2 emissions tax. Between 1996 and 1998, 143 companies, representing 45% of total industrial energy consumption, entered into agreements, under which they agreed to implement all "profitable" energy savings projects (payback periods up to four years). In addition, companies must introduce energy management and motivate staff to ensure investments in new equipment will be energy efficient. Subsidies are provided for up to 30% of the cost of efficiency investments. One analysis of this program found that firms with an agreement in 1993 had electricity savings of 7% while those who did not have agreements (and thus

were subject to the full CO_2 tax) had electricity savings of 8% (Bjorner and Togeby, 1999). To date, these agreements have seen a reduction in energy consumption of 2 to 4% of total energy consumption per agreement after three years (exceeding business-as-usual by about 1% per year) (Togeby *et al*., 1999). If this rate of improvement continues, it is projected that the goal of 4.6% reduction in total CO2 emissions from industry in 2005 relative to 1988 will be met (Togeby *et al*., 1998).

In its review of 350 voluntary actions and programs, the International Energy Agency found that "past and present experiences with voluntary actions show that, properly designed and implemented, they can achieve stated objectives, sometimes even exceeding those of minimum regulatory standards, and help integrate economic and environmental goals" (IEA, 1997b).

A recent analysis of five of industrial sector voluntary agreement programs found significant differences between the structure of the agreements and the performance and effectiveness of the agreements. This analysis concluded that "the effectiveness of Voluntary Agreements can be seen as strongly dependent on the accompanying policy mix and the supporting framework which has to be adapted to the specific conditions of the target group envisaged" (Krarup and Ramesohl, 2000)

Another analysis of seven voluntary agreement programs found that the programs could be credited with about 50% of the observed energy-efficiency improvement or emissions reductions. In addition to these so-called direct effects of the programs, there are also important medium- and long-term impacts including: changes of attitudes and awareness of managerial and technical staff regarding energy efficiency; addressing market, institutional, and regulatory barriers to technology adoption and innovation; fostering market transformation to establish greater potential for sustainable energy-efficiency investments; promoting positive dynamic interactions between different actors involved in technology research and development, deployment, and market development; and facilitating cooperative arrangements that provide learning mechanisms within a sector or industry to combine knowledge and develop new competencies in industry (Dowd, *et al*., 2001; Delmas and Terlaak., 2000).

Based on experience to date, the "Seven Golden Rules" for voluntary agreements are:

1. Make sure they are negotiated agreements based on assessments of energy efficiency potentials that are more than "business-as-usual",
2. set clear, well-defined targets and specific timetables for achieving those targets,
3. ensure long-lasting government support in the form of policies and programs that assist industries in implementing energy-efficiency improvements,
4. focus on large, energy-intensive industries to start with because this is where the greatest savings are found,
5. establish clear monitoring guidelines,
6. evaluate progress using physical energy intensity measurements, and
7. provide for independent verification of progress (Blok, 2000).

The positive lessons of experience in the Netherlands and Denmark, as well as Canada, are reinforced by less successful programs elsewhere. For instance, Sweden's Eco-Energy Program was a voluntary agreements program that was implemented in the 1990s. While some energy savings were achieved, an assessment found that results would have been better if there had been: improved and more frequent communication among the stakeholders; clearer and mutually valid goals written into the voluntary agreement contracts; better specification of the phases and tasks; and greater availability of supporting measures, including information exchange, technical assistance, and audits (Lindén and Carlsson-Kanyama, 2002).

2.15.4. Community energy management

Community energy management (CEM) is a regional integrated approach to urban residential, commercial, and transportation energy use that combines a variety of policy measures, in a manner similar to voluntary agreements, but involving more stakeholder groups. At present, it is mainly a conceptual development, driven by the observation that much energy use is determined by land use and urban form. Key elements of CEM include "best practices" in land-use planning, transportation management, site and building design, and energy supply and delivery systems. Table 5 shows one possible combination of sectors and strategies that could comprise the elements of an integrated CEM plan.

Table 5. Elements of a Community Energy Management Strategy

Policy Area	Goals	Sample Strategies
Land Use Planning	• Access-by-proximity • Support utilization of waste heat (cogeneration) and other resources	• Target strategic locations for high-density, mixed-use, transit-oriented development • Offer financial incentives to developers for preferred densities, mixes and amenities • Increase proportion of multi-family housing • Establish strict urban boundary • Locate heat sources near heat sinks • Establish district heating zones with special standards for density, diversity, growth
Transportation Management	• Shift mode of travel • Shift to alternative fuels	• Improved transit, high-occupancy vehicle, pedestrian and cycling facilities and services • Parking pricing strategies • Employer trip-reduction programs • Fleet fuel switching
Site and Building Design	• Increase building energy efficiency • Take advantage of microclimatic features	• Reduced lot size and setbacks from street • Use of vegetation for shading, wind shielding • Building energy standards, performance certification • Financing and technical assistance for efficiency improvements
Energy Supply	• Utilize local resources • Increase use of "clean" resources	• Distributed generation • District heating and cooling • Heat pumps, solar technologies • Recovery of waste heat • Financing and technical assistance for homeowners, businesses and developers to invest in new technologies

Source: adapted from Jaccard *et al*., 1997.

The efficiency potential represented by a well designed suite of measures is much greater than that of the measures individually. Integration of transport measures can be mutually enhancing, in the way that appliance efficiency standards and appliance labels are. Road and gas taxes imposed on end users may alone reduce transport demand, but they will not be nearly so effective as when there are also concurrent policies to reduce the cost to consumers of public transport, or to increase coverage and services provided by public transport. CEM is intended to take advantage of synergies such as these.

The potential for applying CEM has been assessed in Canada, China, and other countries, and regional energy studies indicate that such an integrated approach would be essential for achieving large changes in systemic energy efficency, but it has yet to be put to the test of actual practice (Sadownik and Jaccard, 2001; Chow, 2001). Implementation of a CEM plan will encounter many challenges, e.g., integrating local and national urban and energy planning, strengthening institutions and organizations. As Jaccard *et al.* (1997) wrote, implementation at the local would require standards and fee schedules for new development, energy-sensitive zoning rules, provisions in the construction and environmental regulatory processes to meet energy objectives, and involvement of local energy utilities. Intervention would also be needed at the regional or national level, including designation of or approval of energy planning as a function of local government, provision of technical and financial support, requirement that utilities cooperate with local governments, establishment of fiscal policies to encourage developers to cooperate, and other activities. Clearly, this involves a major set of initiatives that would need to be coordinated across many lines of authority, and the institutional challenges would be great.

3. Best-Practice Technologies

Determining best-practice technologies for a given situation is usually feasible. These can be chosen from internationally available options, and are generally well characterized. Examples of such resources include the European Integrated Pollution Prevention and Control Bureau's Best Available Technology reference documents, and a variety of sectoral resources, e.g., the "Eco-Tech" and "All-Tech" technology characterizations prepared by the International Iron and Steel Institute. Approaches to greater system efficiency and decarbonization tend to fall into the following categories (Worrell *et al*., 2001):

- more-efficient end uses (devices),
- process integration,
- reduction of energy losses,
- reduction of non-CO_2 emissions,
- new production technologies/processes,
- combined heat/cooling and power generation
- fuel switching (to higher-efficiency or lower/no-carbon energy), and
- more-efficient materials use.

Availability of technology is, of course, not the only factor. The extensive literature on technology transfer makes clear that a wide variety of barriers stand in the way of smooth

adoption of new technologies (Martinot, *et al*., 1997, Worrell *et al*., 2001). Many of these barriers are amenable to intervention from the public sector. Processes, buildings, and equipment can be redesigned, retrofitted or replaced, and planners and users can be trained, but uptake is dependent on government and market conditioning of decision-making environment—so policy is of critical importance.

Figure 3. Example of best-practice technology: Electric arc furnace (steel)

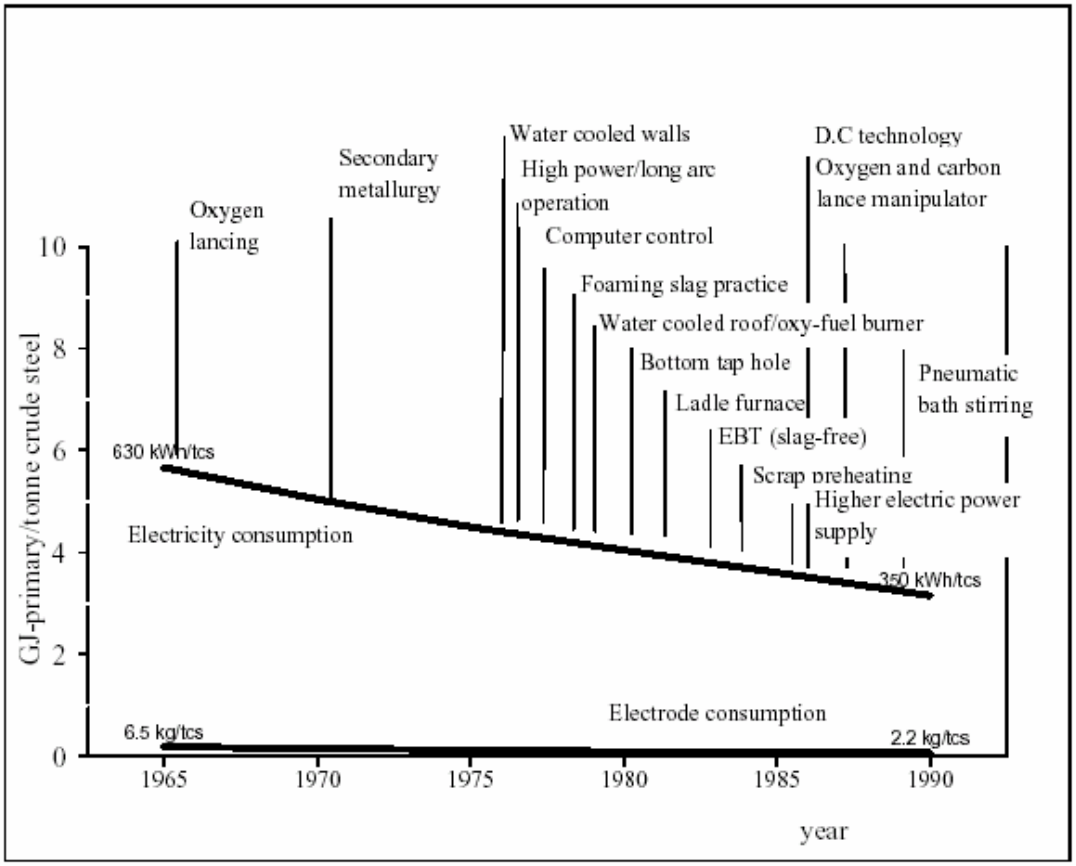


Figure 5.3: Development in the energy use of electric arc furnaces. Based on data from [Szekely, 1994] and [Bock, 1994].

It is possible to construct curves showing the progress of energy efficiency for best-practice technologies in particular applications. Figure 3 shows this for electric arc furnaces, used to make steel using large fractions of scrap steel. Such curves can be used to quickly locate where a given facility stand with regard to currently available and past technologies. Examples of similar progressions exist for many major technologies, some of which are discussed in the remaining sections of this subreport.

4. Industrial Energy Use: International Overview

Industrial energy use comprises a significant portion of total energy use in most countries. In 1995, manufacturing industries accounted for 41% of global energy use or 131 EJ (1 exajoule=10^{18} J) (Price *et al*., 2000). Between 1971 and 1995, industrial energy use grew at a rate of 1.7% per year, slightly less than the growth rate of world total energy demand, which averaged 2.1% per year (Price *et al*., 2000). This growth rate has slowed in recent years, and was virtually flat between 1990 and 1995, primarily due to the decline in industrial output within the transition economies of Eastern Europe and the former Soviet Union. Energy use in the industrial sector is dominated by the industrialized countries, which accounted for 43% of world industrial energy use in 1995. Industrial energy consumption in these countries increased at an average rate of 0.6% per year between 1971 and 1990, from 49 EJ to 54 EJ. Industry's share of total energy consumption in the industrialized countries declined from 40% in 1971 to 33% in 1995 (Price *et al*., 2000). The decline partly reflects the transition toward a less energy-intensive manufacturing base, a shift towards more a more service-oriented economy, and continued growth in transportation demand caused by the rising importance of personal mobility (automobile use) in passenger transport use.

The industrial sector dominates energy use in Eastern Europe and the former Soviet Union, accounting for more than 50% of total primary energy demand. Average annual growth in industrial energy use in this region was 2.0% between 1971 and 1990 (from 26 EJ to 38 EJ), but dropped by an average of –7.3% per year between 1990 and 1995. Even with this decline, in 1995 industry accounted for 51% of primary energy use in these countries (Price *et al*., 2000).

In the Asian developing countries, industrial energy use grew rapidly between 1971 and 1995 with an annual average growth rate of 5.9%, jumping from 9 EJ to 35 EJ. It also accounted for the greatest share of primary energy consumption, comprising 58% in 1995. The fastest growth in this sector was seen in China (which alone accounted for 23% of world industrial energy use) and in other rapidly-developing Asian countries (WEC, 1995; Price *et al*., 2000). The nature and evolution of the industrial sector varies considerably among developing countries. Some economies that are experiencing continued expansion in energy-intensive industry, such as China and India, show relatively unchanging shares of industrial energy use. In other countries, such as Thailand, the share and/or growth of the transportation sector dominates. Many smaller countries have remained primarily agrarian societies with modest manufacturing infrastructure.

Future trends in industrial energy use will be affected by many different factors. Globalizing trade patterns will affect industrial competition as well as technology transfer. Global environmental challenges such as climate change will lead to an increased focus on energy efficiency and changing energy consumption patterns and fuel choices. Regional and local environmental problems will also drive changes in industrial energy use, both in industrialized and developing countries.

4.1. Energy Intensity Trends in the Industrial Sectors

Since the 1970s, most countries have seen declines in the energy intensities of major industrial products. The overall energy intensity of industry has dropped at a historical rate of slightly more than 1% per year, a rate that rose to 2.5% per year from the 1970s to the mid-1980s, as industries vigorously sought ways to reduce dependence on high-cost energy supplies (WEC, 1995). During and after the years of the oil shock U.S. industrial energy intensity declined by 3.5% per year (from 1975 to 1983). Between 1984 and 1994 industrial energy intensity declined by less than 1% on average. Table 6 gives an overview of energy intensity trends in the industrial sector in the United States. With falling energy prices, and the easiest opportunities for energy efficiency already taken, and the decline in energy intensity has slowed, but has not stopped as technological innovation continues and the product mix changes. Even with these continued efficiency improvements, energy use in the US industrial sector has climbed throughout the 1990s, as the national economy has expanded. Large potential for further improvements remains, however, as a variety of barriers remain that prevent many cost-effective efficiency measures from being taken (ASE *et al*., 1997). China's industrial sector has followed a similar trend since the 1980s, and much scope remains for further improvement, since energy intensities for most industrial products in China remain significantly higher than those in developed countries.

Table 6. Energy Intensities and Energy Costs in Selected U.S. industries.

Sector	**1973**		**1985**		**1994**	
	Energy Intensity (primary energy)	**Energy Costs** (share of production costs)	**Energy Intensity** (primary energy)	**Energy Costs** (share of production costs)	**Energy Intensity** (primary energy)	**Energy Costs** (share of production costs)
Iron & Steel	30.5 GJ/t	7%	27.8 GJ/t	11%	25.4 GJ/t	8%
Pulp & Paper	43.1 GJ/t	6%	42.7 GJ/t	6%	32.8 GJ/t	6%
Cement	7.3 GJ/t	40%	5.2 GJ/t	36%	5.4 GJ/t	33%
Primary Aluminum	N/A	14%	17.6 MWh/t	19%	16.2 MWh/t	13%
Petroleum Refining	6.2 GJ/t	4%	4.3 GJ/t	3%	4.5 GJ/t	3%

N.B. Energy intensity is expressed in primary energy, where the efficiency of electricity generation is assumed to be 33%. Energy intensity of primary aluminum production is given in MWh (1,000 kWh).

The trends demonstrate the capability of industry to improve energy efficiency when there is an incentive to do so. Energy requirements can be cut by improved energy management and new process development. In addition, the amount of raw materials demanded by a society tends to decline as countries reach certain stages of industrial development, leading to a decrease in industrial energy use. At the same time, the mix of fuels used by industry changes over time, affecting energy intensity as well as emissions. Overall changes in the manufacturing fuel mix are driven by price changes, the availability and reliability of supply, efficiency gains, and changes in sectoral structure. For example, in the U.S. manufacturing industry there has been a general trend towards the reduced use of coal and oil use since 1958. While coal consumption remained fairly constant after the oil price shock of the early 1970's, it has since declined. This change is partially a reflection of the

decline of the energy-intensive industries in the U.S. economy. Natural gas, an easier and more efficient fuel to use, shows a dramatic increase in share of the fuel mix over time. Also important is the increased use of electricity throughout industry, and away from direct use of oil and natural gas, reflecting an overall societal trend of increased penetration of electric devices and equipment (Unander *et al*., 1999). Lighting industries tend to consume more electricity relative to the energy-intensive industries.

The accounting of trends and interactions in industry structure, material intensity, and technical energy efficiency can be extremely difficult. Reduction of energy intensity is closely linked to the definition of structure, structural change, and efficiency improvement. Decomposition analysis is used to distinguish the effects of structural change and efficiency improvement. Structural change can be broken down into intra-sectoral (e.g., a shift towards more recycled steel), inter-sectoral (e.g., a shift from steel to aluminum within the basic metals industry) changes. A wide body of literature describes decomposition analyses, and explains the trends in energy intensities and efficiency improvement (provide references of examples). Decomposition analyses of the aggregate manufacturing sector exist mainly for industrialized countries, but have also been done for China and selected other countries. The results show that different patterns exist for different countries, which may be due to specific country conditions and differences in driving forces such as energy prices and other policies in these countries. More detailed analyses at the sub-sector level are needed to understand these trends better. Changes in energy intensities can also be disaggregated into structural changes and efficiency improvements at the sub-sector level.

While it is generally assumed that technical progress leads to greater efficiency, some analysts have concluded that industrial development overall can lead to higher energy intensities. In a study of 39 developed and developing countries, Miketa (2001) found that investment is not necessarily associated with reduced energy intensity in industry, and that industrial expansion tends to lead to higher energy intensities. The implication is that autonomous investment and scale effects cannot be relied on to push down energy intensity in industry; there is a strong need for policy measures. The study also concluded that higher energy prices tended to be associated with reductions in energy intensity, as standard economic theory predicts. On the other hand, other research indicates that energy intensity in manufacturing can continue to fall, even when energy prices decline (Unander *et al*., 1999). In general, prices, GDP, and other macro-level variables are insufficient to understand trends in energy intensity; a more detailed understanding of economic and technical changes within sectors is needed to provide a model of energy dynamics that is useful for policy formulation (Price *et al*., 1999).

4.2. Potential for Energy Efficiency Improvement

Much of the potential for improvement in technical energy efficiencies in industrial processes depends on how close such processes currently are to approaching their thermodynamic limit. There are two methods of increasing the energy efficiency of a process. The first is to obtain the more efficient use of existing equipment through improved operation, maintenance or retrofit. The second is to use more efficient new equipment by introducing more efficient processes and systems at the point of capital

turnover or expansion of production. More efficient practices and technologies exist for all industrial sectors. In the United States and other countries, various studies have assessed the potential for energy efficiency improvement in industry, but the conclusions vary significantly depending on how that potential is defined.

It should be noted that barriers may partially block the uptake of those technologies. Barriers to efficiency improvement may include an unwillingness to invest, a lack of available and accessible information, economic disincentives, and organizational barriers. The degree in which a barrier limits efficiency improvement is strongly dependent on the situation of the actor (e.g., small companies, large industries). A range of policy instruments is available, and innovative approaches or combinations have been tried in some countries. Successful policy can contain regulation (e.g., product standards) and guidelines, economic instruments and incentives, voluntary agreements and actions, information, education and training, and research, development and demonstration policies. Successful polices with proven track records in several sectors include technology development, and utility/government programs and partnerships. Improved international cooperation to develop policy instruments and technologies to meet developing country needs in particular will be necessary, especially in light of the large anticipated growth of the manufacturing industry in this region.

4.3. Overview of the Energy-Intensive Industries

4.3.1. Iron and Steel Industry

The first record of the use of iron goes back to 2500-2000 BC, and the first deliberate production of iron began around 1300 BC. Small furnaces that burned charcoal were used in iron production. High temperature processes were first introduced in Germany around 1300 AD, using a very similar design to today's modern blast furnaces. Charcoal was the primary fuel used in the furnaces until 1718 when the first use of coke is reported in the United Kingdom. The higher strength of coke allowed larger furnaces to be built, increasing energy efficiency. By 1790, coke iron making contributed to 90% of the British iron production. The development of the modern blast furnace after the Second World War resulted in an annual reduction of energy intensity of 3-4% per year from the use of improved raw materials, ore agglomeration, larger blast furnaces and higher air temperature. Today the blast furnace is the main process used to make iron and provides the largest raw material stream in steelmaking.

Steel is made by reducing the carbon content in iron to levels below 2%. The reduction of carbon reduces the brittleness of the material, making it easier to shape. The first industrial steelmaking process was invented in 1855 by Bessemer. In the Bessemer converter air was blown through hot iron to oxidize the carbon, the same principle used in modern steelmaking processes. In the U.S. the last Bessemer converter was retired in the 1960's. In the late 19th century the open hearth or "Siemens-Martin furnace" (OHF) was invented, which uses preheated air to oxidize the carbon and melt the steel. Today, this process is currently only found in developing countries and in Eastern Europe. The U.S. was one of the industrialized countries that phased out OHF at a very late stage. In the 1980's the dominant steelmaking process became the basic oxygen furnace (BOF), which uses pure

oxygen instead of air for carbon oxidation. The BOF process was developed in Austria in the 1950's. The productivity of this process is much higher, as is the energy efficiency. An alternative process is the electric arc furnace (EAF). Today, the EAF process is mainly used to melt scrap. Performance of EAFs has improved now that fuel and oxygen are supplementing electricity use. In the future it is expected that the BOF and EAF processes will follow similar development paths.

Once the liquid steel is made, it is cast into ingot or slabs, and shaped in rolling mills to the final product. Although most energy use is concentrated in the iron and steelmaking stages, reduced material losses and productivity gains in the casting and shaping phases of the process (e.g., continuous casting, and currently thin slab casting) have contributed to dramatic increases in the energy efficiency of steelmaking.

Today, the global iron and steel industry produces around 840 Million tons of steel (Table 7). The industry is made up of *integrated steel mills* that produce pig iron from raw materials (iron ore, coke) using a blast furnace and steel using a basic oxygen furnace (BOF), and *secondary steel mills* that produce steel from scrap steel, pig iron, or direct reduced iron (DRI) using an electric arc furnace (EAF). The majority of steel produced today is from integrated steel mills (62% in 2001), although the share of secondary steel mills (or "mini-mills" with EAFs) is increasing, growing from 24% in 1982 to 35% in 2001 (IISI, 2002).

Total global energy consumption for steelmaking is estimated at 20 EJ. The worldwide average energy intensity of steelmaking is estimated at 24 GJ/ton, although large variations occur between countries and plants.

Table 7. Crude Steel Production Volumes and Shares of the Main Iron and Steel Production Processes in Selected Countries, 2001

Country	Crude steel (Mt)	Basic oxygen furnace	Electric arc furnace	Open hearth furnace	Other	Continuous casting
China	148.9	57.7%	24.2%	1.2%	16.9%	87.3%
Japan	102.9	72.4%	27.6%	-	-	97.3%
US	90.1	52.6%	47.4%	-	-	96.9%
World	845.3	57.7%	35.0%	4.3%	3.0%	86.6%

Source: IISI, 2002 (www.worldsteel.org).

Today the most energy efficient process would use 19 GJ/ton for integrated steelmaking, and 7 GJ/ton for making steel out of scrap. Table 8 provides an overview of best practice energy intensities for the different processes involved in steel production. Projections are made as to where best practice process intensities are expected to be in the year 2015. (Note that projections made throughout this report are "best guesses" based on expert opinion and the current literature.)

Analyses have shown that many technologies already exist that could further improve energy efficiency. For example, in the U.S., the potential for energy efficiency improvements is estimated at 18% using proven and cost-effective practices and

technologies with a payback period of 3 years or less. A large number of energy-efficient technologies are available in the steel industry including continuous casting, energy recovery and increased recycling (see Table 9). Worrell *et al.,* (1999) examined 48 energy-efficiency measures that could be applied to US steel plants, and produced cost of conserved energy (CCE) curves, estimating a cost-effective potential to reduce energy use by 18%. Energy savings opportunities are larger for minimills than for integrated mills; in 1994, cost-effective measures could have reduced energy use in EAF mills in the US by 25%, while integrated mills in the US could have reduced energy use by 11% (Worrell *et al*., 1998). Application of advanced technologies now under development will increase this potential in the future. Large technical potentials for reducing energy efficiency in steel making exist in most countries, ranging from 25 to 50% in both industrialized and developing countries. For example, in Japan, 10-20% improvements in efficiency are expected by 2015. New technologies are under development, e.g., smelt reduction and near net shape casting, that will reduce energy consumption, as well as environmental pollution and capital costs.

Table 8. Overview of Best Practice Energy Intensities and Projected Intensity in 2015 for Steel Production Processes (GJ / tonne of product)

Process	Best Practice Intensity	Intensity Expected 2015
Basic Oxygen Furnace (slab)	Fuel: 14.24 Electricity: 0.36 Primary Energy: 15.3	Primary Energy: 14.0
Secondary Steel Production (Electric Arc Furnace)	Primary Energy: 4.1	Primary Energy: 2.9
Hot rolling	Fuel: 1.53 Electricity: 0.35 Primary Energy: 1.98	The hot rolling process is being replaced by the thin slab/strip casting process
Thin Slab/Strip Casting	Fuel: 0.1 Electricity: 0.15 Primary Energy: 0.5	
Cold Rolling	Fuel: 1.10 Electricity: 0.53 Primary energy: 2.7	Primary Energy: 2.6

Sources: Kim and Worrell, 2002; Worrell *et al*., 2001.

In addition, many new technologies are under development which could considerably lower the energy intensity of steelmaking. For example, smelt reduction in ironmaking would integrate the production of coke and agglomerated ore with that of iron making, leading to reductions in production costs and energy use. The development of direct casting techniques that abandon rolling would increase productivity while reducing energy use further. Combined, these technologies could reduce the energy intensity of primary steelmaking to 12.5 GJ/ton steel, and for secondary steelmaking to 3.5 GJ/ton, a reduction of 34% and 50% respectively (De Beer *et al*., 1999). In the highly competitive and increasingly globalizing steel industry, manufacturers must continuously look for ways to lower their energy intensity and costs.

Table 9. Examples of Energy-Efficiency Improvement Measures in the Iron and Steel Industry

Overall Measures (applicable to both integrated and secondary plants)
- Preventive maintenance
- Energy monitoring and management systems
- Variable-speed drives for flue-gas control, pumps, and fans
- Cogeneration

Integrated Steelmaking Measures

Iron Ore Preparation/Sintering
- Sinter plant heat recovery
- Waste fuels
- Reduction of air leakage
- Increasing bed depth
- Improved process control

Coking
- Coal moisture control
- Programmed heating
- Variable-speed drives on coke oven gas compressors
- Coke dry quenching

Ironmaking—Blast Furnace
- Pulverized coal injection (medium & high levels)
- Natural gas injection
- Top pressure recovery turbines (wet type)
- Blast furnace gas recovery
- Hot blast stove automation
- Recuperator on hot blast stove
- Improved blast furnace control

Steelmaking—Basic Oxygen Furnace
- BOF gas & sensible heat recovery
- Variable-speed drive on ventilation fans

Secondary Steelmaking Measures

Electric Arc Furnace
- Improved process control
- Flue gas monitoring and control
- Transformer efficiency measures
- Bottom stirring/gas injection
- Foamy slag practices
- Oxy-fuel burners/lancing
- Post-combustion
- Eccentric bottom tapping (EBT)
- Direct current arc furnaces
- Scrap preheating
- Consteel process
- Fuchs shaft furnace
- Twin shell DC arc furnace

Casting and Rolling (applicable to both integrated and secondary plants)

Casting
- Continuous casting
- Efficient ladle preheating
- Thin slab casting

Rolling
- Hot charging
- Recuperative burners in reheating furnace
- Controlling oxygen levels, variable-speed drives on combustion air fans
- Process control in hot strip mill
- Furnace insulation
- Efficient drives in hot rolling mill
- Waste heat recovery from cooling water
- Heat recovery from annealing line (integrated plant only)
- Automated monitoring and targeting system
- Reduced steam use in pickling line

Source: Worrell *et al*., 1999.

4.3.2. Nonferrous Metals

ALUMINUM

In 2001 primary aluminum was produced in 43 countries. Russia and China have now surpassed the United Sates as the world's largest producers, with Russia producing 14%, China producing 13% and the United States and Canada each producing 11% of the aluminum produced in 2001. Although primary aluminum production has been decreasing in the United Sates, world production levels have remained relatively stable as this decrease was offset by increased production in other countries including Canada, China and Mozambique (USGS, 2001).

Aluminum is a metal used extensively for applications in power systems, transport, and construction, as well as for containers and packaging. The production of aluminum is very

energy intensive, and can be three times as energy intensive as steel manufacturing (Das and Kandpal, 1998). Nevertheless, the efficiency of primary aluminum production is already close to the potential maximum (Table 10) when using the fluoride-route to produce aluminum. The extraction of aluminum involves the electrolysis of alumina dissolved in molten cryolite (Na_3AlF_6) at 960-970 °C in electrolytic cells (smelter). The cathode is made from graphite. Pre-baked anodes can reduce the electricity consumption in the smelter. Approximately 70% of the world's aluminum is produced using pre-baked anodes, the Hall-Heroult process (Das and Kandpal, 1998).

Table 10. Overview of Best Practice Energy Intensities and Projected Intensity in 2015 for Aluminum Production Processes

Process	Best Practice Intensity	Intensity Expected 2015
Primary Aluminum Production	12-13 MWh/tonne	11 MWh/tonne (not much room for improvement)
Secondary Aluminum Production	Fuel use = 2 GJ/tonne	Aluminum produced this way is of lesser quality and only suitable for castings

Many conventional energy efficiency measures that are often used in an industrial environment can also be applied to aluminum smelters, namely the conversion of one form of energy to another, control of electrical demand, replacement of a standard efficiency motor with a high-performance motor, installation of variable speed drives on motors, optimization of compressed air and ventilation systems and installation of insulating material (Table 11). However, most energy is used in the electrolysis. Changes in cell design, the use of pre-baked anodes, high currencies, and reduction of over-potential will reduce the electricity consumption. Long-term efficiency improvements include the development of the inert anode, wettable cathode, new cell designs aimed at improved heat distribution, and reduction of voltage loads.

Table 11. Examples of Energy-Efficiency Improvement Measures in the Aluminum Industry

Energy Form	Plant	Measures Required	Possible Reduction
In Alumina Plants:			
Steam	Existing and new plants	Tube digestion	Reduces steam consumption by about 30%
		Evaporation less technology	Reduces steam consumption by about 10-15% (average 12.5%)
Fuel oil for calcination	Existing plants	Retrofitting rotary kilns	Reduces oil consumption by 20-25% (average 22.5%)
	New plants	Replacement of rotary kilns with fluidized bed/gas suspension calciners	Reduces oil consumption by 35-40% (average 37.5%)
Electricity	Existing and new plants	Improved control systems and thyristor drives, sequential operation, efficient pumping, etc.	Contributes to reduction of about 60-100 kWh/tonne alumina (average 80 kWh/tonne)
In Smelter:			
Electricity	Existing plants	Modernization of Soderberg cells	1-2 kWh/kg electricity savings (average 1.5 kWh/kg)
	Existing and new plants	Modernization of Hall-Heroult cells	1 kWh/kg electricity savings

Source: Das and Kandpal, 1998.

4.3.3. Pulp and Paper Industry

Paper can be manufactured in either an integrated pulp and paper mill close to their main raw material input, or in a mill using imported pulp or waste paper. The annual primary energy consumption of the pulp and paper industry worldwide was estimated at 8 EJ in 1990. It is the fourth largest consumer of primary conventional energy in the industrial sector worldwide (de Beer *et al*, 1998b)

Paper consists of aligned cellulosic fibers. The fibers may be from wood or other crops, or from recycled waste paper. When starting the paper-making process with wood fibers, the fibers must be separated from the wood by first pulping the wood. The separation can be done with chemicals, heat or by mechanical means. In the chemical pulping process chemicals and hot water are used to separate the cellulosis from the ligno-cellulosis. The amount of pulp produced is about half of the amount of wood used. Chemical pulping results in high quality paper. In mechanical pulping the wood is ground under pressure, separating the fibers from each other. The ligno-cellulosis is not removed, resulting in a lower quality paper that is typically used for newsprint, but also a higher recovery (about 90% of the used wood). In chemical pulping, steam is used to heat the water and concentrate the chemical by-products. Recovery of the by-products to be recycled in the process can actually produce sufficient steam for the whole paper mill. The mechanical process uses large quantities of electricity, while some processes can recover steam from the grinding process. Waste paper is pulped by mixing with water, after which ink is removed and the pulp refined. Paper recycling reduces the energy needed for the pulping process. Waste paper use in the production of paper varies widely, due to the different structures of the industry in different countries.

While energy efficiency improvement options do exist in the pulping step of the paper-making process, greater opportunities exist in the chemical recovery step. The most common pulping process in the U.S. is the Kraft pulping process. Black liquor is produced as a by-product. The chemicals are currently recovered in a recovery boiler, combusting the ligno-cellulosis. Because of the high water content, the efficiency of the recovery boiler is not very high. The steam can be used to generate electricity in a steam turbine. Gasification of the black liquor would allow the use of the generated gas at a higher efficiency, and would make a Kraft pulp mill an electricity exporter (Martin *et al*., 2000a).

In papermaking the pulp is diluted with water at about 1:100. This pulp is then screened and refined. The solution of the refined fibers (or stock) is fed to the paper machine, where the water is removed. In the paper machine, the paper is formed into a sheet, and the water is removed by dispersing the pulp solution over a wire screen. At the end of the forming section, 80% of the water has been removed. The rest of the water is removed in the pressing and drying section. Although only a small amount of water is removed in the drying section, most of the energy is used in the drying section of the process. Hence, most opportunities for energy efficiency are in trying to reduce the water content by increasing the water removed by pressing. In a long nip press, the pressing area is enlarged. The larger pressing area results in extra water removal. New technologies under development aim to increase the drying efficiency considerably (Martin *et al*., 2000a).

Because energy consumption and intensity depends on the amount of wood pulped, the type of pulp produced, and the paper grade produced, there is a wide range globally in the energy intensity of the paper-making process. In Europe, energy use for papermaking in the early 1990's ranged between 16 GJ/ton to 30 GJ/ton of paper. The Netherlands uses the least energy per ton of paper, largely because most of the pulp is imported. Countries like Sweden and the U.S. have higher energy intensities due to the larger amount of pulp produced. Sweden and other net exporters of pulp also tend to show higher energy intensities. Energy intensity is also influenced by the efficiency of the processes used. Many studies have shown considerable potential for energy efficiency improvement using currently available technologies including heat recovery and improved pressing technologies (Martin *et al*., 2000a). Some countries, like China produce a considerable amount of paper using straw pulp, and thus confront slightly different challenges in achieving greater energy efficiency. Opportunities for greater efficiency exist in this segment as well, as demonstrated in a large-scale, energy-efficient plant in Spain that manufactures corrugated containerboard using straw pulp (Marcus, 1994).

Large potentials for energy savings exist in nearly all process stages of pulp and paper production, e.g., improved dewatering technologies, energy and waste heat recovery and new pulping technologies (Table 12 and Table 13). Technical potentials are estimated up to 40%, with higher long term potentials.

Table 12. Overview of Best Practice Energy Intensities and Projected Intensity in 2015 for Pulp and Paper Production (GJ / tonne of product)

Process	Best Practice Intensity	Intensity Expected 2015
Pulping Mechanical Chemical Other	 Fuel: 2.7, Electricity: 9.7 Fuel: 11, Electricity: -1.8 Fuel: 11, Electricity: -1.8	There are two technologies (impulse drying and condebelt drying) that if successful may be able to reduce the amount of steam needed in the paper making process, perhaps by as much as 50%.
Newsprint	Fuel: 3.2 Electricity = 2.1	
Printing/writing	Fuel: 6.9 Electricity = 1.9	
Sanitary	Fuel: 5.3 Electricity = 2.4	
Packaging	Fuel: 5.0 Electricity = 1.8	
Other	Fuel: 5.0 Electricity = 1.3	

Source: de Beer *et al*., 1998; Worrell *et al*., 1997a.

Table 13. Examples of Energy-Efficiency Improvement Measures in the Pulp and Paper Industry

- Continuous digester, displacement heating/batch digesters, chemi-mechanical pulping
- Black liquor gasification/gas turbine cogeneration
- Oxygen predelignification, oxygen bleaching, displacement bleaching
- Tampella recovery system, falling film black liquid evaporation, lime kiln modifications
- Long nip press, impulse drying, and other advanced paper machines
- Improved boiler design/operation (cogeneration), and distributed control systems

Source: Worrell *et al..,* 1997a.

4.3.4. Oil Refining and Petrochemicals

Oil refineries produce fuels as well as feedstocks for the petrochemical industry. The petrochemical industry produces simple organic chemicals including ethylene, propylene and benzene. These chemicals form the building blocks for many products such as plastics, resins, fibers, and detergents. The single most energy-consuming step in the petrochemical industry is the steam cracking of hydrocarbon feedstocks to produce ethylene, propylene, butadiene and aromatics (benzene, toluene and xylenes).

OIL REFINING

Petroleum refineries extract and upgrade the components of crude oil to produce many petroleum products. Different refineries can process different types of crude oil, depending on the types of processing units used. More complex refineries have multiple processing and treatment options and more flexibility in selecting crude inputs. A high level of complexity allows a refinery to respond to changes in product demand and supply and shift their own range of products produced.

There are five categories of refinery operations: 1) topping: the separation of hydrocarbons; 2) thermal and catalytic cracking of hydrocarbons; 3) combination/

rearrangement of hydrocarbons; 4) treating and blending of products; 5) specialty product manufacture. Petroleum processes are very energy intensive, and consumption ranges considerably with the technology used. The most energy intensive refining processes (excluding lubricating oil manufacture that is done at some refineries) are ethers manufacture, alkylation, and C_4 (butylenes) isomerization. Refinery energy consumption is dominated by a few processes (Table 14). Atmospheric and vacuum distillation may account for 35-40% of total energy consumption. Hydrotreating, the process used to remove sulfur, nitrogen, and metal contaminants from petroleum feed in order to improve catalyst life and enhance product quality, accounts for about 19% of energy use (DOE, 1998).

Energy savings in petroleum refining are possible through improved process integration, cogeneration, energy recovery and improved catalysts (Table 15). Compared to state-of-the-art technology, the savings in industrialized countries are estimated to be 15-20%, and higher for developing countries.

Table 14. Overview of Best Practice Energy Intensities and Projected Intensity in 2015 for Oil Refining (GJ / tonne of product)

Oil Refinery Product	Best Practice Intensity	Intensity Expected 2015
Gases (LPG, refinery gas)	1.3	n/a
Gasoline	3.8	
Kerosene	1.6	
Gasoil (including naphtha)	3.2	
Fuel oil	1.8	
Others	1.8	

Source: Worrell *et al..,* 1994.

Table 15. Examples of Energy-Efficiency Improvement Measures in the Refining Industry.

- Reflux overhead vapor recompression, staged crude pre-heat, mechanical vacuum pumps
- Fluid coking to gasification, turbine power recovery train at the FCC, hydraulic turbine power recovery, membrane hydrogen purification, unit to hydrocracker recycle loop
- Improved catalysts (reforming), and hydraulic turbine power recovery
- Process management and integration

Source: Worrell *et al..,* 1997a.

ETHYLENE

Ethylene and its derivatives are the feedstocks for many plastics and resins, as well as fibers and detergents. Global ethylene production is over 80 Million tons and is growing. The U.S. is currently the world largest ethylene producer, accounting for approximately 30% of world capacity. Since 1974, ethylene production has grown by 3% annually while propylene has grown by over 4% annually. Propylene has increased more rapidly over the last decade with a growth rate of 5% per year. In 1990 energy consumption was estimated to be about 1 EJ (or 950 TBtu, excluding feedstock energy consumption), with ethylene production amounting to 50 Million tonnes (WEC, 1995).

Ethylene and other co-products are produced through the cracking of hydrocarbon feedstocks. In the presence of steam, hydrocarbons are cracked into a mixture of shorter, unsaturated compounds. In the cracking process, hydrocarbon feedstocks are preheated to 650°C (using fuel gas and waste heat), mixed with steam, and cracked at a temperature of about 850°C. A series of separation steps produce fractions consisting of ethylene, propylene, a C_4 fraction (e.g., butadiene) and pyrolysis gasoline (containing benzene, toluene and xylenes). The gas mixture is rapidly cooled to 400°C (or quenched) to stop the reaction, during which high-pressure steam is produced. The injection of water further decreases the temperature to about 40-50°C, forming a condensate that is rich in aromatics. The liquid fraction is extracted, while the gaseous fraction is fed to a series of low temperature, high pressure distillation columns. The feedstocks used for this process include ethane, LPG, naphtha, gasoils (GOs) and sometimes coal-derived feedstocks. Many of the installations used today can handle different (if not all) types of feedstock (WEC, 1995; Worrell *et al.,* 1994a)..

The single most energy-consuming step in the petrochemical industry is the steam cracking of hydrocarbon feedstocks into a mixture of shorter, unsaturated compounds, and future improvements in efficiency of this process will account for most of the drop in intensity (Table 16). It is estimated that the total global energy consumption used in the production of ethylene and its co-products is greater than 1 EJ. The energy consumed for ethylene production can be separated into the initial feedstock and the energy used during the production process. Feedstock energy use is generally equivalent to the heating value of the product, so approximately 42 GJ/ton (LHV). Specific energy consumption for the process varies depending on the feedstock used, the technology used, the age of the plant, the total capacity and the plant operating conditions. Energy use will generally range between 14 (ethane feedstock) and 30 GJ/ton ethylene (gas/oil feedstock), while older plants can use more energy (Worrell *et al*., 2000a)).

Table 16. Overview of Best Practice Energy Intensities and Projected Intensity in 2015 for Ethylene Production (GJ / tonne of ethylene, excluding feedstock) assuming naphtha feed.

Process	Best Practice Intensity	Intensity Expected 2015
Naphtha cracker	21	18

Source: Worrell *et al*., 2000a; Phylipsen, 2000.

4.3.5. Chemicals

The chemical industry produces the intermediate compounds that are used as the basis for many chemical products. The chemical industry produces more than 50,000 chemicals and formulations. In addition, many processes in the chemical industry produce different co-products. Chemical industries consume fuels and electricity as energy and feedstock. This makes the energy analysis of the chemical industry more complicated than other industries.

A small number of bulk chemicals are responsible for the largest part of the energy consumption in the chemicals industry. These are the basic chemicals that are used as building blocks for many chemicals further down the production chain. The most

important basic chemicals are the family of petrochemicals (i.e., ethylene, propylene, butadiene and benzene) described above, and ammonia and chlorine/caustic soda from the inorganic chemicals industry.

AMMONIA

The production of ammonia, a key component in the manufacturing of nitrogenous fertilizers, is a highly energy intensive process. Roughly 80% of ammonia production is used as fertilizer feedstock. Ammonia is produced through the high-pressure synthesis of gases. Global ammonia production in 1999 was estimated at 130 Million tons. Growth in ammonia production is found mainly in developing countries where the expansion of production has been concentrated. China's ammonia manufacturing industry currently uses mainly coal as feedstock, while international best-practice technology relies on natural gas feedstock.

Ammonia is produced by the reaction of nitrogen and hydrogen, i.e., the Haber-Bosch process. The main hydrogen production processes used in the U.S. are steam reforming of natural gas and partial oxidation of oil residues. Hydrogen is produced by reforming the hydrocarbon feedstock and producing synthesis gas which contains a mixture of carbon monoxide and hydrogen. The carbon monoxide is then reacted with steam in the water-gas-shift reaction to produce carbon dioxide and hydrogen. The carbon dioxide is removed from the main gas stream, and recovered for urea production, exported as a co-product, or vented. The hydrogen then reacts with nitrogen in the final synthesis loop, to form ammonia. The ammonia is often processed into different fertilizers including urea and ammonium nitrate, while ammonia is also used as input to make other chemicals (Worrell *et al*., 2000a).

The energy intensity of ammonia-making depends on the feedstock used and the age of the process. Natural gas is the preferred feedstock and is used for over 80% of global ammonia production. Coal is still used in countries like China with limited natural gas supplies. The use of natural gas not only provides a hgher production efficiency but also lower capital costs. Part of the energy input is used as feedstock, for example the hydrogen in natural gas ends up in the ammonia. This is generally equivalent to the thermodynamic mininum energy consumption for the Haber-Bosch synthesis, corrected for losses. Therefore, feedstock use is estimated at 19-21 GJ/ton NH_3 (LHV, lower heating value). Energy use varies between 9 and 18 GJ/ton. The most efficient plants in the world consume around 28 GJ/ton NH3 (feedstock and energy use; Table 17). In the U.S. the specific energy consumption is equal to around 37 GJ/ton (LHV) (Worrell *et al*., 2000a). An analysis of energy intensities of ammonia manufacture in Europe showed that the average 1989 SEC in the European Union is estimated at 35.5 GJ/ton (LHV). Total potentials for energy savings in ammonia making are estimated to be up to 35% in Europe and between 20% and 30% in Southeast Asia through a variety of process improvements (Table 18).

Table 17. Overview of Best Practice Energy Intensities and Projected Intensity in 2015 for Ammonia Production (GJ / tonne of product)

Process	Best Practice Intensity	Intensity Expected 2015
Total (including feedstock)	28-29	27

Source: Worrell *et al*., 2000a, WEC 1995.

Table 18. Examples of Energy-Efficiency Improvement Measures in Ammonia Manufacturing

- Reformer Feed
- Reformer Fuel
- Primary Reformer
- Secondary Reformer
- Waste Heat Boiler
- Shift + CO2 Removal
- Methanator
- Synthesis Loop
- Aux. Boiler
- Turbines/Compressor

Source: Worrell *et al* 2000a.

CHLORINE (CHLOR-ALKALI)

Total global Chlorine production capacity is approximately 50 Million tons, produced at 650 sites. About half of the world's chlorine is produced in Asia. The production of chlorine gas is an energy intensive chemical process in which a brine solution is converted into two co-products through electrolysis: chlorine gas and sodium hydroxide (caustic soda). The three main electrolysis cell types that are used to separate and produce the chlorine gas and caustic are the mercury flow, diaphragm, and ion-selective membrane. In the diaphragm and membrane cells the caustic soda requires an additional step of concentrating the solution so that it can meet market specifications for most products.

Table 19. Overview of Best Practice Energy Intensities and Projected Intensity in 2015 for Chlorine Production (GJ / tonne of product)

Process	Best Practice Intensity	Intensity Expected 2015
Total Process	Electricity: 9.8 Primary Energy: 30	Electricity: 9 Primary Energy: 27

Worrell *et al.,* 2000a.

Chlorine production is the main electricity consuming process in the chemical industry, followed by oxygen and nitrogen production. Energy use for chlorine production significantly depends on the cell type used for the electrolysis, with the most efficient processes already close to the most efficient considered technically feasible (Table 19). Power consumption varies from between 2,800 kWh/ton for the membrane process to 4,300 kWh/ton for the mercury process. In addition, steam may be used to concentrate the caustic soda in the membrane process (Worrell *et al*., 2000a). Membrane cells require the least amount of energy to operate, and the membrane process is considered "state-of-the-art." Countries in Asia and Europe have a higher share of membrane processes than the US and Canada. In the U.S., chorine production uses 48 TWh of energy per year, with an

average intensity of 4380 kWh/ton. Potential improvements include process-specific measures, and cross-cutting measures common to other sectors, like improved motors systems and controls (Table 20).

Table 20. Examples of Energy-Efficiency Improvement Measures in the Chemicals Industry

- Process management and thermal integration (e.g., optimization of steam networks, heat cascading, low and high temperature heat recovery, heat transformers), mechanical vapor recompression
- New compressor types
- New catalysts
- Adjustable speed drives
- Selective steam cracking, membranes
- High temperature cogeneration and heat pumps
- Autothermal reforming

Source: Worrell *et al.,* 1997a.

4.3.6. Building Materials

CEMENT

Cement production is a highly energy-intensive process. Cement making consists of three major process steps: raw material preparation, clinker making in the kiln, and cement making. Raw material preparation and cement making are the main electricity consuming processes, while the clinker kiln uses almost all of the fuel in a typical cement plant. Clinker production is the most energy-intensive production step, responsible for about 70-80% of the total energy consumed. Raw material preparation and finish grinding are electricity-intensive production steps. Energy consumption by the cement industry is estimated at 6 to 7 EJ (Worrell *et al*., 2000b).

The theoretical energy consumption to produce cement can be calculated based on the enthalpy of formation of 1 kg Portland clinker which is about 1.76 MJ. In practice energy consumption is higher. The kiln is the major energy user in the cement making process. Energy use in the kiln basically depends on the moisture content of the raw meal. Most electricity is consumed in the grinding of the raw materials and finished cement. Power consumption for a rotary kiln is comparatively small.

Cement is an inorganic, non-metallic substance with hydraulic binding properties. When mixed with water it forms a paste that hardens due to the formation of hydrates. After hardening the cement retains its strength. There are numerous different types of cement due to the use of different sources for calcium and different additives to regulate properties. The exact composition of the cement determines its properties.

In 1999, global cement production was estimated to be 1,600 Million tonnes. Due to the importance of cement as a construction material, and the geographic abundance of the main raw materials, cement is produced in virtually all countries. The widespread

production is also due to the relatively low price and high density of cement, which in turn limits ground transportation due to high transport costs (Worrell *et al*., 2000b).

The most common raw materials used for cement production are limestone, chalk, gypsum and clay. The collected raw materials are selected, crushed, and ground so that the resulting mixture has the desired fineness and chemical composition for delivery to the pyroprocessing systems. The grinding process differs with the pyroprocessing process used. The feed to the kiln is called 'raw meal'.

Clinker is produced by pyroprocessing the raw meal. The raw meal is burned at high temperatures, first calcining the materials (driving off the CO_2) followed by clinkering to produce clinker. Various kiln types have been used historically or are used around the world. Besides the rotary kiln, the vertical shaft kiln is mainly used in developing countries. In industrialized countries, the ground raw materials are predominantly processed in rotary kilns (Worrell *et al*., 2000b).. In processing without precalcination, the decomposition (calcination) of $CaCO_3$ to CaO and CO_2 takes place in the kiln. The clinker is cooled. The cooling air serves as combustion air. The largest part of the energy contained in the clinker is returned to the kiln in this way.

Grinding of cement clinker, together with additives to control the properties of the cement is done in ball mills, roller mills, or roller presses. Coarse material is separated in a classifier to be returned for additional grinding. Power consumption for grinding depends strongly on the fineness required for the final product and the additives used.

In the United States cement industry, primary energy intensity has decreased from 7.9 GJ/t in 1970 to 5.6 G/t in 1997 at an average rate of 1.3% per year (Worrell *et al.,* 2000b). This is still much higher than current best practice internationally (Table 21). Although there was a slow decrease in overall intensity during this period, intensity actually began to climb in the early 1990s at 0.9% per year on average from 1992-1997. The energy intensity of the dry process decreased by more than double the intensity of the dry process, at -0.4% and 1.0% per year respectively. Carbon dioxide emissions reductions during this time resulted from increased dry process clinker production capacity, improved energy efficiency, and a decreasing clinker/cement-production ratio. Despite a shift towards the use of more carbon-intensive fuels like coal and coke, overall fuel mix trends were more than offset by energy intensity reductions, resulting in an overall decrease in carbon dioxide emissions during this period.

Table 21. Overview of Best Practice Energy Intensities and Projected Intensity in 2015 for Cement Production (GJ / tonne of product)

Process	Best Practice Intensity	Intensity Expected 2015
Clinker Production (dry)	2.9	2.8

Energy savings in cement production are possible through increased use of additives (replacing the energy-intensive clinker), use of dry process and a large number of energy efficiency measures (e.g., reducing heat losses and use of waste as fuel). Energy savings potentials of up to 50% do exist in the cement industry in many countries through

efficiency improvement and the use of wastes like blast furnace slag and fly-ash in cement making (Table 22).

Table 22. Examples of Energy-Efficiency Improvement Measures in the Cement Industry

- Improved grinding media and linings, roller mills, high-efficiency classifiers, wet process slurry
- Dewatering with filter presses
- Multi-stage preheating, pre-calciners, kiln combustion system improvements, enhancement of internal heat transfer in kiln, kiln shell loss reduction, optimize heat transfer in clinker cooler, use of waste fuels
- Blended cements, cogeneration
- Modified ball mill configuration, particle size distribution control, improved grinding media and linings, high-pressure roller press for clinker pre-grinding, high-efficiency classifiers, roller mills

Source: Worrell *et al.,* 1997a, Martin et al., 1999.

BRICKS AND CERAMICS

Bricks, tiles and other ceramics are made from clay that is formed, dried, and baked. There are three main types of brick produced: 1)facing bricks, used for outer walls of houses and have a high aesthetic standard; 2)common bricks, used where appearance is not important but other qualities are similar to facing bricks; 3) engineering bricks, having superior mechanical and corrosion properties and therefore used where severe environmental conditions may be experienced. There are six process stages of brick manufacture, including raw material excavation, transport, body preparation (mixing and grinding), shaping (extruding or pressing), drying in driers, and drying and firing in kilns. The four processes used for forming bricks are the stiff plastic process, the extrusion process, the soft-mud process, and the semi-dry process. The process used determines the amount of energy required to dry and fire the bricks (HMSO, 1984)

In the past, flame and ring-kilns were used to do this, needing a production cycle of up to 14 days. Today the most common process used in brick-making is the tunnel kiln (Table 23). Tunnel kilns have a production cycle of 75-140 hours, and use an automated firing process to bring the bricks through preheating, baking and cooling stages (Martin *et al*., 2000b).

Table 23. Overview of Best Practice Energy Intensities and Projected Intensity in 2015 for Solid Brick Production (GJ / tonne of product)

Process	Best Practice Intensity	Intensity Expected 2015
Tunnel Kiln	Fuel: 2.5 Electricity: 0.1 Primary Energy: 2.8	Primary Energy: 2

Source: Ceramic Bulletin, July 1999. WEC, 1995.

The newest technology being developed for use in ceramics is the roller kiln (Table 24). This technology uses a rapid firing process in which the clay is prepared dry with appropriate additives to maintain the forming and baking characteristics required. This reduces the amount of water used to 6-8% from 18-20%. The fired products are then

transported on refractory rollers rather than lorries. The roller kiln reduced the heating time to approximately 8-9 hours, and uses a shorter firing curve. The flue gas volumes in the roller kilns are lower than in the tunnel kiln, reducing the heat losses. This reduces both the heat demand and the power consumption needed for air circulation.

Table 24. Technologies and Processes to Improve Energy Efficiency in Brick Production

-	Introduction of roller kilns
-	Carbonaceous additives
-	Increased brick perforations
-	Kiln heat recovery
-	Heat recovery from driers
-	Improved process control
-	Alternative gas supplier – colliery methane and landfill gas
-	Insulation with low thermal mass materials (LTM)

Source: HMSO, 1984; Martin *et al*., 2000b.

Roller kilns are used to manufacture structural clay products and ceramics, particularly the production of building bricks, roof tiles, sewer pipes, sanitary ware and wall and floor tiles. However they are a state-of-the-art technology for and are not yet used for brickmaking. In the Netherlands a roller kiln has been demonstrated to reduce energy consumption by 60% compared to the previously used tunnel kiln, and to reduce the specific energy consumption to 3.8 GJ/t product from 10.8 GJ/t (LHV) (Martin *et al*., 2000b). The current roller kilns have only a single or double layer for products, which is suitable for ceramic products but not large capacity brick kilns. Some developers (primarily an Italian firm called Mori) are trying to develop multi-layer kilns to increase use for this purpose. The roller kilns will likely be used when conventional tunnel kilns need to be replaced, but will face competition from new more efficient tunnel kilns that are being developed in Europe and the U.S. The tunnel kilns can also be retrofitted with improved insulation using low thermal mass materials that can both reduce energy use by as much as half and reduce NO_x emissions as well (Martin *et al*., 2000).

GLASS

Glass is a collective term for an unlimited number of materials of different compositions in a glassy state. In the Glass Industry the term is usually used to refer to silicate glasses, substances containing a high proportion of silica (SiO_2) and which naturally form glasses under normal conditions of cooling from the molten state. Glasses are divided into two categories. Hard glasses have a thermal expansion coefficient below 6×10^{-6}/K, and soft glasses have a higher thermal expansion coefficient. Container and flat glass comprise the majority of glass production. For example, in the U.S., 70% of glass produced is container and flat glass.

The choice of melting technique used to make glass will depend on many factors including the total capacity required, the glass formulation, fuel prices, existing infrastructure and environmental performance. Large capacity installations (> 500 t/d) generally use cross-fired regenerative furnaces (Table 25). Medium capacity installations (100 to 500 t/d) use regenerative end port furnaces, though cross-fired regenerative, recuperative unit melters, and in some cases oxyfuel or electric melters may also be used in some cases. Small

capacity installations (25 to 100 t/d) use recuperative unit melters, regenerative end port furnaces, electric melters and oxy-fuel melters (IPPC, 2000).

Glass making is a very energy intensive activity. The choice of energy source, heating technique and heat recovery method are central to the design of the furnace and are some of the most important factors affecting the environmental performance and energy efficiency of the melting operation. The three main energy sources for glass making are natural gas, fuel oil and electricity. In the first half of the century many glassmakers used producer gas from reactions of air and water with coal at incandescent temperatures. Fuel oil has been the predominant fuel used for glass making. It is thought that oil flames, which are more radiant than gas flames, give better heat transfer to the melt. However, the use of natural gas is increasing in the Glass Industry due to its high purity, ease of control and the lack of requirements governing storage facilities. As the industry gains more experience with gas firing it is thought that the efficiency and operational control achieved with gas firing is progressively approaching that of oil firing. Many large furnaces are equipped to run on both natural gas and fuel oil, with only a change of burners being necessary (IPPC, 2000).

The third common energy source for glass making is electricity, which can be used either as the exclusive energy source or in combination with fossil fuels. Electricity can be used to provide energy in three basic ways: resistive heating, where a current is passed through the molten glass; induction heating, where heat is induced by the change in a surrounding magnetic field; and the use of heating elements. Electric boosters are used in fuel-fired furnaces to increase melting capacity. Modern large-scale furnaces use oxy-fuel technology while using waste heat to preheat cullet. Oxy-fuel fired furnaces, with cullet preheating, are now used for the production of containers, flat glass, and fibers (IPPC, 2000).

Table 25. Overview of Best Practice Energy Intensities and Projected Intensity in 2015 for Glass Production (GJ / tonne of product)

Tank Furnace Type	Glass Type	Best Practice Intensity	Intensity Expected 2015
Fuel-oxygen-fired furnace	Container glass	3.1-3.5	3.0 (this is the main glass production technology)
Cross-fired furnace with regenerative preheating	Container glass or water glass	4.2	
Regenerative end fired furnace	Container glass	3.8	
Recuperative furnace	Container glass	5.0	
Cross-fired furnace with regenerative air preheating	Flat Glass	6.3	
Cross-fired furnace with regenerative air preheating	Television tube glass (screen)	8.3	
Furnace with recuperative air preheating	Tableware	6.7	
Furnace with recuperative air preheating	Glass fiber	4.3	

Source: IPPC, 2000.

5. Transportation Technologies

In the OECD developed countries transportation energy use increased at the rate of 1.8% per year over the past 20 years, and in the formerly planned economies at 2% per year. In Asia, where transport energy use per capita is the lowest in the world, growth has been averaging 6.4% per year since the early 1970s (IWG, 2000). Transportation is the fastest growing component of world energy demand, particularly in the developing world, and has been the only sector of growing oil demand over the past 20 years (Greene, 1996). Reducing future energy use and emissions from transport in the future will be difficult because, in most countries, freight volumes will continue to rise faster than freight energy intensities fall, miles driven per vehicle have been rising, and fuel economy of personal vehicles has stagnated or deteriorated (Schipper *et al*., 1997; IEA, 1997c).

Technology determines the form and quantity of energy needed for transportation. It is difficult to write about international energy demand trends in the global transportation sector because countries are so varied in their transport vehicle fleet mix and VMT. The most advanced vehicles and transport fuels are being developed mostly in the E.U. and the U.S., however it is not necessarily the newest or most efficient vehicle technologies that are growing most rapidly in fleet share, as demand for transport is influenced by many complex social and political factors. For example in the United States, new light-duty passenger vehicles have been adopting fuel-efficient technologies over the past decade and a half. At the same time, increasing vehicle size, weight and performance have nullified the fuel economy gains these technologies might have brought (IWG, 2000). The characteristics of the various fleets in the global transportation sector and recent trends in energy use can provide important clues to the likely future energy use in the sector and the potential for energy efficiency improvements.

In the United States, freight transport consumes about 30 percent of U.S. transportation energy. Freight energy use is dominated by heavy truck carriage (over 50 percent of energy use), while only one-quarter of gross ton miles are from heavy truck carriage. Heavy truck carriage is the most energy-intensive mode aside from air freight. Air freight and freight truck energy use are the most rapidly growing freight modes because of the U.S. economy's shift towards higher value (and more time-sensitive) goods. Another trend is greater use of multi-modal shipments advanced by the rationalization of U.S. freight railroads and the benefits of improved computerized information systems (IWG, 2000).

Important new technologies that have entered the U.S. fleet include port fuel injection, four-valves/cylinder engines, variable valve control, structural redesign using supercomputers, growing use of high strength steel and steel substitutes such as aluminum and plastics, and low rolling resistance tires (Table 26). A trend unique to the United States has been the growing sales share of light-duty trucks, especially Sport Utility Vehicles, which now comprise 46 percent of light-duty vehicle sales compared with 17 percent in 1980. Four-wheel drive was installed on 47 percent of 1999 model year light trucks along with an increase in other luxury features and continued increases in the stringency of emissions and safety standards (IWG, 2000).

The "potential technology" portfolio for automobiles has been enhanced substantially by the Partnership for a New Generation of Vehicles (PNGV), a government/industry joint research and development program The PNGV program has had both direct and indirect effects on new vehicle technology, simulating competitive technology developments in Europe and Japan in addition to its own technological advances (IWG, 2000).

The transportation sector has a wide variety of available and emerging technologies with the potential to significantly reduce the energy use and greenhouse gas emissions associated with transportation services. Some evolving technologies are actually the constant redesign and improvement of existing technologies, like the steady reduction in engine friction from introduction of lighter materials in valve-trains, changes in machining, design, and assembly that yield improved tolerances, and other incremental changes (IWG, 2000). Other technologies have been gradually gaining market share, such as variable valve timing, used today primarily for its ability to flatten an engine's torque curve obtaining high torque throughout the engine's speed range, but whose fuel economy benefits are not highly valued in today's market. There is also a new range of technologies either just entering the marketplace or currently under advanced development. The table below provides an overview of the newest technology developments in the transport sector that are likely to experience increased use over the next decade.

It should be mentioned that aside from technological advances, there are many factors that can affect energy use in the transport sector. These include the increased use of public transportation, traffic flow improvements, or size limits placed on commercial or private vehicles.

Table 26. Technology Trends in the Transportation Sector

Technology	Description	Status
Cellulosic Ethanol	Fuel produced from corn, substitute for gasoline. May result in 20-80% lower GHG emissions than gasoline depending on composition.	Market penetration is increasing, and significant quantities of cellulosic ethanol could be used over next decade. Likely will depend on price of oil, and land availability for growing source materials.
Hybrid Electric Drivetrains	Combines an internal combustion engine or other fueled power source with an electric drive train (electric motor and battery). Increases efficiency by recapturing braking energy; downsizing engine using the motor/battery as power booster; avoid idling losses by turning off the engine or storing unused power in the battery; and increasing average engine efficiency by using the storage and power capacity of the electric drive train to keep the engine operating away from low efficiency modes. Can boost fuel economy up to 50%.	Several models have already been introduced by Japanese companies and American companies are planning to introduce several in the near future. Greatest efficiency gains possible in stop and go traffic, therefore potential for applications to taxis, buses and service vehicles (e.g., a hybrid) heavy garbage truck could achieve gains as high as 140 percent).
Lower Weight Structural Materials	New space frame-based structure, advanced new manufacturing technology for plastics and aluminum, and improved modeling techniques for evaluating deformability and crash properties have resulted in new developments in materials that do not sacrifice surface finish quality, predictable behavior during crash tests, or reparability.	New ULS (ultralight-weight steel) designs claim up to a 36 percent reduction in weight for the basic automobile "body-in-white" structure at essentially zero cost.
Direct Injection Gasoline and Diesel Engines	Can reduce fuel consumption by 20%, with a 10% increase in power output. Problem with catalytic converters that reduce NOx emissions from lean burn engines are very sensitive to fuel sulfur content.	Introduced in Japan and Europe, restricted in US because of resultant sulfur emissions. Potential for use in heavy trucks, marine and rail applications.
Fuel Cells	Promises zero or near-zero criteria pollutant emissions with very high efficiency. Problem still in working out fuel source. Hydrogen would yield the cheapest and most fuel-efficient vehicle, but there is no hydrogen distribution and refueling infrastructure. A fuel cell vehicle powered by compressed hydrogen could achieve 90 mpg. A methanol fuel cell vehicle could achieve 65 mpg (gasoline equivalent). A gasoline powered fuel cell vehicle could achieve 60 mpg.	All major auto manufacturers are developing fuel cell vehicles and it is estimated they will be introduced between 2003-2005. However, fuel cells remain extremely expensive, and long-term costs are by no means clear with important technical roadblocks remaining.
Aircraft Technology	Technologies such as laminar flow control to reduce drag, greater use of composite materials to reduce weight, and advanced propulsion concepts such as ultra-high bypass turbofan and propfan engines could all contribute to aircraft fuel efficiency.	The Aeronautics and Space Engineering Board of the NRC concluded that it was feasible to reduce fuel burn per seat mile for new commercial aircraft by 40 percent by about 2020: 25% from improved engine performance, and 15% from improved aerodynamics and weight.

Source: Interlaboratory Working Group (IWG), 2000. *Scenarios for a Clean Energy Future*.

6. Commercial and Residential Buildings Technologies

Energy is used in buildings to provide a variety of services, including space heating and cooling, water heating, lighting, refrigeration, and electricity for electronics and other equipment. The buildings sector is currently responsible for an estimated 35% of carbon emissions in the United States, and 9% of global anthropogenic emissions (U.S. buildings are responsible for more carbon emissions than the total anthropogenic emissions of any single country in the world except China). The U.S. Energy Information Administration projects that carbon emissions from the U.S. buildings sector will grow from 531 million metric tons of carbon equivalent (mmtce) in 1999 to 726 mmtce in 2020 (EIA, 2000 and EIA, 2001a). These emissions arise primarily from various forms of fossil energy used either directly at the building site or offsite at electric utility power plants. Energy demand forecasts for the residential buildings sector (and by extension commercial buildings sector as well) need to take into account that falling energy prices will not necessarily lead to rising energy demand; past experience has shown that, due to irreversible technological changes, household energy demand does not necessarily "rebound" when energy prices fall (Haas and Schipper, 1998).

There are many measures that can be used in and on residential and commercial buildings to improve energy efficiency (Table 27). This includes specific technologies, practices, fuel-switching measures, and more efficient or renewable energy sources that save primary energy used. Hundreds of technologies and measures exist that can improve the energy efficiency of appliances, equipment, and building structures in all regions of the world (IPCC, 2001; Kinzey *et al*., 2000). Areas with large opportunities for energy savings include HVAC, lighting, and integrated new building design technologies. Other technology areas with opportunities for energy savings include appliances, water heating, on-site power production, and building shells.

A study that examined projected energy supply curves for the United States and the result of implementing a series of energy efficiency measures in the building sector showed that 45% of building sector energy use could be saved at a cost of over $29 billion dollars. (Rosenfeld *et al*., 1993).

Table 27. High priority emerging technologies and practices for residential and commercial buildings

Appliances:
- Low-leak home electronics
- 1 kWh/day refrigerator/freezer
- High efficiency vertical-axis clothes washer
- High efficiency dishwasher
- Improved compressors (A/C)
- Improved compressors (refrigerators)
- Advanced clothes washer and dishwasher controls

Water Heating:
- Integrated space/water heating systems (electric)
- Integrated space/water heating systems (gas/oil)
- Residential heat pump water heater

Drivepower:
- Switched reluctance drive

HVAC:
- Aerosol-based duct sealing
- Commercial distribution systems air sealing
- Commissioning existing commercial buildings
- Dual source heat pump
- Improved ducts and fittings
- Improved heat exchangers
- Indirect-direct evaporative cooler
- Evaporative condenser air conditioning

Lighting:
- Improved fluorescent dimming ballast
- Integrated lighting fixtures/controls
- Reduced-cost, high efficiency CFL
- Metal halide replacement for incandescents
- One-lamp fixtures and track lighting
- CFL floor and table lamps

Power:
- Fuel cells
- Microturbines
- Dry-type distribution transformers

Shell:
- Heat reflecting roof coatings
- High R (>4) windows

Other:
- Advanced metering/billing systems
- Integrated new home design
- Integrated commercial building design

Source: Nadel *et al*., 1998

7. Electricity Generation Technologies

Worldwide electricity consumption for the year 2000 was 13,719 billion kWh (TWh), up from 10,549 TWh in 1990 (EIA, 2002). The mix of primary fuels worldwide that are used to generate electricity has changed substantially over the past thirty years. Coal has remained the dominant fuel used for electricity generation. Nuclear power increased rapidly from the 1970s through the mid-1980s, but growth rates have slowed since.

Natural-gas-fired electricity generation has been increasing through the 1980s and 1990s. In contrast, the use of oil for electricity generation has been slowing since the mid-1970s.

Natural-gas-fired electricity generation is expected to dominate much of the new generation capacity of the near future. Industrialized nations are increasingly using combined-cycle gas turbines which generally are cheaper to construct and more efficient to operate than other fossil-fuel-fired generation technologies. Natural gas is also a cleaner fuel than other fossil fuels. In the future, natural gas use for electricity generation worldwide is projected to double by 2020 as technologies for gas-fired generation continue to improve and ample gas reserves are exploited (EIA, 2002). In the developing world, particularly in Central and South America, natural gas is expected to be used increasingly to diversify electricity fuel sources where heavy reliance on hydroelectric power has led to shortages and blackouts when reservoirs are low.

Generation from hydropower and other renewable energy sources currently makes up 20 percent of electricity generation globally. New renewable electricity generation capacity is projected to grow by more than 50 percent over the next 20 years, but their share of total electricity generation is projected to remain near the current level.

Worldwide electricity consumption is projected to increase at an average annual rate of 2.7 percent from 1999 to 2020. The most rapid growth in electricity use is projected for the developing world, particularly developing Asia, where electricity consumption is expected to increase by 4.5 percent per year for the next twenty years. By 2020, developing countries in Asia are expected to consume more than twice as much electricity as in 1999. China's electricity consumption alone is projected to triple, growing by an average of 5.5 percent per year through 2020. Similarly, in Central and South America, high rates of economic growth are expected, resulting in a growth rate for electricity use of 3.9 percent per year between 1999 and 2020

Electricity consumption in industrialized countries is expected to grow less rapidly than in the developing world at 1.9 percent per year through 2020. In addition to expected slower growth in population and economic activity in the industrialized nations, market saturation and efficiency gains in many electronic appliances are expected to slow the growth of electricity consumption.

There have been some general changes in the electricity sector in many countries that may affect the way the industry works in the future. One change is that foreign direct investment is increasingly becoming involved in the electricity sector if developing countries. Greater access to foreign investment in the electricity sector has in some cases allowed nations to construct the infrastructure needed for increased access to electricity. Another common trend in the electric industry is electricity reform. Many countries have implemented reforms to the rules governing electricity generation and distribution in an effort to allow access to foreign direct investment. In primarily industrialized countries, the goal of electricity sector reforms has been to introduce competition in domestic markets in an effort to reduce the costs of electricity to consumers.

Table 28. **Technology Trends in the U.S. Electric Power Sector**

Technology	1997 average grams carbon/kWh	Possible future improvement	Issues/comments
Coal boilers	260	New plant efficiency could be as much as 1/3 greater than existing plants; existing plant efficiency could be improved to a lesser extent	
Coal IGCC	210	Combination with fuel cell could yield high efficiency and carbon separation and achieve near zero carbon and criteria air pollutant emissions	Three demonstration plants in the US; used commercially in other countries
Gas Turbine	170	New plant efficiency >40%; current plants ~32%	Largely peak load, so lower impact on total emissions
Gas Combined Cycle	100	New plant efficiency Could be 60-70% with ternary cycle. Current models are 43-57% efficient	Designed for base load, could replace retiring coal plants and inefficient gas plants
Fuel Cells	≥0 depending on fuel source	Can be combined with other cycles	Cost needs to be reduced, tech improvements needed
Nuclear	0	Improved efficiency and life extension of current plants possible at low cost	Safety concerns, problem with spent fuel storage
Hydro	0	Increased efficiency and enhanced environmental performance with advanced technology	Large potential, concern with environmental impacts
Wind	0	Cost competitive in near future in some markets	1998 growth rate of 35% world wide
Biomass cofiring	0	Can be increased to 2-4% of coal generation	Requires fuel collection infrastructure
Geothermal/ Hydrothermal	0	Resource identification	
Photovoltaics	0	Cost reductions possible	Large potential in buildings
Solar Thermal	0	Limited cost reduction potential	
Cogeneration		Improved heat transfer and network efficiency	Co-siting of generator and demand required

Source: IWG, 2000.

Table 28 summarizes technology opportunities for the electric sector in the U.S., along with the issues that may stall their development. This table is primarily based on technologies available for the U.S. market. In the U.S., the current stock of power plants is quite old, with two thirds built before 1970. There is therefore much opportunity for these new, more-efficient technologies to be deployed as existing plants are retired and replaced.

8. Conclusions

Worldwide, a great deal of progress has been made since the 1970s in improving the energy efficiency of economic activities, despite countervailing trends such as increased per capita economic activity. Much of this progress has been unintentional, but policies and programs directed at fostering improve energy efficiency, both on the supply and the demand sides, have contributed greatly. Wide scope remains for further reducing energy intensity by improving technologies, changing the structure and patterns of human economic activity, and modifying individual behavior. Sustained support by national governments and by other organizations will be needed for continuing policy interventions in order to take advantage of the current potential for greater energy efficiency, as well as opportunities for efficiency that will arise in the future.

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