

## The Role of Chemical Engineers in Green Engineering

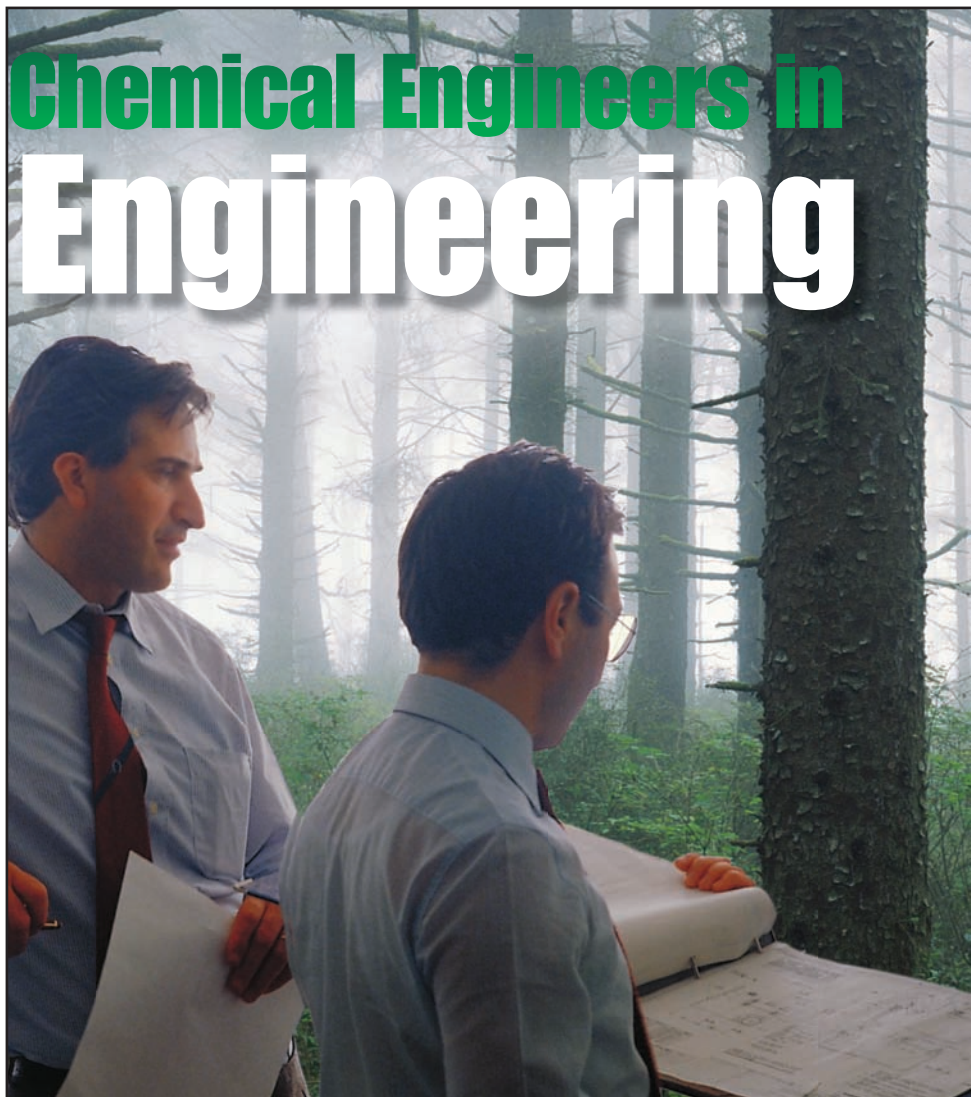
What we can do to support its goals

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**G**reen engineering, as explained by chemists and bio-scientists, includes production of energy and materials from “green” feedstocks, such as biomass and microorganisms, with the intent of reducing energy, waste, greenhouse gases (GHGs) and water consumption. By extension, other contributions that reduce GHG emissions also support green engineering.

The obvious solution to creeping global GHG inventories is to cut back extraction of fossil carbon from below the ground. It is unlikely we will stop using fossil fuels, but it is reasonable to expect we will curb GHG emissions to rates sustainable by the earth’s natural sequestration systems. Efficient use of fossil fuels and wide spread use of renewable energy are required to meet this goal.

Everyone can make their personal contribution to reduce GHG emissions by driving fuel-efficient vehicles and judiciously adjusting the thermostat at home. For engineers, however, the responsibility is greater since the decisions we make can have orders-of-magnitude higher impact.



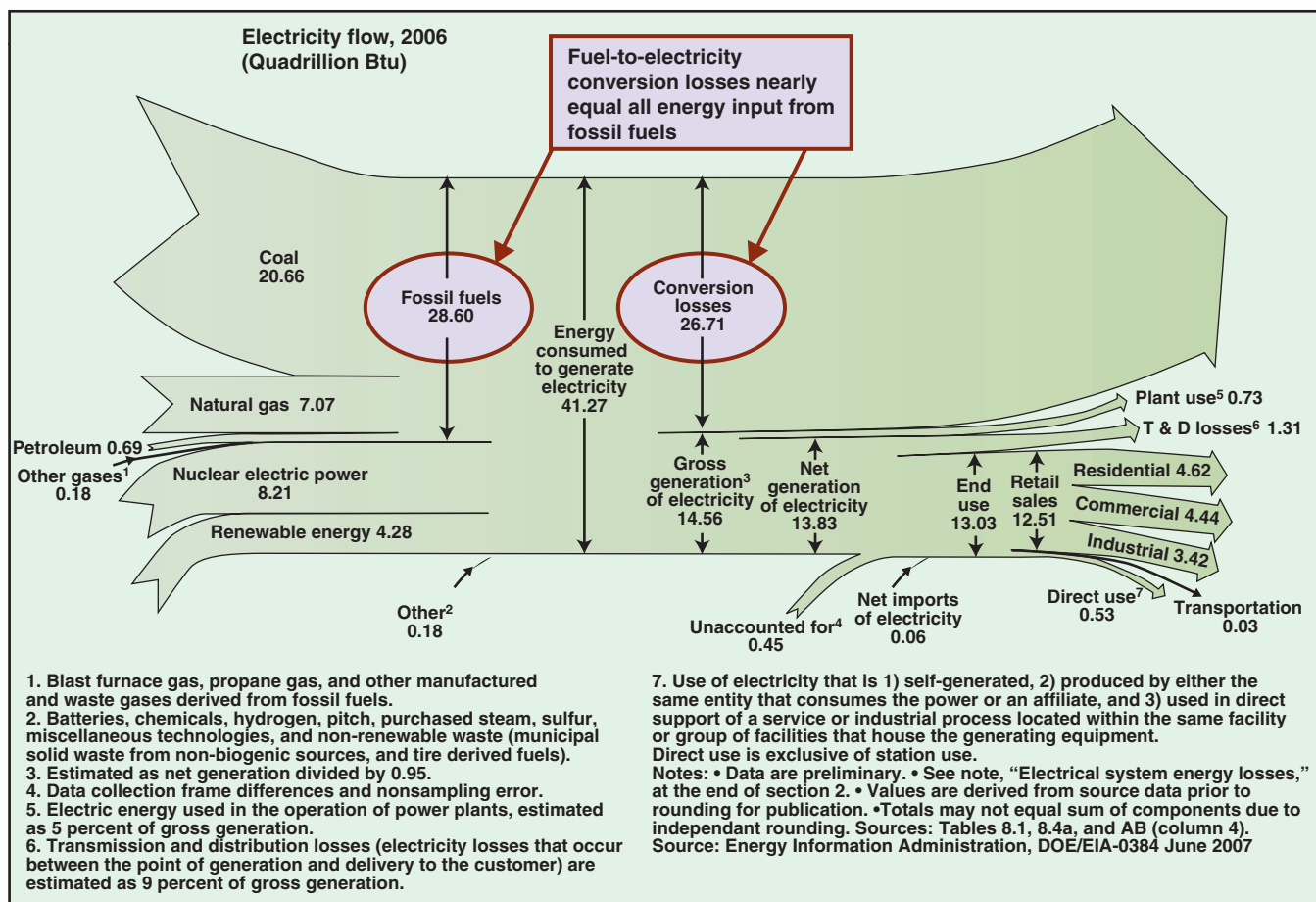
GHG mitigation presents opportunities for chemical engineers to devise, quantify, and implement innovative green solutions. By identifying and evaluating options and resources useful to support green engineering, significant and invaluable improvements can be gained.

### Top sources of GHG emissions

**Power.** Today hundreds of aged power plants release large volumes of GHGs while supplying electricity for the U.S.

These seldom top 38% thermal efficiency even though technologies exist that can better 50%. A 1% efficiency improvement out of 26 quadrillion Btu conversion losses from U.S. power production (see Figure 1) would result in savings of 260 trillion Btu, an equivalent of GHG emissions from 3.5-million passenger automobiles.\*

\*Note. Equivalent emissions from passenger automobiles provides an idea of the impact in terms most of us can relate to. The basis is  $7.50 \times 10^7$  Btu/yr per automobile, 12,000 mi/yr and 20 mi/gal mileage.



**FIGURE 1.** The national (U.S.) energy-to-electricity balance for 2006 (Source: Energy Information Admin., DOE/EIA-0384, June 2007)

Integrated gasification, combined-cycle (IGCC) leads the list of solutions to this problem. IGCC combines two thermodynamic cycles: a gas combustion cycle and a steam cycle, each with its own turbine and generator. Natural gas or coal gasification provides energy for the first cycle. Heat from the flue of the first cycle is used to generate superheated steam to drive the second set of turbines. Larger temperature differences between the hot and cold ends of the combined cycle allow higher thermal efficiency relative to single cycles, netting benefits of 20% less GHG and 20–40% lower water usage.

IGCC capacity planned for 2014 is 14.8 GW with 27 projects in 16 states. Worldwide, nearly 4 GW of IGCC currently operate and 50 new projects totaling 27 GW have been announced [1].

Ocean and terrestrial (vegetation and soils) CO<sub>2</sub> sequestration are being investigated. The environmental impact of these methods is unknown at this time. CO<sub>2</sub> storage in soils as magnesium carbonates or as CO<sub>2</sub> clathrate are promising as safe, solid materials offering compact storage with potential commercial value [2].

**Transportation fuels.** Transportation fossil fuels release the second largest volume of GHGs. Renewable fuels (bioethanol and biodiesel) are leading solutions reducing GHGs from 7 to 90% per gallon, compared to gasoline, depending on feedstock and process type, according to Argonne National Laboratory [3]. Applying the low end of this range to the 160-billion gal/yr of gasoline consumed in the U.S., 133-million tons of CO<sub>2</sub> emissions would be prevented. For companies interested in biofuels production, an excellent repository of reports and models is accessible at the National Renewable Energy Laboratory's (NREL) website [4].

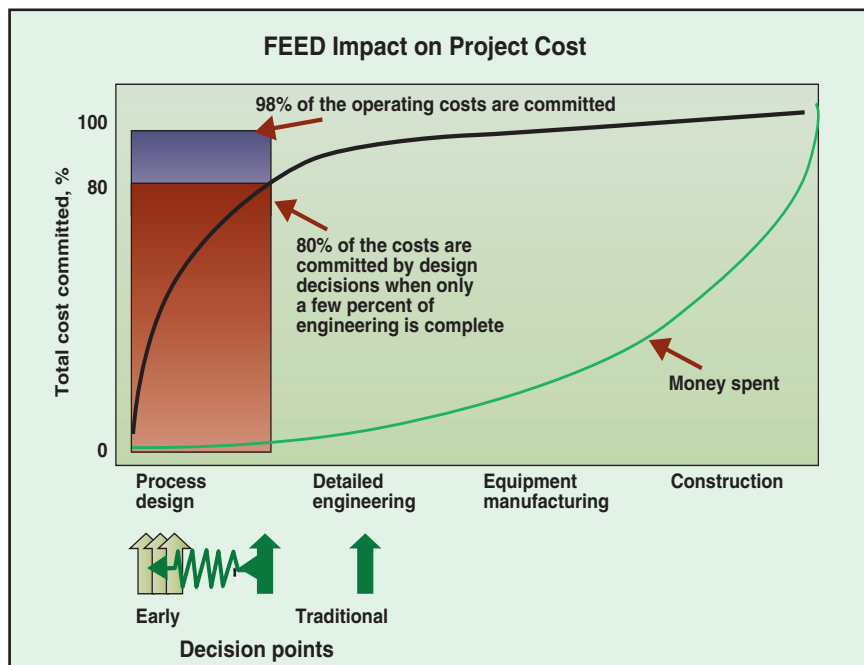
**Industry, including chemicals.** Energy consumption per unit of chemical output decreased 40% between 1974 and 1990. Since 1990 however, improvement slowed to a relatively flat rate [5]. In 2005, Oak Ridge National Laboratory reported possible energy savings for the twelve largest energy users in chemicals totaling 252 trillion Btu/yr. Paper, ethylene, oxygen, ammonia and styrene lead the list (in that order) with 219 trillion Btu [6].

Chemical Industry Vision2020 and the U.S. Dept. of Energy (DOE) estimate

inefficiencies of 2.7 quadrillion Btu in the chemical industry, and estimate that innovations could cost-effectively achieve 30% improvement by 2020 or 750 trillion Btu/yr [7], an equivalent to emissions from 9-million passenger cars — enough to account for most cars in New York City, Los Angeles, Chicago, and Houston combined.

Many companies responded early to the challenge: Boise Cascade generates 54% of its energy needs from renewable resources; Dow Chemical built seven new cogeneration power facilities since 1994 that reduced usage by approximately 23 trillion Btu/yr, eliminating approximately 1.2-million metric tons of CO<sub>2</sub> emissions [8].

Another development is significant investment in biorefining. Archer Daniels Midland recently launched commercialization of biochemical replacements for petroleum-derived chemicals and stated its intentions to develop new chemicals with increased functionality and lesser environmental impact [9]. More information on biorefining can be found on DOE's Integrated Biorefinery Program webpage ([http://www1.eere.energy.gov/biomass/integrated\\_biorefineries.html](http://www1.eere.energy.gov/biomass/integrated_biorefineries.html)).



**FIGURE 2.** The best opportunity for designing an energy-efficient plant exists during the conceptual design stage

Ethylene from ethanol is also being considered in China [10]. SRI Consulting reported in 1980 on the economics of this concept [11]. With crude oil approaching \$100/bbl, the argument for pursuing this technology is strong.

### Green-engineering checklist

The following items are useful in assessing your situation to evaluate options that support green-engineering goals. Analysis technologies that can help complete checklist items quickly are outlined in Table 1.

#### New plant considerations.

- Consider the conceptual design. The best opportunity to design an energy efficient plant exists during the conceptual stage. Figure 2 illustrates this point: typically 98% of operating costs and 80% of capital costs are committed during front end engineering design (FEED). Simulations, conceptual design software, and pinch analysis tools are of great help during this stage
- Look for opportunities to apply low-energy separation technologies, such as adsorption, membrane separators and pervaporation [12]
- Consider materials of construction for higher process temperatures and applicable, ancillary energy-recovery

equipment (see “Know your options” section below). Begin by proving the process on a small (pilot) scale, then scale up

- Identify the best location for a new plant. Use supply chain technologies and services to identify locations that reduce transportation costs and inventories
- Safety and health are more important than profitability. Consider designs that are safer for workers and environmentally benign even if slightly less profitable. Safety and environmental responsibility are justifications for longer pay-back periods; you will save on insurance and avoid fines
- Balance the trade-off between capital and energy costs. Capital is spent once, but you will pay for energy over and over again with near zero chance its cost will decrease in the future

#### Assess your existing facilities.

- Know where you stand first. Assess the energy efficiency of your plants and compare it to your industry average and to state-of-the-art technologies. If your plant is at the top of its class you will feel assured you’re doing all you can; if you are at the bottom there is much more you can do. EERE’s Industrial Technologies Program and AICHE

provide free software for assessment of energy-efficiency-improvement opportunities. The software called Plant Energy Profiler (PEP Chemical Industry) can be downloaded from EERE’s website (<http://www1.eere.energy.gov/industry>)

- Training: Learn all aspects of your process. If you can’t run or model your process yourself you probably don’t understand it, in which case you should rely on others who can advise on energy improvements. Train your operators to know the variables that influence energy efficiency. Process training and training simulators are good tools for this
- Clean heat exchangers. To make your facilities more efficient, institute heat-exchanger-cleaning programs for your plants
- Consider revamping or retiring old plants. Estimate recoverable energy waste to identify current and future costs

#### Know your options.

- Consider green feeds. Find out if your products or energy can be made from green materials
- Seek knowledge from other industries. Partners from other industries can often help you identify efficiency solutions applicable to your process
- Improve thermal efficiency through well-selected materials of construction. An illustration of this point is an innovation patented by MECS (formerly Monsanto EnviroChem Inc.) known as the Heat Recovery System (HRS). It uses alloys that harness waste heat from sulfuric-acid-absorber coolers for the production of medium- and low-pressure steam. For decades this heat has been rejected to cooling water in plants. The gain is approximately 0.5 lb of steam per pound of acid produced, which for a typical 1000-ton/d plant translates to 337-billion Btu/yr; this is in addition to the 0.9 to 1.3 lb steam per pound of product already recovered
- Dry ice can be used for direct spot chilling instead of expensive indirect refrigeration
- Wet product can save energy. If your customer is near, they may not require dry product, as might be the case with cattle feed from corn-to-ethanol plants

**TABLE 1. CHEMICAL ENGINEERING TOOLS FOR SUPPORTING GREEN ENGINEERING**

Technology — Primary function	Role in supporting green engineering
<b>Steady-state simulation —</b> Heat and material balances, energy optimization offline and online	Compare competing process configurations. Rate operations to spot energy waste, for example, excessive reboiling or refluxing. Find ways to recycle waste streams. Cogeneration, CHP and IGCC are accurately analyzed with steady-state simulators.
<b>Dynamic-process simulation —</b> Dynamic response of systems (equipment and controls)	Configure process control schemes that yield more stable systems and get you closer to optimal energy operation
<b>Advanced controls</b>	Multivariable controllers and on-line optimizers help run plants in a stable manner and at optimal conditions 24 h/d, seven days a week. Stable plants are more energy efficient
<b>Pinch analysis —</b> Minimization of utility usage; exchanger network design	Methodology for optimal matching heating and cooling loads to reduce utilities usage (steam, cooling water, and so on), fossil fuel usage and GHG
<b>Separations design —</b> Separation synthesis design	Useful for devising new separation schemes or improving existing ones. Might help reduce the number of columns in complex separations trains
<b>Detailed heat-exchanger-design tools —</b> Size, rate and simulate heat exchangers	Optimization of heat-exchanger design minimizes capital cost. Detailed exchanger performance analysis combined with simulation can help estimate the effect of heat-exchanger fouling on energy efficiency
<b>Cost-estimation software —</b> Estimate costs as early in the project as possible	Energy efficiency features often cost less than anticipated and quick and accurate estimates improve the chances that innovations will be implemented. These days it is easier for chemical engineers to do cost estimation of process alternatives in parallel with process design
<b>Computational fluid dynamics (CFD) —</b> Analysis of flow patterns inside vessels.	Better mixing and flow distribution can allow hotter process designs with integral cooling systems; important for designing high temperature vessels such as gasifiers

- Consider using waste heat from your neighbors, such as power plants
- Combined heat and power (CHP) is applicable if you burn fuels for indirect heating. CHP delivers steam and electricity for essentially the same fuel cost as steam alone. Although additional capital is required, CHP projects typically pay-back quickly
- Advanced controls and online optimi-

zation are proven technologies that can help save large quantities of energy and raw materials

- Reexamine ideas that might have been too costly or impractical in the past
- Perform complex-wide optimization. Optimization of individual systems seldom equals a more broadly based analysis

### Closing remarks

Many opportunities exist for chemical engineers to support the goals of green engineering. Our profession has made great strides in this effort, but there is still much more to be done. Each year of inaction to curb GHGs reduces our chances of acting in time to avert a worldwide crisis. Expediency is essential as is the need for greater corporate participation, making it our social responsibility to encourage our organizations to get involved. ■

*Edited by Gerald Ondrey*

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