Reinventing Fire Industry Sector Methodology

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Rocky Mountain Institute®

REINVENTING FIRE INDUSTRY MODEL METHODOLOGY

The Reinventing Fire (RF) industry model assesses the financial implications of transitioning the U.S. industrial sector off coal and oil by 2050.

Based on a stock-flow modeling framework and baseline data from EIA's *Annual Energy Outlook 2010* (AEO), the industry model simulates the adoption of energy-saving measures within the industrial sector annually from 2010 to 2050, and tracks the resulting changes in energy consumption, fuel expenditures, and capital investment.

Figure 1 shows the industry model's key interactions with the other RF models: it meets liquid fuels demands from the transportation, buildings, and electricity sectors, and it demands electricity from the electricity sector. Its primary outputs (energy demand by fuel, saved energy expenditures, incremental capital investment) are sent to the overall integrating model.

There are three sets of exogenous inputs: 1) AEO 2010 data (such as capital stocks, combined heat and power (CHP) capacity, and industrial fuel prices), which define the "business-as-usual" (BAU) baseline scenario; 2) the energy saving measures, defined by incremental capital cost and relative energy savings; and 3) technology adoption rates, which drive the transition off coal and oil.

This document details each of the major components of the industry model: 1) capital stock turnover and the baseline forecast; 2) efficient technologies/combined heat and power (CHP) adoption; and 3) refining transformations.

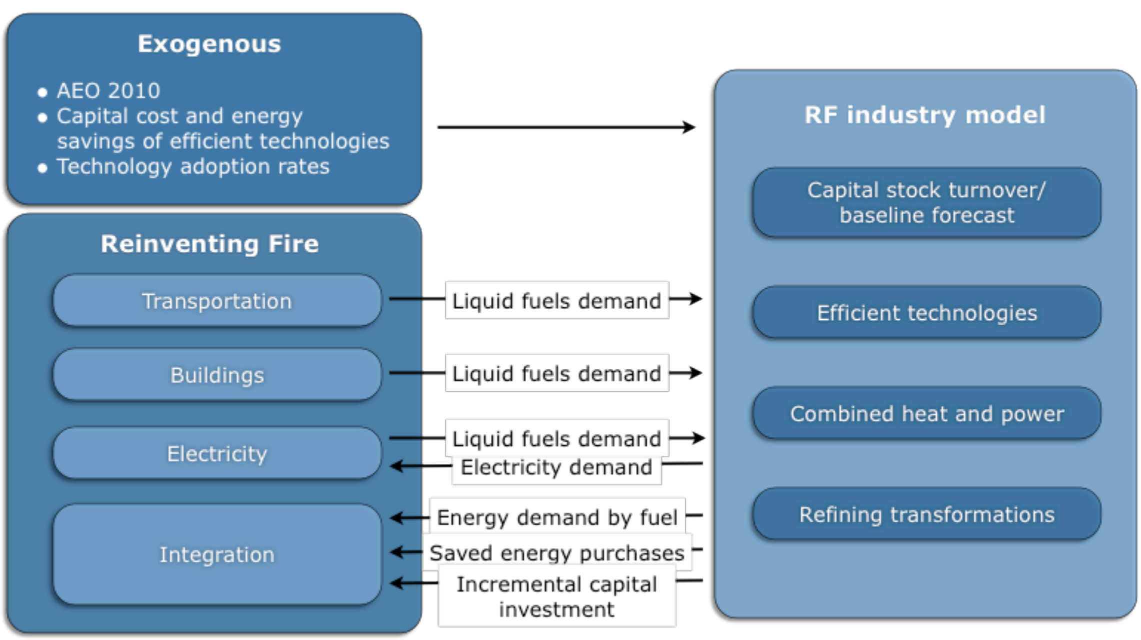

Fig. 1. The industry model in the context of the overall RF system.

1. BUSINESS-AS-USUAL BASELINE FORECAST

The industry model uses a stock-flow modeling framework and data from AEO 2010 (which was linearly extrapolated from 2035 to 2050) to simulate BAU industrial production capacity turnover and energy consumption from 2010 to 2050.

The AEO data are disaggregated by the following industries:

Manufacturing:

- Food products
- Pulp and paper
- Bulk chemicals
- Glass products
- Cement
- Iron and steel
- Aluminum
- Fabricated metals
- Machinery
- Computers and electronics
- Electrical equipment
- Transportation equipment
- Wood products
- Plastic products
- Balance of manufacturing

Non-manufacturing:

- Crop agriculture
- Other agriculture
- Coal mining
- Oil and gas mining
- Other mining
- Construction
- Refining

For each industry, two stocks of production capacity are maintained: the existing (pre-2011) stock and the new (post-2010) stock. The starting values and retirement of existing stocks, and the growth of the new stocks are based on AEO's annual throughput (2000$) projections and annual capacity retirement rates (%/y).

The energy intensity of each industry is based on AEO's unit energy consumptions (UECs) (thousand BTU/2000$), which are disaggregated by end use (process heating, process cooling, machine drive, electrochemical, other process, facility lighting, facility HVAC, facility support, and facility transportation) and fuel type (electricity, natural gas, stream coal, coking coal, residual oil, distillate oil, petroleum coke, LPGs, steam, motor gasoline, and biomass); UECs decrease over time according to AEO's assumed rate of technological improvement for each industry.

BAU energy consumption by industry, capacity stock, end-use, and fuel type is determined by multiplying capacity by UEC, and BAU fuel expenditures are calculated by multiplying energy consumption by AEO's energy price projections.

The model correctly reproduces (within 3% error) AEO energy consumption data by end use and fuel type, as well as CHP and non-CHP steam production and associated on-site electricity generation.

2. EFFICIENT TECHNOLOGIES/COMBINED HEAT AND POWER/WASTE-HEAT-TO-ELECTRICITY

The costs and savings of efficient technologies and CHP were adopted from three Lawrence Berkley National Laboratory (LBNL) reports[1,2]. We converted each measure's cost of conserved energy (CCE) to 2009$. The CCE spreads the incremental net capital cost over the lifetime of the measure into equal annual payments at a certain discount rate, then divides the annual payment by the annual savings. For our analysis, there are no assumptions regarding program costs or the costs of implementing the measures (for internal projects, program costs can be considered normal overhead, whereas for mature utility-funded industrial programs, costs are normally very low – approximately 0.1¢/kWh). The cost of conserved energy assumes a 12% real discount rate, and all values were adjusted to 2009 dollars using the GDP implicit price deflator.

[1] Martin, N., E. Worrell, M. Ruth, L. Price, R. Elliott, and A. Shipley. 2000. *Emerging Energy-Efficient Industrial Technologies*. Lawrence Berkeley National Laboratory.
[2] Xu, T., J. Slaa, and J. Sathaye. 2010. *Characterizing Costs and Savings Benefits from a Selection of Energy Efficient Emerging Technologies in the United States*. BOA-99-205-P, Lawrence Berkeley National Laboratory.

For the efficient technologies, including CHP, we assumed that the real costs and relative savings of the technologies remained constant over the entire *Reinventing Fire* time horizon (2010–2050). We have chosen to hold the potential energy savings constant over time because energy efficiency is not a diminishing resource—as we capture the opportunity, it will also continue to grow through innovation and learning: The percentage savings available today compared to the BAU forecast will still be available in 2050 compared to the 2050 BAU forecast, and at the same real cost. We believe there is substantial evidence of sustained significant technology development (moving along the learning curves of existing technologies while introducing many new ones) to justify this assumption (see *Reinventing Fire*, pp. 137 and 157).

The waste-heat-to-electricity measures were modeled slightly differently. Based on a Lawrence Berkeley National Laboratory (LBNL) report[3], we selected technologies that could cost effectively generate electricity from non-traditional methods (such as waste heat, waste pressure, etc). We applied an average cost for adoption of these measures (for simpler integration into the model).

INTEGRATIVE DESIGN

We estimated additional savings can be attributed to integrative design. In theory, integrative design can be applied to many industrial processes, but our analysis focuses solely on machine drive, chiefly in its two dominant uses (pump and fan systems), for multiple reasons. First, machine drive energy efficiency has huge cross-industry potential as it is used in nearly all subsectors. Second, machine drive consumes electricity, whose end-use energy savings can be leveraged with compounding savings upstream. Third, while integrative design can be applicable in process heating applications, past experience has shown that industry already optimizes process heat relatively well. (However, that is not the same thing as fundamentally redesigning the process so it needs much less heat or at lower temperatures. Our practice confirms that such opportunities are common, but because they are process- and plant-specific, we have not tried to extrapolate them to all industry. Omitting this potential for process redesign makes our integrative-design savings estimates conservative.)

The estimate for machine drive integrative design is based on best-in-class retrofit estimates for fluid handling systems by Dr. Frigyes Lestak[4] and Lee Eng Lock[5]. These two world-class practitioners have redesigned, or are familiar with the redesign of, fluid-handling systems that achieved energy reductions of 80–90% from current energy use, integrating improvements in

[3] Bailey, Owen, and Ernst Worrell. 2005. *Clean Energy Technologies: A Preliminary Inventory of the Potential for Electricity Generation*. Lawrence Berkeley National Laboratory.

[4] Personal communication, Dr. Frigyes Lestak (Shell), April 18, 2011.
[5] Personal communication, Lee Eng Lock (Trane), April 11, 2011.

pipe and duct systems, pumps and fans, controls, and drivesystems[6][7]. Based on that experience, consistent with cases in our own practice, we assume that similar results can ultimately be achieved throughout the industrial sector. We assume a universal 80% savings opportunity that is only applicable to fluid-handling systems, namely pump, fan, and compressed air systems (~50% of machine drive energy consumption).[8]

Because there may be significant overlap between these savings and baseline energy efficiency measures, AEO's baseline savings were subtracted from the estimated potential to generate the resulting integrative design savings potential. Thus, the 80% energy savings potential in pumps, fans, and compressed air systems is reduced to 60.6% savings (after subtracting out the AEO spontaneous efficiency savings of 19.4%). And because the case-studies only apply to pumps, fans, and compressed air systems, we assume that there is 27.3% remaining savings potential for machine drivesystems. Lastly, removing any possible overlap with LBNL motor measures savings (10% total savings), we project a 17.3% savings potential for integrative design.

TECHNOLOGY ADOPTION

In addition to understanding how much energy the industry sector can save through efficient technologies, we also had to estimate the rate of adoption—how much efficiency improvement is installed in a given year. The assumptions for adoption rates are adapted from work and research at the Electric Power Research Institute (EPRI). The EPRI adoption rate is based on the success of past utility programs and is intended to serve as an estimate for energy efficiency adoption if we continue the current trajectory. [9] Based on that work, we have chosen an 85% default adoption rate.

Adoption for energy efficiency technologies (including CHP) is based on a "phased-in" approach, where the implementation and adoption of measures is constrained by the BAU capacity stock turnover. This approach is well grounded because it gives us all a greater idea of the constraints to achieving high levels of energy efficiency: the capital stock will be replaced relatively slowly and few, if any, early replacements are expected to occur.

We do not assume that the U.S. will be able to achieve 85% adoption rates immediately; rather, we assume a linear ramp-up to this rate over twenty years (2011–2030).

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[6] Easton Consultants 1996, S. Nadel, R.N. Elliott, M. Shepard, S. Greenberg, G. Katz, & A.T. de Almeida, *Energy-Efficient Motor Systems*, ACEEE (Washington DC), 2002.
[7] The State of the Art: Drivepower, RMI/Competetik (1989).
[8] United States Industrial Electric Motor Systems Market Opportunities Assessment, Department of Energy, 2002. The *United States Industrial Electric Motor Systems Market Opportunities Assessment* is a survey on motor type and energy consumption and served as the primary source of total motor energy consumed throughout industry.
[9] EPRI. *Assessment of Achievable Potential from Energy Efficiency Demand Response Programs in the U.S* (Palo Alto, CA: EPRI, 2009).

Waste-heat-to-electricity measures, however, were adopted differently. Whereas efficiency measures were based on replacing inefficient equipment, waste-heat-to-electricity measures are not dependent on retiring stock; they can be adopted as applicable. However, since these waste-heat-to-electricity measures are relatively new to many industries, the model adopted these measures at half the rate of efficiency measures.

In addition, because the technical potential of these measures were estimates and may not necessarily reflect feasible applications, the total adoption of waste-heat-to-electricity measures were capped at ~40% of LBNL's estimated technical potential.

3. REFINING TRANSFORMATIONS

Refining transformations are driven by changes in the demand for liquid fuels—oil, biofuels, and hydrogen. Demand from the transportation sector shifts from oil to biofuels and hydrogen; demand from buildings, industry, and electricity decreases as their oil use is phased out.

Oil refining is based on baseline AEO data; we assume no further changes in the process. Biofuels production is assumed to be an advanced cellulosic ethanol process based on NREL's cellulosic ethanol from corn stover process[10]. Hydrogen production is assumed to be from distributed natural gas reforming at the point of fueling (forecourt reformers); energy use and capital costs are based on the H2Gen reforming system[11].

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[10] 2007 NREL/RMI Cellulosic Ethanol Workshop Pre-Read NREL, Lignocellulosic Biomass to Ethanol Process Design . . . , 2002. These process assumptions are conservative, since as noted in *Reinventing Fire*, p. 276, n. 390, a 2007 NREL/RMI/industry charrette found major improvements were feasible.

[11] H2Gen HGM2000/HGM10000 Specifications