ENERGY-EFFICIENT TECHNOLOGY IN THE IRON AND STEEL INDUSTRY: SIMULATION OF NEW TECHNOLOGY ADOPTION WITH ITEMS

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INTRODUCTION

The Industrial Technology and Energy Modeling System (ITEMS) (referred to as ISTUM in Jaccard and Roop, 1990) is an end-use industrial modeling system that is technology based. Because it includes technologies in the process description of industry, it is possible to introduce new technologies to determine, based on economic and performance data, how rapidly these new technologies will penetrate the market (Hyman and Roop, 1996). As these new technologies penetrate the market, energy savings and, possibly, emissions reductions occur that can be tracked with the model as well. This report documents the use of ITEMS to investigate the impact of three new technologies under development with funding from the Department of Energy's Office of Industrial Technologies (OIT), that apply to the iron and steel industry.

While the results of this application are interesting, this exercise points out how important it is to understand how the technologies work and how they make a difference. This report shows that ITEMS can be a useful tool in estimating market penetration of new technologies and the resulting energy savings, but these results are only as reliable as the data. If the model is to be used to compare technologies, the technical data concerning these technologies must be collected using the same set of assumptions and with the same vision of what characterizes a technology. While an effort has been made to understand how these technologies work, there is no assurance that the data used for this analysis were, indeed, collected using the same vision and the same set of assumptions.

The report is organized into five additional sections. The next provides a brief overview of ITEMS and describes how the technical information about OIT projects is use in the model. The third section describes the three technologies that were introduced into ITEMS and reports the relevant data for those projects. The fourth section describes the iron and steel industry, as characterized in ITEMS, in which the data are embedded. This section also provides an overview of the major assumptions that define the simulations that are run for each technology. The fifth section then reports results of the model simulations, showing the rate of penetration of the technologies and the energy savings that result from the penetration of the OIT project technologies. A final section concludes the report.

ITEMS: INDUSTRIAL TECHNOLOGY AND ENERGY MODELING SYSTEM

ITEMS is an economic-engineering model of the industrial sector. It consists of eleven industry modules, one of which is for the iron and steel industry. The beginning year is 1991 and the model will run for 20 periods, with the usual period being a year. It contains twenty "slots" for fuels and ten for emissions. Carbon dioxide is the only emission currently in all modules, although several industries have some SOx and NOx emissions data as well. The software is written in APL, but most interaction is through spreadsheets. As with other engineering-economic models, capacity is fixed at the year of calibration, then is allowed to be retired with age. New capacity is added, based on the calculation of market shares for new equipment, where the governing consideration is costs: annualized capital costs, O&M costs, and fuel costs. This new capacity is retired as it ages as well. Thus over time, new capacity replaces existing capacity, and new capacity is, probablistically, more efficient. This replacement logic generates the typical S-curve showing how new, more efficient equipment replaces older equipment.

Capacity is represented as a collection of technologies, tied together or otherwise linked to changes in the output of the industry. Each technology is described in terms of energy or energy service use, emissions, capital costs, O&M costs and life time. For example, a natural gas fired boiler used to raise steam would be represented by four alternative "technologies," one standard boiler, one with heat recovery, one with regenerative burners, and one with both heat recovery and regenerative burners. These technologies would have slightly different operating characteristics. These different characteristics would allow the penetration of slightly more efficient equipment over time, as new boilers were added or old boilers were retrofitted with these additional features.

This capacity can be linked together to produce a "process flow" description of industry, as is done with all the single industry models, or can be linked directly with the growth of the industry under examination. A basic industry without a flow model would be described in terms of its steam requirements and cogeneration possibilities, its lighting and space conditioning requirements, various heating requirements and five types of auxiliary equipment powered by motors: pumps, fans, compressors, conveyance, and process drive. A process flow description of an industry would provide more detail on how the industry worked, and would include specific types of equipment such as a blast furnaces or basic oxygen furnaces or strip mills. Of the ten modules in ITEMS seven are characterized as process flow.

Model Data

The model is calibrated to energy used in manufacturing as reported in the 1991 Manufacturing Energy Consumption Survey (MECS) (USDOE, 1994). For simulation of the model, the major drivers are industry output and fuel prices (the latter may be derived taken from any of a number of publications; the simulations for this paper use the 1997 Annual Energy Outlook). Output forecasts are derived from the technical appendix to the same source. The MECS data are used to calibrate the end uses for each industry and the fuel types for each industry. This is done with varying success: Food Processing, for example, is within one percent of total energy consumption, but uses more oil than reported by about 7 percent. For iron and steel, the calibration matches fuel consumption by fuel type to within 3 percent for all fuels. To date, no calibration has been done to assure that the industry models track historical data over the recent past.

Economic and Financial Aspects

If new equipment is needed to produce forecast output, capacity is added based on the cost of new technologies. A market share for each new equipment addition is determined by relative costs of technologies, and these market shares affect the speed with which more efficient technologies penetrate. Relative costs are determined by comparing the costs of competing technologies. These costs are calculated based on the initial capital costs that are annualized using a capital recovery factor (CRF), O&M costs and fuel costs (which are calculated based on the technical fuel use coefficients). The capital recovery factor uses information about the cost of capital (i.e., a discount rate) and the life of the equipment to translate capital costs into an annual capital charge for the equipment. In addition, the model can introduce tax write-offs in the form of an investment tax credit or more lenient depreciation schedules (the default is straight-line recovery). All the financial information underlined above is an assumption from the point of view of model simulation.

Model Characteristics

ITEMS is currently a national model, though it could be disaggregated to any region or set of regions for which there is adequate data. There are eleven industry modules: Food and Kindred Products (SIC 20), Wood Products (SIC 24), Pulp and Paper (SIC 26), Chemicals (SIC 28), Petroleum Refining (SIC 29), Stone, Clay and Glass (SIC 32), Iron and Steel (SIC 331), Other Primary Metals (the remainder of SIC 33), Fabricated Metals and Equipment (SICs 34-37), Other Industry (the remaining Manufacturing industries) and Non-Manufacturing Industry.

Technology is represented by end-use energy services, of which there are about 45 industry specific technologies and 10 generic technologies: steam and power generation, direct heat, space conditioning (space heating, ventilation, and cooling), lighting, pumping, fans, compression, conveyance, process drive, and on-site transportation (for non-manufacturing this includes off-road equipment). In iron and steel, there are 7 industry specific technologies. Technologies are represented if they have different fuel use characteristics (coal or residual fuel fired boilers) or if they contain add-on equipment that improves their efficiency (computer controls, for example). One technology may be retrofitted to another technology at a specific cost (changing the burner tip to fire natural gas rather than oil, is an example). In addition to these technical characteristics, the model also contains information about throughput, lives of the equipment and capital and operating and maintenance (O&M) costs.

The fuel slate is industry specific and can include any from these: coal (high sulfur, low sulfur, metallurgical), residual fuel (high and low sulfur), distillate fuel, motor gasoline, LPG, coke, breeze, still gas, blast furnace gas, biomass, electricity and petroleum coke. In addition, the model can associate up to ten environmental residuals (with only carbon currently included in all models) with each technology. In this way, taxes on these residuals can be easily accommodated.

How the Model Works

Each module contains a process flow description of the industry with the major driver a measure of industry activity (output). Engineering coefficients link the process requirements so that each process produces the output or product needed to satisfy the forecast industry output. This assures that, for example, enough molten steel is produced to satisfy the demand for galvanized cold rolled sheet as well as other industry output. The level of process activity gives rise to other service demands such as motor drive, which in turn are satisfied. When all the process and service demands are in balance with output, the module has completed a single year's forecast.

Moving from the prior year to the current year's forecast adds the complication of equipment stock retirement and replacement. A fraction of the prior year's stock of equipment is retired moving from one period to the next, then the remaining stock is compared with the stock needed to meet current output. If addition stock is needed, it is added based on a market share calculation (discussed next). Additions to the stock of equipment are tracked by vintages and are retired probablistically. The calibrated initial stock of equipment is retired on a straight-line basis.

The market share calculation is based on costs of the competing technologies, where costs include annualized capital costs, O&M costs and fuel costs. Fuel costs for a particular technology are calculated based on fuel prices and the technical information about how much of which fuel is used by this equipment. The most cost-effective technology captures the largest market share with the precise amount determined by the cost advantage and a probability (logit) function. Generally, an 80 percent market share will be captured if the cost advantage is 15 percent.

So the model components, then, consist of a process flow model that gives rise to auxiliary service requirements, technologies that provide these process and service requirements, and forecasts and technical information about the technologies. Changes to forecasts, technical information and economic assumptions are done on spreadsheets, with that information then loaded into the model.

DESCRIPTION OF OIT PROJECT DATA

The OIT project data are reported on forms that name the technology, describe competing technologies and estimate the size of the market for the technology. The analysts that provide the data are asked to provide estimates of when the technology will be commercialized, what percent of the market it will capture and how rapidly the technology will gain market share. In addition, estimates of the capital and operating and maintenance costs are provided, along with the estimated size of the units and the energy efficiency, operating factor and equipment lifetime of the project and currently competitive technologies. If emissions reductions for the new technology are significant, they are also compared to current emissions. In addition to this summary data, detailed tables show how the data are calculated and provide much of the underlying assumptions about the technology and current competitive technologies.

Embedding OIT Project Data

To use this information in ITEMS, the competing technologies are identified and new (OIT) technologies are added to the industry module for that industry. From a decision-maker's perspective, it is the relative costs that are important, not the absolute costs, so the technical information provided by the project data sheet is modified so that relative differences are maintained. That is, if the capital costs for an OIT drying technology are 10 percent higher than current competitive technologies, then the new technology is introduced into ITEMS with a capital cost that is higher, by ten percent, than the current technology currently described in ITEMS. Similarly, we modify other technical characteristics of exiting technologies -- throughput, efficiency, O&M costs -- by the percentage difference provided on the project data sheet. These changes to the model are described in more detail in the next section.

The technologies embedded in ITEMS were taken directly from the OIT project data collected as part of the Quality Metrics (QM) program. The three technologies that were selected for inclusion in ITEMS were -- waste oxide recycling, dezincing of scrap steel and advanced process controls. The relevant characteristics of these technologies, along with the model simulations numbers, are shown in the Table below:

Table 1. Steel Industry Technologies

Characteristics of QM Technologies Embedded in ITEMS					
Model Run	Description	Energy Savings	Cost Changes Capital	O&M	Other Impacts
1	Waste Oxide Recycling	10.0%	-40.0%	-30.0%	Yes[+]
2	Dezincing of Scrap Steel	-2.5%	Yes[#]	Yes[#]	Yes[*]
3	Advanced Process Controls	1.15%	Yes[#]	-1.13%	SOx and NOx

[+] Yes: SOx, NOx and VOCs are all reduced.
[#] Incremental costs not relative to existing costs.
[*] Increases zinc credit and reduced unusable scrap by 87 percent.

The project data sheets provided a project/technology name, technical and commercial characterization of the technology, an indication of competing technology, the market targeted for this technology, environmental characterization of the technology and some measure of both the commercial and technical uncertainty surrounding the research effort. The data extracted from these sheets was then embedded in the model.

While the project data sheets show these technology characteristics, this information cannot be simply embedded into ITEMS. First, dezincing is not represented in the model at all, so capturing the benefits of this technology would not be possible without altering the model, which was not done for this paper. Secondly, the waste oxide would have to be processed to include it into the iron-making stage, and how this is done is not explained in the data sheets, although the project staff have a clear vision of this. Third, the process controls apply to many different technologies, so intoducing these incremental savings is quite easily done, but again, the data sheets do not make this clear.

Further, while costs are indicated in millions of dollars, they are presented in the table as percentages for two reasons. First, the calibration year for the model is different from the date used as a base year for the QM data. Second, more than a single size is used in the model while the QM data apply to a "typical" unit size. When the technology changes were introduced into ITEMS, the percentage changes were applied to the capital and O&M costs for each size class used in the model for the new technology. For the two technologies that do not have comparable costs, new technologies were not actually embedded; rather, the incentives to adopt more efficient technologies were provided by reducing the capital costs by 10 percent.

With this information embedded into ITEMS, several simulations were conducted. First, a base case was run with all of the technologies turned off; i.e., the QM technologies were simply not available to be used by the industry. For the base case and all technology cases, there were three assumptions about the industry's implicit discount rate (d): 1) a business-as-usual assumption, that the payback period was 2 years or less (d=0.5); 2) a rate close to the QM project data assumption, usually d=0.15; and an intermediate assumption with a payback of about four years (d=0.33). Then the technologies were turned on to simulate the introduction of these technologies.

THE INDUSTRY AND THE BASE CASE ASSUMPTIONS

The iron and steel industry is represented in ITEMS as a separate module. The flow diagram of the industry is shown in Figures 1 and 2, and consists of several major process activities. At the top of Figure 1 is the primary output demand, measured by inflation adjusted value of gross output for the iron and steel industry.

This output is partitioned into product demand for several major steel products, space conditioning and lighting. The three major products considered are slabs, blooms and billets. Slabs are further processed into pickled slab, hot rolled sheet, cold rolled sheet and castings. Cold rolled sheet are further processed in the model by annealing and tempering, galvanizing and electroprocessed sheet. Blooms go to heavy structural shapes, tubes and to castings. Billets are processed into bar, rod, castings and light structural shapes. Molten steel is used to produce all of these major products, with reheating used where needed. The molten steel comes from either a mini-mill using an Electric Arc Furnace (EAF) to process mainly scrap, or an integrated producer that produces the molten steel either in an EAF or a Basic Oxygen Furnace (BOF). Options allows ladle refining and preheating. A separate process is included for the production of oxygen.

All of this gives rise to auxiliary service demands, that are shown in Figure 2. In addition to the production of oxygen, a number of other auxiliary services are needed, including conveyance, compression air displacement, and pumping, represented by the next four output groups. The process output group represents the motor drive requirements for process stages, such as cryogenic compressors. These motor drive requirements are provided by motors (electric or steam) of various size categories. When all the electric and steam requirements are known, a decision can be made between cogenerated and boiler produced steam, shown as the steam output group.

The major drivers of this process model are industry output forecasts and projections of energy prices. In addition, there are also a number of assumptions that are integral to the base case assumption. Output forecasts and price increases are based on the *1997 Annual Energy Outlook*. This scenario indicates that output from the industry will grow by about one-quarter of one percent until 2000, then decline first by 0.37% to 2005, then by 0.44% through 2010. Declining output after 2000 makes for a harsh environment into which to introduce new technologies. Moreover, energy prices remain flat in current dollar terms from 1997 though the end of the forecast period, which implies a declining set of prices relative to the base year, 1991. For this simulation, these output movements were smoothed so they increase gradually to the 2000 peak, then decline though the forecast period. Energy prices wer taken directly from the AEO-97 output files.

The other assumptions that are important to the base case and forecasts are the discount rate used to calculate the capital recovery factor and the effective lives of capital equipment. In no case was the life of the equipment different from that contained in the model. The discount rates used have been explained above. A number of other assumptions -- the growth of different steel products, for example -- may have some effect on the outcome of the simulations, but we have not explored these assumptions systematically.

Flow Model:
Iron and Steel Industry

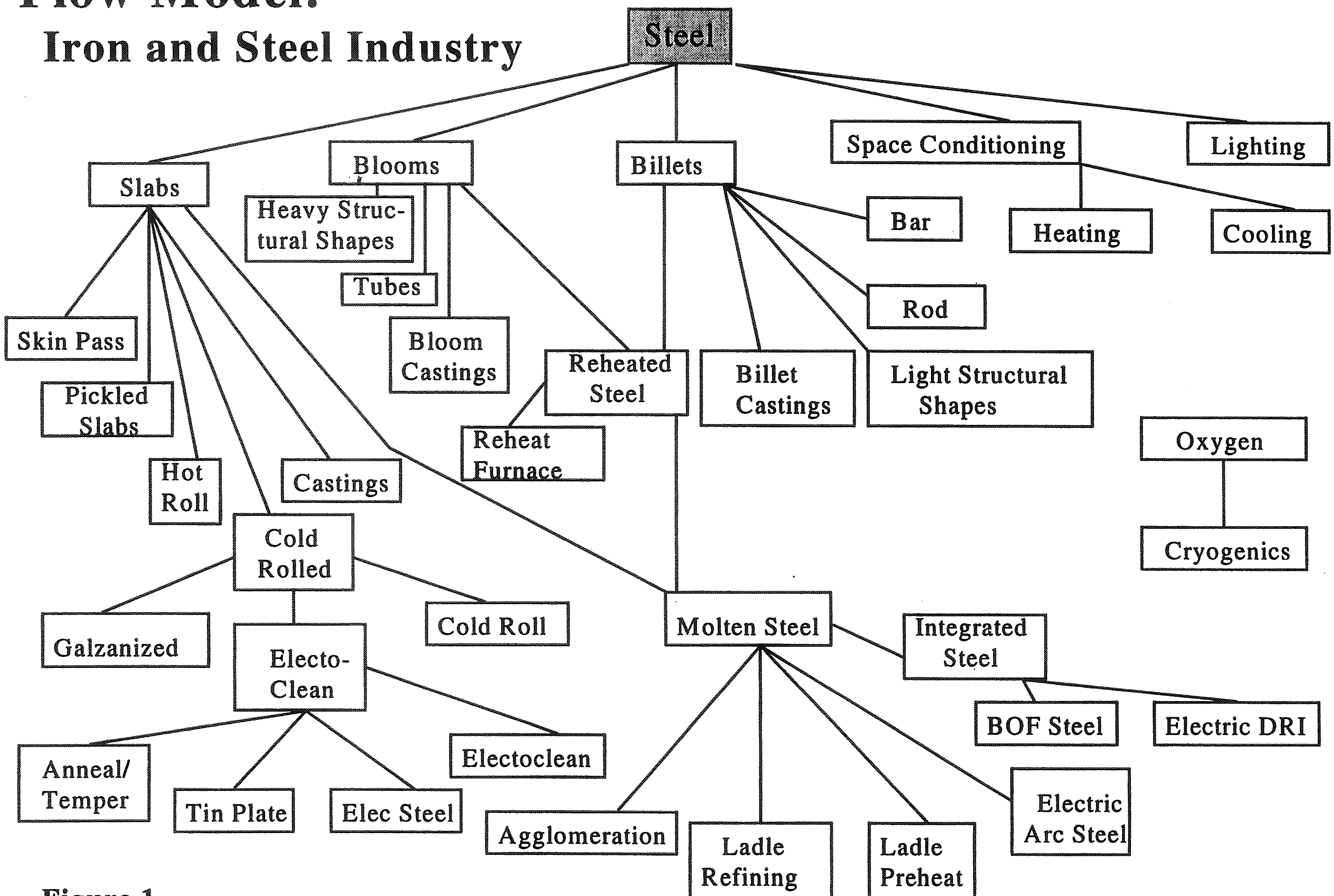

Figure 1

Auxiliary Process Components

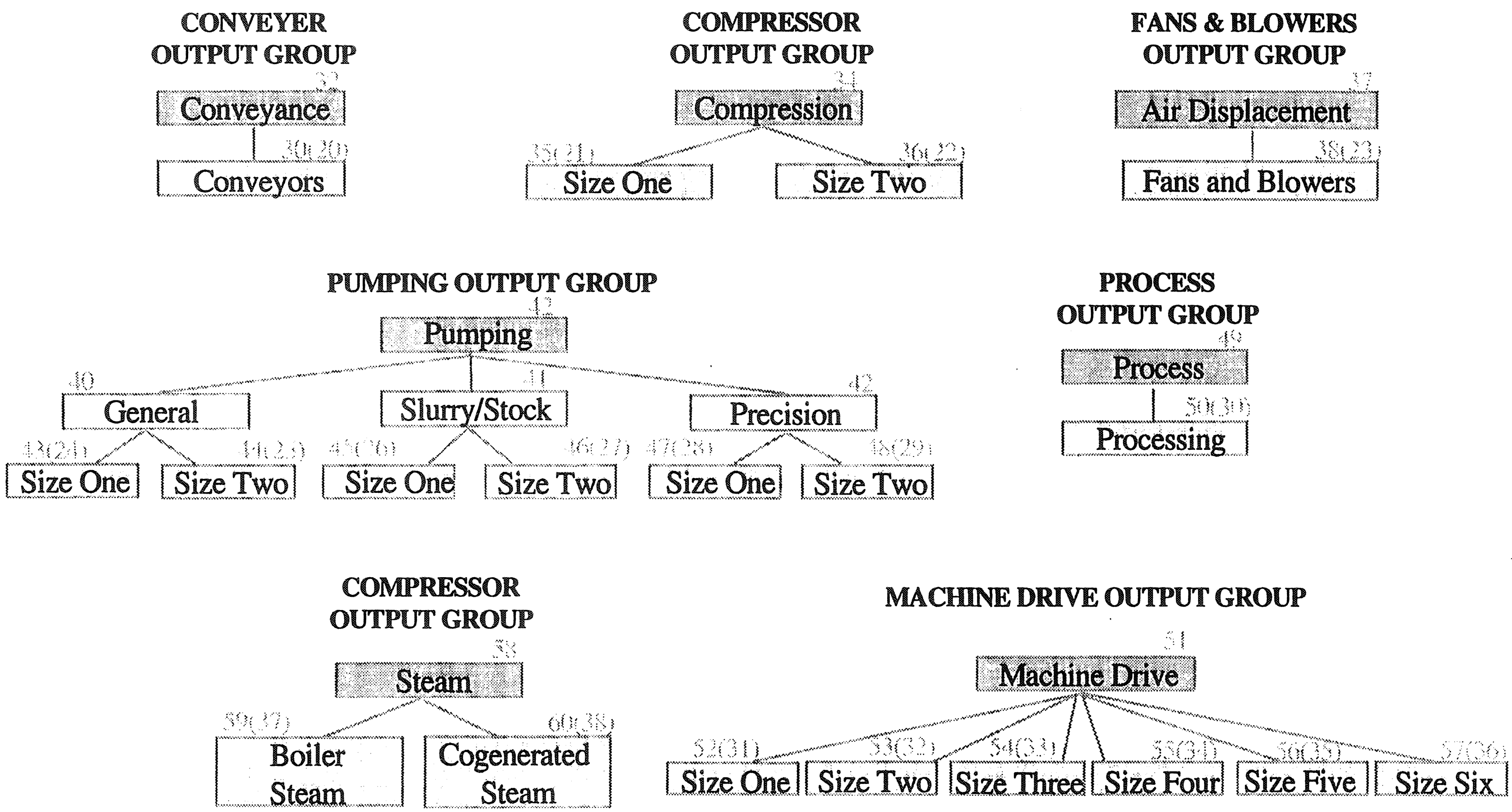

Figure 2

RESULTS

A close look at the Table 1 suggests that one of the technologies, the first, ought to penetrate immediately and substantially -- there is substantial energy savings and the capital and O&M costs are both lower. One would reach this conclusion because energy savings and emissions reduction occur while costs are either reduced or unaffected. For advanced process controls, the incremental costs is $1 million, which instantly saves $4.5 million in O&M costs and $1.34 million in fuel costs. In other words, the industry can get something for nothing, at least compared to competing technologies. To make this technology less obviously a winner, the simulation incorporated just the energy savings, not the capital cost reductions or the O&M savings..

The more interesting cases are those technologies that may not obviously penetrate -- dezincing of scrap steel and advanced process controls. In the case of dezincing, the project data sheets indicate that the capital costs will increase by $4.09 million dollars for a typical sized dezincing recovery facility. In addition, $2.4 million will be incurred in O&M costs but will save about $1.5 million in energy costs. Moreover, this will provide about 990,000 lbs of zinc by-product and prevent 95,700 tons of scrap from being unusable.

But there is more to this story than just the model results, and it reflects on the story that the project data sheets do not tell. For a dezincing process to penetrate as suggested by the QM data, there would have to be a premium to the price of dezinced steel relative to that of galvanized steel. Our industry contacts suggest otherwise; indeed, it can be argued that the mini-mill producers would pay as much for galvanized as clean steel scrap, because zinc is recovered in the process, and the recovered zinc is a source of revenue to the firm. This sort of conflict is not something that is resolved well within the confines of the QM data sheet, nor in these model runs. Indeed, because of this conundrum and because there is no dezincing technology in the model, this case was not run.

We introduced a new technology into the model that competes with steel making via the blast furnace route, using a basic oxygen furnace (BOF). This technology saves 10% of the energy, but costs are identical to the least cost route without the savings. A more complete analysis of this technology would integrate, into the model, the new technologies needed to recover the iron from the oxide wastes in this process and in other processes.

So what effect does this technology have on the iron and steel industry? Total energy for the industry is reduced by about 40 petajoules (PJ) or 38 trillion Btu (TBtu) as a result of introducing this technology. This savings occurs regardless of the discount rate used, an example of which is shown in Table 2 for the waste oxide recycling technology. The impact of the discount rate on energy consumption is also shown in Table 2. The lower discount rate encourages the penetration of more efficient technologies thus lowering the cost of fuels. The discount rate impact on energy consumption has about four times the impact on energy savings than does the introduction of a single new technology.

This new technology captures a third of the relevant market for new technology when introduced, but this advantage is eroded over time as alternative iron-making technologies penetrate the market. By the end of the period, this share has eroded to only 22 percent, with most of the difference captured by direct reduction of iron. An elaboration on this point is warranted.

Whipp (1997) argues that a revolution is going on in the steel-making industry as a result of three factors. The first is the expansion of the direct reduction of iron. The world production of direct reduction iron (DRI) and hot briquetted iron (HBI) has increased from 17.7 million tonnes (= metric tons) in 1990 to 33.3 million tonnes currently with an expected production of 55 million tonnes by 2000. The second factor is thin-slab casting and the third is increase in the quality of electric arc furnace (EAF) steel. The first and the third factors are not unrelated.

This growth is occurring in the U.S. as well. Currently (1996) the U.S. imports nearly 4 million tonnes of alternate iron (half of which is pig iron) and has plans to expand EAF capacity from 8 million tonnes per year to 24 million tonnes per year by 2000. The feed for EAF can be either scrap, which dominates in the U.S., or DRI/HBI. The choice between these two is based on quality and price.

Table 2. Energy Consumption and Changes for Oxide Technology

Energy Consumption Summary (Petajoules)

	1991	1996	2001	2006	2011
Scenario 3 – Base Case					
TOTAL FUELS	1435.2	1816.0	2054.2	2082.4	2136.6
Scenario F3 – Base with New Technologies					
TOTAL FUELS	1435.2	1813.9	2032.7	2051.1	2096.3
Delta, S3 - S4	0	15.5	25.3	31.5	38.2
Delta, S4 - S3	0	49.4	87.8	110.7	132.1
Delta, S5 - S3	0	64.9	113.2	142.2	170.2
Delta, S3 - SF3	0	2.1	21.5	31.3	40.4
Delta, S4 - SF4	0	2.1	21.5	31.5	39.8
Delta, S5 - SF5	0	2.7	23.3	32.8	41.4
Delta, SF3 - SF5	0	65.5	114.9	143.6	171.2

The introduction of better controls was applied to a variety of technologies, not as the introduction of new technologies by rather as incentives to adopt more efficient technologies. Specifically, The most energy efficient technologies for integrated steel-making, EAF steel-making, and casting was given a cost advantage of five percent relative to the base case. The results of that simulation are shown in Table 3.

Table 3. Process Controls Simulations

Energy Consumption with Process Controls

Proc Control, Base	1435.2	1791.7	1998.5	2011.5	2049.9
Base w/ New Techs	1435.2	1729.7	1865.2	1837	1835.3
Proc Contol, 15% DR	1435.2	1791.7	1974.3	1974.2	1999
Delta w/ New Techs	0	62	133.3	174.5	214.7
Delta for Disc Rates	0	0	24.1	37.3	51.0

In this case, the process control technologies improve energy consumption by about 215 PJ (204 TBtu) in 2011. By reducing discount rates to 15 percent, a further 51 PJ can be saved.

A final simulation examines the impact of a $50 a tonne carbon tax on the base case and the lowest discount rate case. A tax of $50 applied differentially across the board (i.e., based on the carbon content of the fuel) would reduce energy consumption under the base case by only about 88 PJ (83 TBtu). Under a decision-making regime of 15 percent discount rates, an additional 145 PJ would be saved. These results are shown on Table 5.

Table 5. Simulation with $50 Carbon Tax

Energy Consumption w ithCarbon Tax

	1991	1996	2001	2006	2011
Base Case	1435.2	1791.7	1998.5	2011.5	2049.9
Base w / Carbon Tax	1435.2	1791.7	1970.5	1952.7	1961.9
15% DR, W/ Carbon Tax	1435.2	1748.4	1864.5	1827.6	1817.3
Delta w / Carbon Tax	0	0	28.0	58.8	88.0
Delta w / Taxes at 15%	0	43.3	106.0	125.0	144.5

CONCLUSIONS

This report shows that ITEMS can provide an estimate of market penetration of new technologies based on their technical and economic performance. Maybe of as great a value is the fact that ITEMS can provide a valuable tool to examine the impact of OIT project technologies on industry performance. The embedding of three iron and steel technologies in that industry module demonstrates these points.

For ITEMS to do its job well, there must be adequate understanding of how new technologies will alter the way the industry produces its product and what is being considered in the cost and other technical estimates. Discussion of the dezincing technology highlights the need for this understanding. What ITEMS does best is explore the impact of multiple technologies, each of which may affect the same stage of production in a process-flow description of that industry. But it is hardly worth using ITEMS for technologies that stand alone and are obvious winners -- that save energy, reduce emissions and have lower capital and operating and maintenance costs.

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