ENERGY ANALYSIS OF COAL LIQUEFACTION SYSTEMS

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Net energy analyses of three integrated coal-liquefaction systems have been performed. In this paper the following facets of the analyses are discussed: methodology, liquefaction systems, energy balances, and energy ratios.

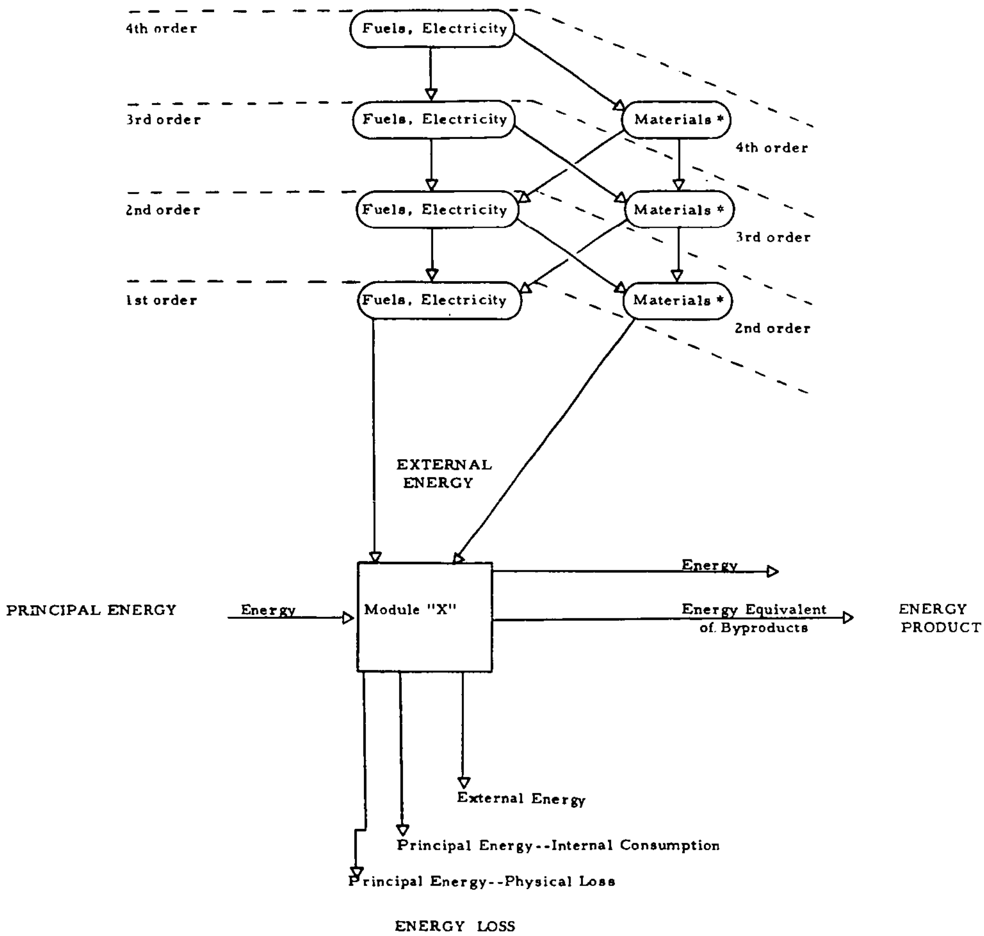
Methodology

Integrated fuel systems can be divided generally into steps. For the purpose of this analysis seven steps, or modules, were chosen. The seven steps with examples are: (1) Extraction- coal surface mining, (2) Transport I- haul to railroad, (3) Process- crushing, (4) Transport II- rail haul, (5) Conversion I- coal liquefaction, (6) Conversion II- electrical generation, and (7) Distribution- electrical transmission. Other examples follow the same general format, though they may require minor adjustments of individual modules (e.g. two-stage transport).

An analysis of a multi-step fuel system naturally reduces to the combination of analyses of individual modules. Consequently we shall next describe the analysis of a single module. A diagram of a module of an integrated fuel system, Fig. 1, displays the important features of modular analysis. The first law of thermodynamics is observed--Ein=Eout. Also, energy derived from and used within the system is always internal to the module. These precautions avoid a problem associated with some energy anlyses, ambiguous construction of system boundaries.

Energy input consists of two parts, Principal Energy and External Energy. Principal Energy is the primary energy input. External Energy is the sum of fuels , electricity, and of the energy embodied in materials which are purchased or "imported" from energy systems other than the one being analyzed.

Figure 1- Modular Analysis



* Materials include raw materials, containers, machinery, consumable manufactured items (catalysts, lubricants, chemicals, process additives, etc.), tools, pipelines, wiring, construction materials, and road materials (asphalt, cement, tar, steel, etc.)

The energy "backup" needed to deliver External Energy must be considered to fully account for energy drain from other energy systems, thus requiring determination of the energy required to support direct inputs. This is diagrammed as ascending higher-orders of External Energy. Two different methods have been used to compute the higher-order energy inputs. Conversion factors developed from input-output data (Herendeen and Bullard 1974) were applied to material dollar costs, after appropriate deflation to the base year of 1967. This method was considered the best available for each material input without employing tedious calculations. However, for fuels and electricity the alternative of iteration combined with empirically derived approximations at or above order three was adopted. This alternative is more precise, and flexible, than the application of conversion factors similar to those used for material energy equivalents.

Energy Product and Energy Loss comprise Eout. Energy Product is defined as the energy of the primary energy form produced by the module, plus the energy of secondary forms produced for outside distribution, plus the energy equivalent of salable byproducts. Energy Loss has been divided into three parts. Physical Loss is the sum of losses of the Principal Energy input due to spillage, leakage, disposal of waste materials, etc. Internal Consumption is the energy required from Principal Energy to provide heat or power for the process. The third loss category is External Loss. Normally this is the sum of the external energy inputs. In some circumstances, however, an external energy input will be incorporated in the Energy Product, e.g. additives to petroleum products; and then the External Loss will be less than the External Energy input.

Modules are combined simply by adjusting the Energy Product of one modules to equal the Principal Energy of the following module, and so on. This automatically requires a corresponding change in the External Energy, the Energy Loss, and the Principal Energy of the first module. Finally, totals for an integrated fuel system, a sequential combination of seven modules, are: (1)Principal Energy--the intial Principal Energy input, (2)External Energy--the sum of External Energy inputs of each normalized module, (3)Energy Loss--the sum of Energy Loss outputs of each module, and (4)Energy

Product-- the final Energy Product output plus the sum of byproduct energies of each module.

Coal Liquefaction Systems Studied

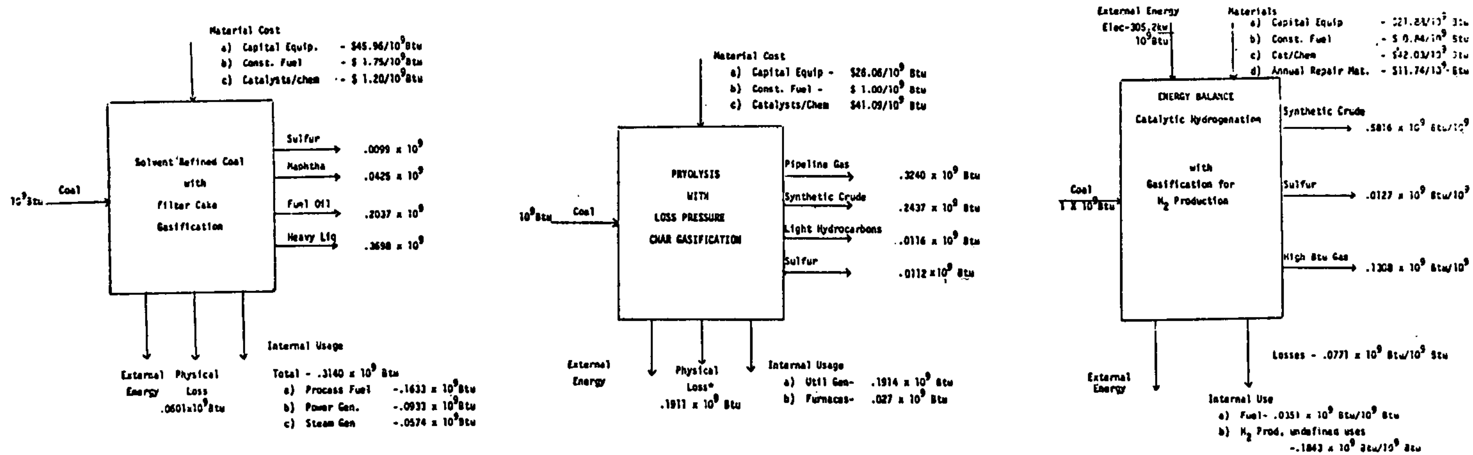
Three proposed coal liquefation facilities were examined in this study, for inclusion in a hypothetical integrated synfuels module string. Data on solvent refined coal, pyrolysis with char gasification and catalytic conversion of coal from engineering studies were utilized to perform the net energy analysis. A brief technical description of each process is given below.

Solvent refined coal (1,2,3,4,5,6) is a process by which coal is converted to a clean boiler fuel by mild hydrogenation in the presence of a solvent. Products of this process are sulfur, naphtha a fuel oil and a heavy liquid or solvent refined coal, which has a higher heating value of approximately 16,000 BTU/lb. Included in the system boundary for this proposed plant are an oxygen plant and filter cake gasification plant to produce process hydrogen, an electric generating power plant for process electricity, a coal preparation plant, and waste water and gas cleanup facilities.

Pyrolysis of coal (7,8,9) was also studied for net energy conversion. The process examined produced both pipeline quality natural gas and a synthetic crude oil, suitable for upgrading in a refinery. Coal is pyrolyzed in multistage fluid-bed reactors, resulting in gas, liquid, and solid (char) fractions. Char is utilized in a low-pressure gasification reactor to produce process hydrogen necessary for upgrading of the pyrolytic liquids. Battery limits of the plant include an oxygen plant and a char gasification facility, a process plant for electric utility generation, and gas gas scrubbing and waste water cleanup subsystems.

The third system studied was catalytic coal conversion (10,11,12). This process produces both a high-quality synthetic crude oil and a high-BTU pipeline gas. The syncrude is suitable for further refining to gasoline and other hydrocarbon products. A coal-solvent mixture is hydrogenated in an ebullating catalyst bed, forming gaseous and liquid byproducts. The process, as entailed in the energy balance includes a coal gasification subsystem for generation of process hydrogen, a coal preparation plant, and gas scrubbing and waste water treatment facilities.

Figure 2- MODULE ENERGY BALANCES



*Physical Loss and Undefined Internal Use

Energy Ratios

The subjects of net enrgy and of net-energy ratios have provoked more heat and less light perhaps than any other feature of the area of energy analysis. Several different ratios have been advanced as the answers to questions of how well one energy system performs relative to another. Objections to energy ratios generally have centered around undifferentiated aggregations of different energy forms -- electricity, petroleum, natural gas, coal. It has been pointed out many times that the value of energy is determined by many other factors than heat content. These arguments are sound, but they only show that ther is no completely adequate standard of comparison among energy systems. With this qualification in mind, we define three different net energy ratios which address three different questions of legitimate concern to the public and their decision-makers.

The net-energy ratio R_1, for an integrated energy system, is defined as the Energy Product divided by External Energy. The ratio R_1 addresses the question, "How much energy is required from other energy delivery systems to support this energy system?" The net-energy ratio R_2 is defined as Energy Product divided by Energy Loss. The ratio R_2 addresses the question of energy system process efficiency. The net-energy ratio R_3 is defined as Energy Product divided by the sum of Energy Loss and Extraction Loss. The ratio R_3 addresses the question of how efficiently natural resources are being used. These three ratios can be helpful in determining the performance of an integrated energy fuel system if care is employed in their use. Two systems should be compared only if their end fuel products are the same or, alternatively, if their final services are the same.

With this qualification in mind, we determined the following net-energy ratios for coal liquefaction plants only. The ratio R_3 does not apply since extraction is not included.

	R_1	R_2
Solvent refined coal	128.21	1.65
Pyrolysis	44.97	1.40
Catalytic hydrogenation	18.49	2.17

These results are not directly comparable, because the plant products are different in each case. However, general conclusions can be drawn. First, coal liquefaction plants produce many times as much energy as they require from external sources. Second, a plant which is more independent of external sources consequently yields a higher R_1, but is not necessarily more process efficient. And third, changes in process details can largely alter net energy ratios, e.g. sustitution of imported power for internally generated power in the Solvent refined coal process would lower R_1 by an order of magnitude.

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