tospheric plasma (2). The application of this torque in turn requires that the ionosphere (and the magnetospheric flux tubes magnetically connected to the ionosphere) rotate somewhat slower than the neutral atmosphere.

A straightforward analysis of this coupling process (3) predicts a specific radial dependence of the required corotation lag, which becomes significant at distances of the order of $L_0 R_J$, with R_J = Jupiter radius and

$$L_0 = (\pi \Sigma R_J^2 B_J^2 / \dot{M})^{1/4}$$

where Σ is the effective height-integrated Pedersen conductivity of Jupiter's ionosphere, B_J is the dipole field strength at the surface, and $\dot{M}$ is the rate at which plasma mass is produced and transported outward in the magnetosphere. Pre-Voyager 1 estimates of Σ ($\sim$ 0.1 mho) and $\dot{M}$ ($\sim 10^{28}$ amu/sec) yielded the expected length scale $L_0 \sim 60$ (3).

The Voyager 1 plasma detector (4) has provided the first measurements of plasma flow in the Jovian magnetosphere. The results (5) are shown in Fig. 1. The departure from ideal corotation is seen to be significant as close in as $L \sim 10$. Figure 1 also shows theoretical curves derived directly from my earlier result (3) for three different values of L_0, corresponding to three possible values of the ratio $\Sigma/\dot{M}$. The large-scale radial dependence of the data is represented adequately for a value $L_0 \sim 20$.

Two interesting conclusions can be drawn from this comparison. First, it is qualitatively apparent that the atmosphere-magnetosphere coupling is indeed too weak to enforce corotation, a possibility that had been anticipated (2, 3) but not generally appreciated before Voyager 1 observations. Second, the comparison indicates that the pre-Voyager 1 estimate of L_0 ($\sim$ 60) was too large by a factor of 3, implying that the ratio $\Sigma/\dot{M}$ was, during the Voyager encounter, some two orders of magnitude smaller than anticipated. The pre-Voyager estimate of Σ ($\sim$ 0.1 mho) would appear, if anything, to be a lower limit because it is based on an ionosphere model that neglects the effects of auroral electron precipitation, which tends to increase the atmospheric conductivity (6). We are thus left with the conclusion that the mass-loading rate $\dot{M}$ was, during the Voyager 1 encounter, much larger than anticipated, namely, $\sim 10^{30}$ amu/sec (corresponding, for example, to 3×10^{28} S^+ ions per second. This exceeds by nearly an order of magnitude the S^+ injection rate suggested by Voyager 1 ultraviolet observations of the Io-associated plasma torus (7), which was itself much larger than had been anticipated. Recent analysis of Voyager 1 plasma data near Io's orbit tends to confirm the large mass-loading rate inferred above (8).

The large fluctuations of the data about the "average" ($L_0 = 20$) profile may be attributable to transient effects, inhomogeneities in Jupiter's ionospheric conductivity, localized convection cells, time variations in the mass-loading rate, and so forth. I will, however, follow the advice of the plasma experimenters that "structure in the curve should not be overinterpreted" (5).

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9. A comparison similar to that made in this report was first presented by G. L. Siscoe (paper presented at the Magnetospheric Boundary Layer Conference, Alpbach, Austria, June, 1979). I am indebted to H. S. Bridge for furnishing a prepublication copy of the data shown in Fig. 1 and relevant details of the data analysis. I have enjoyed stimulating discussions on this subject with A. J. Dessler and G. L. Siscoe. Supported in part by NSF grant ATM78-21767.

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Net Energy Analysis of Alcohol Production from Sugarcane

Abstract. *Energy requirements were calculated for the agricultural and the industrial phase of ethyl alcohol production from sugarcane grown in Louisiana. Agricultural energy requirements comprised 54 percent of all energy inputs, with machinery, fuel, and nitrogen fertilizer representing most of the energy subsidies. Overall net energy benefits (output:input) for alcohol production ranged from 1.8:1 to 0.9:1 depending on whether crop residues or fossil fuels were used for industrial processes.*

In the search for alternative energy sources, considerable attention has been directed toward the production of alcohol to serve as a gasoline extender (gasohol) for internal combustion engines (1-4). Many gasoline retailers in the Midwest are already selling gasohol for use in automobiles (4). Although most industrial alcohol is produced from petroleum, most ethyl alcohol presently produced for blending with gasoline is based on agricultural crops as the raw material.

Table 1. Energetic cost of surgarcane production in Louisiana.

Input	Amount (per acre)	Energy expended ($\times 10^3$ kcal/ha)	Percent of total
Labor*	16.4 hours	22	0.3
Machinery†	$83	1576	18.6
Fuel‡	47 gal	4063	47.9
Nitrogen§	96 lb	1992	23.5
Phosphorus§	32 lb	120	1.4
Potassium§	48 lb	125	1.4
Seed‖	83,000 kcal	205	2.4
Insecticide¶	2.0 lb	54	0.6
Herbicide¶	10.6 lb	288	3.4
Total		8481	100

*From Campbell (11, 12); based on 8723 hours of labor per 675-acre farm plus one full-time manager at 45 hours per week; calorie equivalent, 544 kcal per man-hour (6). †From Campbell (11, 12), Pimentel *et al.* (6), and Ricaud (20); see (14) for explanation. ‡From Campbell (11, 12); includes transportation, tractors, harvesters, loaders, pickup trucks, and repair trucks; hours used times gallons per hour or miles per gallon; 35,000 kcal per gallon (22). §From Campbell (11, 12) and Carville (13); 120 lb of nitrogen, 40 lb of phosphorus, and 60 lb of potassium per acre planted. From Pimentel *et al.* (6) 8400, 1520, and 1050 kgal per pound for nitrogen, phosphorous, and potassium, respectively. ‖From Da Silva *et al.* (5); calorie equivalent of cane plant, 820,000 kcal/ha per 4 years. ¶From Campbell (11, 12) and Carville (13); 2.25 lb of insecticide per planted acre and 10.6 lb of herbicide applied per acre per year. From Pimentel *et al.* (6); 11,000 kcal per pound of insecticide or herbicide.

The gasohol production process needs to be thoroughly examined, however, before a large-scale production commitment is made in the United States. With the energy and land constraints that already exist for food production, it is important to analyze the net energy yield of alcohol production from agricultural crops, and to examine the consequences of the removal of significant portions of agricultural land from the food production base (5-9). In this report we analyze the net energy yield of fuel alcohol derived from sugarcane. The net energy analysis methodology presented here is adaptable to the analysis of other food (grain) crops and can therefore be used to make direct energy comparisons.

In modern agricultural systems, cultural energy subsidies have become integral and indispensable to the production process. In this study, direct energy (energy used for product manufacture as process heat) and material energy (capital equipment, services, labor input) subsidies to sugarcane were evaluated. Environmental inputs [rain, sun, wind, and soil; see Gilliland (10)] were not included, nor were federal, state, or local drainage project subsidies and costs of transporting alcohol and blending it with gasoline.

Crop data and yields for Louisiana sugarcane were from Campbell (*11, 12*) and Carville (*13*). Labor, machinery (*14*), fossil fuel use, fertilizer, and insecticides were translated to an energetic basis by using the conversion factors reported by Pimentel *et al.* (*6*), Heichel (*8*), and Da Silva *et al.* (*5*). The energy components were calculated for fallow plowing, planting, cultivation or production, harvesting, and other farm operations. Calculations were based on a late summer sugarcane planting, two ratoon crops, and a winter, spring, and summer fallow period. At any one time, one-quarter of the Louisiana sugarcane acreage is fallow, one-quarter has cane less than 1 year old, one-quarter has 2-year-old cane (first ratoon), and one-quarter has 3-year-old cane (second ratoon crop). The average annual yield of first-crop cane and two ratoon crops of sugarcane is 53 net millable tons (wet weight) per hectare (*11, 12, 15*). This average includes a rotation in fallow after the second ratoon crop.

Energy requirements for alcohol production from sugarcane (*5*) included the energy necessary for raw material processing and absolute (anhydrous) alcohol distillation, which is accomplished by steam generation. Capital costs of processing plants were also included (*16*). Distillery energy requirements were determined and compared for sugarcane crop residues (*5*) and fossil fuel as fuel.

The materials used in producing sugarcane and their energetic equivalents are listed in Table 1. In this high-technology enterprise three inputs (fuel, nitrogen fertilizer, and machinery) account for 90 percent of all energy inputs to the agricultural phase of alcohol production. Fuel used to operate machinery accounts for the highest consumption of energy, approximately 48 percent of the total. Labor comprises less than 0.3 percent of the energy inputs to sugarcane production in Louisiana.

For the industrial phase of alcohol production it has been shown that 66 liters of anhydrous alcohol are produced per ton of sugarcane, that 1 liter of alcohol consumes 5.5 kg of steam for production, that 1 ton of sugarcane produces 250 kg of bagasse, and that 1 kg of bagasse produces 204 kg of steam (*5, 16*).

A net yield of 53 tons of cane per hectare in Louisiana would allow the production of 3498 liters of anhydrous alcohol, 13,250 kg of bagasse, and 31,800 kg of steam. Of the steam produced, 12,561 kg is excess over that required for distillation. This is equivalent to 6.78×10^6 kcal [at 540 kcal per kilogram of steam (*5*)].

Table 2. Energy balance of alcohol production.

Quantity	Value	Total	Net energy balance*	Output: input
Agricultural yield (ton/ha-year)		53		
Alcohol production (liters)				
Per ton		66		
Per hectare per year		3498		
Energy expended ($\times 10^6$ kcal/ha-year)				
Agricultural	8.5			
Industrial structure	0.4			
Industrial fuel	10.4	19.3		
Energy produced ($\times 10^6$ kcal/ha-year)				
Case 1				
Converting all bagasse to steam	17.2			
Content of alcohol produced	18.4*	35.6	+16.3	1.8:1
Case 2				
Converting enough bagasse to meet all industrial requirements	10.4			
Content of alcohol produced	18.4	28.8	+9.5	1.5:1
Case 3				
Burning fossil fuel to meet all industrial requirements	0			
Content of alcohol produced	18.4	18.4	−0.9	0.9:1

*See (*21*).

The energy balance of ethyl alcohol production from sugarcane is presented in Table 2. The total energy requirement is 19.3×10^6 kcal/ha-year (44 percent is related to the agricultural phase). Total energy produced depends on the type of fuel used to run the industrial plant. If all available bagasse were converted to steam, total energy produced would be 35.6×10^6 kcal/ha-year, and if fossil fuel rather than bagasse were used, total production would be that attributable to alcohol only, or 18.4×10^6 kcal/ha-year. This analysis shows that alcohol production has a net energy yield between 1.8:1 and 0.9:1 (output:input). It should be noted that with the high estimate, 27 percent of the energy yield is in the form of excess steam, the utilization of which is highly doubtful. At present, plants under design in Louisiana will use approximately a 50:50 mixture of bagasse and fossil fuel to fire the industrial apparatus (*17*). The resultant net energy balance would then be 1.2:1.0. Such a small return on energy investment is not likely to help solve the national energy problem. If the industrial phase were dependent entirely on fossil fuel rather than sugarcane bagasse, alcohol production would be an energy sink (*18*). For comparison, the net energy benefit of gasoline from Gulf of Mexico oil is about 6:1 (*19*).

Da Silva *et al.* (*5*) showed that sugarcane could be used quite efficiently for producing alcohol in Brazil. Compared to Louisiana, the agricultural phase of sugarcane production was less mechanized and used less fertilizer, insecticide, and herbicide. Fuel, machinery, and nitrogen inputs represented only 83 percent of all inputs, compared to 90 percent in Louisiana. Labor made up 3 percent of the total. Agricultural yield in Brazil was similar to that in Louisiana (54 versus 53 tons per hectare) but had only 49 percent of the cultural energy inputs. Consequently, the net energy balance of the agricultural and industrial phases of alcohol production was a positive 2.4:1 (21.3×10^6 kcal/ha-year).

These results emphasize the importance of site-specific energy balance evaluations of crops used for alcohol production. All industrial and agricultural processing inputs must be considered if we are to find a satisfactory substitute for or extender of petroleum. For sugarcane, the net energy analysis indicates that, with current agricultural practices, alcohol production is a marginally profitable enterprise energetically if plant byproducts are used to supply at least 10 percent of the industrial energy requirement. Alcohol from crops produced in excess of food requirements will not make a significant contribution to national energy needs.

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References and Notes

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(D-Iowa) has presented a bill that would lend $600 million for building alcohol fermentation plants. The U.S. Department of Agriculture has increased funds for research on alcohol by $4 million and has lent $30 million for pilot plant construction. President Carter has promised $11 million for plant construction.
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18. However, as discussed by Wade (*4*), price incentives and tax subsidies allow alcohol production to be economically appealing. Tax benefits amount to $44 per barrel of alcohol in Iowa. Supposedly, the purpose of tax breaks is to stimulate increased fuel supplies. But this analysis shows that there will not necessarily be a net energy gain. At the same time, there will be a substantial loss of government revenues.
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21. On the basis of total Louisiana sugarcane acreage, total alcohol production could equal the energy content of 36 percent of the gasoline consumed in the state. However, for plants in design that will use a 50:50 ratio of crop residues and natural gas for industrial fuel, the net energy yield will be 4.3×16^6 kcal/ha-year. This is only 9 percent of state gasoline consumption and would be insignificant in the context of total energy consumption in Louisiana. It should be noted that all labor-energy conversions in this analysis are based solely on the food energy consumed by a worker laboring a unit length of time. A more accurate assessment would include the cost of production and maintenance of a worker, as is done for machinery. These costs can be estimated by converting the worker's salary to energy (assuming all salary is spent on meeting the food, clothing, shelter, and entertainment needs of a worker's family), using the 1970 dollar:energy ratio of $1:20,000 kcal (*8*). With this approach, labor represents 19 percent of all agricultural energy inputs and is second in importance to fuel energy inputs. The resultant net energy ratios in Table 2 then become 1.7:1, 1.4:1, and 0.8:1 for cases 1, 2, and 3, respectively.
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Graphoglyptid Burrows in Modern Deep-Sea Sediment

Abstract. *The complex, highly patterned, invertebrate burrow systems known as "graphoglyptids" in ancient sedimentary rocks have now been recovered in box cores of modern deep-sea sediment.* Spiroraphe, Cosmoraphe, *and* Paleodictyon *occur as grooves in the tops of washed cores, and they apparently were produced and maintained as horizontal tunnel systems just a few millimeters below the sediment surface. These burrows, which are important as indicators of deepwater sedimentary environments in ancient strata, have been predicted in the modern deep sea but have not been found there until now.*

Complex, geometrically patterned burrow systems of benthic invertebrates are especially characteristic of deep-sea environments, and they are abundantly preserved in ancient flysch deposits all over the world (*1–4*). The most spectacular of the flysch trace fossils are those burrows belonging to the group known informally as "graphoglyptids" (*5*), highly organized systems of tunnels arranged in meandering, radiating, or anastomosing netlike patterns. Such burrow systems are very important in paleoecological and paleoenvironmental investigations as indicators of deepwater sedimentary environments. Graphoglyptid burrows have been predicted in the modern deep sea on the basis of ancient trace fossils (*5*), but heretofore they have not been found there.

I report here the first recoveries of modern graphoglyptids from the deep ocean floor. The ichnogenera *Spiroraphe*, *Cosmoraphe*, and *Paleodictyon* (*6*) were collected in deep-sea box cores on four Scripps Institution of Oceanography cruises between March 1975 and November 1978 (*7*). All the graphoglyptids occurred in pelagic calcareous ooze, and all were observed as surface features on the box core tops. None of the burrows contained the animal responsible for producing it.

Spirorаphe (Fig. 1, A and B) may be the most abundant graphoglyptid in modern sediment as it is one of the most common biogenic structures on deep-sea box core surfaces (*8*). Several specimens of the tightly coiled trail *S. involuta* [figure 5a in (*5*)] were collected on each of the four cruises at depths ranging from 3358 to 5119 m (Table 1). *Spirorаphe involuta* is distinctive in that the course of the trail spirals inward to the center, where it makes a 180° turn and spirals outward again alongside the earlier trail. In the box cores, the trail was always about 2 mm wide and the circular outline of the whole structure varied from 3 to 13 cm in diameter. In nearly every case *S. involuta* occurred in the form of rounded, spiraling furrows on the core tops. No vertical repetition of *Spirorаphe* specimens, such as stacked tiers of spirals, was observed in any box core.

Cosmoraphe (Fig. 1C), a uniformly meandering horizontal trail, is not as abundant in modern deep-sea sediment as *Spirorаphe*. Partial specimens were recovered in box cores from both the Pacific and the Atlantic at depths ranging from 4296 to 4742 m (Table 1). All occurred as regularly meandering grooves incised several millimeters into the surficial sediment on the box core tops. One specimen in core INMD 98BX (Fig. 1C) from the Gambia Abyssal Plain in the central Atlantic was particularly noteworthy in that the first- and second-order meanders that characterize the ichnogenus (*6*) were easily recognized. In this occurrence the grooved trail itself was about 2 mm wide; the amplitude of the first-order meanders was about 30 mm, and that of the second-order meanders was about 5 mm. This specimen appears to fit the diagnosis for *C. sinuosa*, which has been reported in Eocene deep-sea deposits of Spain by Seilacher [figures 3a and 4, a and b, in (*5*)] and Crimes [plate 7c in (*3*)] and in Eocene flysch of Poland by Książkiewicz [figure 2, a and b, and plate 3, a and b, in (*1*)].

Paleodictyon (Fig. 1D) is a very distinctive burrow system with horizontal tunnels anastomosing to form a regular net with hexagonal mesh. The first *Paleodictyon* specimens to be recognized in samples collected from a modern depositional environment were found in two cores from the South Atlantic, one (sample INMD 109BX) on the western flank of the Mid-Atlantic Ridge and the other (sample INMD 128BX) on the northern flank of the Rio Grande Rise (Table 1). As with the *Spirorаphe* and *Cosmoraphe* specimens, all the *Paleodictyon* specimens appeared as grooves in the tops of the box cores. Two specimens of different sizes occurred in core INMD 128BX (Fig. 1D). Both appeared to be *Paleodictyon* (*Glenodictyum*) *minimum*, which is common in late Cretaceous and Tertiary flysch deposits [figure 14f and plate 2a in (*5*)]. One was a patch of 1-mm-wide polygons 3 cm in diameter; the other was a patch of 2-mm-wide polygons 9 cm in diameter. In both cases the structures had been partially washed away by water trapped in the box core at the time of collection, but the hexagonal shape of several of the poly-