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Energy Inefficiency in Industrial Agriculture: You Are What You Eat

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Introduction

Modern industrial farming technologies for growing fruits, vegetables and grains have changed substantially in recent decades. In many locations such as Arizona, these industries are highly energy and water-intensive operations. As such, the sustainability of these operations is called into question. The economic, social and climate implications of energy use in agriculture are worth further discussion.

Pimentel (2009) makes a social justice argument that the *amount* of energy inputs used to produce (primarily) food grains begs adjusting in order to provide continuing food availability (although much of his argument is based on the premise that food is not currently available to much of the world's population) as worldwide population growth continues. "If current trends in human population growth and fossil fuel consumption continue into the future, projections for tomorrow's nutritional needs are not encouraging." (Pimentel, 2009, page 19) He calls for major economic and environmental policy change to address the needs of a healthy human population coupled with a "vital ecological integrity." His recent article is the latest in a lengthy career investigating energy inputs for food production.

Recently Acker *et al.* (2009) investigated the energy and water use in agriculture in Arizona. In their article the authors composed production functions for various crops grown in Arizona and then identified the requisite costs of production in terms of direct fossil fuel and water use. The analysis was "from seed to the edge of the field" to include all operations from planting the seed, including the embodied energy in the seeds, to harvest. Estimates were made to include all the energy necessary to irrigate the fields and to produce the myriad chemicals applied to the fields. Tables 1 and 2 show the energy conclusions from Acker *et al.* and show the high and low estimates for energy conversion in the production of various crops in terms of kilocalories per unit of production.

Table 1: High energy estimates for crops grown in Arizona.

	Total Diesel High			
Crop	**acres**	**total diesel**	**head/acre**	**Kcal/head**
Broccoli	9,900	2,823,894	9,728	16,173
Cabbage	3,400	791,537	10,647	12,061
Cantaloupes	17,700	4,336,552	12,165	11,109
Cauliflower	4,600	1,129,660	11,460	11,820
Chile Peppers	5,400	954,899	6,800	14,344
Dry Onions	1,600	388,114	36,000	3,717
Head Lettuce	900	358,438	27,888	7,877
Honeydews	2,500	491,586	6,488	16,717
Leaf Lettuce	7,100	2,827,674	27,888	7,877
Potato	6,200	2,978,368	29,200	9,074
Romaine	17,300	5,897,631	27,888	6,743
Spinach	6,000	1,017,796	27,888	3,355
Watermelons (pounds)	6,400	1,960,460	44,000	3,840

Source: Acker *et al.* 2009.

Table 2: Low energy estimates for crops grown in Arizona.

Crop	acres	Total Diesel Low total diesel	head/acre	Kcal/head
Broccoli	9,900	2,582,073	9,728	14,788
Cabbage	3,400	594,174	10,647	9,054
Cantaloupes	17,700	3,603,554	12,165	9,231
Cauliflower	4,600	1,012,567	11,460	10,595
Chile Peppers	5,400	585,251	6,800	8,791
Dry Onions	1,600	301,605	36,000	2,888
Head Lettuce	900	293,422	27,888	6,448
Honeydews	2,500	397,349	6,488	13,513
Leaf Lettuce	7,100	2,314,773	27,888	6,448
Potato	6,200	2,304,763	29,200	7,022
Romaine	17,300	5,500,610	27,888	6,289
Spinach	6,000	748,221	27,888	2,466
Watermelons (pounds)	6,400	1,583,453	44,000	3,102

Source: Acker *et al.* 2009.

Acker *et al.* use cabbage as their exemplar crop, so we will follow that model. Acker *et al*. estimate that the production of a head of cabbage takes between roughly 9,000 and 12,000 *kilocalories.* They were focusing on the engineering and production aspects of agriculture in Arizona and made no interpretive statements concerning the results.

Similarly they estimated water use in growing various crops as shown in Table 3.

Table 3: Water estimates for crops grown in Arizona.

Crop	Acre feet high	Acre feet Low	Water Use Gallons Water/head High	Gallons Water/head Low
Broccoli	2.83	1.88	95	63
Cabbage	3.50	2.08	107	64
Cantaloupes	3.33	1.67	89	45
Cauliflower	3.08	2.08	88	59
Chile Peppers	4.50	1.82	216	87
Dry Onions	2.75	1.94	25	18
Head Lettuce	4.29	3.42	50	40
Honeydews	3.33	1.86	167	93
Leaf Lettuce	4.29	3.42	50	40
Potato	5.00	2.03	56	23
Romaine	4.29	3.42	50	40
Spinach	3.00	1.25	35	15
Watermelons (pounds)	4.17	1.86	31	14

Source: Acker *et al.* 2009.

The conclusions from the engineering analysis in Acker *et al*. are disturbing at some level even if that level is evanescent. That same head of cabbage takes between 64 and 107 *gallons* of water to produce. The authors indicate that the irrigation estimates are more likely to be toward the high end for Arizona crops due to the lack of precipitation and thus the energy values are also likely toward the high end. Pimentel (2009, page 14) also indicates the costs of irrigation:

> Producing food crops employing irrigation requires enormous amounts of water and fossil energy to pump and apply the fresh water. For example, a corn crop grown in an arid region requires about 1,000 mm of irrigated water. This is ten thousand cubic meters or 2.6 million U.S. gallons per hectare. To pump this water from a depth of only 30.5 m (100 feet) and apply it requires about 20.5 million kcal of fossil energy.

As such, the Acker *et al.* study was actually conducted in a perfect "laboratory" since the production of crops in southern Arizona is unable to count on *any* precipitation, so all water must come from irrigation.

Pimentel and Pimentel (1996) summarize several decades of similar work conducted mostly prior to the industrialization and chemicalization of agriculture and primarily based on geographies with substantially more precipitation than the Acker *et al.* study. As such, the input requirements presented in Pimentel and Pimentel are substantially smaller, even at the order of magnitude measure, than those of Acker *et al.*. Although there are few crops that directly overlap between the two studies Table 4 shows some direct comparisons.

Table 4: A direct comparison between Acker *et al.* (2009) and Pimentel and Pimentel (1996).

	Inputs required for 1 food calorie		
Crop	**Acker-Input High**	**Acker- Low**	**Pimentel**
Corn	82.4	23.3	2.5
Sorghum	15.9	13.8	14.4
Oranges	203.2	184.4	1.7
Spinach	70.6	41.9	.23
Potatoes	34.4	23.3	1.2

On average, more than one half of the direct energy consumption used in growing crops in Arizona is due to the application of irrigation water and the production of various chemicals applied to the fields. The remaining energy expense is primarily due to machine operations, such as plowing, in the field. The production of seeds proved to contribute minimally to the process. Overall, the apparent gross inefficiency of modern industrial agriculture in Arizona and elsewhere requires further analysis.

Energy Budgets

An interesting approach to evaluating industrial agriculture might be to understand the energy budget paradigm as discussed in Rolf Peter Sieferle's work (2001a). In his fascinating book, *The Subterranean Forest*, he initially hypothesizes the social and economic processes by which human societies might have made the shift from being primarily hunter-gatherer cultures to primarily agricultural cultures. He then applies those lessons to explain how the agrarian cultures began to live beyond the flow of incoming solar energy and began to harvest the available stock of fossil fuels. In other writings he argues that Europe's transformation to a fossil based energy regime led to the modern developed socio-economic global structure that is inextricably linked to the harvest of fossil fuels. (Sieferle, 2001b)

Sieferle's hypothesis is that the social-metabolic regime of a society is limited by the conversion of energy to allow for the harvest of more energy. Each human has a particular energy requirement which varies according to activity and is limited by the need to replenish the transitory energy spent harvesting more energy. Of course, this is merely a convergence of the conservation of energy and entropy during energy conversion via work. Since humans are not physiologically able to convert solar energy via photosynthesis, each human must expend a certain amount of energy harvesting food, in whatever form, to allow for continued life to allow for more food harvesting and so on.

If an individual's energy budget is such that more energy is expended capturing energy than is captured, then, obviously, the individual will die. Of course, much of the ingested energy is converted into work unrelated to the physical needs of harvesting food-based energy. The metabolic rate of the human body is such that perhaps 20% of the energy consumed can be directly applied to capturing more energy through hunting, gathering or working in the fields.[2] Thus, the individual must harvest at least 5 units of energy for each unit of energy spent in the process of harvesting in order to survive. Any deficit below the 1:5 ratio will be unsurvivable and any surplus above the ratio will allow for additional work unrelated to energy harvesting such as singing and dancing. Any member of society earning less than this ratio by engaging in unrelated work must be supported by the surplus of other individuals.

Sieferle compares the economic output under three prehistoric regimes. In a megafauna hunting society he estimates an output of 40-60 megajoules (MJ) per hour of labor. Simply put, harvesting the energy embodied in a mastodon is profitable. (This does not include the hazards concomitant with hunting megafauna!) One hour of labor produced between 9,500 and 14,300 kilocalories. With the disappearance of the megafauna societies were reduced to a productivity of 4-6 MJ of output per hour for small game hunting. The reduction in productivity was by a magnitude of 10. With the advent of agriculture the typical output of a worker increased to 12-20 MJ per hour of labor. This converts to between 2,900 and 4,800 kilocalories per hour. He does not explain the real socio-evolutionary process by which agrarian societies came to be since his main interest is the energy regime, but the reduction in profitability of hunting certainly contributed to the rise of agriculture. Once agriculture became the social-metabolic regime, societies underwent substantial organizational and cultural changes.

> The socio-economic basis of the agrarian civilizations lies in the tributary appropriation of surplus. This means that the producers (peasants) have to regularly contribute a part of their harvest as rent, tribute or tax of which a "ruling class" with its retinue of specialists and servants are supported and provided for. The result is a fortifying vertical social differentiation, normally in the following categories:
> peasants, landlords (aristocracy), warriors, priests (scholars), the court (rulers, bureaucrats), craftsmen, merchants. In addition there is usually a lower class that can include up to 10% of the population earning their livelihood as wage laborers, barterers, beggars or thieves. (Sieferle, 2001a, page 25)

The social organizational changes, due to the metabolic change in society, eventually led to the need for yet a new energy regime as the populations grew and a solar-based energy regime was no longer sustainable. Thus fossil fuels entered the energy budget and eventually the food stream.

Twidwell and Weir (2006, pages 328-330) estimate that the maximum efficiency of photosynthesis is 5%. They further estimate that the photosynthesis of cassava and cereal is 2% and 3% respectively. (It should be noted that the works by Acker *et al*. (2009), Pimentel and Pimentel (1996) and Pimentel (2009) do not account for the solar energy absorbed by the various crops.) Combining the conversion estimates, a solar-based energy regime must convert one unit of human energy into, grossly, between 100 and 250 units of gross solar energy to be merely survivable. As more and more human work was diverted to non-food production, the energy regime reached the capacity of the available acreage to harvest incoming solar energy.

In a solar-based energy regime, the amount of energy embodied in food production must always exceed the value of the energy necessary to produce and harvest that food. Industrial agriculture, reliant

[2] Other authors estimate smaller and greater estimates.

on fossil fuels and non-gravity fed irrigation, has completely turned the energy budget of growing food upside down.

Serving Analysis

In order to arrive at meaningful serving unit estimates for the typical serving size and the caloric value of that serving were provided by Calorie King (2008). Further estimates for the usefulness of each plant were discerned. Table 5 provides estimates for the serving sizes and the caloric value of each serving.

Table 5: Serving Analysis.

Crop	Size ounces	Kcal	refuse	unit weight pounds
Broccoli	3.2	31	0.39	2.6
Cabbage	3.1	21	0.2	2.89
Cantaloupes	1.9	19	0.49	3.78
Cauliflower	3.5	25	0.61	2.27
Chile Peppers	2.6	30	0.27	0.41
Dry Onions	3	36	0.1	0.55
Head Lettuce	1.9	8	0.05	1.64
Honeydews	4.4	45	0.54	3.27
Leaf Lettuce	1.9	8	0.05	1.04
Potato	2.6	58	0	0.85
Romaine	1.7	8	0.06	1.66
Spinach	1.1	7	0.28	0.80
Watermelons	4.3	37	0.48	15.76

A single serving of cabbage is 3.1 ounces by weight. This serving provides 31 kilocalories worth of food intake. Approximately 20% of a cabbage plant is refuse or unused during eating. Direct estimates for the sizes of the various produce were collected on September 29, 2007. On average a head of cabbage weighs 2.89 pounds. [3]

Acker *et al.* provide estimates for the number of heads produced per acre. The serving sizes are measured by weight. Various levels of processing take place from the original harvest of each plant to the point of purchase. In order to approximate the translation from field harvested plants to serving sizes, research staff weighed various sample sizes of produce at a grocery store as "presented for sale." Since many varieties of produce are regularly watered at the grocery store, broccoli for example, these

[3] Although broccoli is the first of the alphabetical crops, it proves problematic as an exemplar crop due to the life-cycle of the plant. The following is an explanation of the growth cycle. In this case, we assumed that the average stock was one fifth of the total output per plant. This modification to the raw data is reflected in Table 5. "Yes, there are as many as 5 harvested heads per broccoli plant. The largest broccoli head is known as the "crown" (you've probably seen these), it's found in the center of the plant and is packed individually. Typically the crowns are the first heads which are harvested and around 10 cents per pound more in the store. During the second and third harvest, the field crews harvest the broccoli "side shoots" which are much smaller in size. As such, they are grouped into a bunch containing 3 shoots, all 3 held together with a rubber band. The bunches have greater proportion of stem compared to the crown which is why they are less expensive. Kurt." Private communication with one of the authors. Kurt D. Nolte, University of Arizona Cooperative Extension, April 16, 2009.

were weighed after being shaken dry to approximate the typical consumer.4 Table 6 shows the output for a day at the grocery store. The second column shows the average weight per head of produce. The third column shows the amount of each unit that is edible and the last column shows the number of servings per unit of produce.

Table 6: servings per unit of produce.

Crop	sample size	sample ounces	useable	serve/unit
Broccoli	31	41.6	25.4	7.9
Cabbage	25	46.2	36.9	11.9
Cantaloupes	31	60.4	30.8	16.2
Cauliflower	22	36.4	14.2	4.1
Chile Peppers	31	6.6	4.8	1.8
Dry Onions	37	8.8	8.0	2.7
Head Lettuce	31	26.2	24.9	13.1
Honeydews	8	52.3	24.0	5.5
Leaf Lettuce	20	16.7	15.9	8.4
Potato	31	13.6	13.6	5.2
Romaine	25	26.5	24.9	14.6
Spinach	13	12.8	9.2	8.4
Watermelons (pound)	10	16.0	8.3	1.9

Since Acker *et al.* measure watermelons in pounds as opposed to individual melons, the final entry in Table 6 shows that there are approximately 2 servings per pound. The average watermelon, as shown in Table 5, weighs almost 16 pounds.

Using the data from Acker *et al.* as presented in Tables 1 and 2 above, the energy inputs per serving are estimated in Table 7. In order to simplify the analysis, the *average* embodied energy as shown in the last column will be used hereafter.

[4] Thanks go to Tony Flores, Safeway, for allowing us to use the produce section of the store for some primary data collection – we got soaking wet weighing everything, but had a good time

Table 7: Embodied energy per serving

Crop	Kcal/serve high	Kcal/serve low	Kcal/serve avg
Broccoli	2286	2024	2155
Cabbage	1212	879	1045
Cantaloupes	807	632	719
Cauliflower	3397	2939	3168
Chile Peppers	6141	3444	4792
Dry Onions	1610	1236	1423
Head Lettuce	685	559	622
Honeydews	3740	2852	3296
Leaf Lettuce	1076	878	977
Potato	1969	1437	1703
Romaine	536	490	513
Spinach	494	334	414
Watermelons	2338	1760	2049

The calculations thus far show that the serving of cabbage requires on average 1,045 kilocalories to grow from "seed to the edge of the field." This is an estimate for the amount of energy used to produce the seeds and chemicals, to treat the fields, to apply the chemicals and irrigate the fields.

Table 8 shows the average amount of water necessary to produce the same crops on a per serving basis as measured in gallons.

Table 8: Water use per serving

Crop	water/serve high	water/serve low	water/serve avg
Broccoli	11.9	7.9	9.9
Cabbage	9.0	5.4	7.2
Cantaloupes	5.5	2.8	4.1
Cauliflower	21.6	14.6	18.1
Chile Peppers	69.3	28.0	48.6
Dry Onions	9.4	6.6	8.0
Head Lettuce	3.8	3.0	3.4
Honeydews	30.6	17.1	23.9
Leaf Lettuce	6.0	4.8	5.4
Potato	10.7	4.3	7.5
Romaine	3.4	2.7	3.1
Spinach	4.2	1.7	3.0
Watermelons	15.9	7.1	11.5

As with the energy use, the average of the high and low values will be used below. The average serving of cabbage takes approximately 7.2 gallons of water to produce.

As with the initial Acker *et al.* (2009) article, these calculations are without any interpretive analysis. However it appears at first glance that in excess of 1,000 Kcals and 7 gallons of water to produce a single serving of cabbage is rather excessive! Pimentel and Pimentel (1996) provide a metric that we borrow here and then extend. They show the energy "efficiency" of producing various foodstuffs (including meats and dairy products) by estimating the amount of energy used in production necessary to produce a single Kcal worth of food. Table 9 shows the "efficiency" of production in terms of energy and water. In order to produce the 21 Kcal in a serving of cabbage the required 1,045 Kcal on inputs results in almost 50:1 Kcal/Kcal of food value. Similarly, the same Kcal of cabbage requires 1/3 gallon or 5.5 8oz glasses of water per kilocalorie.

Table 9: Efficiency measures by crop

Crop	energy efficiency	water efficiency	glasses of water
Broccoli	69.5	0.3	5.1
Cabbage	49.8	0.342	5.5
Cantaloupes	37.9	0.217	3.5
Cauliflower	126.7	0.725	11.6
Chile Peppers	159.7	1.621	25.9
Dry Onions	39.5	0.222	3.6
Head Lettuce	77.8	0.429	6.9
Honeydews	73.2	0.530	8.5
Leaf Lettuce	122.2	0.674	10.8
Potato	29.4	0.129	2.1
Romaine	64.1	0.384	6.2
Spinach	59.2	0.424	6.8
Watermelons	55.4	0.311	5.0

Interpreting Table 9 is problematic without any meaningful baseline for comparison. With the exception of potatoes, the crops under investigation are rarely eaten for their caloric values, so the interpretation is even more difficult.

Menus

Alternative ways of interpreting the energy efficiency of food production is to evaluate various diets. Using the calculations from Acker *et al.* (2009) and Pimentel and Pimentel (1996) we have constructed some sample menus for comparison. The simplest diet is one of pure energy! Although we strongly recommend against this idea, consuming 0.46 ounces of pure diesel fuel will supply a 2000 Kcal intake for the day! This is a thimble full of diesel fuel for equivalent energy to maintain a USDA approved 2000 Calorie diet.

Although a rather boring and not terribly enticing diet is envisioned, if one were to eat 2000 Kcal worth of each crop in the study, one would be consuming the equivalent amount of diesel fuel as shown in Table 10.

Table 10: Diesel fuel equivalents for a 2000 Kcal diet.

Crop	Kcal per day	Gallons/day	Ounces/day	Glasses/day
Broccoli	139040	.25	32.3	1.03
Cabbage	99600	0.18	23.10	2.89
Cantaloupes	75800	0.14	17.58	2.20
Cauliflower	253400	0.46	58.78	7.35
Chile Peppers	319400	0.58	74.09	9.26
Dry Onions	79000	0.14	18.32	2.29
Head Lettuce	155600	0.28	36.09	4.51
Honeydews	146400	0.27	33.96	4.24
Leaf Lettuce	244400	0.44	56.69	7.09
Potato	58800	0.11	13.64	1.70
Romaine	128200	0.23	29.74	3.72
Spinach	118400	0.21	27.46	3.43
Watermelons	110800	0.20	25.70	3.21

Based on the amount of energy input for a single Kcal of output food energy, the columns show the total amount of energy input, the amount of diesel per day in gallons and ounces as compared to the 0.46 ounces of straight diesel intake and finally the number of 8 ounce glasses of diesel. This is a rather perverse way of showing the inefficiency of industrial farming. More appetizing menus were created as follows:

***(Almost) Vegetarian Diet*[5]**

BREAKFAST = 400 calories

4 eggs = 320 calories
1 orange = 80 calories
9096 input to 400 food calories

SNACK: 2 oz. peanuts = 340 calories

476 input to 340 output

LUNCH: Sushi! = 900 calories

1/2 cup dry rice = 320
1/2 cup salmon = 180
2 cups edamame (soy beans) (in shells) = 400
3996 input to 900 food calories

DINNER = 350

3 oz Spinach = 30 cal
1 med tomato = 35 cal
1 ear corn = 83 cal
½ c. cowpeas a.k.a. black eyed peas= 110
947 inputs to 306 food calories

TOTAL: 14,514 inputs to 1,946 food calories

The result of the Vegetarian Diet is a 7.5:1 energy inefficiency of inputs to outputs.

[5] The specific calculations are based on Acker *et al.* (2009) and Pimentel and Pimentel (1996). Contact the authors for the detailed calculations.

A Meat Eater

BREAKFAST: 406

4 slices bacon= 240 calories

8 oz milk = 86 calories

1 orange = 80 calories

18090 input to 406 output

LUNCH: 265

3 slices beef = 135 calories

2 slices whole wheat bread = 110 cal

1 oz Spinach = 10 cal

2 slices tomato = 10

4975.3 input to 761 output

SNACK: 1 oz. peanuts = 170 calories

238 input to 170 output

DINNER = 520

4 oz chicken = 240 cal

1 cup = 60 cal

baked potato w/ skin= 220 cal

4152 input to 520 output

TOTAL = 27,455 input to 1,361 output calories

A meat based diet yields an 20.2:1 level of inefficiency and a full 2000 kcal day uses 40,345 Kcal of diesel fuel to produce.

Alternative Menu

BREAKFAST: 480

2 c cooked oats = 290 cal

1 oz sugar = 110 cal

1 orange = 80 calories

2013 input to 480 food calories

LUNCH 615

4 oz Shrimp = 70 cal

3 oz Spinach = 30 cal

1 tomato = 35 cal

7667 input to 615 food calories

TOTAL = 9,680 input to 1,095 output calories

This diet results in an inefficiency rate of 8.8:1.

The vegetarian day would be the equivalent of 0.4 glasses of diesel. The meat eater would gulp 1.17 glasses and the shrimp eater would need 0.5 glasses. The vegetarian diet is clearly more efficient

(7.5:1) than the meat eater (20:1), but neither menu reaches Seiferle's optimal level of 5:1 previously mentioned. Shrimp is the most inefficient food found in these menus. Shrimp require about 70 calories worth of input for one calorie of output (Pimental). This inefficiency may be in part due to the fact that shrimp are relatively low in calories (70 calories in 4 oz.) in addition to the energy intensiveness of harvesting shrimp. Bacon was not far behind, at 68 to 1, this pork product is also very energy intensive. Vegetables like spinach and tomatoes had much more efficient ratios, according to Pimental's data. Spinach was the most efficient at .23:1 and tomatoes were .6:1. Keep in mind these crops were much less efficient in the Arizona crop budget.

Conclusions and Afterthoughts

David Pimentel's recent article (2009) revisits many of the reasons why industrial agriculture, based so heavily on the use of fossil fuels, degrades the environment. The initial Acker *et al*. (2009) analysis of agriculture in Arizona was stimulated by the increasing costs of fossil fuels and the extreme need to reduce water consumption within the desert state. The current article focuses sometimes whimsical research methods and analysis on the continuing use of fossil fuels as the primary basis for energy inputs – as opposed to photosynthesis – in food production.

Pimentel (2009) studied foods that are eaten primarily for their caloric values – grains and cassava – or fruits that are very photosynthetic and lightly irrigated – apples and tomatoes – and reached cautionary conclusions. Acker *et al.* (2009) investigated primarily vegetable crops grown in sand with no free precipitation in a desert. However disturbing this production process appears, agriculture in the Yuma area of Arizona is known as the winter salad bar for America. Our current analysis is equally disturbing from an energy inefficiency perspective. Instead of achieving the sustainable energy input to energy output ratio of 1:100, the fossil fuels based menus show a vegetarian diet with a ratio of 10:1 and an omnivore's diet with a reverse ratio of roughly 20:1. This reversal of the production matrix calls for a reconsideration of the food matrix.

The environmental, ecological and social justice issues of modern industrial agriculture require a reassessment from myriad perspectives: farm subsidies, consumer demand and preferences, engineering technologies and water policy. For example, related work by Acker and Smith (2008) has shown how a substantial reduction in energy inputs can be achieved with modernized and technically more advanced irrigation systems in the agricultural production in Arizona.

The current analysis focuses on the input/output calculations based on calories. A more advanced analysis would investigate the overall nutritional analysis of food production. Modern linear and non-linear programming techniques should be useful to analyze the minimum energy requirements to reach a combination of constraints concerning dietary intakes for variety of caloric and nutritional – vitamin – requirements as indicated by the USDA.[6] Such analysis would provide a richer series of conclusions and possible market adjustments.

The foretold carbon emissions policies for the United States and the upcoming Copenhagen round of climate change negotiations will likely require industrial agriculturalists to clearly focus on the fossil fuel inputs in food production. Since the current analysis only focuses on food production, the issues of washing, refrigerating, packaging, transporting, storing, and cooking need to be included into the analysis matrix for complete understanding. Once the complete life of food is understood, perhaps a new energy matrix can be employed.

[6] Any reader interested in this type of research, and having the requisite skills, should contact the authors.

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