UTILITY OF ORGANIC RENEWABLE RESOURCES

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At this time, U.S. consumption of energy, mostly from fossil carbon sources, is about equal to the net annual storage of solar energy in the U.S. biomass system. The latter is estimated at about 5 billion tons of biomass per year, which in dry form corresponds to a heat value of about 80 Q Btu. We are indeed at an interesting point in our cultural history, and policies on how we govern the carbon system, including the photosynthesized resources, are pertinent. We are facing some deep philosophical questions on how we in the future should manage our organic materials, land, nutrient, and water systems. How long can we continue a fossil-carbon-based industrial development? Will we ultimately have to come "back" to the solar energy driven carbon system on which we were almost totally dependent only 100 years ago?

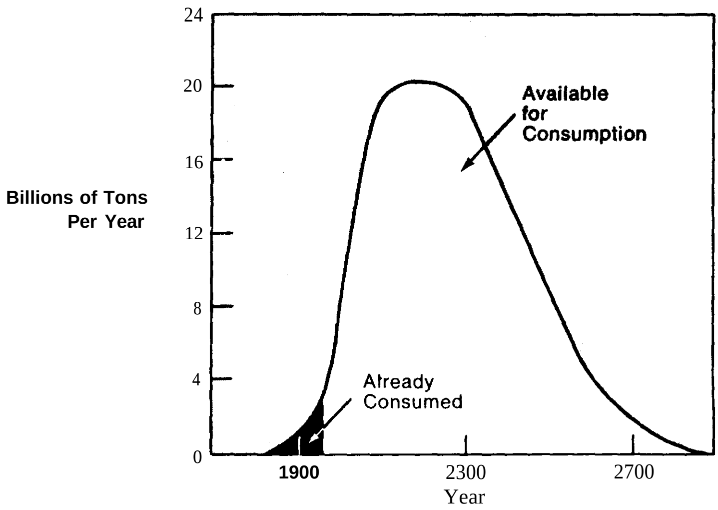
I would like to quote a Zen proverb: "For the man who is ignorant, trees are trees, waters are waters, and mountains are mountains. When that man gains understanding, then trees are not trees, waters are not waters, mountains are not mountains. And when, at last, he attains wisdom, then once again, trees are trees, waters are waters, and mountains are mountains,"

Will we be wise in shifting back to solar energy and renewable organic resources to meet human needs for not only food, but also fuels and materials? Maybe we have to within the next 100 years. In assessing this, I will contend that most of our "problems" are systemic in nature—we truly cannot see the forest for the trees, As Morowitz has put it, "We are confronting an entropy crisis more than just an energy crisis, "

This conference deals with materials, and I will discuss energy only in the context of energetic of materials. It should be pointed out that about 94 percent of the fossil oil resources today are used for fuel purposes. Of the 6 percent going to the petrochemical industry, probably only one third actually ends up as a material. The energy intensity in production of synthetic organic materials is on the average about 3 tons of oil per ton of product. The competition for some oil fractions and for gas is likely to intensify, and we might see a certain conversion to coal in the petrochemical industry within the next 10 years (figure 1),

It is through the energy flow (subsidy) in the form of solar energy stored in fossil carbon reserves that we have been able to carry out what we refer to as the industrial revolution during the

FIGIJRE 1.—Fossil Carbon Consumption Scenario



last 100 years. This is a short time span in the history of humans and the biosystem, as King Hubbert and others have pointed out. (1,2,3) (figure 2).

One of the major concerns in the extended transfer of carbon from the fossil sources to the biospheric systems relates to the impact of additional C02 generation, half of which is raising the C02 level in the atmosphere and half of which is absorbed by the ocean and the biosystem (figure 3), It is estimated that the stock of biomass on earth has increased by 15 billion tons the last century, mostly as a result of the higher C02 level. The increased absorption of heat radiation by C02 should result in a warming trend of the climate which might be an ultimate concern in relation to how much carbon is handled in the biosystems (4,5) (table 1). However, because of the sun's cyclic activity, we experience a cooling off in the northern hemisphere which might be expected to cause droughts and crop failures in the 1990's. The stock of biomass, mostly forests, can be considered as a food reserve, and policies on future uses of lignocellulosic materials should consider the requirements for adaptation during such discontinuities in the food producing system. The climatic effects of C02 in the atmosphere might only be of concern around year 2020, but probably earlier in the Southern Hemisphere.

At this point it appears highly desirable to increase photosynthesis, and net and gross bioproductivity, The management of these processes and the alternative uses of the biomass will be the subject of debate during coming years. The shift in value

FIGURE 2.—The History of Fossil Carbon

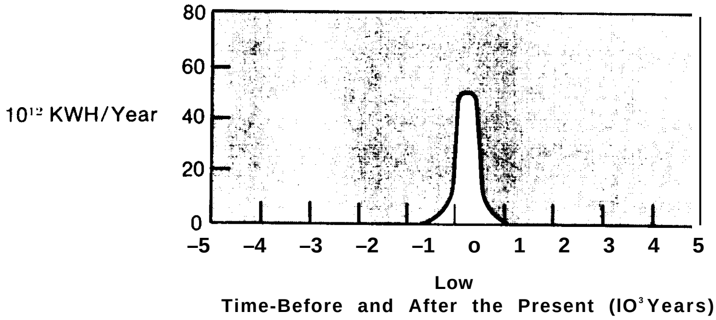
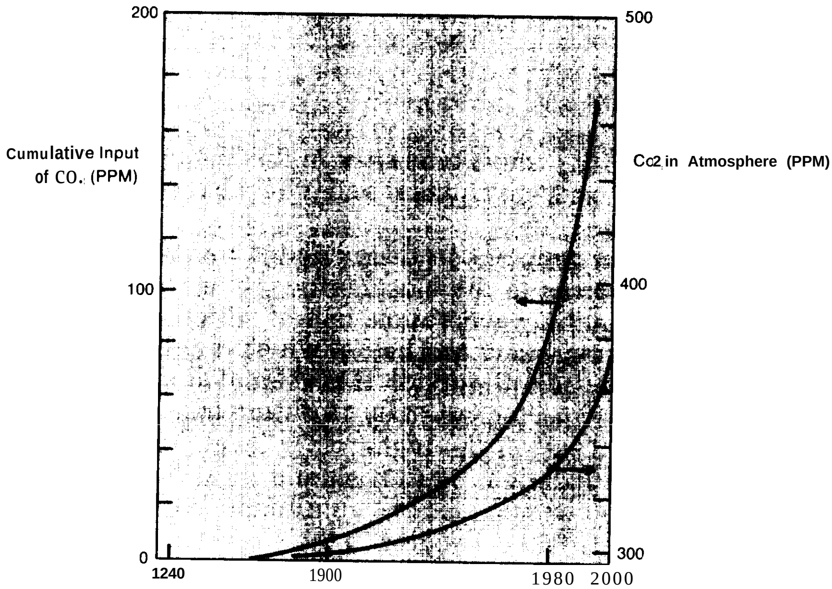


FIGURE 3.—Carbon Dioxide in Atmosphere (BOLIN)



system from "man over nature" to "man in or with nature" plays an important role.

Systems View and Time Frame

It is my view that in assessing the extended roles of renewable resources we should not only address the operational or tactical questions of how to alleviate immediate shortages and pressures, but it is imperative that we act in resonance with strategic and

TABLE 1.—Carbon in the Biosphere (BRODA, 12)

FORM	TONS x 10^{12}
Carbonate in Sediment	18,000
Organic Carbon in Sediment	6,800
CO_2 in Atmosphere	0.65
Living Matter on Land	0.08
Dead Organic Matter on Land	0.7
CO_2 in Ocean	35.4
Living Matter in Ocean	0.008
Dead Organic , Matter in Ocean	2.7

normative considerations. As a communication tool, I will use the planning model proposed by Ozbekhan (6). I will attempt to address the various levels discussed in that model as they might relate to renewable resources, but emphasize the normative view and my perception of reality (figure 4).

It is apparent that the assessment will require an interdisciplinary effort and a general systems approach with consideration for hierarchal levels (7), the complexity and desirable diversity and adaptability of natural systems, the cyclic nature of materials and energy flow patterns in renewable systems, purposeful goal seeking and evolutionary processes, etc. The vertical and horizontal integration we talk about in industry is used all the time in nature to improve survivability.

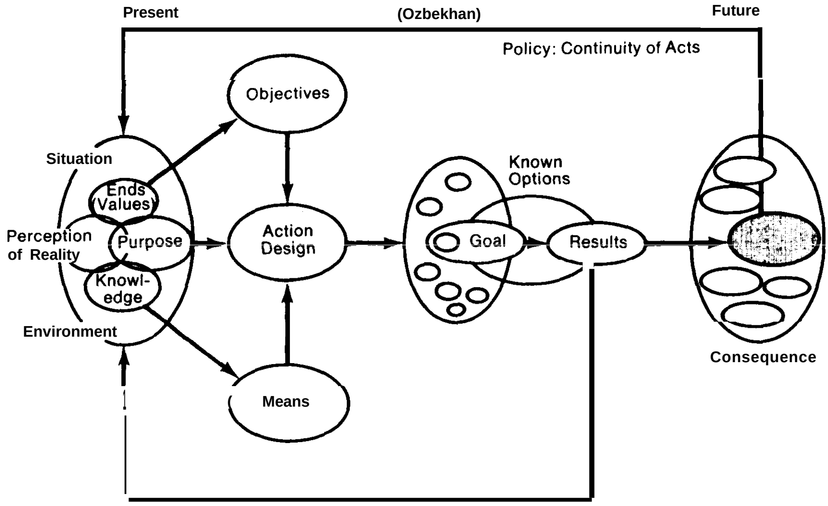
Two questions immediately come up in considering renewabIe resources for new and extended uses,

1. Is it technically feasible to produce the major petrochemicals and polymers from renewable resources?
2. Are there, in the United States, enough renewable resources available for a shift from oil as a raw material without adversely affecting food, lumber, and paper production?

The answer to these questions today appears to be yes.

The substitution for oil and gas in polymer and organic materials production is not a matter of technical feasibility and resource availability but rather a matter of driving forces, constraints, and uncertainties affecting a change. The energetic in producing a product from alternative raw materials varies and can be in favor of renewable resources. Optimum plant size, logistics, labor intensity, and the cost and availability of capital enter into the economic picture. The environmental and social

FIGURE 4,



costs in relation to alternatives have to be assessed. Traditional economics does not account for "renewability," Georgescu-Roegen (8) has discussed the need to account for the "entropic loss" with "non-renewable resources," "The economics of scale" is being challenged by Schumacher (9) and others, and such terms as "appropriate technology" are increasingly heard, Some of these emerging concepts are more applicable to renewable resources than to fossil carbon sources, The competitiveness of natural rubber compared with the synthetic product is a case in point.

The assessment of renewable resources uses thus has to include not only aspects of what we call economics, but also environmental, social, and political factors. As Sarkanen (10) has pointed out, "The area should be looked at as a whole, rather than having separate groups of parochial researchers concentrate on forest residues, waste products from the pulping industry, agricultural residues, or marine resources, This calls for a broader interdisciplinary endeavor than is possible in the framework of existing Government agencies. " I want to amplify and extend on that statement and add a warning about the simplistic, "plug-in" approach of producing "petrochemicals from wood," It is likely that we will continue to see integrated systems similar to the present lumber-board-paper-tall, oil-energy system. We should stay at highest possible systemic levels. The energy farm as a single output system is justifiable only if markets and needs for higher value materials than energy do not exist. An immediate issue is how we can upgrade renewable resources that today are "wasted" or used for energy production.

Renewability

The Board on Agriculture and Renewable Resources of the National Academy of Sciences organized the CORRIM program, CORRIM defines as "renewable" a material that can be restored when the initial stock has been exhausted, The dynamic nature of the concept of renewability is recognized, A "renewability ratio" is defined as the ratio of replenishment rate to depletion rate. "Renewable resource" is used as a synonym for a resource of biological origin, while "nonrenewable resource" is used as a synonym for a resource of geological origin.

A carbon atom in a biological material might have its origin in oil or coal or even in a mineral like calcium carbonate. The energy source that causes the "renewing" is the sun for the phototrophs (autotrophs), the plants, and the photosynthesizing bacteria. Electromagnetic radiation and gravitational forces give the energy flow in biology that has driven evolution, and produced our biomass stock and fossil carbon sources. The enormous bioproductivity of the salt water marsh (Spartina alterniflora) is possible because of solar radiation and tidal pulsation. We have in that case a sun- and moon-powered system. The water splitting by light quanta resulting in C02 reduction starts the process. In fact, our primary concern should be with the process of renewing our resources,

"Solar resources" or "phototrophic resources" through a "solar processes" or "photosynthesis" could be the emerging concepts and terms.

We have a classical matter-energy and structure-process issue. Renewable resources can be looked upon as a temporarily "frozen" solar energy process.

ERDA's Solar Energy Division has a great task ahead, and I hope it will extend the present "Fuels from Biomass" philosophy.

Present Organic Materials System in the United States

The use intensity of new supply of materials has been discussed by Radcliffe (10). The per capita consumption of synthetic polymers (derived from fossil sources) constitutes only 6 percent of the total organic materials consumption, and thus renewable materials today are consumed at a rate 16 times greater than nonrenewable organic materials (table 2),

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TABLE 2.—Use Intensity of New Supply of Materials in the U.S. (RADCLIFFE)

	LBS PER CAPITA FOR 1974
NONRENEWABLE RESOURCES	
Nonmetallic Minerals	18,900
Metals	1,340
Synthetic Polymers	180
RENEWABLE RESOURCES	
Wood and Wood Products(1971)	2,222
Fibers (Other than wood)	29
Natural Rubber	6
Leather	14

The increase in rate of materials and energy consumption follow each other closely, As pointed out by Keyfitz, (11) the growth attributable to affluence is greater than the population growth (figure 5).

Published data (10,13,14,15,16,17,53) on the production of renewable organic resources and various uses and non-uses vary considerably, but an attempt has been made in table 3 to differentiate between food-feed, materials, energy, and residuals or unused material. The latter group will generally be referred to as “waste.” Some figures are estimated and several resources have not been listed. The noncommercial timber stock is estimated to over 1 billion tons but this may not be the annual out-take. The recoverable quantity of the residuals depends on economics and environmental considerations.

The various traditional uses of wood products for structural. and fiber applications are shown in table 4. The wood requirements are indicated according to one scenario for 1985 and 2000. CORRIM (13) also dealt with three other scenarios with assumptions of lower rate of population growth and higher rate of growth of prices for nonrenewable resources.

Some projections by the American Paper Institute for paper and paperboard (13) are shown in table 5. Substitutions are discussed in the CORRIM report and will also be dealt with under the Reference Materials System.

It seems likely that the consumption of renewable resources for the traditional materials (lumber, plywood, particle board, flakeboard, fiber board, insulating board, paper, paperboard, hardboards, etc.) will at least double by year 2000. (10) The pri-

FIGURE 5.—U.S. Energy Consumption

Growth Attributed to Population vs. Affluence (K EYFITZ)

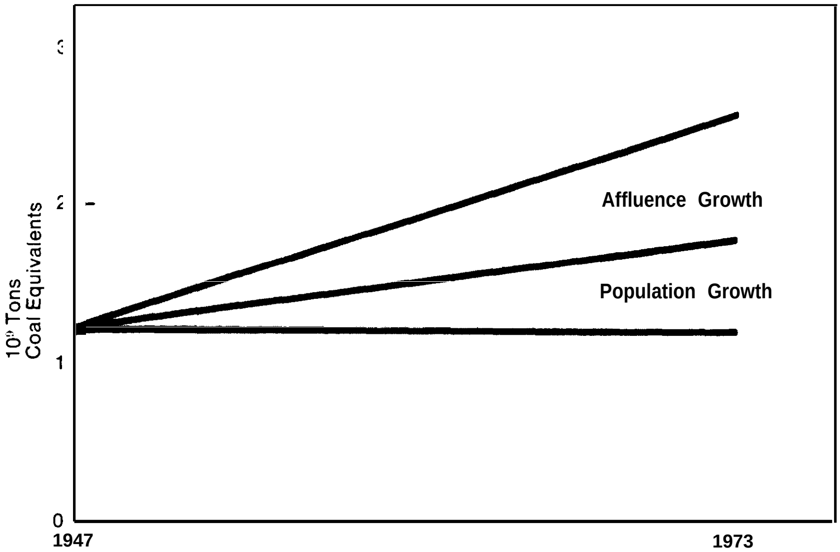


TABLE S.–Organic Materials Production and Use in the U.S.
[Approximate Figures, 1972-1974)

	Tons x 106/Year				
	Food-Feed	Mate-rials	Energy	Resid-uals	Total
Synthetic Polymers	—	18	(36)		
Lumber & Rigid Panels	—	119	16	25	160
Paper & Paperboard	—	57	30	—	87
Forest Residues	—	—		150	
“Noncommercial Timber”	—	—		100	
Municipal Waste	—	—	—	100	
Bushes, Shrubs, Foliage	—	—	—	>50	
Hardwoods on Pine Sites	—	—	—	>50	
Cotton	—	3	—	13	
Fats & Oils	6	3	—	—	
Soybeans & Peanuts	40	—	—	65	
Grain Crops	250	2	—	300	
Forage	240	—	—		
Sugar Crops	10	0.2	5	6	
Animal Wastes	—	—	—	360	
Approximate totals	550	200	50	1,200	2,000
Total Net Biomass Production					5,000

TABLE 4. Projected Demand for Roundwood and By-Products for Manufacture of Wood-Based Commodities According to One Scenario[13]

Commodity	Wood Requirement 1970 MM 0.D. tons From Roundwood	From By-Product	1985 MM O.D. tons From Roundwood	From By-Product	2000 MM 0.D. tons From Round wood	From By-Product
Structural						
1. Softwood lumber	73.41	2.6	80.4	3.5	64.6	4.0
2. Softwood plywood	15.08	—	17.7	—	14.6	—
3. Hardwood lumber	24.51	—	34.5	1.4	42.2	1.4
4, Hardwood plywood	2.28	—	3.1	—	3.1	—
5. Particleboard	—	2.4	—	5.3	—	8.5
6. Med. densitty fiberboard	18	.2	0.4	0.4	0.6	0.6
7 1nsulation board	—	1.2	—	1.9	—	2.2
8 Wet-formed hardboard	—	1.1	—	1.9	—	2.9
9. Structural flakeboard No. 1	—	—	3.0[1]	—	5.1[1]	—
10. Structural flakeboard No. 2 (RCW)	---	---	3.0	—	5.1	—
11. Laminated-veneer i umber	—	—	2.3[2]	—	4 4[3]	—
Fibrous						
12. Paper and paperboard	61.30	24.5	104.2	38.2	154.9	45.1
13. Miscellaneous-industrial and fuelwood	16.62	—	11.3	—	12.2	—
Total	193.38	31.9	259.9	52.6	306.8	64.7

1. Yielding flakeboard cores equivalent to veneer from 5.9 MM tons of veneer logs in 1985 and 9.7 MM tons in 2000. These equivalents have consequently been subtracted from projected roundwood demand for softwood plywood.
2. Of which 1,5 MM 0.D, tons is converted to finished softwood lumber and 0.8 MM O.D. tons is converted to finished hardwood lumber.
3. Of which 2.8 MM O.D. tons is converted to finished softwood lumber and 1.8 MM O.D. tons is converted to finished hardwood lumber.

TABLE 5.–Production of Total Paper and Paperboard (Corrim)

10^3 Short Tons	1972	1985F	2000F
Newsprint	3,436	5,350	8,400
Groundwood	1.329	2.020	3,300
Other Printing & Writing	10.958	18.115	29,300
Packaging & Industrial Converting	5.695	7.895	12.000
Tissue	3,977	5,935	9,000
(TOTAL PAPER)	(25.396)	(39,315)	(62.000)
Solid Wood Pulp Paperboard	20.965	32.040	48,330
Recycled Paperboard (incl. Wet Machine Board)	7,686	11,875	18,530
(TOTAL PAPERBOARD)	(28.503)	(43.780)	(66.700)
(TOTAL WET MACHINE BOARD)	(148)	(135)	(160)
Construction Paper and Board excl. Hardboard	3.444	5.130	8.000
Construct Ion Paper and Board incl. Hard board	5,352	8,015	12.500
TOTAL PAPER AND BOARD excl. Hardboard	57,491	88.360	136.860
TOTAL PAPER AND BOARD including Hardboard	59.398	91.245	141,360

F– Forecast trend by American Paper Institute
Real GNP trend 1972 to 2000 – 2.580 X 28 years 3.5% per year average.

Real GNP: for 1972 $ 792.5 billion
for 1985 $1.222.0 billion
for 2ooo $2.000.o billion

mary needs of the forests-products industries relate to reducticn in energy intensive processes, and improved environmental control processes, The CORRIM (13) discusses future needs in the conventional structural and fiber uses of wood, and they will not be dealt with extensively in this paper in spite of their obvious importance.

Bioproduction Potential and Potentially Available Renewable Resources

Human activities in the United States interfere with about 25 percent of the net biomass production through various forms of harvesting, but probably only about 15 percent leaves the land. Some of this "used" biomass (food, feed, and materials) is again returned to the soil.

Various forms of management techniques such as fertilization, pest control, irrigation, genetic plant selection, thinning, etc., can improve productivity considerably; the recommendation for increased productivity made for agriculture (19) can in principle be applied also to forestry and biomass plantations.

The 500 million acres of commercial forest land has a net annual productivity of less than 1 ton per acre. The biological potential (10) of 400-500 million tons per year can probably be increased by at least 50 percent. Whole-tree utilization concepts (18) are being adopted, and intensive, short rotation forestry of hardwoods can give yields of up to 4 tons per acre a year, A primary concern in the use of these intensive techniques relates to the tolerable removal or organics and nutrients from the soil (2o) and other environmental impacts (21,18).

In addition to the commercial forest land, there are 250 million acres of noncommercial forests of which 20 million acres are assigned as parks, wilderness areas, etc. The forests totally occupy about one-third of the US. land area. The use of non-forest, non-agricultural land for biomass production should be the subject of assessment.

Intensive biomass production on land or in water can, under optimum conditions, give yields of up to 30-50 tons per acre a year for C4 plants (22,16).

It appears that production of lignocellulosic materials can remain complementary with food production and that, depending on population growth rate and international developments, adequate quantities of non-food biomass will be available for materials, including synthetic polymers, if necessary. The statement by Marvel at the centennial ACS "Symposium on Macromolecules and Future Social Needs" that this would not be possible (23) is typical of the views of many polymer chemists. However, it is not likely that the use of biomass for energy can increase to any major extent.

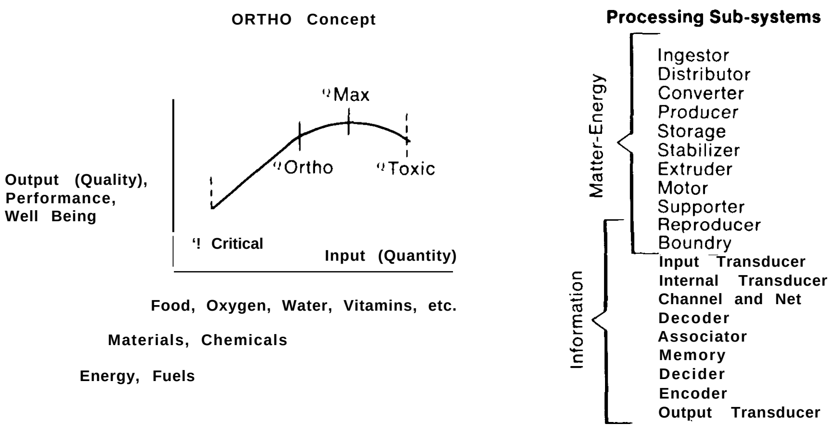
With a time frame of more than 30 years and with continuation of present growth rate increases, major stresses are likely to occur in the organic materials and land use systems. It seems plausible that new patterns of materials use will have to develop before that time. It is now appropriate to see how we can harmonize our use patterns with the production capacity of the photosynthetic system. It is now up to materials policy analysts to set some of the guidelines for the future, The multiple interdependencies make this a very complex task.

Natural Products and Systems

What is nature then capable of producing qualitatively, and how can the biosynthesized materials meet shifting human needs? Have our materials requirements in terms of performance, as achieved through the marvelous developments in polymers and composite materials, deviated so much from the properties-performances of natural materials that we must increasingly rely on the "feedstock approach" of using renewable resources as another carbon raw material source, comparable with coal, shale oil, lignite, and peat?

As a thought experiment, we can look at the materials-energy system as part of an earth metabolic system (24), and for the purpose of discussion one can consider analogs based on biological systems, Figure 6 shows some of the subsystems of an organism (7) and its functional characteristics. The food, oxygen, water, vitamins, trace metals, etc., participating in anabolic and catabolic processes in organisms can be viewed as the analogs of materials, chemicals, and fuels in the larger (external) metabolic system, This is obviously a much too simplified system but can be used as a conceptual framework for discussion of such questions as "throughput," energy-materials intensity, substitution, etc. Information can be viewed as an input or output depending on the level of abstraction.

FIGURE 6.—Internal and External Human Metabolic System



If we allow ourselves to adopt Pauling's (25) orthoconcept as applied to medicine, we can develop an idealized picture of what would be "correct" ("ortho" is Greek for "right" or "correct"), in terms of materials-energy input for the optimum performance (as opposed to the maximum performance) or well-being of the organism (individual, group, society) and its subsystems.

Obviously the shape and "height" of the curve as well as "critical" and "toxic" levels of an input will vary dependent on the nature of the input (which can be subject to substitution). The optimum rate of use of a material, product durability, utility and reuse, materials loss and recycling, etc., are concepts increasingly considered in the so-called materials cycle. The evaluation of "ortho points" for various materials and social systems can be the subject of normative assessments that might affect policies. The Symington (54) statement in relation to a national materials policy is of interest in this context.

We can also look at the biomaterials cycle and flow involving humans in a more dynamic manner and distinguish among a) production-conversion (biological and by man), b) use, and c) post-handling degradation (55) The "loss" of renewable resources to the environment is not of critical importance as we have a renewing energy system available. In the long term, however, it will be critical for "depletable" (nonrenewable) resources (figure 7).

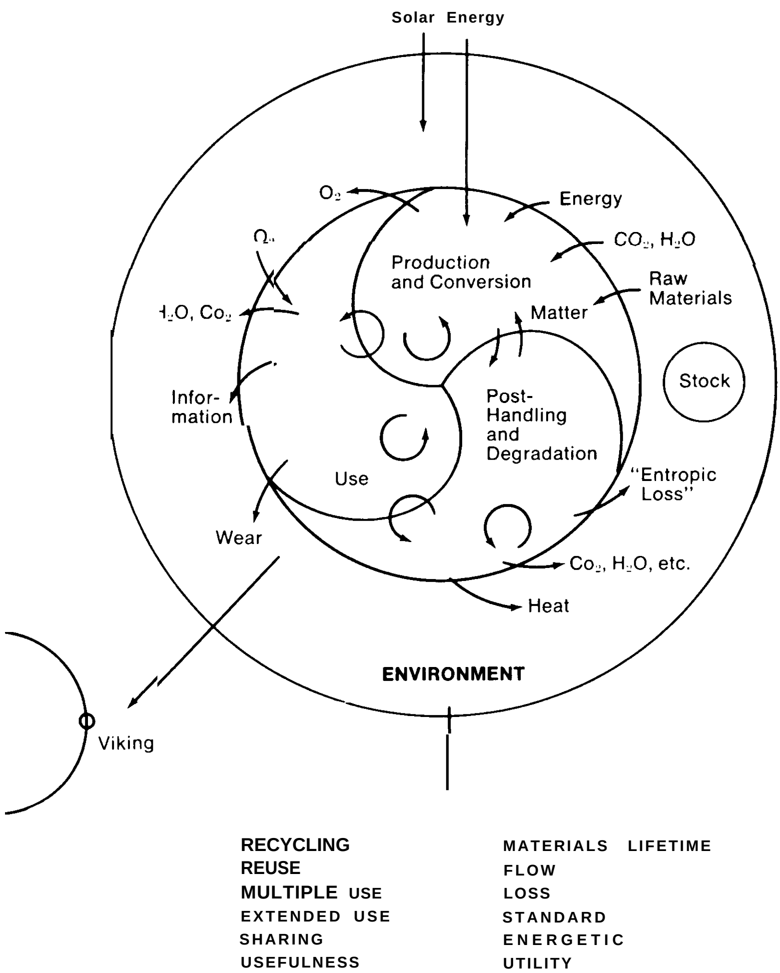
If we distinguish among bioproduction, conversion, and consumption, we can look at the capability of the solar energy-driven production system to produce molecules and structures at various free energy levels which have to be modified to meet the thermodynamic requirements of the human consumption system. (16) The symbiotic relationship between the earth and humankind has recently been discussed by Dubos (56) (figure 8).

The hierarchal levels of the natural materials system is shown in table 6. Only a single example is given at each level. (In the oral-visual version of this paper a series of slides is shown, indicating the systemic levels from an ecosystem to the molecular structure of cellulose, a hemicellulose, and lignin.) The manner in which we go down the systems scale is of course a primary question. The "cost" of going down the scale to meet a social need can be expressed in energetic terms.

The broad groups of plant types and the chemistry of their components are shown in tables 7 and 8. The lignocellulosic plants, which constitute by far the greatest stock of biomass on earth (2,1012 tons), are not digestible by man but can be made digestible for ruminants. The foliage is, however, directly digestible by various animals and could be a source of protein for man if adequate collection and separation processes were developed (18). The foliage can constitute up to 7 percent of the weight of the plant and for hardwoods can contain up to 8 percent of protein (half as much as alfalfa). The "starchy," the sugar, and the protein (legumes) type plants have generally more than 50 percent ligno-cellulosic material in the roots, stem, and branches. It is, of course, often the seeds we eat.

From a chemical point of view, we can group the materials into carbohydrates, phenolics, proteins, lipids, and special biomolecules, such as chlorophyll, vitamins, etc. The component

FIGURE 7.—Biomaterials Cycle



roles can be as building stones and adhesives, energy sources synthesizers, environmental protectors (stress adjusters), etc., participating in both anabolic and catabolic processes (7).

We often hear about cellulose as being the major polymer on earth. In terms of volume and weight, this is true, but in terms of storage of solar energy, lignin is the dominating biomaterial. Trees have 35-45 percent cellulose and 20-30 percent lignin, but lignin has almost twice as high enthalpic level (heat of combustion) as cellulose, Presumably nature has a purpose in this (table 9).

FIGURE 8.—Plant—Human Symbiosis

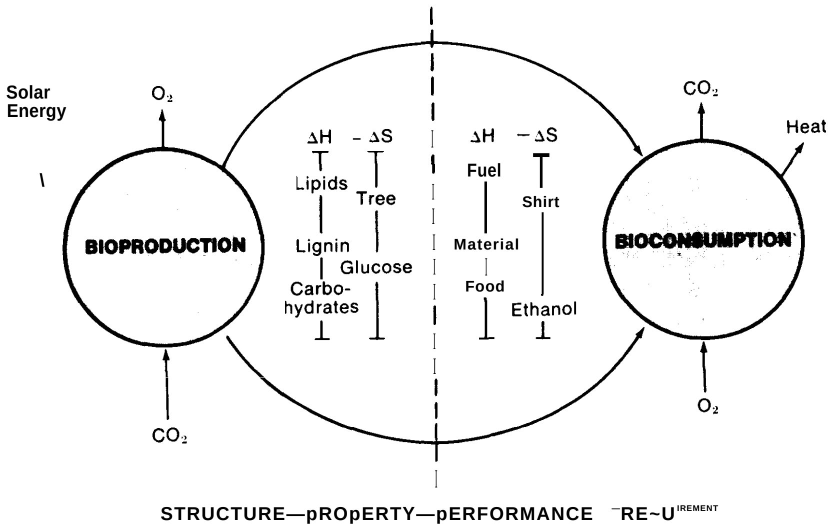


TABLE 6.– Hierarchal Material System Levels

Biosphere	
Autotrophs	Heterotrophs
Forest	Human Society
Tree	Supply System
Stern	Transportation
Wood	Pallet & Goods
Fiber	Box
Cellulose Fiber & Fibril	Carton (Paper)
Microfibril & Protofibril	Film Barrier
Cellulose Molecule	Polyethylene
Glucose	Ethylene
Ethanol	

TABLE 7. –Plant Types and Components

1. LIGNOCELLULOSICS:	Trees, straw, woody tissues in various plants. Contain Cellulose, Hemicelluloses, Lignin, Lipids
2. STARCHY PLANTS:	Corn, Wheat. Potatoes (seeds)
3. SUGAR PLANTS:	Cane. Beet
4, PROTEIN PLANTS:	Legumes, Foilage rich plants
5. ISOPRENOID PRODUCERS:	Rubber Plant. Guayule

TABLE 8. – Chemistry of Plant Components

CARBOHYDRATES:	Cellulose
	Hemicelluloses: Hexosans
	Pentosans
	Starch
	Sucrose
	Pectin Etc.
PHENOLICS:	Lignin
	Flavanoids
	Aromatic Aminoacids
PROTEINS AND PEPTIDES	
LIPIDS AND HYDROCARBONS:	Fatty Acids
	Rosin Acids
	Sterols
	Fatty Alcohols
	Rubber
CHLOROPHYLL, VITAMINS. TRACE ELEMENTS ETC.	

TABLE 9.—Heats of Combustion for Some Plants Components

	ΔHc (25°C)	
COMPOUNDS	BTU/LB	CAL/gM
α — Pinene	19,600	10,900
Oleic Acid	17,000	9,500
Lignin	12,700	7,100
Cellulose	7,500	4,200
CO_2	0	0

State of Reduction ↑

$$\text{COMPOUND} + O_2 \xrightarrow{\Delta Hc} CO_2 + H_2O$$

Some of the "functions" of lignin can be described as (27):

- Response to stresses:
  Mechanical,
  Biochemical (degradation),
  Physical-chemical (water), and
  Chemical (O_2, O_3, UV-light, fire);
- Energy storage; and
- Contributions to soil (humus) properties.

Cellulose and hemicelluloses have relatively simple composite materials functions in wood, while the protein and chlorophyll have very complex functions. The lipids might act as surfactant, hydrophobizing (sizing) agents and agents for control of insects, fungi, diseases, etc. A better understanding of the functional roles of plant components and means of affecting their biosynthesis should have high priority as a research area. We know a considerable amount about the organic chemistry of plant components, but much less about the biosynthesis and the manner in which the molecular, macromolecular, and morphological structural features relate to processes and property-performance-requirement characteristics of the plant.

The free energy in various plant components is there for a purpose. We can simply use the enthalpic value and burn the biomass for energy, or we can attempt to use renewable resources at highest possible systems level (see table 6). We should not increase entropy and destroy a composite material, a fiber, or a macromolecule when we don't have to in order to meet our need. The manner in which we manipulate the biomass and make cross levels transformations and changes at the molecular level by changing carbon-hydrogen-oxygen balances can be the framework for important research policy recommendations. To a certain extent, these questions can be approached through thermodynamic tools (28,30). Work on natural products in this area is badly lacking, as the petrochemical interests have controlled thermodynamics research. Non-equilibrium thermodynamics (29) and systems opening and closure (31) can be particularly important for living systems and evolutionary processes.

From the point of view of materials science, the research field is open. We don't know much about the composite materials contributions of the various components in wood. The interplay of natural products at various systems levels with synthetic polymers and inorganic materials has room for many innovations. A definition of materials performance requirements is often the bottleneck. Table 10 shows some material system types, many of which are already used for natural products.

TABLE 10. –Materials Systems

Type	Examples
Uniform. Amorphous	Lignin-Phenol Resin
Partially Crystalline	Rayon (Cellulose)
Laminated Sheets	Plywood
Fiber Network	Paper
Bonding Agent	Rosin Adhesive
Fiber Reinforcement	Wood
Particle Reinforcement	Lignin-Rubber Composite
Polyblend	Wood Middle Lamella
Coating	Starch
Powder Compaction	

A better understanding of structure-process relationships at various hierarchal levels (32) is much needed. In fact, general systems science could contribute considerably to the renewable materials understanding, Workshops by NSF (33,34) could put more emphasis on renewable polymers and materials. Although we are in the space age, we need to get down to the earth (even soil) in materials research,

Let me show you one example of where a renewable resource (lignin) can substitute for a nonrenewable material (carbon black). Adequate (but slightly different) properties in the reinforcement of rubber can be achieved with a lignin replacing HAF or ISAF carbon black (table 11). Lignin as a reinforcing filler (below 100 Å) is not like carbon black in its properties, and hypotheses on filler parameters' effect on materials properties, cannot be extrapolated (27).

The abrasion resistance with a lignin-reinforced rubber does not appear to be governed by the failure properties but rather by the visco-elastic properties of the cured rubber. Lignin is a macromolecular material with lower modulus and hardness than carbon black. The modulus of the reinforcing particle has been shown to affect the reinforcement properties, and work of the type done by Morton at the University of Akron can thus be highly relevant for renewable resource composites.

The shift from carbon black to lignin in the rubber industry is primarily controlled by institutional factors, lack of economic incentive, and concern for pulp mill impacts by recovery of a large fraction of the lignin which has to be replaced with another fuel source with present recovery systems. The quantity of lignin burned annually in U.S. kraft pulp mills is about 16 million tons.

TABLE 11. –Physical Properties of Lignin and Carbon Black Reinforced Styrene-Butadiene Rubber at 68 Parts Lignin per 100 Parts Rubber (Oil-Extended SBR)

	Lignin A	Lignin B	HAF	ISAF
Modulus (psi)	520	650	610	730
Tensile Strength (psi)	3165	3380	2500	2930
Elongation (%)	720	630	720	750
Tear Resistance (ppi)	355	300	320	335
Hardness (Shore A)	54	54	56	61
Corrected Pico Abrasion	86	85	91	II-4

Biosynthetic Pathways

Before discussing the "feedstock approach" of producing chemicals from renewable resources, it might be useful to look at the photochemistry and biosynthetic pathways of making chemicals, an area justifiably emphasized by Calvin (35) for many years. Solar energy can be used for both heat and quantum collection. In the latter category are photosynthesis, photochemistry, and photoelectric processes,

The primary and most important step in photosynthesis does not have to do with carbon but is rather the split of H20 leading to oxygen and highly reduced products which can affect the C02-reduction. The carbohydrate synthesizing cycles are then the starting point for synthesis of proteins, lipids, and phenolics.

A conscious human effort to design photosynthetic systems (plants, bacteria, or nonlive systems) to produce food, materials, and energy for internal as well as external metabolic systems might be as important an evolutionary event as the domestication of plants and animals in what we call agriculture. Philosophical questions of maintaining (increasing) diversity and complexity to safeguard adaptability get into the picture in considering the further "domestication of biosynthetic pathways."

Practical examples of controlling the production of specific chemicals are the natural rubber and naval stores industries. Termite-resistant, resin-loaded pine beams were once produced in the South, Ongoing efforts to triple the production of rosin and turpentine by chemical stressing of pines is being actively studied by the Forest Service and is funded by ERDA (36). Ecological impact is of major concern in this project, and the bioenergetics in relation to endproduct value has to be researched.

Zaborsky (16) has proposed a long range strategy of bioconversion using regulated plants or microbes or isolated cellular components for the selective production of small active moIecules. The argument would be that photosynthesized macromolecules and plant components cannot be made to meet material needs and that fragmentation processes are expensive, consume energy, and require complex separation processes as multiple (water-soluble) products are formed. An exception of easy separation is methane from anaerobic digestion. If we need other hydrocarbons, we can, as Ehrensvard (37) has proposed, achieve an enzymatic "instant fossilization, " but this would be quite expensive. If we would calculate the net energy of producing the oil we pump from the ground, we might get indications of what the "cost" will be when we have run out of it,

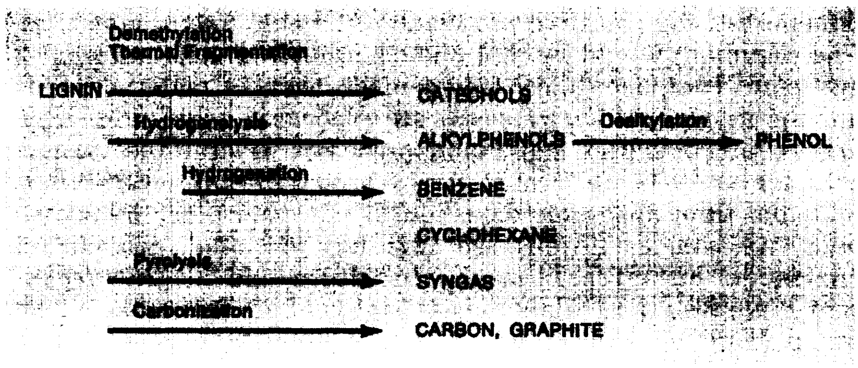
However, the photosynthetic system can be used to produce chemicals by:

1. Modifying productivity of existing organisms,
2. Affecting the selective component synthesis with existing organisms,
3. Interference with biosynthetic pathways as, for example, to catch an intermediate,
4. Biosynthetic production of complex molecules with needed properties, and
5. "Photosynthetic feed stock" approach by production of small molecules such as H_2, O_2, H_2O_2, CH_4, CH_3OH, CH_2O, CO, NH_3, C_2H_2O, C_2H_5OH.

The Chemical Feedstock Approach

Various recent assessments (10,13,14,38) indicate that abundant biomass resources are potentially available for chemical conversion and that conversion of lignocellulosic material to glucose, ethanol, syngas, methanol, furfural, and phenol are technically possible, although in most cases demonstration work is required and optimization has to be achieved (figures 9 & 10). The economics at present energy and wood cost do not yet appear to justify production of bulk chemicals from wood or waste, but considerable uncertainties still exist on actual costs. If renewable resource-derived chemicals or substitutes are less energy intensive than fossil carbon-derived chemicals, a substitution might be justified at a certain oil (or coal) cost. Uncertainties about coal conversion processes add to the difficulties in decisionmaking. More information about differences in conversion costs, labor, and social costs are needed and justify extensive Federal funding for research, development, and demonstration projects. The two major types of feedstock chemicals are the

FIGURE 9.—Lignin Fragmentation



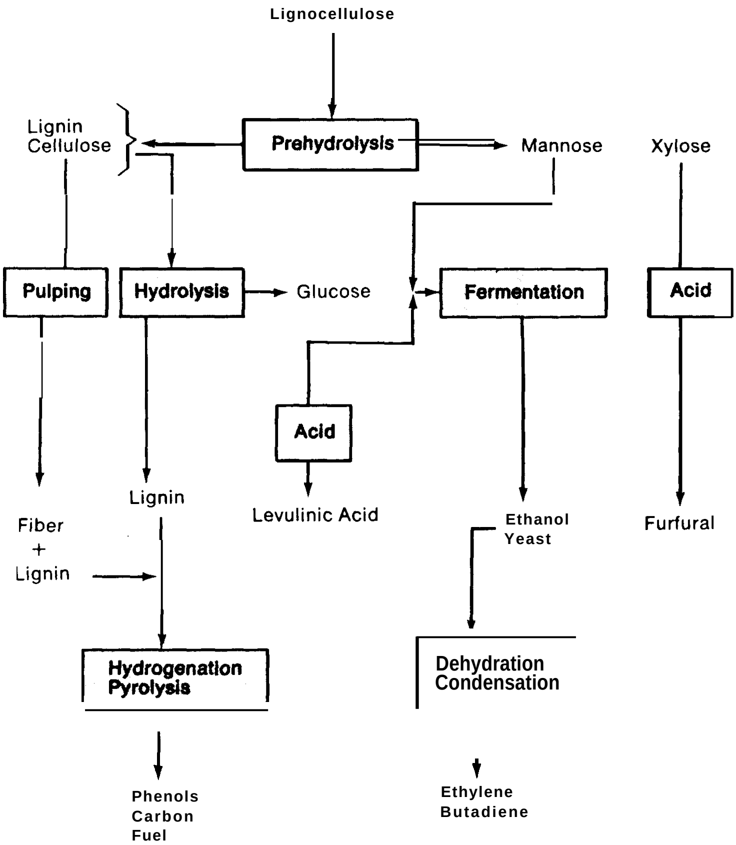
olefins and the aromatics. Carbohydrates are most conducive to conversion to the former while lignin can be a source of aromatics. Coal will probably be a more economic source for aromatics than for olefins.

The Forest Service study (14) financed by NSF is the most recent U.S. assessment. It concludes that petrochemical feedstock replacement through wood residue conversion would not significantly impact national petroleum consumption, No single chemical could be economically produced today. However, an integrated plant producing ethanol, furfural, and phenol could be economical at today's energy and wood prices. Dr. Zerbe of the Forest Service is manager of this project which should be well funded and complemented with technology assessment activities (figure 11).

Reference Materials System

As earlier pointed out, all of these assessments have to consider multiple interactions in the energy-materials sytem. The concepts of net energy and energetic in materials production can usefully be applied. Berry (39) has discussed the thermodynamics and energetic of alternative materials in packaging, transportation, etc. Hoffman and his group at Brookhaven National Laboratory (26) have developed guidelines for a reference materials system similar to the energy reference system (figure 12). This can be an extremely useful tool towards providing a framework for materials policy. Hoffman's input to the systems group in the CORRIM study (13) has led to a preliminary trajectory for the renewable resource system with a quantitative materials flow and some inputs of the energy requirement

FIGURE —Schematic Flow Chart of a Sample Lignocellulosic Chemical Plant (CORRIM)



at the various steps from the growing and harvesting to the final use,

The technique can also include inputs of labor, capital, and environmental activities and might be particularly useful in studying the effects of perturbations in the various parameters, A comparison of the energetic in producing a 1 gallon milk container from plastic versus paper is illustrative. Measured by the criterion of energy, paper is most favorable. Further research in this area is very much justified.

U.S. Materials Studies Related to Renewable Resources

During 1973, four studies (40,41,42,43) were released, all emphasizing timber and conventional uses of wood:

87-315 0 -77 - 14

FIGURE 11.—Multiple Product Waste Hardwood Facility Ethanol, Furfural, and Phenol

Basis of Projection

Wood Waste (hardwood)	1500 T/ D.O.D.	Ethanol 25 mm GPY 190 Proof
Investment Estimate	$100 mm	Furfural 75 mm lb/yr
Phenol Recovery	20% of Lignin in Residue	Phenol 52 mm lb/yr
Furfural Recovery	7.2% Of Wood Waste	

Production Costs	Investment
Depreciation	8
Maintenance	4
Taxes and Insurance	2

Labor

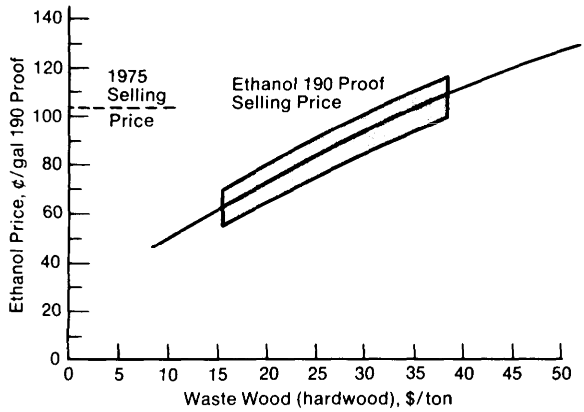
Operators	$20,000/yr
Foremen	25,000/yr
Management	30,000/yr

Profit 20 "/0 of Investment (10% after taxes)

Overhead 100°/0 of Labor

Credit 1975 Selling Price

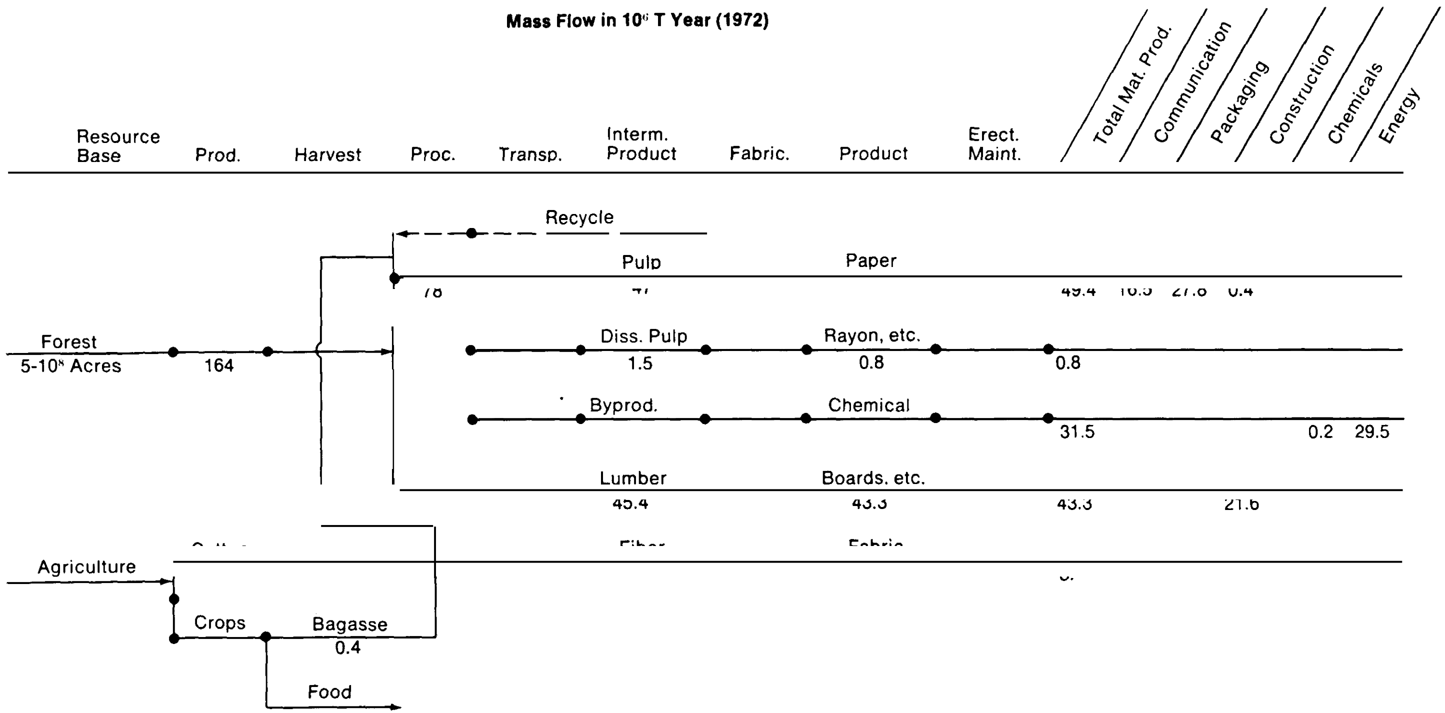
Furfural at 80% of	$0.37
Phenol at 80% of	$0.27



- **USDA-Forest Service: "The Outlook for Timber in the United States;"**
- **National Commission on Materials Policy: "Timber—The Renewable Material;"**
- **Report of the President's Advisory Panel on Timber and the Environment; and**
- **National Commission on Materials Policy: "Material Needs and the Environment Today and Tomorrow."**

The 1974 summary report of the National Academy of Sciences Committee on the Survey of Materials Science and Engineering (COSMAT), "Materials and Man's Needs," had a strong (and by wood scientists welcome) recommendation on renewable resources: "that studies be undertaken on the feasibility of using renewable resources, including organic wastes, as a raw material base for synthetic polymers." The COSMAT report recognized the low level of materials R&D on renewable resources and recommended an increase. It did not identify any applied or basic research problems for renewable resources but rather emphasized high-performance composite materials, biomaterials, energy, environment, recycling, etc. It was amazingly ignorant about the Iignocellulosic system. It defined pulping liquors as

FIGURE 12.—Aggregate Reference Materials System



waste, when in reality the organics are used for fuel value and the inorganic are recovered. It claimed that lignin "has not responded to scientific attack" and that new hope lies in methods "such as high resolution electron microscopy "-a poor definition of the materials research problems in the eyes of lignin scientists. It did make a meaningful conclusion that lignin might be employed as bonding agent in wood products. This is still a valid research objective. (In **1976,** there is to this writer's knowledge no academic polymer-material scientist in the United States doing research on lignin — indeed amazing considering that lignin energetically is the most important macromolecular material in our biosphere.)

The National Academy of Sciences–National Academy of Engineering report, "National Materials Policy," published in 1975, made recommendations on increased timber yield and referred to renewable resources under "waste utilization and materials conversion" advising on "research into development of feedstocks for polymer production."

The National Academy of Sciences Board on Agriculture and Renewable Resources formed the Committee on Renewable Resources for Industrial Materials on September, 1974, and will soon be ready to publish the general report. Several parts of the study were reviewed in the February 20 issue of Science. One panel dealt exclusively with the conversion of lignocellulosics to energy and chemicals, recommending accelerated R&D efforts both with the "macromolecular" and "feed stock" approaches (see earlier discussions).

CORRIM recommended as a top priority that an "advisory office for policy issues related to the use of renewable materials" be established under the Office of Science and Technology Policy in the Executive Office of the President, Studies should be undertaken to evaluate the Nation's materials supply systems, the capacity to develop and advance new technology, and the manpower and training needs in the field of renewable resources. It is concluded that the biological productivity of commercial forest land can be doubled within half a century through application of proven silvicultural practices, CORRIM recommends major efforts by USDA in this area. Deficiencies in the research and educational systems are being recognized. CORRIM recommends that NSF create and maintain university centers of research in renewable resources and that cooperative industry, university, and Forest Product Laboratory studies be encouraged,

The Technical Association of the Pulp and Paper Industry, Wood Chemistry Committee, represents an active group of wood chemists in the United States and has taken a strong stand in favor of "wood chemicals" and increased research effort and funding by Federal agencies. The Committee organized, jointly with Syracuse University, an international symposium "Wood Chemicals–A Future Challenge" now published as a special volume of Journal of Applied Polymer Science (17). It is now planning another international conference in Madison in June 1977 (jointly with the Forest Biology Committee). The conference will bring together various international assessment studies of renewable resources conversion to chemicals, food, and materials,

The NSF-Forest Service study on "The Feasibility of Utilizing Forest Residues for Energy and Chemicals "(14) is through its first phase and will now go into a systems definition and analysis phase. This program should lead to a demonstration of the technical and economic feasibility of processes for producing feedstock chemicals, like ethanol, furfural, and phenol, from lignocellulosic materials, The emphasis is on products that can be used within the forest industry. Of particular significance can be the part of the program related to adhesives for reconstituted wood products. Furfural and phenol can of course be involved, but adhesives end-objectives can also consider the use of lignin in macromolecular form, and a good material science effort will be required.

The Washington Center for Metropolitan Studies organized a well attended and publicized conference on "Capturing the Sun through Bioconversion" with a large number of papers and panel inputs which will be published. The emphasis on technology assessment and a participative, multidisciplinary format can make such activities very valuable, By unifying around biomass concepts and solar energy conversions, a much needed bridging between forestry, agriculture, and intensive biomass production advocates may come about.

The Battelle Columbus Laboratories have an ERDA-sponsored program on Fuels from Sugar Crops and have organized a Tutorial Conference, October **13-15, 1976.**

Institutions

Just as we are emphasizing "renewable resources" rather than "processes of renewal" and the energy-materials flows, it seems that institutions are mostly looked upon as structures with well-determined processes. This might be well so long as we have a homeostatic system with agreed upon ends and purposes. Forest Service has performed excellent statistical surveys of wood supply according to the merchantable bole concept, but it was not prepared to survey the total bioproductivity (net and gross) in various ecosystem. The two futures conferences (46,47) of the paper industry during 1973 both emphasized technical trends and needs, and employed as primary forecasting tools trend extrapolation and "surprise free futures" concepts. However, there is emerging a consensus that the research and educational system in relation to renewable resources and the forest industry should be revitalized, The technological initiative now comes largely from Scandinavia whose industry can compete in spite of twice as high wood cost, A wood chemistry or paper technology conference in this country will generally have more than half of the papers coming from Europe. The international orientation typical of wood science (necessary to reach a "critical mass") has many positive aspects to it, however.

The emphasis on structure shows up in the names of institutes and departments (wood, cellulose, forest products, paper, etc.), although a recent trend has been to include "environmental science" and thus a more interdisciplinary outlook. The wood chemistry research during recent years had, to perhaps 80 percent, been oriented towards oxygen bleaching-pulping for paper making (mostly justified because of beneficial environmental attributes). Some wood chemists had a professional identity problem which was accentuated when the American Chemical Society excluded "wood" from the division now called "Cellulose, Fiber, and Textile." In response to this, the TAPPI Wood Chemistry Committee became an active force with conferences, such as the Wood Chemicals Symposium in Syracuse, 1975, and an effort to affect NSF-RANN and other agencies. Wood Technology departments at universities might in a halfhearted way apply material science concepts, but material science or polymer departments will rarely work with wood, lignocellulosic components, or renewable resources in general.

NSF, RANN, and ERDA show a flexible attitude in defining the place for research on renewable resources and the processes for generating and converting these resources. ERDA deals with "Solar Energy" and "Bioconversion" and has listed in its scope "petrochemical substitutes," but emphasizes "fuel from biomass." NSF should formulate its policies in relation to renewable materials,

If we are truly approaching a state where we will view our photosynthesized resources in a new way with regard to generation, conversions, and end-uses, we might not be able to rely on trend extrapolation; and we might in fact as scientists confront a major paradigm shift (48), Harman (49) at Stanford Research Institute has compared a "transformation perspective" with the "Kahn post-industrial perspective." Henderson (50), Beer (51), and others have applied the "metalanguage-metasy stem" thinking about institutional change and concepts of managed, rather than exploited, resources, Emerging understanding of self-organizing systems (3o), systems opening and closure (31), homeorhetic vs. homeostatic systems, and the evolutionary view of Jantsch (52) could be of particular relevance in dealing with questions of our interdependencies with the photosynthesizing systems and the resulting products: food, "renewable resources," and other bioproducts.

It could be a major task for OTA to assess the technical, social, economical, and ecological implications of a major shift in our management of the phototroph system and renewable resource generation and utilization. NSF should study the educational and science policy implications of such a shift.

In summary, we might talk about renewable resources through renewable organizations and institutions.

Implications for Scientists and Engineers

The "renewable resource" and "materials renewal" issues involve major uncertainties and high complexity (multiple interdependencies) with regard to the extended and "new" uses. The time frame for change is important in the nonconventional uses of renewable resources, Considerations about the total biomass system and the mutualities between forestry and agriculture add to the need for interdisciplinary and systems-oriented views of the pattern of change.

The existing areas of renewable resource use confronts such needs as:

1. Safeguarding raw material supply,
2. Less capital-intensive technology,
3. Less energy-intensive processes,
4. Improved environmental control,
5. Less dependency on depletable resources, and
6. Better utilization of all resources.

The extended or new uses of renewable resources raise challenges in many areas in relation to the production, conversion, and uses of renewable resources. Most traditional institutions are not very well oriented towards handling some of the tasks ahead, and this is particularly true in the materials science and engineering areas.

The "age of substitutability" has been used to describe our present materials situation. The extent to which we can rely on trend extrapolation or will have to prepare for a major (paradigm) shift in our view of organic raw materials uses is still up for discussion,

The implications of a transformation in the renewable resource system should, however, be the subject of well organized assessments, incorporating technological, economic, social, environmental, and educational concerns.

Some examples of research, development and demonstration activities at three planning levels are outlined below:

A. Bioproduction

1.. Normative level (ends)

Develop an awareness about the functional roles of the components in phototrophs, the ability to direct the selective production of valuable components, and the manner in which plant components, macromolecules and chemicals can best be integrated (symbiotically) with the human needs system, using the biosynthesized product at highest possible systems level.

2. Strategic level (objectives)

Develop joint forestry-agriculture programs in such areas as biological nitrogen fixation, water management, genetic selection of plants (for optimum production of a combination of plant components for food, materials, chemicals and fuel), nutrient flows, and tolerable biomass removal from ecosystem, etc.

3. Operational level (goals)

Survey the existing biomass systems with regard to type, quantity of different plants, economics of harvesting and transportation to potential use sites, etc.

B. Harvesting, collection, transportation, processing, conversion, and fabrication, etc., to needed products

1. Normative level

Assess alternative socioeconomic systems for ecologically acceptable transformations of photosynthesized materials to end products meeting human needs in an adaptable manner (according to shifting priorities).

2. Strategic level

Develop a Reference Materials System enabling the assessment of the benefits and constraints in choosing alternative raw material sources for functional end products.

3, Operational level

Demonstrate technical feasibility and economics of integrated production of ethanol, furfural, and phenol from wood.

C. Product development and use

1. Normative level

Determine the structure-property -performance relationships for materials components and systems derivable from renewable resources, assess future organic materials requirements and substitutions, and develop approaches for optimization (according to "ortho philosophy") of the use of renewable resources to meet materials needs in manners compatible with food and other needs.

2. Strategic level
   Develop relevant composites and polyblends using renewable resource materials and macromolecules in combination with synthetic polymers (when necessary for performance) and inorganic materials.
3. Operational level
   Assess the feasibility of using modified lignins as adhesives for reconstituted wood products.

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