Survey of Biocrude-Producing Plants from the Southwest[1]

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One hundred ninety-five species of plants native to the southwestern United States and northwestern Mexico were surveyed for potential feedstocks for biocrude production in arid lands. Biocrude is the hydrocarbon and hydrocarbon-like chemical fraction of plants which may be extracted by organic solvents and upgraded to liquid fuels and chemical feedstocks. Plants were evaluated using a set of models which provide estimates of oil and energy production costs.

Plants producing either latex or resinous exudates had the highest percentage of high energy extracts. Total extracts were highest in smaller, potentially less productive plants. The optimum combination of percentage biocrude and potential yield occurred in plants of intermediate size having higher than average extractables. High biomass yields do not appear necessary for the economic production of biocrude in irrigated, arid regions. Several desert plants might produce biocrude for between $10–15 per million BTU without by-product credits.

Green plants synthesize reduced constituents that can be directly extracted for use as petroleum-like feedstocks (Calvin, 1979; Buchanan et al., 1978; Haag et al., 1980). This extractable biocrude is a complex mixture of triglycerides, waxes, terpenes, phytosterols, and other modified isoprenoid compounds. Biocrude can be catalytically cracked to produce high yields of either liquid fuels or chemical feedstocks (Haag et al., 1980; Hinman et al., 1980).

Presently several species are being investigated as potential biocrude feedstocks. Latex-bearing plants, particularly *Asclepias* spp. and *Euphorbia* spp., have received the most attention. *Euphorbia lathyris* L. is the subject of a research program at the University of Arizona, and *Asclepias speciosa* Torr. is being evaluated by the Plant Resources Institute in Salt Lake City. These 2 genera have also been examined as potential feedstocks for rubber (Whiting, 1943) and wax (Hodge and Sineath, 1956).

Calvin (1979) and Bassham (1977) have suggested that "energy farms" be developed specifically for arid and semiarid lands, particularly in the southwestern United States. This area is potentially highly productive because of its high solar radiation (Bassham, 1977) and long growing season. The Southwest also has considerable acreage of uncultivated land that is unsuitable for conventional food and fiber crops, but which might be used for cultivation of energy crops (Lipinsky and Kresovich, 1979). Johnson and Hinman (1980) stressed that developing biocrude farming and extracting facilities on marginal lands are desirable because they would not compete with food and fiber crops.

We have conducted a survey of numerous desert plants from the southwestern United States and northwestern Mexico to determine their economic potential as biocrude producers. This paper describes our procedures for evaluating these plants and summarizes the results obtained from the survey.

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Previous attempts to evaluate plants for potential biomass yields, growing costs, and percentage of extractables have used criteria based on rating points (Buchanan et al., 1978). We experimented with several such rating criteria with unsatisfactory results—the rating systems failed to discriminate adequately among species. In addition, a species' numerical rating provided no indication of the plant's economic potential. Our current procedures provide direct estimates of unit costs for production of biocrude and energy for every species evaluated.

METHODS

Plant collection

Each plant collected from the wild included a sample for solvent extraction and a voucher specimen, and field notes were kept which included habit, height, and pertinent environmental and phenological data. Voucher specimens were deposited in the University of Arizona Herbarium (AZ).

Samples for extraction were at least 20 g dry weight. Few species whose individuals typically weigh less than 20 g dry weight at maturity were included in the survey since such species have a limited potential for biomass production. A sample representative of the entire aboveground portion of the plant was collected from large individuals for which it was impractical to collect the whole plant. Since it was observed that the amounts of extractables vary within many species, those species which appeared to have good potential were collected several times throughout their ranges and at different phenological stages.

Laboratory analyses

The objectives of the laboratory analyses were to provide estimates of the amounts of extractable material, expressed as percentages of the plant dry weight, as well as the energy contents of those extracts.

The extraction procedure which was followed during this study has been described briefly by Hinman et al. (1980). Twenty g of oven-dried and ground (3 mm mesh) plant material were extracted with 300 ml of cyclohexane for 12 h followed by a second extraction with 300 ml of ethanol for 12 h using Soxhlet extractors. The extracts were dried to a constant weight in a fume hood, followed by drying under high vacuum for 24 h.

Energy values for the 2 extracts and the residue or bagasse were estimated from elemental analyses of each fraction from several species. The energy values were first estimated from the C:H:O ratios by comparison with compounds of similar composition. These estimates were confirmed by bomb calorimetry of extracted and unextracted samples of the same collections used for elemental analysis. The cyclohexane and ethanol extracts were characterized as high BTU (17.5 kBTU/lb) and medium BTU (10.0 kBTU/lb) feedstocks, respectively (Hinman et al., 1980). By comparison, crude oils vary from 19–22 kBTU/lb. For the purpose of conducting the survey, it was assumed that the energy values of extracts were similar for all species. Biocrude was defined as the sum of the cyclohexane and ethanol extracts.

Selection criteria

Our selection criteria are a set of models or computing formulas (Table 1) for estimating unit costs of oil and energy production based on agricultural costs for Arizona.

The energy content of biocrude was calculated as a weighted average of the cyclohexane and ethanol extracts [formula (*1*)].

Ovendry biomass yields for each species were estimated as a function of the annual height growth (H, in cm) by formula (*2*). Since the majority of the species surveyed were annual or perennial herbs, H was generally the height of the plant. Formula (*2*) also can be used for woody plants because it is essentially a biomass predictor. When the current year's growth can be determined from morphological evidence, the annual yield can be estimated as the difference in biomass as calculated from the current and previous seasons' heights. Alternately, the biomass as calculated by formula (*2*) can be divided by an estimate of plant age to obtain an annual yield estimate. Formula (*2*) was derived from data on the size and mass of whole plants, and it applies to plants which are between 40–250 cm in height.

The yield of biocrude (bbl/acre) was calculated by formula (*3*), and the energy yield by formula (*4*)[3]. The energy yield given by formula (*4*) is for the biocrude fraction of the plant only. The energy content of the bagasse remaining after solvent extraction is approximately:

$$\overline{\text{M}}\text{BTU/acre} \simeq .14\ (\text{tons/acre})\ [100 - (\%\ \text{total extracts})]$$
$$\text{GJ/ha} \simeq .16\ (\text{tons/ha})\ [100 - (\%\ \text{total extracts})].$$

The latter values are useful for total system energy budget calculations, and for determining the potential for the bagasse to meet process energy requirements or to generate electricity for sale.

The crucial step in our procedure is the estimation of growing costs. Formula (*5*) was used to estimate growing costs for irrigated agriculture in central Arizona. This model, which estimates per acre costs in 1980 dollars, was derived from information provided by N. G. Wright, staff agricultural economist, Office of Arid Lands Studies, University of Arizona. The model assumes average fertilizer (30 lb N + 8 lb P per dry ton yield) and water (8 acre-in per ton dry yield) requirements. Alternative models have been developed for variable water requirements, since water use is the principal factor influencing growing costs in irrigated agriculture.

Biocrude and energy costs were estimated by formulas (*6*) and (*7*), respectively, which include a cost of \$20 per ton for extraction of biocrude using continuous solvent extraction equipment currently available for use in the seed oil industries. The estimate for processing costs was based on information provided by N. Hunt

[3] These formulae are simple contractions of longer equations containing several constants, e.g., formula (*3*):

$$\begin{aligned}\text{bbl/acre} &= \text{tons/acre} \times [(\%\text{CH} + \%\text{EtOH})/100] \times (2{,}000\ \text{lb/ton}) \times (1\ \text{bbl}/285\ \text{lb}) \\ &= .07\ (\text{tons/acre})\ (\%\text{CH} + \%\text{EtOH})\end{aligned}$$

TABLE 1. COMPUTING FORMULAS COMPOSING THE UNIVERSITY OF ARIZONA SELECTION CRITERIA.

Formula no.	Parameter estimated	English system Units	English system Equation	Metric system Units	Metric system Equation
(*1*)	Biocrude quality[a]	kBTU/lb	$Y = \frac{17.5\ (\%CH) + 10\ (\%EtOH)}{(\%CH + \%EtOH)}$	MJ/kg	$Y = \frac{40.7\ (\%CH) + 23.3\ (\%EtOH)}{(\%CH + \%EtOH)}$
(*2*)	Biomass yield[b]	tons/acre	$Y = .0053\ H^{1.40}$	tons/ha	$Y = .012\ H^{1.40}$
(*3*)	Biocrude yield[c]	bbl/acre	$Y = .07\ (ton/acre)\ (\%CH + \%EtOH)$	bbl/ha	$Y = .077\ (ton/ha)\ (\%CH + \%EtOH)$
(*4*)	Energy yield[d] (in biocrude)	M̄BTU/acre	$Y = .29\ (bbl/acre)\ (kBTU/lb)$	GJ/ha	$Y = .13\ (bbl/ha)\ (MJ/kg)$
(*5*)	Growing costs	$/acre	$Y = 100 + 55\ (tons/acre)$	$/ha	$Y = 250 + 60\ (ton/ha)$
(*6*)	Biocrude costs	$/bbl	$Y = \frac{100 + 75\ (tons/acre)}{(bbl/acre)}$	$/bbl	$Y = \frac{250 + 82\ (ton/ha)}{(bbl/ha)}$
(*7*)	Energy costs	$/M̄BTU	$Y = \frac{100 + 75\ (tons/acre)}{(\bar{M}BTU/acre)}$	$/GJ	$Y = \frac{250 + 82\ (ton/ha)}{(GJ/ha)}$

[a] %CH = % cyclohexane extracts; %EtOH = % ethanol extracts; MJ = Megajoules.
[b] H = height in cm.
[c] bbl = barrels, defined here as 285 lb (~42 gal) of extract.
[d] GJ = gigajoules (10^9 J).

Moore and Associates and Crown Iron Works and applies to a single-step extraction at a 1,000 ton/day plant. The 2-step laboratory procedure, while providing working estimates of both the amount and energy content of extractables, would be prohibitively expensive as a commercial process. We are currently experimenting with various solvents and methods of feedstock preparation that would be appropriate for a single-step commercial extraction.

RESULTS AND DISCUSSION

We surveyed over 400 collections of plants from southwestern North America. Although the collections encompassed considerable taxonomic diversity (195 species and varieties in 107 genera in 35 families), plants producing either latex or resinous exudates were emphasized. Laboratory analyses of all species included in the survey are presented in the Appendix.

The yields of extractable materials in different groups of plants are summarized in Table 2 and Fig. 1. Plants producing neither latex nor resinous exudates produced an average 2.5% cyclohexane extract and 14.9% ethanol extract (percentage by weight of ovendry, aboveground biomass). Cyclohexane extracts were higher in the latex-bearing plants. Average yields of *Euphorbia* spp. and *Asclepias* spp. were similar. *Amsonia* spp. produced consistently high ethanol extracts.

The highest cyclohexane extracts were found in resinous species. Such plants occur in several families, but most of the resinous plants in our sample were members of the Compositae, tribe Astereae (e.g., *Baccharis, Chrysothamnus, Grindelia, Gutierrezia, Haplopappus, Xanthocephalum*). The resinous substances coat stems, leaves, and involucres of these plants.

The legumes in our sample showed low cyclohexane and total extracts. Legumes have received considerable attention as potential bioenergy feedstocks because of their ability to fix nitrogen which would result in lower fertilizer costs. However, desert legumes do not appear to be good candidates as feedstocks for biocrude production.

The cyclohexane extract is the high-energy component of plants that has proved amenable to upgrading to liquid fuels and chemical feedstocks. The distributions of percentage yields of cyclohexane extracts in our collections of latex

TABLE 2. SUMMARY OF PERCENTAGE EXTRACTABLES IN 195 SPECIES OF SOUTHWESTERN PLANTS.

		Percentage yields		
Plant group	No. spp.	Cyclohexane	Ethanol	Total
Latex-bearing plants	69	4.9a[a]	17.4a	22.3a
Euphorbia spp.	26	4.5	16.5	21.0
Asclepias spp.	16	5.4	15.0	20.4
Amsonia spp.	9	5.5	26.1	31.6
Resinous plants	23	8.1b	14.2b	22.3a
All other plants	103	2.5c	14.9b	17.4b
Legumes	10	1.8	15.5	17.3

[a] Means not followed by same letter are significantly different ($P < .05$).

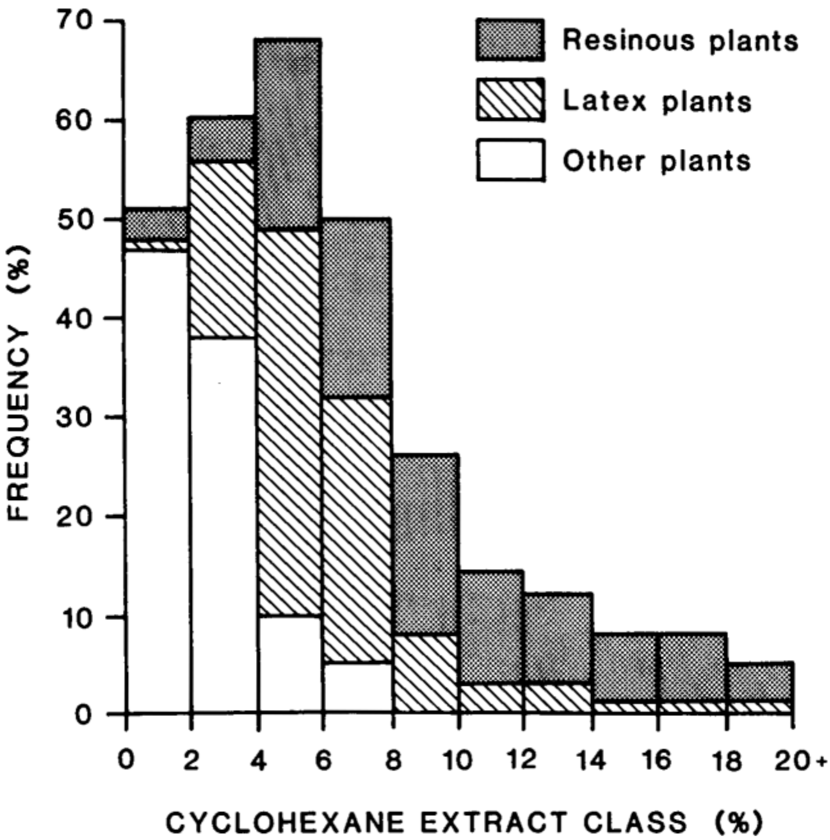

Fig. 1. Frequency distributions of percentage cyclohexane extracts for resinous, latex, and other plants.

species, resinous species, and other plants are shown in Fig. 1. Most collections of nonresinous, nonlatex plants varied between 0–4% cyclohexane extracts, and none exceeded 8%. Most latex plants analyzed contained between 4–8% cyclohexane extracts. Although resinous species showed the greatest variation in cyclohexane extracts, these plants predominate among species with cyclohexane extracts exceeding 10%.

Fig. 2 illustrates a major finding of the survey—maximum observed total extractables appeared to be inversely proportional to plant size. Thus, species with the best potential for annual biomass production contained the least amount of high-energy extractable material. Some possible explanations for this observation include: production of hydrocarbon and hydrocarbon-like compounds requires an

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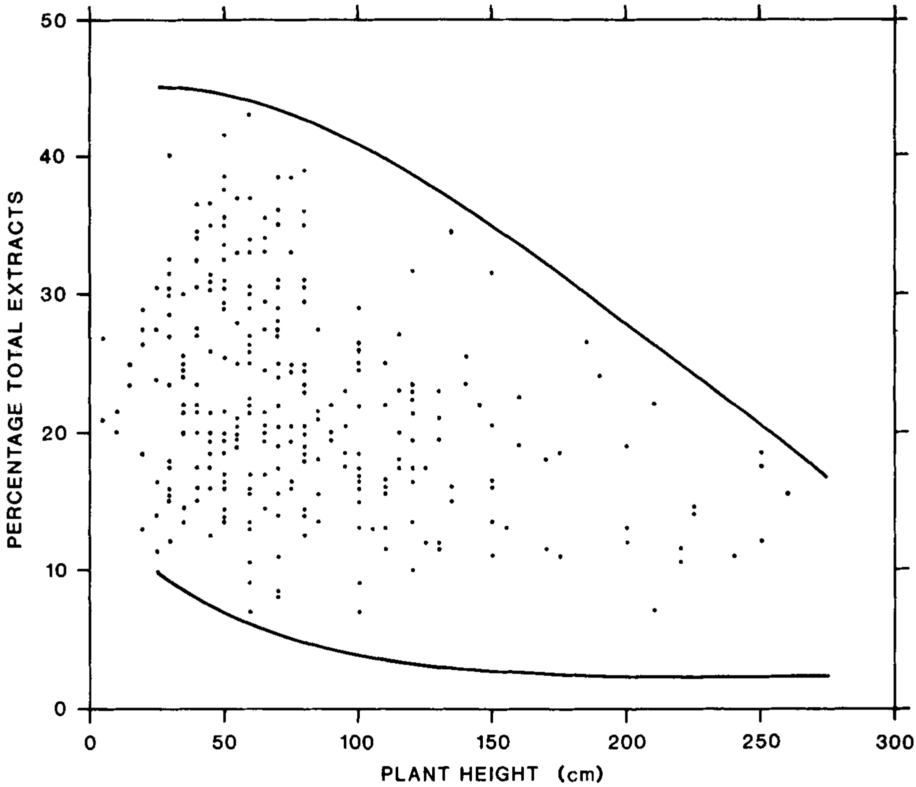
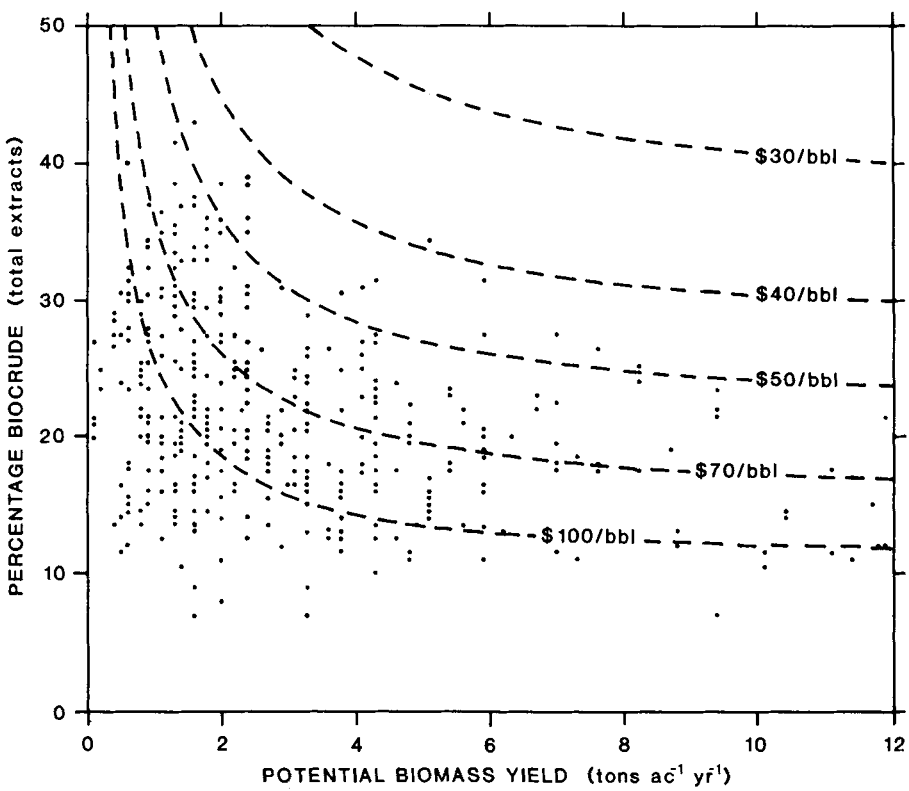
Fig. 2–3. Fig. 2. (*Top*) Percentage extractables (cyclohexane followed by ethanol) and plant height in 300 collections of plants from southwestern North America. Fig. 3. (*Bottom*) Application of the Arizona selection criteria, showing relationship of biocrude content (percent of aboveground dry weight) and estimated biomass yields to biocrude cost. Each point in Fig. 2–3 represents a single plant collection.


PERCENTAGE TOTAL EXTRACTS
0
10
20
30
40
50
PLANT HEIGHT (cm)
0
50
100
150
200
250
300


PERCENTAGE BIOCRUDE (total extracts)
0
10
20
30
40
50
$30/bbl
$40/bbl
$50/bbl
$70/bbl
$100/bbl
POTENTIAL BIOMASS YIELD (tons ac⁻¹ yr⁻¹)
0
2
4
6
8
10
12

energy expenditure by the plant, thus reducing growth; large plants are required to partition a larger fraction of their photosynthate into polymeric carbohydrate structural materials in order to support the increased mass; and hydrocarbon production could be a response to stress, which would be correlated with reduced growth.

This trade-off between plant size and percentage extractables is largely responsible for the difficulty of devising useful selection criteria based on rating points. A high rating for potential yield tends to be offset by a low rating for percentage extractables, and vice versa. Our current criteria were designed to evaluate this trade-off, as shown in Fig. 3, where percentage biocrude is plotted against potential biomass yield. The dashed lines are isograms for predicted biocrude costs. These isograms were calculated by setting the price of biocrude constant and combining and rearranging formulae (*3*) and (*6*):

$$(\%\text{ total extractables}) = \frac{100 + 75\ (\text{tons/acre})}{.07\ (\$/\text{bbl})\ (\text{tons/acre})}$$

Few plant collections fall above the $50/bbl isogram, and they are all plants with low to moderate predicted biomass yields.

High yields are generally considered mandatory for economical production of energy from plants (Hinman et al., 1980; Johnson and Hinman, 1980). However, our results show that all plants with yields exceeding 9 tons $\text{acre}^{-1}\ \text{yr}^{-1}$ would produce higher cost biocrude than several plants with projected yields of 2–6 tons $\text{acre}^{-1}\ \text{yr}^{-1}$. Although feedstock costs ($/ton) would decline with increasing yields, extraction costs ($/bbl) would increase because of the lower fraction of biocrude in higher yielding plants.

All species identified by our selection criteria as having the potential to produce biocrude for $15.00 or less per million BTU are listed in Table 3. The cost figures

TABLE 3. PLANT SPECIES IDENTIFIED BY THE ARIZONA SELECTION CRITERIA WITH THE POTENTIAL TO PRODUCE BIOCRUDE FOR $15 PER MILLION BTU OR LESS.

	Morphology[a]			Extractables			Yields		Costs	
Species	Habit	Type	Coll. No.[b]	%CH	%EtOH	kBTU/lb	Ton/acre	Bbl/acre	$/bbl	$/MBTU
Pedilanthus macrocarpus Benth.	Shrub	L	2477	25.0	11.1	15.2	4.1	10.3	40	9.00
Asclepias albicans Wats.	Shrub	L	1963	14.0	20.4	13.1	5.1	12.3	39	10.30
A. subulata Decne.	Shrub	L	1986	9.3	22.2	12.2	4.3	9.5	44	12.60
Chrysothamnus paniculatus (Gray) Hall	Shrub	R	2427	18.3	14.3	14.2	2.2	5.1	52	12.60
C. nauseosus spp. *bigelovii* (Gray) Hall	Shrub	R	2408	15.1	20.8	13.2	2.0	5.0	50	13.10
Amsonia grandiflora Alexander	Per.	L	2228	5.1	33.2	11.0	2.4	6.6	42	13.30
Xanthocephalum gymnospermoides (Gray) B. & H.	Ann.	R	2345	12.1	14.8	13.4	4.1	7.7	53	13.60
Amsonia hirtella var. *pogonosepala* (Woodson) Wiggins	Per.	L	2354	8.6	29.8	11.7	2.0	5.4	46	13.60
A. kearneyana Woodson	Per.	L	2178	5.2	30.6	11.1	2.4	6.1	46	14.30
Asclepias erosa Torr.	Per.	L	2499	13.0	10.8	14.1	4.6	7.6	59	14.30
Grindelia camporum Greene	Bien.	R	2390	13.0	11.8	13.9	3.8	6.6	58	14.50

[a] Ann. = annual; Per. = herbaceous perennial; Bien. = biennial; L = latex-bearing; R = resinous.
[b] All collection numbers are those of S. P. McLaughlin; voucher specimens are deposited at AZ.

in Table 3 should be viewed as indicative only. A thorough economic analysis would require more precise data on each species' yield, biocrude production, water requirement, and fertilizer requirement under cultivation. The estimates in Table 3 fulfill the objective of identifying the best species for further agronomic and chemical research and development.

All species listed in Table 3 are either latex-bearing or resinous plants. It is important to note that in no case do the projected yields exceed those commonly reported for irrigated crops in the Southwest. Bioenergy projects dependent on extremely high yields with consequent high water use have little chance of succeeding in the arid Southwest. Biocrude yields vary from 5–12 bbl $acre^{-1}$ yr^{-1} among the plants listed in Table 3.

Factors other than the projected costs of energy production limit the potential of some of the species listed in Table 3. *Pedilanthus macrocarpus* Benth., a native of Baja California, Mexico, is probably too frost sensitive to be cultivated in most of the agricultural areas of the southwestern United States. Biocrude quality (kBTU/lb) in *Amsonia* spp. may be too low for upgrading to liquid fuels, although these species might be good feedstocks for fermentation. From our results it seems that the best candidates are probably *Asclepias* spp. and various resinous plants.

The cost figures in Table 3 indicate that biocrude might be produced in the arid Southwestern States for between $10–15 per million BTU. Imported crude oil at $42 per barrel costs approximately $7.80 per million BTU. An economical use of the bagasse after solvent extraction would be required before biocrude could compete as a substitute for imported crude oil. Several options exist, including direct combustion to produce steam and electricity, the manufacture of animal feeds or soil amendments, or further conversion to other energy products.

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APPENDIX

Laboratory analyses of Southwestern plant species. Collection numbers are those of S. P. McLaughlin except where otherwise noted. All voucher specimens are deposited at AZ. Ann. = annual; Bien. = biennial; Per. = perennial herb; Suff. = suffrutescent; L = latex-bearing; R = resinous; NLR = neither latex nor resinous. Many species were collected several times, but only the collections with the highest and lowest percentage extractables are included.

Taxa	Coll. No.	Morphology Habit	Morphology Type	Height (cm)	% Extractables CH	% Extractables EtOH
Santalaceae						
Comandra pallida A.DC.	2277	Per.	NLR	35	5.1	15.0
Polygonaceae						
Eriogonum abertianum Torr.	2270	Ann.	NLR	30	0.8	11.2
E. alatum Torr.	2296	Per.	"	130	0.6	22.0
Chenopodiaceae						
Atriplex elegans (Moq.) D. Dietr.	2291	Per.	NLR	65	1.3	15.6
Chenopodium berlandieri Moq.	2368	Ann.	"	200	2.0	11.0
C. dessicatum Nels.	2236	"	"	110	1.4	10.0
Salsola kali L.	2232	"	"	85	6.4	11.4
Amaranthaceae						
Amaranthus palmeri Wats.	2233	Ann.	NLR	80	1.9	23.0
" "	2340	"	"	250	1.1	10.8
Nyctaginaceae						
Mirabilis longiflora L.	2266	Per.	NLR	50	0.8	12.8
M. tenuiloba Wats.	1997	"	"	45	7.3	27.6
Caryophyllaceae						
Silene scouleri Hook.	2314	Per.	NLR	45	3.7	17.8
Ranunculaceae						
Thalictrum fendleri Engelm.	2274	Ann.	NLR	45	2.0	17.4
Papaveraceae						
Argemone platyceras Link & Otto.	1649	Ann.	NLR	70	1.4	12.6
Cruciferae						
Lepidium thurberi Wooton	2265	Ann.	NLR	50	1.6	19.9
Sisymbrium linearifolium (Gray) Payson	2268	"	"	100	1.8	5.0
Capparidaceae						
Cleome lutea Hook.	2309	Ann.	NLR	130	1.5	9.8
C. serrulata Pursh	2300	"	"	80	1.0	11.6
Polanisia trachysperma Torr. & Gray	2239	"	"	50	3.5	13.0
Wislizenia refracta Engelm.	2304	"	"	80	2.3	16.7

APPENDIX -- Continued

Taxa	Coll. No.	Morphology Habit	Morphology Type	Height (cm)	% Extractables CH	% Extractables EtOH
Leguminosae						
Acacia angustissima (Mill.) Kuntze	2261	Suff.	NLR	40	2.8	31.8
" " "	2346	"	"	60	3.9	22.4
Astragalus albulus Woot. & Standl.	2326	Ann.	"	70	1.4	16.3
Cassia leptocarpa Benth.	2251	Per.	"	80	2.6	18.1
Dalea albiflora Gray	2357	"	"	135	1.8	13.0
Desmanthus cooleyi (Eaton) Trel.	2262	Suff.	"	35	2.8	10.8
Hoffmanseggia microphylla Torr.	2415	"	"	65	0.9	18.4
Medicago sativa L.	2280	Per.	"	60	1.2	7.7
Melilotus indicus (L.) All.	2267	Ann.	"	100	0.8	16.0
Oxytropis lambertii Pursh	2295	Per.	"	45	1.8	14.4
Parryella filifolia Torr. & Gray	2335	Suff.	"	100	1.8	14.4
Linaceae						
Linum lewisii Pursh	2289	Per.	NLR	70	3.8	11.5
Zygophyllaceae						
Larrea tridentata (DC.) Coville	2361	Shrub	R	120	1.6	15.9
Viscainoa geniculata (Kell.) Greene	1995	"	NLR	140	2.7	22.8
Rutaceae						
Thamnosma montana Torr. & Frem.	2419	Shrub	NLR	85	7.6	21.9
Burseraceae						
Bursera hindsiana (Benth.) Engler	1982	Tree	NLR	300	2.5	12.3
Euphorbiaceae						
Acalypha californica Benth.	1992	Shrub	NLR	120	3.2	20.4
A. lindheimeri Muell. Arg.	1665	Per.	"	55	2.2	19.0
Cnidoscolus angustidens Torr.	1708	"	"	75	2.9	24.7
Croton californicus Muell. Arg.	1996	Shrub	"	100	2.4	15.1
C. corymbulosus Engelm.	1687	Per.	"	50	1.8	16.6
C. sonorae Torr.	2148	Shrub	"	85	3.3	12.4
C. texensis (Klotzsch) Muell. Arg.	1740	Ann.	"	60	1.7	14.3
" "	2324	"	"	50	1.8	14.5
Ditaxis brandegii (Millsp.) Rose & Standl.	2098	Per.	"	150	1.6	9.4
D. lanceolata (Benth.) Pax & Hoffmann	1937	Suff.	"	30	1.4	13.4
Euphorbia alta Norton	2290	Ann.	L	30	4.4	12.9
E. antisyphillitica Zucc.	n.s.[a]	Suff.	"	40	10.8	9.2
E. bilobata Engelm.	1778	Ann.	"	25	3.1	13.4
E. capitellata Engelm.	1660	Per.	"	10	2.4	19.0

APPENDIX -- Continued

Taxa	Coll. No.	Morphology Habit	Type	Height (cm)	% Extractables CH	EtOH
E. chamaesula Boiss.	2224	"	"	50	6.4	23.2
" "	2332	"	"	60	6.8	19.4
E. dentata Michx.	1866	Ann.	"	35	3.1	11.4
E. eriantha Benth.	1979	"	"	45	5.0	12.3
" "	2146	"	"	40	7.7	15.6
E. exstipulata Engelm.	1696	"	"	15	5.3	19.6
E. florida Engelm.	1766	"	"	25	4.8	22.9
E. heterophylla L.	1699	"	"	30	3.2	11.7
" "	2341B	"	"	50	3.0	11.2
E. hyssopifolia L.	1733	"	"	35	2.6	27.6
E. incisa Engelm.	2166	Per.	"	40	5.4	22.1
E. incisa var. mollis (Norton) Wheeler	1826	"	"	35	5.1	20.2
E. lathyris L.	2373-3	Bien.	"	70	13.4	8.4
" "	2385-1	"	"	155	3.8	9.0
E. lurida Engelm.	2204	Per.	"	25	5.1	25.2
E. magdalenae Benth.	2096	Shrub	"	70	1.9	18.4
E. marginata Pursh	2365	Bien.	"	110	6.0	10.4
E. melanadenia Torr.	1667	Per.	"	10	2.4	17.8
E. misera Benth.	2081	Shrub	"	50	6.0	8.1
" "	2107	"	"	160	5.3	17.0
E. oblongata Griesb.	2379	Per.	"	100	2.1	13.0
E. pediculifera Engelm.	1920	Ann.	"	5	3.9	16.9
E. rigida Bieb.	n.s.[a]	Per.	"	35	5.3	20.0
" "	n.s.[a]	"	"	60	3.2	18.4
E. robusta (Engelm.) Small	2212	"	"	20	3.6	23.7
E. serrula Engelm.	1807	Ann.	"	5	5.5	21.3
E. tomentulosa Wats.	2099	Shrub	"	55	3.6	15.2
E. xanti Engelm.	2074	"	"	100	3.8	13.2
Jatropha cinerea (Ortega) Muell. Arg.	2048	"	NLR	250	3.9	14.8
J. macrorhiza Benth.	1672	Per.	"	35	2.9	21.8
Manihot angustiloba (Torr.) Muell. Arg.	1670	"	"	25	3.2	20.6
M. davisiae Croizat	1682	"	"	95	3.1	17.3
Pedilanthus macrocarpus Benth.	2037	Shrub	L	95	8.6	14.3
" "	2477	"	"	115	25.0	11.1
Sapium biloculare (Wats.) Pax	2143	"	"	135	1.8	14.4
Stillingia linearifolia Wats.	2113	Ann.	"	60	3.8	18.4
Tragia stylaris Muell. Arg.	1921	Per.	NLR	25	2.0	9.6

APPENDIX – Continued

Taxa	Coll. No.	Morphology Habit	Type	Height (cm)	% Extractables CH	EtOH
Malvaceae						
Gossypium thurberi Todaro	2255	Per.	NLR	105	3.6	9.5
Horsfordia newberryi (Wats.) Gray	1936	Shrub	"	150	1.7	18.6
Sphaeralcea angustifolia (Cav.) G. Don	2264	Per.	"	70	2.9	5.2
Onagraceae						
Epilobium paniculatum Nutt.	2377	Ann.	NLR	220	1.6	8.8
Gaura parviflora Dougl.	2236	"	"	170	2.1	9.3
Oenothera hookeri Torr. & Gray	2275	Per.	"	120	1.0	8.9
Umbelliferae						
Foeniculum vulgare Mill.	2369	Bien.	NLR	225	2.8	11.0
Gentianaceae						
Swertia radiata (Kellogg) Kuntze	2317	Per.	NLR	150	3.6	27.8
Apocynaceae						
Amsonia brevifolia Gray	2172	Per.	L	40	5.0	22.7
" " "	2194	"	"	50	5.6	36.0
A. eastwoodiana Rydb.	2152	"	"	30	6.3	25.2
" "	2208	"	"	65	4.1	28.7
A.grandiflora Alexander	2228	"	"	75	5.1	33.2
" "	2397	"	"	50	8.1	27.6
A. hirtella Standl.	2350	"	"	60	7.4	35.8
" "	2356	"	"	60	6.6	20.4
A. hirtella var. pogonosepala (Woodson) Wiggins	2162	"	"	60	5.1	24.0
" " "	2354	"	"	70	8.6	29.8
A. jonesii Woodson	2153	"	"	15	6.0	17.5
" "	2308	"	"	50	4.2	21.3
A. kearneyana Woodson	2178	"	"	80	5.2	30.6
" "	2249	"	"	80	5.7	23.8
A. palmeri Gray	2174	"	"	50	4.7	26.1
" "	2403	"	"	60	7.8	22.4
A. peeblesii Woodson	2301	"	"	70	5.8	19.1
" "	2303	"	"	70	7.0	28.0
A. tomentosa Torr. & Frem.	2157	"	"	35	5.0	19.5
" "	2195	"	"	45	5.0	26.2
A. tomentosa var. stenophylla Kearney and Peebles	2150	"	"	40	5.3	16.2
" " " "	2207	"	"	70	6.0	24.4
Apocynum androsaemifolium L.	2223	"	"	30	4.4	22.6

APPENDIX -- Continued

Taxa	Coll. No.	Morphology Habit	Morphology Type	Height (cm)	% Extractables CH	% Extractables EtOH
A. cannabinum L.	2217	"	"	65	3.4	11.0
Macrosiphonia brachysiphon (Torr.) Gray	1737	"	"	35	5.1	19.0
Asclepiadaceae						
Asclepias albicans Wats.	1963	Shrub	L	135	14.0	20.4
" " "	2430	"	"	310	5.8	17.1
A. angustifolia Schweig.	2285	Per.	"	60	3.8	10.6
A. asperula (Decne.) Woodson	2404	"	"	85	6.0	15.0
A. elata Benth.	1681	"	"	75	4.4	14.9
A. eriocarpa Benth.	2528	"	"	85	5.3	24.2
" "	2529	"	"	150	5.7	10.6
A. erosa Torr.	2494	"	"	145	5.0	8.5
" "	2499	"	"	125	13.0	10.8
A. fasicularis Decne.	2372	"	"	55	5.7	15.0
"	2388	"	"	100	3.8	22.2
A. latifolia (Torr.) Raf.	2206	"	"	40	3.6	12.6
" "	2302	"	"	85	6.4	11.6
A. lemmoni Gray	1931	"	"	120	10.6	12.9
" "	2348	"	"	100	9.5	17.2
A. linaria Cav.	1685	Suff.	"	55	5.6	14.8
" "	2234	"	"	40	9.8	17.3
A. nyctaginifolia Gray	1674	Per.	"	35	3.6	18.4
A. speciosa Torr.	2216	"	"	60	1.3	24.9
" "	2330	"	"	175	4.6	6.6
A. subulata Decne.	1986	Shrub	"	120	9.3	22.2
" "	2449	"	"	135	4.6	0.3
A. subverticillata (Gray) Vail	1704	Per.	"	80	4.5	26.3
" "	2310	"	"	90	5.1	14.9
A. tuberosa L.	1753	"	NLR	65	4.4	25.1
" "	2222	"	"	55	1.6	18.1
A. viridiflora Raf.	2293	"	L	20	5.0	8.2
Basistelma angustifolium (Torr.) Bartlett	1848	"	"	30	6.5	24.1
Calotropis procera (Ait.) R. BR.	n.s.[a]	Shrub	"	120	2.6	17.0
Metastelma arizonicum Gray	1752	Per.	"	30	7.7	15.7
Convolvulaceae						
Ipomoea longifolia Benth.	1773	Vine	L	20	4.0	14.7
Polemoniaceae						
Gilia longiflora (Torr.) G. Don.	2254	Per.	NLR	30	1.4	16.8

APPENDIX -- Continued

Taxa	Coll. No.	Morphology Habit	Type	Height (cm)	% Extractables CH	EtOH
Hydrophyllaceae						
Eriodyction angustifolium Nutt.	2165	Shrub	R	65	4.7	29.1
Boraginaceae						
Lithospermum cobrense Greene	2263	Per.	NLR	60	1.8	11.2
Verbenaceae						
Verbena bonariensis L.	2387	Per.	NLR	260	2.2	13.0
V. ciliata Benth.	2287	"	"	25	1.4	12.8
V. macdougalii Heller	2306	"	"	70	1.7	10.5
Labiatae						
Agastache breviflora (Gray) Epling	2276	Per.	NLR	60	2.6	4.4
A. pallidiflora (Heller) Rydb.	2318	"	"	55	2.3	16.6
Hyptis emoryi Torr.	2019	Shrub	"	200	6.5	12.6
Monarda austromontana Epling	1686	Per.	"	45	3.2	15.4
M. menthaefolia Graham	2225	"	"	60	3.6	13.3
Poliomintha incana (Torr.) Gray	2320	Shrub	"	45	4.6	26.4
Salazaria mexicana Torr.	2169	"	"	40	2.4	19.2
Solanaceae						
Datura metaloides DC.	2252	Per.	NLR	80	1.4	12.7
Nicotiana glauca Graham	2230	"	"	175	4.0	14.6
Ni trigonophylla Dunal.	2288	"	"	60	3.9	12.0
Solanum elaeagnifolium Cav.	2256	"	"	60	2.5	10.7
Scrophulariaceae						
Cordylanthus wrightii Gray	2323	Per.	NLR	65	1.1	26.2
Pedicularis grayi A. Nels.	2333	"	"	130	0.5	20.7
Penstemon ambiguus Torr.	2319	Suff.	"	35	1.4	20.4
P. barbatus (Cav.) Roth.	2271	Per.	"	70	0.8	26.2
Verbascum thapsus L.	2297	Bien.	"	130	1.0	10.6
Bignoniaceae						
Chilopsis linearis (Cav.) Sweet	2366	Tree	NLR	340	0.4	24.1
Rubiaceae						
Galium asperrimum Gray	2281	Per.	NLR	40	1.2	13.8
Caprifoliaceae						
Sambucus coerulea Raf.	2305	Tree	NLR	220	2.0	9.4
Cucurbitaceae						
Cucurbita foetidissima HBK	2269	Vine	NLR	30	2.0	13.0

APPENDIX -- Continued

Taxa	Coll. No.	Morphology Habit	Morphology Type	Height (cm)	% Extractables CH	% Extractables EtOH
Compositae						
Tribe Anthemideae						
Artemisia dracunculoides Pursh	2294	Per.	NLR	110	3.1	13.2
A. ludoviciana Nutt.	2260	"	"	50	2.9	13.6
Tribe Astereae						
Baccharis glutinosa Pers.	2342	Shrub	R	240	1.7	9.5
B. sarothroides Gray	2417	"	"	95	4.8	18.0
" "	2418	"	"	40	4.9	14.0
Chrysothamnus nauseosus ssp. bigelovii (Gray) Hall	2408	"	"	70	15.1	20.8
" " " "	2409	"	"	55	16.0	12.0
C. nauseosus ssp. consimilis (Greene) Hall	2406	"	"	75	7.9	16.4
" " "	2410	"	"	75	10.4	14.1
C. nauseosus ssp. gnaphalodes (Greene) Hall	2405	"	"	100	4.9	17.1
C. nauseosus spp. junceus (Greene) Hall	2407	"	"	60	6.2	15.8
C. nauseosus spp. latisquameus (Gray) Hall	2396	"	"	125	2.5	9.7
C. paniculatus (Gray) Hall	2425	"	"	65	9.7	10.7
" "	2427	"	"	75	18.3	14.3
C. viscidiflorus ssp. stenophyllus (Gray) Hall	2322	"	"	30	22.6	17.2
Conyza coulteri Gray	2339	Ann.	NLR	210	1.7	5.2
Erigeron neomexicanus Gray	2272	Per.	"	55	2.2	8.1
Grindelia aphanactis Rydb.	2411	Bien.	R	75	7.2	9.2
G. camporum Greene	2390	"	"	110	13.0	11.8
" "	2531	"	"	120	5.5	6.8
G. robusta Nutt.	2370	"	"	65	8.4	12.2
G. squarrosa (Pursh) Dunal.	2311	"	"	80	13.8	9.9
" " "	2510	"	"	80	8.8	6.9
Gutierrezia lucida Greene	1825	Suff.	"	50	5.6	25.2
" " "	2343	"	"	85	3.9	9.6
G. microcephala (DC.) Gray	1929	"	"	60	9.9	20.4
Haplopappus acradenius (Greene) Blake	2391	"	"	70	7.5	19.4
H. heterophyllus (Gray) Blake	2351	"	"	90	9.5	12.5
H. laricifolius Gray	2362	"	"	80	2.4	16.0
H. linearifolius DC.	2422	"	"	65	11.9	20.6
Heterotheca grandiflora Nutt.	2386	Per.	NLR	225	3.6	11.0
H. psammophila Wagenk.	2253	"	"	100	5.4	7.6
" "	2344	"	"	150	2.2	13.8
Lessingia germanorum Cham.	2392	Ann.	R	20	9.5	12.5

APPENDIX -- Continued

Taxa	Coll. No.	Morphology Habit	Type	Height (cm)	% Extractables CH	EtOH
Machaeranthera tanacetifolia (HBK) Nees.	2364	Per.	NLR	120	2.6	14.0
Solidago altissima L.	2307	"	"	70	5.6	13.6
S. missouriensis Nutt.	2283	"	"	65	6.2	15.1
S. wrightii Gray	1828	"	"	70	5.0	22.0
Xanthocephalum gymnospermoides (Gray) B. & H.	2345	Ann.	R	115	12.1	14.8
" " " "	2522	"	"	105	4.7	13.3
Tribe Cichoreae						
Lactuca serriola L.	2299	Ann.	L	160	4.1	15.0
Rafinesquia neomexicana Gray	2137	"	"	45	2.9	28.5
Stephanomeria pauciflora (Torr.) Nels.	2145	Per.	"	75	2.7	17.8
S. virgata Benth.	2394	Ann.	"	210	5.0	16.8
Tragopogon dubius Scop.	TRP/b	"	"	30	5.0	10.6
Tribe Cynareae						
Centaurea rothrockii Greenm.	2284	Per.	NLR	100	3.7	12.6
Tribe Eupatoreae						
Hofmeisteria laphamioides Rose	2144	Suff.	NLR	75	2.6	13.6
Tribe Helenieae						
Dyssodia anthemidifolia Benth.	2082	Ann.	NLR	35	2.3	26.4
Hymenothrix wislizeni Gray	2259	Per.	"	60	1.0	21.5
H. wrightii Gray	2347	"	"	140	0.5	23.2
Hymenoxys quiquesquamata Rydb.	2273	"	"	70	1.4	6.6
H. richardsoni (Hook.) Cockerell	2298	"	"	30	1.8	15.8
Porophyllum gracile Benth.	2083	Ann.	"	45	1.4	11.2
Tribe Heliantheae						
Encelia farinosa Gray	2363	Shrub	NLR	50	6.1	13.4
Flourensia cernua DC.	2238	"	R	80	6.1	7.9
Helianthus annuus L.	2227	Ann.	NLR	250	0.8	16.6
Tribe Heliantheae						
H. petiolaris Nutt.	2258	"	"	150	4.1	9.4
Xanthium saccharatum Wallr.	2257	Per.	"	100	4.8	4.4
Tribe Inuleae						
Gnaphalium macounii Greene	2278	Per.	NLR	40	5.0	12.3
Tribe Senecioneae						
Cacalia decomposita Gray	2247	Per.	NLR	55	2.7	22.5
Peucephalum shottii Gray	2367	Shrub	R	80	5.4	15.0
Senecio bigelovii Gray	2328	Per.	NLR	110	1.6	11.4

/a Cultivated plant   /b T.R. Peoples, not sequenced