NREL/SR-430-22765• UC Category 600 • DE97000254

The Environmental Costs and Benefits of Biomass Energy Use in California

Future Resources Associates, Inc.

Berkeley, California

Technical Monitor: Ralph Overend

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401-3393
A national laboratory of the U.S. Department of Energy
Operated by Midwest Research Institute
for the U.S. Department of Energy
Under Contract No. DE-AC36-83CH10093

Prepared under Subcontract Number ACK-6-16357

May 1997

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

Available to DOE and DOE contractors from:
Office of Scientific and Technical Information (OSTI)
P.O. Box 62
Oak Ridge, TN 37831
Prices available by calling (423) 576-8401

Available to the public from:
National Technical Information Service (NTIS)
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

Contents

	Page
Tables	iv
Figures	iv
Acronyms and Abbreviations	v
Introduction	1
California Biomass Power Production Database	2
The Development of the Biomass Power Industry in California	5
The 1980s: Decade of Growth	5
The 1990s: Maturity and Decline	5
Characteristics of California's Biomass Power Plants	7
Biomass Fuel Use in California	11
Types of Biomass Fuels Used in California	11
Trends in the Use of Biomass Fuels in California	15
Biomass Fuel Market Price Trends	18
Fuel Use during Watershed Year 1993	19
The Environmental Performance of the Biomass Power Industry	22
Environmental Impacts of Biomass Fuel Use	22
Environmental Impacts of Fuel Loading in California Forests	25
Environmental Impacts of Biomass Disposal in Landfills	26
Environmental Impacts of Open Burning of Biomass Wastes	27
The Impacts of Biomass Plant Closures after 1993	31
Environmental Costs and Benefits	32
Investment and Employment	33
The Value of the Biomass Power Sector in California	34
The Future of the California Biomass Energy Industry	35
References	38

Tables

		Page
Table 1:	California Biomass Power Plants	4
Table 2:	Emissions from Biomass Power Plants	24
Table 3:	Biomass Power System Emissions	28
Table 4:	Loss in California Biomass Fuel Demand, 1993–1996	31
Table 5:	Cost of Electricity Production from Biomass	35

Figures

		Page
Figure 1:	California Biomass Power Capacity	6
Figure 2:	Map of California Biomass Energy Facilities	8
Figure 3:	Trend in Generating Efficiency, Biomass Facilities in PG&E Service Territory	10
Figure 4:	California Biomass Fuels Market	12
Figure 5:	California Biomass Fuels Market by Category	17
Figure 6:	California Biomass Fuel Supply Curve	20
Figure 7:	Benefits of Biomass Energy Production	23
Figure 8:	Comparison of Biomass and Fossil-Fuel Emissions	30
Figure 9:	Cost of Biomass Power Production	36

Introduction

Responding to two oil crises during the 1970s, and to burgeoning environmental concerns, California developed a strong program to promote the development of its renewable energy sources. By the early 1990s California led the world in the production of power that uses a variety of renewable resources, including biomass, geothermal, solar, and wind. But world energy markets had also undergone radical change, and California was awash in cheap natural gas. Moreover, the technology for converting natural gas to electricity was improving dramatically. With deregulation of the California electricity industry looming on the horizon, the future commercial viability of renewable energy production was in doubt.

Renewable energy generators provide important benefits to the state's power system. These are not reflected in the short-run avoided cost (SRAC) rate that is the basis for the payment of electricity revenues[*s] to renewable power producers under current contracts with the electric utility companies. These benefits include environmental advantages, rural employment and economic development opportunities, and resource diversity and distributional benefits. Renewables generally have lower levels of environmental impact than fossil fuel-powered generating systems. However, biomass power systems have the unique advantage, in addition to avoiding fossil fuel use, of providing ancillary environmental services by providing a beneficial use alternative for a variety of waste materials that is environmentally superior to conventional waste disposal practices. The loss of these services would have severe negative environmental consequences, and would complicate efforts to comply with air quality and solid waste diversion requirements and implement fire and water plans.

The California renewable energy industries have worked diligently during the past couple of years to develop public policies conducive to the future of renewable energy production within the context of electric market restructuring and the evolving competitive electric services industry. The state's biomass power industry has organized itself as the California Biomass Energy Alliance (CBEA), and has participated vigorously in the regulatory and legislative processes. In order to reward biomass power generators for the special services they provide, CBEA has promoted the concept of providing incentives specifically targeted to biomass within the context of any renewables program enacted in the state. This concept has been embraced by the other renewables industry organizations, but resisted by the utilities.

This study represents an effort to identify, characterize, and quantify the environmental costs and benefits of biomass energy use in California, and to elucidate the future role of biomass power production within the context of the evolving deregulation of the California electricity industry. The report begins with a review of the development and growth of the California biomass power industry during the past 15 years. This is followed by an analysis of the biomass fuels market development during the same period. It examines trends in the types and costs of biomass fuels. The environmental performance of the mature California biomass energy industry is analyzed, and takes into account the environmental impacts of the industry, and the impacts that would be associated with disposing of the materials used as fuels if the biomass power industry were not in operation. The analysis is then extended to consider the environmental and economic consequences of the loss of biomass generating capacity since 1993. The report ends with a consideration of the future prospects for the industry in the context of restructuring.

[*s] Many renewables in California are paid at fixed energy rates for the first 10 years of their operation. The fixed rates have turned out to be significantly higher than the SRAC. However, by the end of the transition period to full restructuring (1/1/02), virtually all renewables in the state will be paid at SRAC rates.

California Biomass Power Production Database

A major activity undertaken as part of this project was the construction of a comprehensive and detailed database of the California biomass power industry which covers the period 1980–1996. The data were collected via thorough survey of the biomass power industry. All biomass power facilities currently operating in California supplied data to the survey, as did most facilities that have shut down, to the extent that data were available. Few biomass generating facilities maintain operating records longer than 5 to 7 years, so data for the earliest years in many cases are based on estimates and anecdotal information. Data for industry operations during the 1990s, with only a couple of minor exceptions, are based on the actual operating records of the facilities.

The facility survey and database are geared toward describing the history of biomass fuel use and the biomass fuels market in California. The facilities that participated in the survey supplied data about their basic system specifications, and about their consumption of biomass fuels during their full (post-1980) operating histories. Fuel use is divided into four categories: wood-processing residues, in-forest residues, agricultural residues, and urban waste wood. Data on each facility were collected in the following categories:

- Name and location
- Net electrical output
- Average annual fuel use
- Whether it has a captive fuel sources
- Operating status
- Purchasing electric utility company and contract type
- Startup and closure dates
- Yearly fuel use during operating life, by fuel type
- Yearly fuel purchase price during operating life, by fuel type.

Table 1 summarizes the data for the biomass power facilities that operated in California from 1980 to 1996. Three facilities are listed twice: Elano, Martell Cogen, and Pacific Lumber. The Delano facility, which is 48 MW, was built in two phases; the startup of the first (27 MW) unit occurred 2 years before the startup of the second (21 MW) unit. Martell Cogen, an 18-MW facility, was shut own in 1995 by the original owners after their power purchase agreement (PPA) was bought out. In 1996 a new owner purchased the Martell Cogen facility and restarted it. The facility now operates at 10 MW, and sells power directly to an adjacent wood-products manufacturing facility. Current power purchase rates are too low to allow Martell to operate at its full rated output and sell surplus power to the grid. Pacific Lumber operated a 10-MW biomass generator at its sawmill beginning during the 1960s. In 1988 the original facility was shut down in conjunction with the startup of a new, more efficient 23-MW biomass-fired power plant.

Sixty biomass power generating facilities have operated in California during the past 15 years. These facilities are located throughout the state. More than half obtain at least some fuel from captive supplies, although only a few obtain all their fuel from captive sources. Thus, most have participated in the biomass fuels market. They range from less than 1 MW to 50 MW, with annual fuel use from about 10,000 to 400,000 bone-dry ton equivalents (bdt). Most obtain the bulk of their fuel from sources within 50 miles, although fuel hauls of more than 100 miles are not unusual. This is especially true when urban wood residues need to be hauled to facilities in rural areas, or in-forest residues need to be hauled from remote locations.

Obtaining detailed annual fuel use data, especially annual fuel purchase price data, from the facilities required confidentiality agreements with the companies that supplied data. Thus, only aggregate data for these categories can be presented in this report. Even with the promise of confidentiality, some facilities were unwilling or unable

to provide current and historical fuel price data; therefore, the statewide fuel market price data are based on a limited data set with curve smoothing.

Table 1: CALIFORNIA BIOMASS POWER PLANTS

	Project	County	Net MW	mBDT/y	Cogen	Own Fuel	Boiler Type	Status	Utility	PPA	Start Up	Shut Down
1	Western Power	Imperial	15.0	122			grate	Buyout	SCE	SO #4	1990	1996
2	Colmac Energy	Riverside	47.0	330			cfb	Op	SCE	SO #4	1992	
3	Proctor & Gamble	Los Angeles	13.5	98	x		grate	Shut	SCE		1985	1988
4	Apex Orchard	Kern	5.5	48	x		grate	Shut	PG&E	Pre SO	1983	1988
5	Delano	Tulare	27.0	200			bfb	Op	SCE	SO #4	1991	
5	Delano 2	Tulare	21.0	175			bfb	Op	SCE	SO #4	1993	
6	Sierra Forest Products	Tulare	9.3	75	x	x	grate	Buyout	SCE	SO #4	1986	1994
7	Lindsay Olive	Tulare	2.2	20	x	x	grate	Shut	SCE		1980	1993
8	Dinuba Energy	Tulare	11.5	97	x	x	bfb	Buyout	PG&E	SO #4	1986	1995
9	Auberry	Fresno	7.5	70	x	x	bfb	Buyout	PG&E	SO #4	1986	1994
10	North Fork	Madera	8.0	68	x	x	bfb	Buyout	PG&E	SO #4	1988	1994
11	Soledad Energy	Monterey	13.5	98			bfb	Buyout	PG&E	SO #4	1990	1994
12	Mendota	Fresno	25.0	185			cfb	Op	PG&E	SO #4	1990	
13	Agrico Cogen	Fresno	25.0	198	x		grate	Gas	PG&E	SO #2	1990	1991
14	Sanger (biomass → feed)	Fresno	0.0	50	x		-	Shut	NA	NA	1991	1991
15	Fresno	Fresno	25.0	180			cfb	Buyout	PG&E	SO #4	1989	1994
16	SJVEP--Madera	Madera	25.0	182			bfb	Buyout	PG&E	SO #4	1990	1995
17	SJVEP--El Nido	Merced	10.2	88			bfb	Buyout	PG&E	SO #4	1989	1995
18	SJVEP--Chowchilla I	Madera	9.9	99			grate	Buyout	PG&E	SO #4	1988	1995
19	SJVEP--Chowchilla II	Madera	10.8	90			bfb	Buyout	PG&E	SO #4	1990	1995
20	Redwood Food Pkg	Stanislaus	4.5	36	x	x	grate	Shut	PG&E	SO #1	1980	1985
21	Tracy Biomass	San Joaquin	19.5	150			grate	Op	PG&E	SO #4	1990	
22	Diamond Walnut	San Joaquin	4.5	35	x	x	grate	Op	PG&E	Pre SO	1981	
23	California Cedar Products	San Joaquin	0.8	11	x	x	grate	Shut	PG&E	SO #1	1984	1991
24	Gaylord Antioch	Contra Costa	30.0	225	x		grate	Gas	PG&E	Pre SO	1983	1990
25	Fiberboard, Standard	Tuolumne	3.0	27	x	x	grate	Buyout	PG&E	Pre SO	1983	1996
26	Chinese Station	Tuolumne	22.0	174			bfb	Op	PG&E	SO #4	1987	
27	Woodland	Yolo	25.0	200			cfb	Op	PG&E	SO #4	1990	
28	Blue Diamond Growers	Sacramento	9.5	68	x	x	grate	Buyout	PG&E	Pre SO	1982	1996
29	Martell Cogen	Amador	18.0	135	x	x	grate	Buyout	PG&E	SO #4	1987	1995
29	Martell Cogen 2	Amador	10.0	75	x	x	grate	Restart	Indus. Customer		1996	
30	Rocklin	Placer	25.0	180			cfb	Buyout	PG&E	SO #4	1990	1994
31	Sierra Pacific Lincoln	Placer	8.0	70	x	x	grate	Op	PG&E	SO #4	1985	
32	EF Feather River	Yuba	16.5	150			cfb	Buyout	PG&E	SO #4	1987	1993
33	Wadham Energy	Colusa	26.5	209			cfb	Op	PG&E	SO #4	1989	
34	Georgia Pacific	Mendocino	15.0	119	x	x	grate	Op	PG&E	SO #1	1987	
35	Koppers	Butte	5.5	110	x	x	grate	Shut	PG&E	SO #2	1984	1994
36	Pacific Oroville Power	Butte	18.0	142			grate	Op	PG&E	SO #4	1986	
37	Sierra Pac. Loyalton	Sierra	17.0	134	x	x	grate	Op	Sierra Pac		1990	
38	Collins Pine	Plumas	12.0	90	x	x	grate	Op	PG&E	SO #2	1986	
39	Sierra Pacific Quincy	Plumas	17.0	145	x	x	grate	Op	PG&E	SO #4	1987	
40	Sierra Pac. Susanville	Lassen	13.0	105	x	x	grate	Op	PG&E	SO #4	1986	
41	Lassen College	Lassen	1.5	12	x		grate	Shut	PG&E	SO #1	1985	1987
42	Jeld Wen Industries	Lassen	2.5	20	x	x	grate	Gas	PG&E	Pre SO	1984	1992
43	Pacific--Westwood	Lassen	11.4	90			grate	Op	PG&E	SO #4	1985	
44	Honey Lake Power	Lassen	30.0	225			grate	Op	PG&E	SO #4	1989	
45	Big Valley Lumber	Lassen	7.5	59	x	x	grate	Op	PG&E	Pre SO	1983	
46	Sierra Pacific Burney	Shasta	17.0	145	x	x	grate	Op	PG&E	SO #4	1987	
47	Pacific--Burney	Shasta	10.0	77			grate	Op	PG&E	SO #4	1985	
48	Burney Forest Products	Shasta	31.0	245	x	x	grate	Op	PG&E	SO #4	1990	
49	Roseburg Lumber	Shasta	4.0	32	x	x	grate	Shut	PG&E	Pre SO	1980	1992
50	Paul Bunyan	Shasta	3.0	24	x	x	grate	Shut	PG&E	Pre SO	1980	1992
51	Wheelabrator Shasta	Shasta	50.0	380			grate	Op	PG&E	SO #4	1988	
52	Wheelabrator Hudson	Shasta	6.0	66	x		grate	Op	PG&E	Pre/SO#4	1981	
53	Redding Power Delmarva	Shasta	25.0	190		x	grate	Gas	PG&E	SO #2	1989	1991
54	Sierra Pacific Hayfork	Trinity	10.0	85	x	x	grate	Op	PG&E	SO #2	1985	
55	LP Samoa	Humboldt	27.5	300	x	x	grate	Shut	PG&E	SO #4	1985	1991
56	Blue Lake	Humboldt	10.0	79			grate	Op	PG&E	SO #4	1985	
57	Pacific Lumber	Humboldt	10.0	115	x	x	grate	Replace	Self Gen		1980	1988
57	Pacific Lumber 2	Humboldt	23.0	225	x	x	grate	Op	PG&E	SO #1	1988	
58	Simpson Paper	Humboldt	29.0	115	x	x	grate	Shut	PG&E	SO #2	1980	1992
59	Fairhaven Power	Humboldt	17.3	140		x	grate	Op	PG&E	SO #4	1987	
60	Arcata Redwood	Del Norte	8.0	88	x	x	grate	Shut	PP&L		1980	1988

The Development of the Biomass Power Industry in California

California has a diversity and extent of agriculture and forestry that are unrivaled in the world. These industries are major producers of solid wastes, most of which are biomass residues that can be used as fuel. Before the federal Public Utilities Regulatory Policy Act (PURPA) was passed in 1978, only a few biomass-fired boilers operated in California, and very little electricity was being generated from biomass. A vast quantity of biomass waste was being disposed of, mainly by landfilling and open burning. PURPA changed all that by requiring that electric utility companies buy privately produced power at the utility's "avoided cost" of generation.

PURPA, and the implementation of energy policies in California conducive to developing renewable energy, stimulated a major development of biomass power generating capacity. In less than 15 years nearly 1,000 MW of generating capacity had been placed into service for generating electricity from solid-fuel biomass. The biomass energy sector had expanded from being an outlet for a small quantity of wood processing residues, to representing an environmentally superior beneficial use for a wide variety of biomass wastes, including wood processing residues, in-forest residues, agricultural residues, and urban waste wood.

The 1980s: Decade of Growth

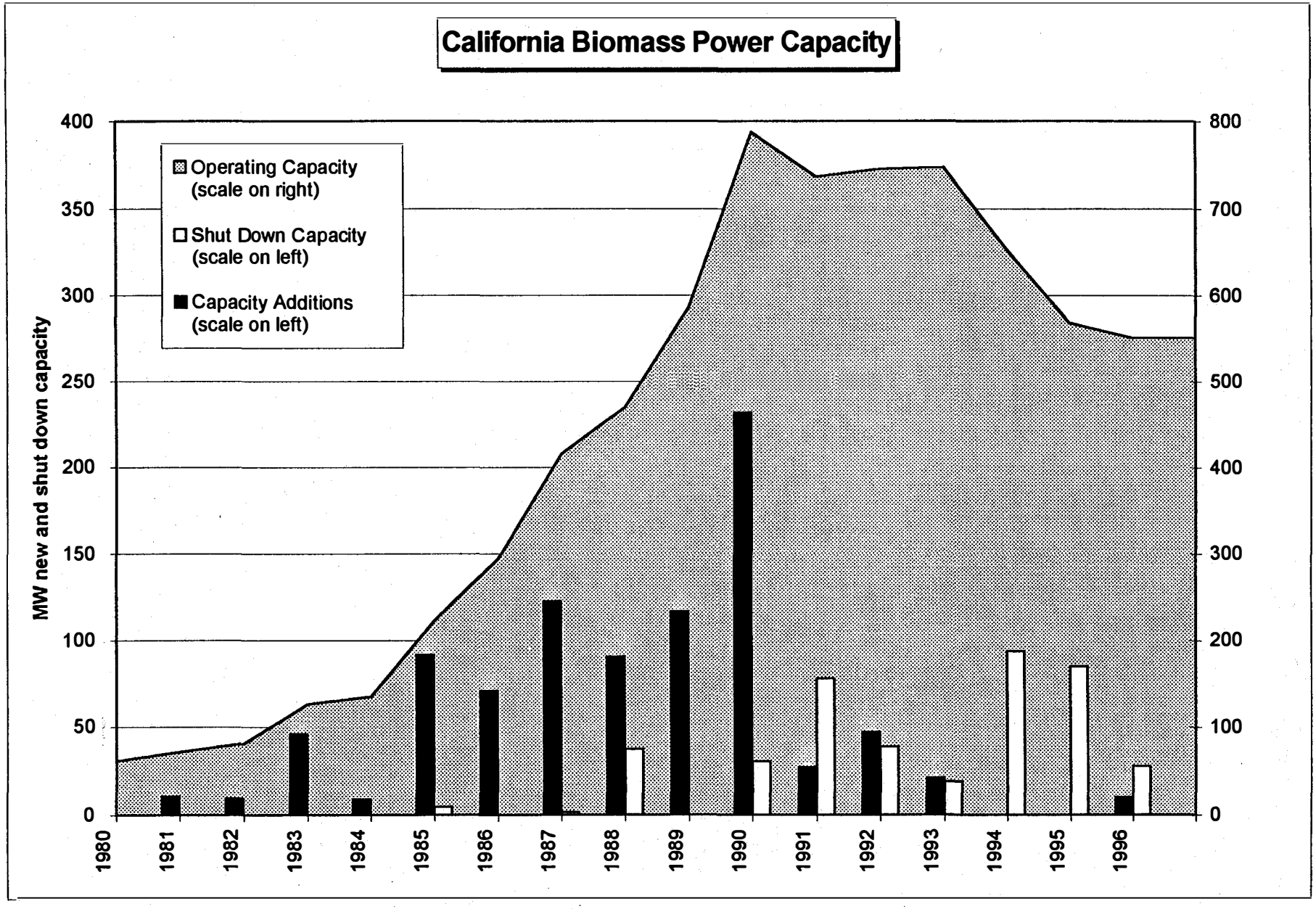
Figure 1 shows the time course of the development of the biomass power generating industry in California from 1980 to the present. The early 1980s, from about 1980 through 1984, marks the nascent period for the biomass power industry. During this period a number of pioneering biomass power generating facilities were brought on line. They tended to be small, generally 2.5 to 10 MW, and most were associated with sawmills or food processing operations. A great deal of biomass project development activity was initiated during this period, which led to an explosion of new facility openings during the second half of the decade. Between 1980 and 1984 the biomass generating capacity in California grew to 136 MW, at an average annual growth rate of 22%. The average size of the facilities built during this period was 8 MW.

During the second half of the 1980s the biomass power industry became an important force in the state's electricity supply mix. The incentives offered during the first half of the decade led to the opening of 33 new biomass generating facilities between 1984 and 1990. A few of the pioneering facilities were shut down during this period, but the operating biomass power capacity grew from 136 MW to 788 MW, an increase of 652 MW, or 34% annually, during a 6-year period. The average size of the facilities brought on line was 17.7 MW. The explosive growth of biomass generating capacity culminated in 1990, when 11 new facilities were commissioned during a single year, adding 232 MW of biomass generating capacity to the state's electricity supply. Many of the facilities that entered service had interim standard offer #4 (SO#4) PPAs with Pacific Gas and Electric Co. (PG&E) and Southern California Edison (SCE). The SO#4 PPAs were the most favorable contracts ever made available in the state. They were available to developers between 1984 and 1985 only, and contract holders had 5 years to bring their projects on line to comply with contract terms. The most significant feature of the SO#4s was the option for energy sales from renewables to be based on a forecasted schedule of energy prices for the first 10 years of facility operations. The forecasted schedules, which were based on early 1980s gas prices, turned out to be well above market.

The 1990s: Maturity and Decline

During the early 1990s the state's operating biomass power generating capacity remained stable at about 750 MW. This period was characterized by a series of facility shutdowns, which were balanced by new facility startups that represented the culmination of the SO#4 process. The new facilities that came on line during the early 1990s averaged 21 MW. Most had the 5-year limits in their SO#4 contracts extended for reasons such as transmission access-related delays. The shutdowns happened for a variety of reasons, including a number of

Figure 1


California Biomass Power Capacity
Operating Capacity (scale on right)
Shut Down Capacity (scale on left)
Capacity Additions (scale on left)
MW new and shut down capacity
400
350
300
250
200
150
100
50
0
800
700
600
500
400
300
200
100
0
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996

facilities that were plagued by technical and operating problems, and other facilities that lost their viability because of changes in circumstances for host facilities that were the sources of fuel and/or users of cogeneration steam. The last of the new biomass power generating facilities started up in 1993. At this point the biomass power industry had attained a level of maturity, and a working equilibrium between fuel supply and fuel demand had been achieved in which fuel producers and fuel users were able to operate profitably.

In April 1994 the California Pubic Utilities Commission (CPUC) issued the *Blue Book* proposal for restructuring the electric utility industry. It launched the electricity deregulation movement in the United States and provided for competition among alternative generating sources on the basis of price alone, without regard to factors such as source diversity and environmental impact. This is a major threat to biomass generators, whose cost of power production is higher than the cost of power generation using natural gas in modern, high-efficiency power plants. If nonprice factors are not taken into account, the future of biomass power generation in California will be bleak.

The most immediate impact of the *Blue Book* restructuring proposal was that it provided an incentive for investor-owned utility (IOU) companies to buy out the SO#4 PPAs they held with operating biomass power generators. Beginning in 1993, the state's two large IOUs, PG&E and SCE, which together purchased more than 95% of the biomass power generated in California, approached many biomass power generators in their territories who were receiving revenues based on the fixed pricing provisions of the SO#4 PPAs with offers to buy out the remaining terms of their contracts for a lump-sum settlement. During the past 2½ years 16 facilities, rated collectively at more than 200 MW, accepted buyout offers and shut down operations. Only one, Martell Cogen, has been brought back on line. This facility operates at half of rated capacity, and sells its electrical output directly to an adjacent retail customer. Available short-term power purchase rates, which currently are about $0.03/kWh, are not sufficient to allow any of the shut down facilities to resume operations.

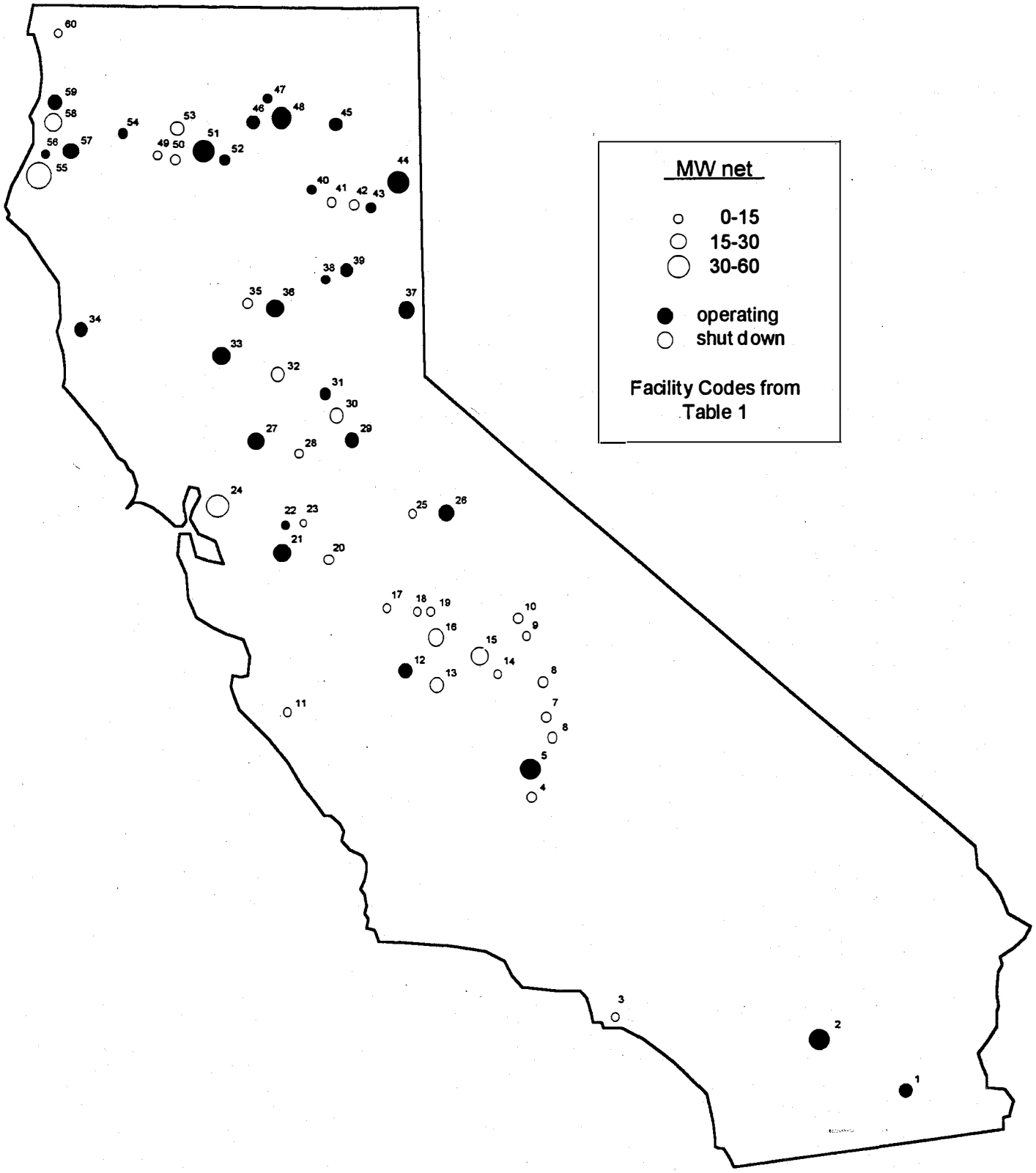
The biomass facility buyouts and shutdowns caused the operating capacity of the biomass power industry to shrink by 25% in a little more than 2 years. Many facilities lost during this period were first-rate and had operated efficiently and profitably until the buyouts. The shutdowns have meant that more than 2 million tons of biomass residues per year have lost a useful application, and are returning to the solid waste stream. This is a major roadblock to achieving solid waste and air quality goals.

During 1996 the California biomass power industry apparently achieved a new level of stability, with an operating capacity of approximately 550 MW. However, beginning in 1995, the first facilities with SO#4 PPAs began to reach their "11-year" cliffs, which presented a new set of pressures that could further shrink the size of the industry. The 11-year cliff refers to the point at which the fixed price provisions in the SO#4 contracts terminate for each operating facility. At that point the rate of remuneration for kWh sales from the biomass facilities to the IOUs reverts from the fixed-price schedule in the contracts to the current SRAC. For facilities in the PG&E territory that reach the 11-year cliff in 1996, this meant a drop in electricity sales price from more than $0.12/kWh to less than $0.02/kWh, a factor of more than six. Capacity sales prices remain fixed; nevertheless, the facilities that reach the 11-year cliff suffer a major drop in total revenues. The first facilities to reach the 11-year cliff still operate; however, as more facilities reach that point during the next several years, there probably will be further casualties.

Characteristics of California's Biomass Power Plants

Figure 2 shows a map of all California biomass power-generating facilities that have operated since 1980. The bulk of the industry is located in the northern two-thirds of the state. Only three biomass facilities were built south of Bakersfield. Most were built with an orientation toward either the forest products industry or agriculture as their major fuel source. Those designed to burn primarily agricultural residues are concentrated in the Central Valley. Those designed to burn primarily residues from the forest products industry are concentrated in

Figure 2:
Map of California Biomass Energy Facilities



the northern and eastern mountain regions. At least three were designed to burn primarily urban wood waste. These were located near Los Angeles and the San Francisco Bay Area. The map shows that biomass facility closures have occurred throughout the state, in all types of facilities. Central California has suffered a higher rate of closures than the northern part of the state.

All biomass power generation facilities in California employ conventional steam-turbine technology to convert biomass fuels to electricity. This technology has been in use for almost 100 years with a wide variety of fuels, including biomass. Nevertheless, it continues to evolve, and has shown significant improvement during the development of the modern biomass power industry. Much of the development since 1980 has been in environmental performance, which includes improvements in combustion and environmental control technologies.

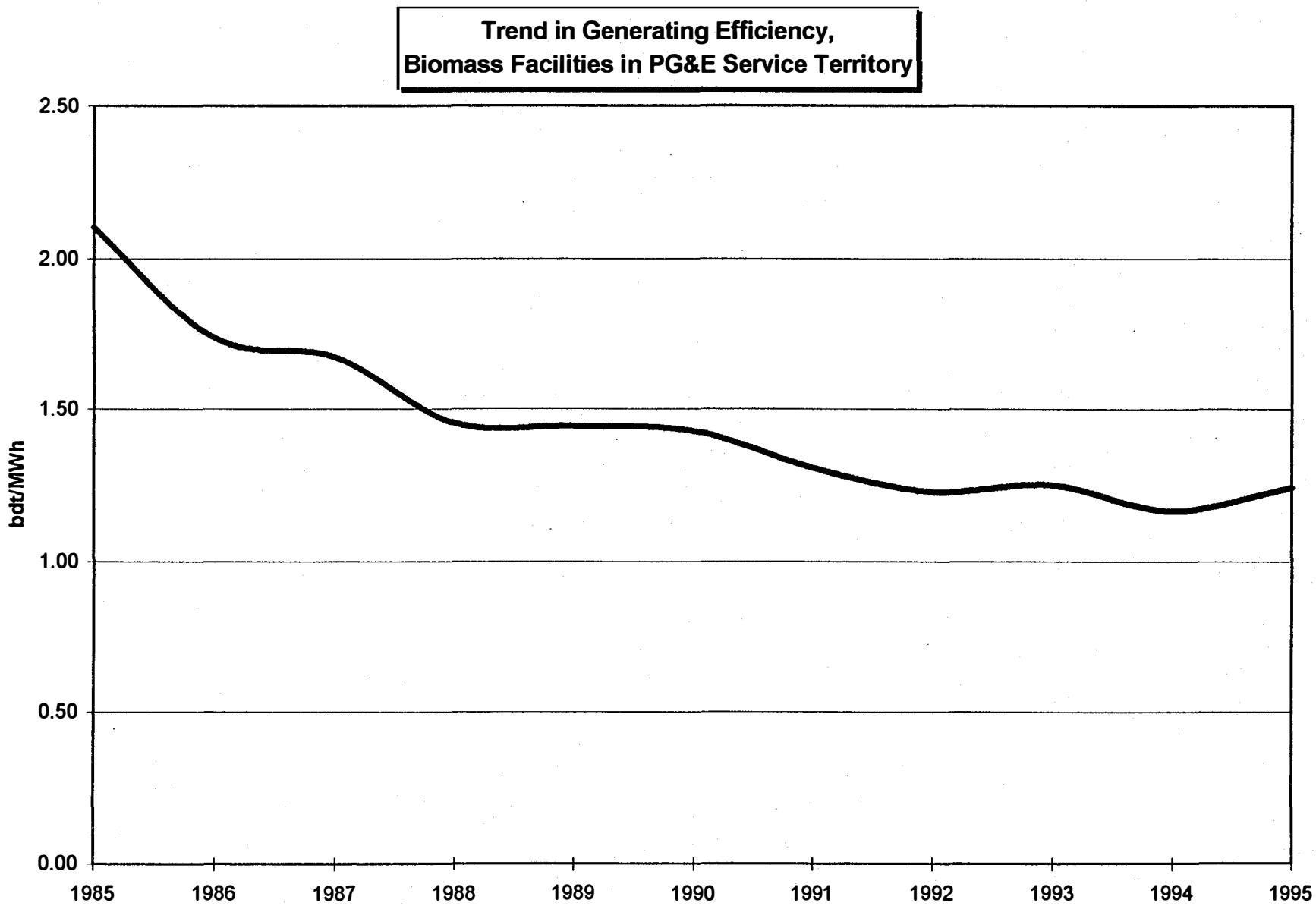
Overall plant energy conversion efficiency has also improved, and is reflected in decreasing heat rates for newer facilities. Figure 3 plots the average annual biomass generating efficiency, measured in terms of bdt/MWh, for 47 biomass generating facilities, for the period 1985–1995. A biomass plant fuel use rate of 1 bdt/MWh corresponds to a facility heat rate of approximately 17,000 Btu/kWh.

Facilities were selected for this efficiency analysis if they are located in the PG&E service territory, and they burned only biomass fuels during the analysis period. The annual fuel use data are taken from the database developed during the course of performing this research project. The annual electricity production of these facilities was supplied by PG&E from its own database on power purchases from qualifying facilities.

The plot shows that the average efficiency for the facilities used for the analysis has improved over time, as measured by a decreasing ratio of fuel use to energy production. The facilities in this analysis include a mix of cogeneration and power-only generators. Cogenerators require more fuel per unit of power production than power-only generators, because cogenerators do not condense all the steam they use to generate power. Whether there is a trend in the mix of cogenerators and power-only generators that might influence the trend in the efficiency of biomass power generation is not known (see Figure 3).

Power-generating efficiency has improved through technology, such as increases in combustion efficiency, and increases in steam temperatures and pressures used to generate power, and because of a trend to build larger facilities, which are inherently more efficient. This efficiency has improved at the same time facilities have been required to meet increasingly stringent environmental standards, which sometimes have a negative effect on power-plant energy-conversion efficiencies.

Figure 3


Trend in Generating Efficiency,
Biomass Facilities in PG&E Service Territory
bdt/MWh
2.50
2.00
1.50
1.00
0.50
0.00
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995

Biomass Fuel Use in California

Before 1980, biomass fuel use in California was limited to a few boiler installations in the wood products industry in the northern part of the state. Most boilers produced low-pressure process steam. Very little power was generated from solid biomass fuels, and most of the product was used for on-site applications. Statewide biomass fuel demand was less than 500,000 bdt/yr. All fuel used was wood processing residue (sawmilling and pulping), including bark, sawdust, shavings, and hog fuel. In most cases the host mills produced more residue than was necessary to supply on-site energy requirements, so the energy conversion equipment tended to be low cost and inefficient. Very little biomass residue was bought or sold for energy applications. There was no competitive market for biomass fuel.

As the independent biomass power industry began to grow during the early 1980s, a market for biomass fuels was established. Demand for biomass fuel for power generation grew gradually during the first half of the 1980s to reach 1 million bdt/yr in 1984. The biomass fuel used during this period was primarily wood processing residues: a few facilities burned agricultural residues, and one large facility in the San Francisco Bay Area, Gaylord Paper, burned urban waste wood beginning in 1983. Figure 4 plots the annual installed capacity for fuel demand, and the actual amount of fuel used each year by the biomass power plants.

The annual biomass fuel demand and use increased rapidly during the second half of the 1980s, reaching more than 6 million bdt/yr of installed capacity for fuel demand in 1990. Annual biomass fuel use in the state during the period 1990–1994 remained stable at a level of approximately 5 million bdt/yr, then dropped in 1994 as facilities began to accept buyout offers for their PPAs. The effects of the shutdowns, as well as a number of short-term curtailment agreements that several facilities entered into during this year of surplus hydroelectric power supply, can be seen in the data for 1995, when statewide biomass fuel use fell below 3.5 million bdt/yr. Projected biomass fuel use in the state for 1996 remains at the 1995 level.

Types of Biomass Fuels Used in California

A wide variety of types of solid biomass fuels are used to produce electricity in California. For functional purposes the solid biomass fuels can be classified into four categories:

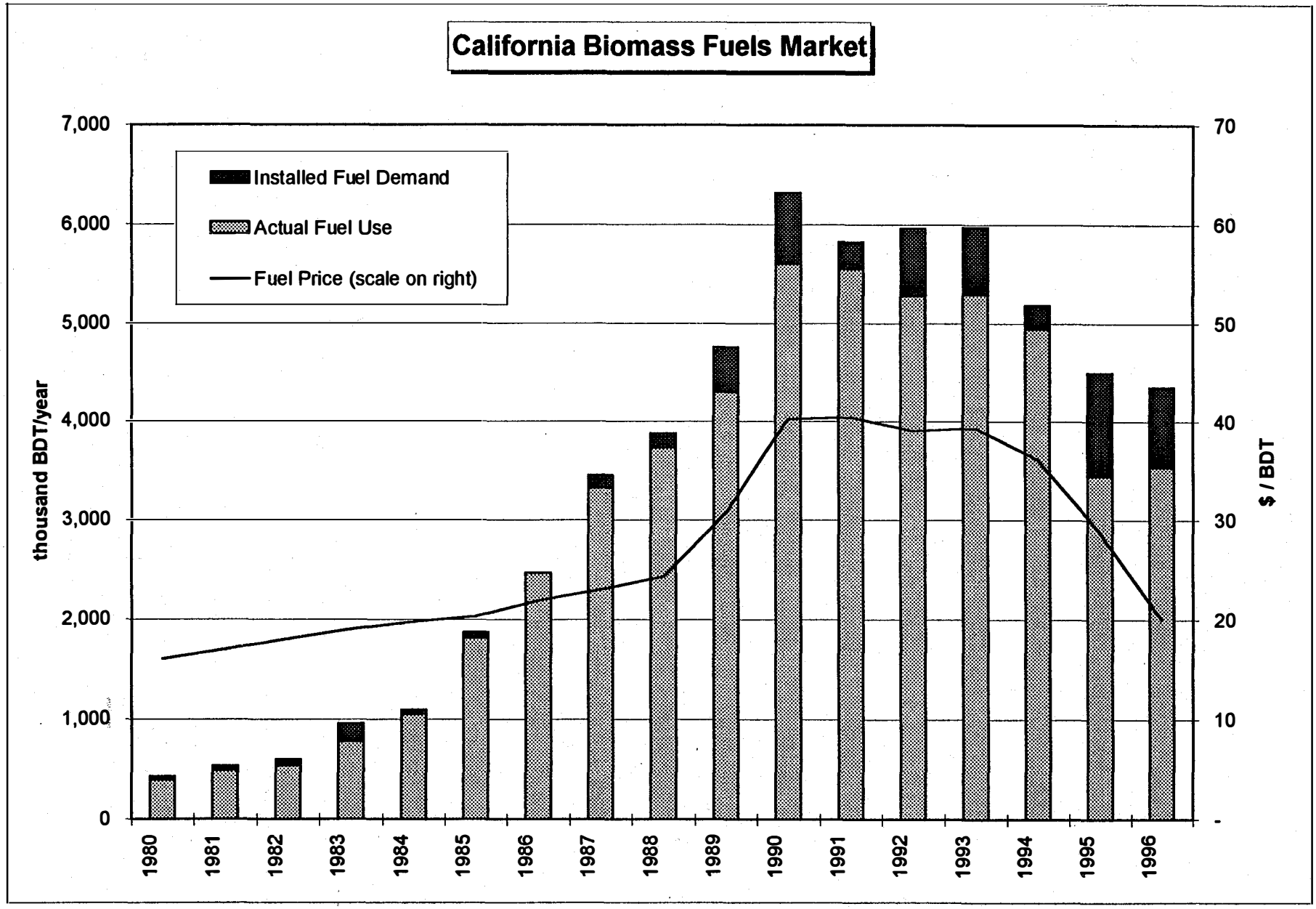
- Wood-processing residues
- In-forest residues
- Agricultural residues
- Urban wood residues.

Some solid-fuel biomass facilities burn supplemental fuels, in addition to solid biomass, in their power plants. Biomass power facilities are allowed to obtain as much as 25% of their input heat from fossil fuels without violating their qualification as a biomass facility. A few biomass power plants also burn other supplemental fuels, such as landfill gas, tires, and petroleum coke. California has 30 power-generation installations powered exclusively by landfill gas, but this report focuses on the solid fuels biomass power industry.

Wood Processing Residues

Wood processing residues are the waste materials from processing and converting round wood into products. Wood processing produces large quantities of residues. In a typical sawmill, for example, approximately half the weight of the logs delivered to the mill becomes residue. The major categories of sawmilling residues include bark, sawdust, shavings, round-offs, end cuts, trimmings, and reject lumber. The sheer magnitude of wood processing residues has stimulated the development of secondary markets for many of these materials. Markets have

Figure 4


California Biomass Fuels Market
Installed Fuel Demand
Actual Fuel Use
Fuel Price (scale on right)
thousand BDT/year
$ / BDT
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
70
60
50
40
30
20
10
-
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996

been developed to convert wood processing residues into products such as pulp, particle board, animal bedding, and garden products. Sawmills are very good at segregating their residues into the highest-value markets available to maximize their benefits. Efficient use of residues is usually necessary for a sawmill to operate profitably.

Even with the development of manufacturing processes that can use a variety of wood residues types, wood processing still produces wastes that have no useful application. More than half the wastes produced at a typical sawmill can be converted into useful products; nevertheless, some 15% to 20% of the roundwood resource is unusable waste. This material must be disposed of. The current option for disposing of material that cannot be used is landfilling, because open or teepee combustion of mill residues has been banned for environmental reasons. This is one reason the wood products industry has championed the development of the biomass power industry in California.

Wood processing residues are the cheapest form of biomass fuel to produce and deliver to biomass power plants. They form the backbone of the biomass fuel supply, and they would probably be the last source of biomass fuel to exit the system if the demand for biomass fuels drops further. The major factor that determines how much mill residue is used as fuel in California is the level of activity in the forest-products industry. The sawmilling industry is very sensitive to overall economic conditions, and environmental restrictions on timber supplies have led many sawmills to shut down. This led to a drop in the availability of mill residues as power plant fuels during the early 1990s.

In-Forest Residues

In-forest residues include the materials left in the forest when timber is cut for processing, and material that naturally occurs in commercial forests whose removal would provide forest management benefits. Wood harvesting residues include the tops and limbs of harvested trees, which traditionally are cut off and left in the forest. The cheapest way to manage this material is to leave it in the forest as it is generated, but that is the worst management practice from a forestry perspective, as leaving residues in the field retards forest regrowth and is a fire hazard. Many timber harvesting contracts require loggers to collect and pile the residues. In some cases these piles are simply left in place; in others they are burned to eliminate the forest fire risk.

The other category of in-forest residue is material that occurs naturally in commercial forests, and is classified as not contributing to merchantable growing stock. This includes downed trees, and standing trees that are dead, dying, twisted, or otherwise not suitable for producing wood products. It also includes overstocked growing material that can be removed during thinning operations.

People have intervened in forest ecosystems since before recorded history, but during the past 100 years the interventions have changed radically. Around the turn of the last century, California (whose geography and climate have caused fire to always be a factor in its forests) began a major long-term commitment to suppressing forest fires, with great success. One of the most significant, unexpected results of the firefighting efforts has been a long-term buildup of biomass in the forests, which causes a variety of undesirable consequences:

- The extent and severity of forest fires in overstocked forests is much greater than in the native ecosystem environment, because fires with positive ecosystem functions are turned into infernos that destroy everything in vast areas.

- High densities of growing stock prevent the growth of healthy, high-quality, individual trees, and diminish wildlife habitat.

- Overstocking biomass in the forest increases evapotranspiration and diminishes the amount of groundwater available for summer runoff, compared to the native forest ecosystem.

In the absence of energy markets, most in-forest residues are left in place. Both the California Department of Forestry and the U.S. Forest Service recognize this as a major impediment to maintaining forest health. These agencies also see the consequences of fuel loading on their firefighting budgets, which have skyrocketed during recent years. The cheapest means of reducing the fuel loading problem in the forests is prescribed burns, and state and federal forest managers are carrying out limited burns to reduce the problem. The amount of prescribed burning, however, is limited because of environmental concerns. Harvesting, processing, and transporting the material to the power plants is more expensive, but provides a beneficial use for the material, and virtually eliminates the pollution associated with open burning.

Forestry officials would like to see large areas of California's forests thinned gradually. The U.S. Forest Service, which owns approximately half of California's forest land, states that at least 250,000 acres/yr under its jurisdiction needs to be thinned to fully realize the fire suppression, forest health, and water yield increases. During the height of the use of in-forest residues by the biomass power industry, only about 60,000 acres per year were being treated statewide.

Agricultural Residues

The category of agricultural residues includes a wide variety of materials. The major types include:

- Food processing wastes
- Orchard and vineyard prunings
- Orchard and vineyard removals
- Straws and stalks from a variety of field crops.

Food processing wastes are generated in concentrated quantities that require some form of disposal. Like wood processors, food processors have worked hard to develop high-value uses for these materials, such as in feed products. However, a surplus of food processing residues remains available for use as biomass fuel. In the absence of fuel markets, these materials would otherwise be landfilled, or, in some cases, open burned. Some food processing wastes that have been used as fuels in California, such as nut hulls, shells, pits, and rice hulls, present special combustion problems that limit their application to facilities able to deal with these properties. Several pioneering biomass generating facilities were built at food-processing facilities specifically to dispose of the processing residues. Although some experienced operating problems when first starting up, most were able to adapt and fix their equipment to handle the fuels they were designed to burn.

Agriculture is one of the most important sectors of the California economy. California's agriculture is very diverse, and includes extensive plantings of orchards and vineyards, permanent woody crops that require extensive annual pruning. Conventional agricultural practice for disposing of these prunings is open combustion. During the early development of the biomass power industry there was a great deal of interest in using orchard and vineyard prunings as fuels. Combustion of this material in a licensed power plant greatly reduces the resulting pollutant emissions compared with open-field burning, and agricultural burning has long been recognized as a major contributor to the air pollution problems in California's major agricultural regions. In addition to the environmental benefits anticipated, many farmers thought fuel sales would offset the cost of pruning, and even create a new profit center.

In recognition of the air quality benefits of biomass power generation, many biomass facilities planned for the Sacramento and San Joaquin Valleys were permitted on the basis of "agricultural offsets," credits granted by air

control agencies against the emissions of pollutants released at the biomass power plants. These facilities are obligated to burn, as a minimum fraction of their fuel, agricultural material that would otherwise be open burned to comply with their permits.

Orchard and vineyard prunings are more expensive and difficult to use as fuels than originally expected because (1) the density of the resource (bdt/acre) is less than originally projected, which means more area needs to be covered to produce a given amount of fuel, which increases fuel production cost; and (2) compared with conventional sources of biomass boiler fuel, prunings are very stick-like, which makes them more difficult to process into fuel form and creates a major hazard for fuel handling and delivery equipment at the power plant. These considerations have limited the amount of fuel produced from these sources. Biomass power producers estimate that only about 5% to 10% of the state's agricultural prunings are converted to fuel.

In contrast, orchard and vineyard removals are very good sources of biomass fuel. They are cleared periodically for replanting and in response to changing land use decisions. Orchard clearing, in particular, provides a high density of material in whole tree form that can be processed into conventional whole tree chips. This material is generally felled in the mid to late summer from plantations that have not been irrigated, so the wood is often very dry compared to other sources of recently cut biomass fuels. Fuels derived from orchard clearings, and to a more limited extent from vineyard clearings, are the major agricultural residue fuels used in California.

California agriculture also produces large quantities of field residues in the forms of straws and stalks that are either open burned or plowed under. These residues can be collected and processed into power plant fuels, and contributes modestly to the biomass fuel supply. Straw- and stalk-based fuels tend to be expensive to produce, and their low density (ton/ft^3) presents materials handling problems and combustion difficulties. As a result, only a few facilities are willing and able to accept these residues as fuels, even though they qualify as agricultural offset fuels.

Urban Wood Residues

The fourth source of biomass fuel used in California is urban wood residues. Fifteen to twenty percent of the material that is traditionally landfilled is clean, separable waste wood. This type of material is brought to landfills in a variety of forms, including loads of chipped wood and brush from public and private tree trimmers and land clearers, debris boxes from manufacturers of wood products and construction and demolition contractors, and mixed loads of yard debris. Transfer station and landfill operators can segregate loads that contain these materials as they enter the landfill gate, and process them to produce a high-quality fuel product. Three biomass power facilities were designed specifically to use fuels derived from urban wood residues. Two are in the San Francisco Bay area, the third is in the Los Angeles basin. Many that did not anticipate using these types of fuel during their planning processes have made urban waste fuels important components of their fuel supply.

In the absence of energy applications urban wood residues would be landfilled, and would occupy a large amount of space and be relatively slow to stabilize. Biomass buried in landfills leads to methane and CO_2 emissions, and significantly increases the greenhouse gas contributions made by the disposal of this material relative to the fuel use option. Landfilling also leads to leachate emissions, and depletes available landfill capacity.

Trends in the Use of Biomass Fuels in California

During the early development of the biomass energy industry in California, wood processing and agricultural residues provided nearly all fuel used by the facilities. As the industry developed, these sources grew and new fuel sources, such as in-forest residues and urban wood residues, came into the market. Figure 5 shows the time course of the use of biomass fuels as a function of fuel type. Wood processing residues have always been the

primary supply source for the biomass power industry throughout the period covered by this study. Their use as fuel increased rapidly during the 1980s, peaking in 1990 at 2.75 million bdt. At that point all but the most remote mill wastes were being used as biomass fuels.

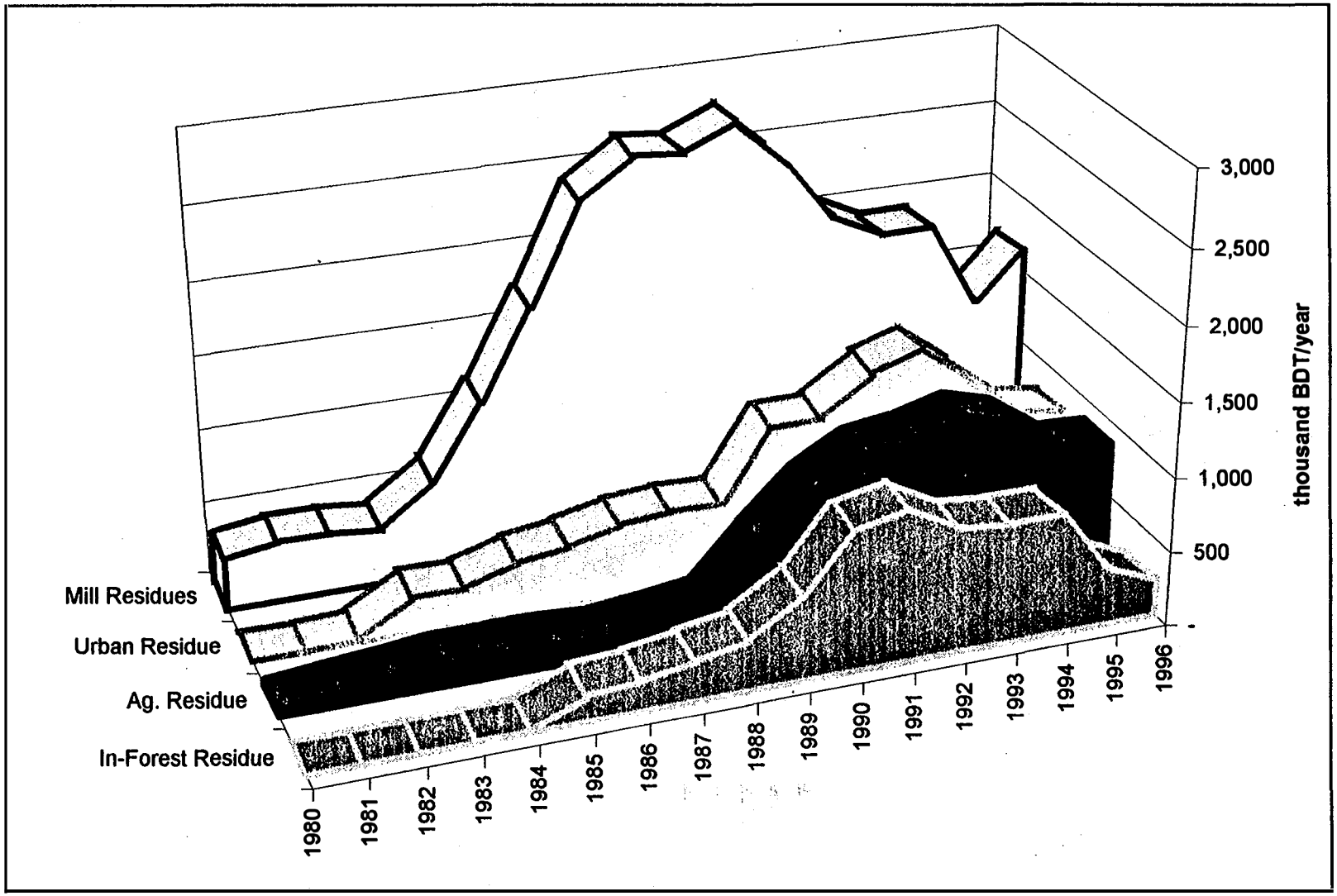
The demand for biomass fuels remained quite stable during the early 1990s, but the use of mill residues decreased precipitously during this period because sawmilling activity dropped in response to poor economic conditions and increasing environmental restrictions on the supply of roundwood, and supplies of the other types of biomass fuels became more available as high fuel prices stimulated a variety of new ventures into the fuel supply business. As the lowest-cost fuel source in the state, mill residues are used as available. The industry would have to shrink to half its current size before significant quantities of mill residues would be landfilled.

The other biomass fuel source that has been in use since the beginning of the development of the biomass power industry is agricultural fuels, the first of which were food processing residues such as nut hulls and pits. Several pioneering biomass power facilities were built at food processing operations. Their use has expanded more gradually than many originally predicted, because converting orchard and vineyard prunings to fuels was more difficult and expensive than expected. These materials have never made a major impact in the biomass fuels market. Agricultural fuel use increased greatly between 1988 and 1990, as the statewide biomass fuel crisis hit, and many new facilities began to operate with permit requirements to burn minimum quantities of agricultural offset fuels. These requirements meant that as fuel demand has decreased with plant closures, agricultural fuels have suffered less contraction in fuel use, and thus have an increased market share.

Urban waste wood began to contribute to California's biomass fuel supply in 1983, when Gaylord Paper Corp. started up its pioneering facility in the San Francisco Bay area. This facility was designed to burn primarily urban wood fuel, and was very successful. In 1985 a second facility designed to burn urban wood fuel, Proctor and Gamble, began to operate in the Los Angeles area. These two facilities, located in the state's two largest metropolitan areas, stimulated the development of an industry for producing fuel from material that traditionally was buried in landfills. As the technical viability of using urban waste wood fuels was proven, biomass power facilities designed to burn primarily sawmill and agricultural residue fuels began to purchase fuels derived from urban waste wood, and the use of urban biomass fuels increased gradually during the mid-1980s. When the statewide biomass fuel shortages hit at the end of the decade, urban biomass fuel use doubled to more than 1 million bdt/yr in 1990. This fuel source continued to grow during the next several years, as statewide fuel demand remained stable, and the availability of wood processing residues decreased. In the watershed year 1993, urban biomass fuel use peaked at more than 1.35 million bdt. Since then, urban biomass fuel use has fallen below 1 million bdt/yr as overall biomass fuel demand has contracted.

In-forest residues are the most expensive sources of biomass fuel. Significant in-forest fuel production did not begin until 1985, and grew gradually until the end of the decade, when the statewide fuel crisis forced fuel prices higher than $40 /bdt. In-forest biomass fuel use peaked in 1990–1991 at about 1 million bdt/yr, then began to fall as the market reached equilibrium, sawmilling activity recovered, and cheaper urban and agricultural fuels outcompeted in-forest fuels. When the buyouts and closures occurred in 1994–1995, in-forest biomass fuel use took the greatest hit, dropping to less than 250,000 bdt/yr in 1996.

Figure 5


California Biomass Fuels Market by Category
Mill Residues
Urban Residue
Ag. Residue
In-Forest Residue
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
-
500
1,000
1,500
2,000
2,500
3,000
thousand BDT/year

Biomass Fuel Market Price Trends

Before the development of the modern biomass power industry in California a surplus of biomass residue material required disposal. Sawmill and urban wood residues were being landfilled, many agricultural residues (and a fraction of the state's sawmilling and in-forest residues) were open burned, some agricultural residues were being plowed under, and fuel was becoming increasingly overstocked in the state's forests. Each alternative has an economic cost and adverse environmental consequences. The producers of residues with the highest disposal costs were among the pioneering developers of facilities and markets for biomass fuels. During the early development of the biomass fuels market in California a surplus of residue material was available, and fuel prices were based on the cost of processing the residues and transporting them to the power plants. During the early 1980s biomass fuel prices were stable, in the range of $15 to $20/bdt. Some sawmill residues were sold to nearby generating facilities for less than $10/bdt. Figure 4 shows the average price of biomass fuels as a function of time.

As biomass fuel demand increased during the mid to late 1980s with the opening of new generating facilities at a rate of approximately 100 MW/yr, the average statewide price of biomass fuels began to drift upward, and reached an average value of approximately $25/bdt in 1988. Between 1980 and 1988, fuel demand grew faster than fuel prices increased. The inflation-corrected price of biomass fuel was virtually unchanged during this period. From that point forward, however, prices shot up, reaching more than $40/bdt during the early 1990s; spot prices topped $50/bdt. The industry was in a fuel crisis, which was precipitated by the extremely rapid increase in generating capacity.

By 1988, statewide biomass fuel demand had grown to the point that it overwhelmed the installed capacity to provide biomass fuels. The cheapest source of biomass fuels, mill residues, had become completely committed to the fuels market, and additional mill residues were no longer available to satisfy new fuel demands. New sources of biomass fuels were required, and a significant investment was required to develop the new fuel supplies. In general, the resources from which this new supply of fuel would be derived were more expensive to convert into fuels than the fuel sources already developed. These were all factors in the rapid increase in biomass fuels prices that occurred between 1988 and 1990, during which statewide average biomass fuel prices increased by approximately 60%.

By the end of 1990 the demand for biomass fuels stabilized, as did their price, which averaged about $40/bdt. The fuel supply infrastructure had a chance to catch up with the level of demand, and a great deal of experience was accumulating with respect to the technologies necessary to produce power plant fuels from new sources of biomass, such as urban wood residues and various types of agricultural and in-forest residues. Fuel prices might have decreased somewhat during the early 1990s as a better balance was achieved between supply and demand, except that the supply of the cheapest source of biomass fuels, mill residues, decreased significantly during this period because of lumber production cutbacks (see Figure 5). Thus, the pressure for fuel price decreases that resulted from an improved supply-demand balance was countered by the loss from the market of a fraction of the wood processing residues. Their loss had to be made up for by more expensive sources of supply.

Beginning in 1994, the regulated California electric utility companies, in response to the initiation of the deregulation process at the CPUC, initiated a series of buyout negotiations with many biomass generating facilities. Approximately 200 MW of capacity accepted buyouts during 1994 and 1995, which shut down 25% of the state's operating capacity, and decreased the demand for biomass fuels by nearly one-third. Supply and demand were again out of balance, and fuel prices began a fall that has brought them back to their pre-1988 levels.

Figure 6 plots the supply curve for biomass fuels in California during the past 15 years. The data points represent the period 1981–1996, and show, for each year in the range, the quantity and the average price of biomass fuel used that year. The curve appears to have two segments. The first corresponds roughly with the supply of

readily available sawmill and food processing residues. This segment, which has a relatively flat slope (low price elasticity), accounts for roughly the first 3 million bdt/yr of available fuel. When demand exceeds that level, the marginal cost of providing additional fuel is considerably higher, as agricultural, urban, and in-forest residues are brought into the mix. This is reflected by the steeper slope of the curve as statewide demand exceeds 3 million bdt/yr (higher price elasticity).

The future for biomass fuel prices in California is difficult to predict. Even if the operating capacity of the industry remains stable for the next few years, there will be continuing downward pressure on fuel prices as old, high-priced fuel contracts expire and fuel suppliers have to conform with current market conditions. In addition, as more facilities reach the 11-year cliff, they simply will not generate sufficient revenues to purchase expensive fuel, which means that fuel use could decrease even as the amount of installed generating capacity remains constant. One aim of the biomass power plant operators is to find ways to reduce fuel costs to near zero, in order to gain a measure of competitiveness in the coming restructured market. To achieve this objective, the generators of the solid wastes used as fuel, or some other source, must contribute to the cost of their disposal. The California Environmental Protection Agency (Cal/EPA) is exploring strategies to shift the fuel cost of biomass power generation away from electric ratepayers, and onto beneficiaries of the environmental services provided.

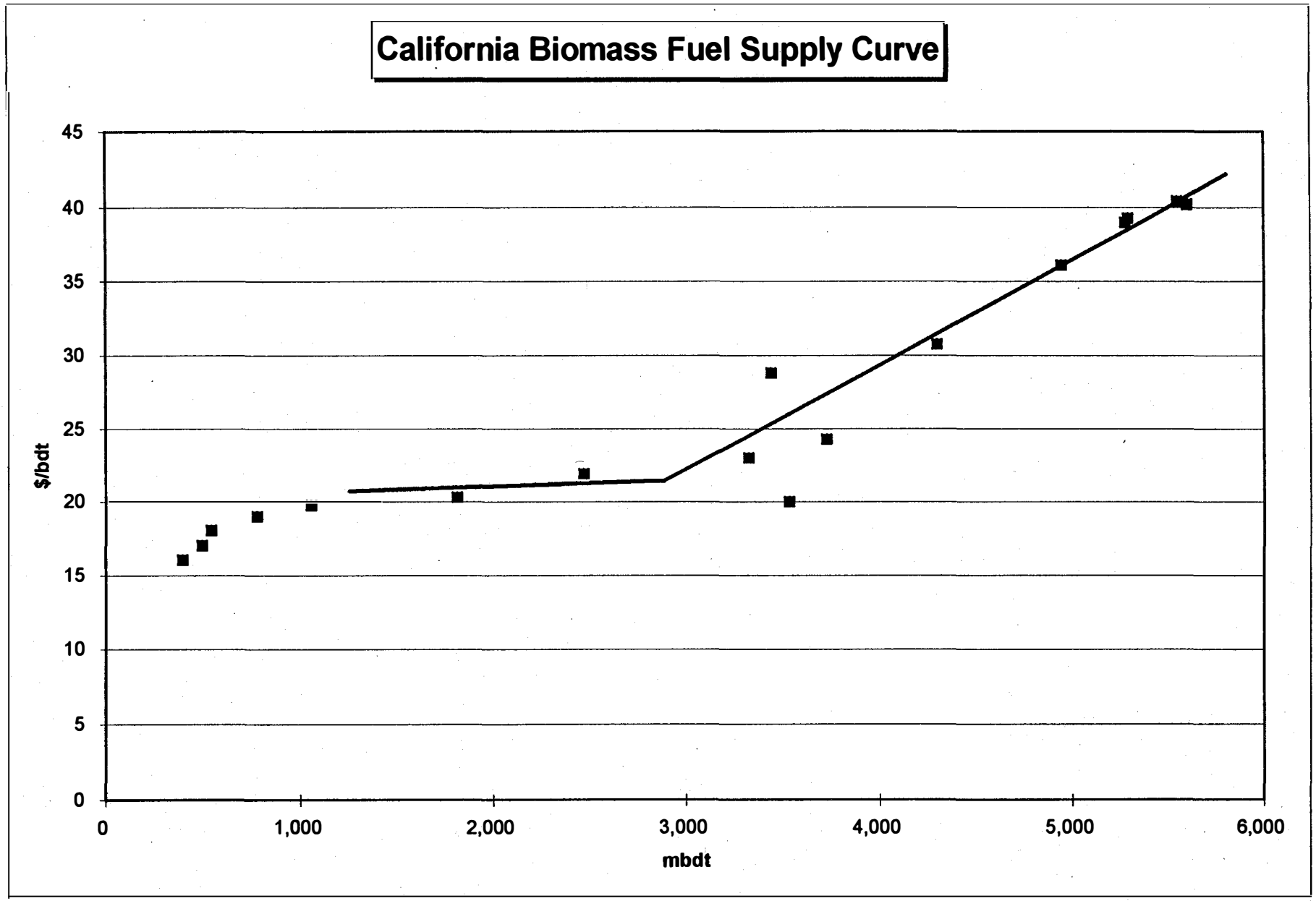
Fuel Use during Watershed Year 1993

The year 1993 can be considered the watershed year for the biomass power industry in California. The last of the facilities to hold 1980s-era PPAs had begun to operate, and no additional new capacity was under serious development. Biomass fuel supply and demand had reached an equilibrium in which suppliers and consumers could prosper. The facilities that had experienced early problems had either been fixed or retired from service. More than 5 million bdt/yr of biomass residues were being used as fuel, and fuel use provided an environmentally superior waste disposal alternative for virtually all this material. The biomass power industry represented an important component of the state's electricity supply. Electric utility restructuring had not yet been conceived.

Total biomass fuel use was fairly constant in California from 1990 to 1993, at a level of about 5.25 to 5.50 million bdt/yr. This level supported an installed biomass generating capacity of approximately 750 MW. Although the total amount of fuel used annually during this period remained fairly stable, the mix of fuel sources was constantly changing. Between 1990 and 1993 the amount of mill residues used as fuel decreased by 0.85 million bdt/yr, which represented 16% of the total biomass fuel market, and 31% of the peak amount of mill residue used in 1990. Urban and agricultural residues took up the slack; in-forest residue use declined slightly. Figure 5 shows the amount used of each major biomass fuel source during the period during which the modern biomass power industry has operated in California.

The amount of mill residue used as biomass fuel during the early 1990s declined by nearly one-third. Mill residue has always been the major contributing source to the state's biomass fuel supply, and the cheapest source of supply. The loss of one-third of this source was a direct result of poor business conditions in the forest products industry. The industry was hurt by increasingly restrictive environmental regulations that decreased the timber supply available to the industry, and by economic recession, which depressed the demand for wood products. As a result, the biomass power industry had to turn to other sources to maintain the supply.

Figure 6


California Biomass Fuel Supply Curve
$/bdt
45
40
35
30
25
20
15
10
5
0
0
1,000
2,000
3,000
4,000
5,000
6,000
mbdt

During 1993, 5.3 million bdt of biomass fuels were used in California. Broken down by residue category, the supply in 1993 came from:

	Fuel Use (% of total)		Price (ave. & range)
Mill residues	1.9 mil bdt	(36%)	$37/bdt ($33–43)
In-forest residues	0.8 mil bdt	(15%)	$40/bdt ($33–43)
Agricultural residues	1.2 mil bdt	(23%)	$41/bdt ($34–50)
Urban wood residues	1.4 mil bdt	(26%)	$40/bdt ($28–45)
Total	5.3 mil bdt		$39/bdt ($28–50)

The Environmental Performance of the Biomass Power Industry

Characterizing and analyzing the environmental performance of the biomass power industry in California requires a consideration of (1) the alternative fate of the residues used as biomass fuels; and (2) the effects of the production and use of the fuels in the power sector. All fuel used is residue or waste material, and, as such, would face some form of disposal or environmental fate if the fuel market were not in place. Energy use is the lowest-value application for biomass materials, so without the energy market, these materials would not be put to any useful application. Thus, to understand the industry's environmental performance, the environmental impacts of fuel production and use and the environmental impacts of the disposal options must be analyzed. The environmental impacts of fuel production and use are fairly consistent for all biomass fuel sources used in the state. The environmental impacts of alternative disposal options vary greatly among the fuel sources.

In the absence of a fuel market, wood-processing residues, urban wood wastes, and some food processing residues would be landfilled. Most agricultural residues used as fuel would be open burned, a common agricul- tural practice. Some agricultural residue fuels would be plowed under. Most in-forest residues would be left in the forest, where their long-term buildup contributes to forest fire risk and ecosystem degradation. Some in-forest materials, particularly logging wastes, are pile burned instead of being left in the forest, which eliminates this material as a source of fuel loading, but contributes to air pollution. Figure 7 shows the alternatives available for disposing of the biomass currently used for fuel in California.

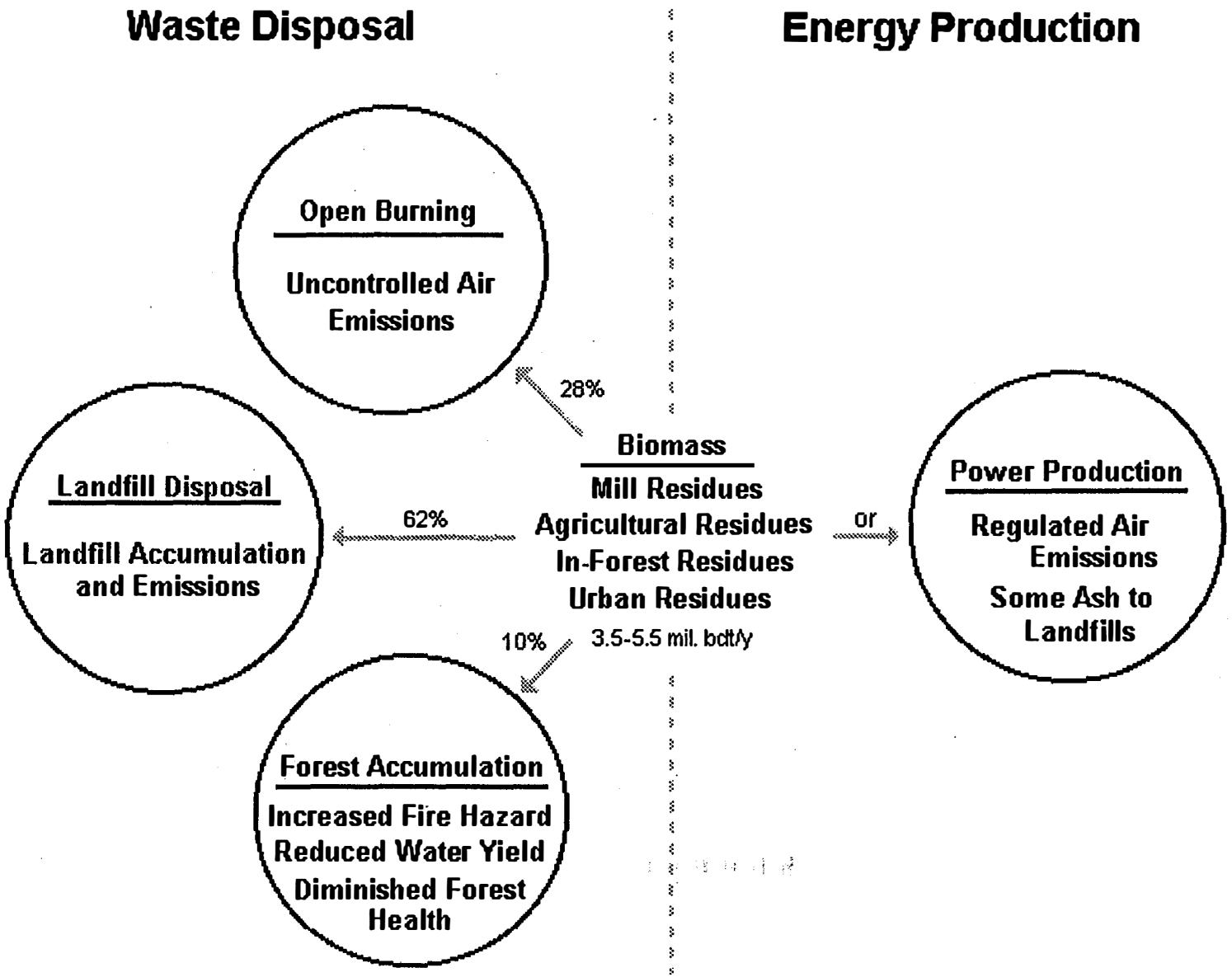
The major environmental impacts associated with the conventional disposal of biomass wastes include air pollution and landfill loading. Air pollution is a particularly severe problem with the open burning of biomass residues, particularly emissions of smoke, particulates, and hydrocarbons. Open burning of agricultural residues is a major contributor to air pollution in California's major agricultural regions, many of which are out of compliance with federal and state air quality standards. Agricultural burning is regulated, and restricted to approved burn days, when atmospheric conditions limit the resulting impacts. Nevertheless, agricultural burning is a major impediment to the attainment of air quality standards in many areas.

California is the country's largest state, and has two of the country's four largest urban areas. Large quantities of solid waste are produced, then landfilled. California's solid waste law mandates increasing diversion goals to reduce the amount of material buried in the landfills. Approximately 15% of the material routinely landfilled is separable wood waste that can be converted into power plant fuel, which greatly reduces landfill loading. It also removes a significant portion of the organic material from the landfill, which decays under anaerobic conditions and produces emissions of noxious gases and methane.

Environmental Impacts of Biomass Fuel Use

Combustion of biomass fuels in modern power plants leads to the same types of pollutant emissions as the use of fossil fuels. These include emissions of the criteria air pollutants (particulates, NO_x, SO_x, hydrocarbons, and CO) and other atmospheric emissions (toxics, CO_2), and solid wastes (ash). Fuel processing, which in most cases involves some type of grinding operation, produces emissions of dust and particulates. Air emissions and water consumption for cooling are the major sources of environmental concern related to the use of biomass fuels for power generation.

Figure 7: Benefits of Biomass Energy Production



Several technologies are used to process woody biomass residues into fuel-usable form. The major alternatives include rotary grinders, hogs, and chippers. All grinding technologies generate large quantities of dust and particulates, which are the major problems associated with this type of equipment. Most grinding is done in the open, and emissions are either uncontrolled, or controlled by water sprays supplied by mobile water trucks. Because of concerns about these emissions, especially in urban areas, one urban wood waste processor in the San Francisco Bay Area was required to install its grinding equipment in an enclosed area, with a baghouse system to collect the dust created in the grinding operations. This system solves the particulate and fugitive dust emission problems.

All biomass power plants in California are required to achieve stringent emissions control levels for criteria pollutants. NO_x, hydrocarbons, and CO are usually controlled by using advanced combustion technologies, which often include fluidized bed combustors, staged combustion, and flue gas recirculation. Many of the new- est biomass power facilities are required to use ammonia injection to further control NO_x emissions. SO_x emis- sions generally are not a major concern with biomass combustion, because biomass, especially in woody form, has a very low sulfur content. Some facilities that have fluidized bed combustors inject limestone to capture sulfur, but no biomass facilities are required to have flue gas scrubbers to control SO_x emissions.

Particulates are controlled at biomass power plants with a variety of technologies. Virtually all biomass power plants employ cyclones to remove the bulk of the large particulates found in the flue gas. Most are equipped with electrostatic precipitators for final particulate removal; some use a baghouse. Most modern biomass power plants are required to achieve zero visible emissions to meet environmental permit conditions. Their emissions of total and sub-micron particulates are also regulated and controlled to stringent levels, comparable to or better than the emissions levels achieved by the large fossil-fuel-fired power plants operated by the electric utility companies.

Table 2 shows average emissions levels of the criteria pollutants for the biomass power industry in California. The data are based on information supplied by 34 biomass facilities, and include permitted emissions levels and actual source test data. The data are further differentiated by combustor type. Eleven have fluidized bed combustors; the rest have grate burners of various designs. The fluidized bed combustors achieve lower emissions levels of all criteria pollutants of concern for biomass power plants, compared to the grate burners. The most dramatic difference is in CO emissions, for which the fluidized bed combustors are more than an order of magnitude better than the grate burners. The fluidized bed combustors achieve emissions factors of half or less than the grate burners for all pollutants for which data are available.

Table 2. Emissions from Biomass Power Plants

	Permit Levels			Source Test Results		
	All	Grates	FBs	All	Grates	FBs
NO_x	2.6	3.1	1.5	2.0	2.5	1.0
SO_x	1.2	0.9	1.7	0.1	NA	0.1
CO	11.5	16.3	2.0	10.3	14.7	0.2
Hydrocarbon	1.7	1.8	1.6	0.5	0.7	0.1
Particulate	0.8	1.0	0.6	0.5	0.6	0.3

Data are average for 34 facilities: 23 with grate furnaces, 11 with fluidized-bed burners.

Environmental Impacts of Fuel Loading in California Forests

California's geographical and climatic characteristics are conducive to growing natural forests that are prone to periodic fires. This propensity has been exacerbated by the commercial management of forests and land use during the past century, when the natural periodic forest fire cycle has been severely disrupted by vigorous fire-fighting efforts, and populations wooded areas have increased. The results of these two phenomena have been to increase (1) the amount of fuel loading in the forests; and (2) the imperative to provide firefighting services in rural, wooded areas (Cal. Dept. of Forestry 1996).

The fuel that is building up in the forests includes standing dead and diseased wood, downed woody material of all varieties, and the forest growing stock, the density of which is growing overall. The accumulation of dead and diseased wood, both standing and downed, is particularly problematic from a forest fire risk perspective because this material tends to have a lower moisture content than growing stock, which makes it easier to ignite, hotter burning, and more likely to spread fire. As the fuel loading in California forests continues to build, fires that become out of control tend to be much more severe and destructive than the traditional fires that were a periodic part of the pre-industrial ecosystem. Contemporary conflagrations burn much hotter than traditional fires and consume much larger areas with more extensive destruction.

Fuel loading also contributes to the degradation of the health and ecosystem functioning of forests and watersheds. Healthy, relatively undisturbed forest ecosystems in California have approximately a 40% level of canopy closure, whereas most forests today have a 60%–65% canopy closure level or higher. This means that the amount of available rainfall that enters the evapotranspiration cycle is higher than in the native ecosystem, and less rainfall moves through the watershed as runoff. Reduced runoff means less water is transferred to the mead- ows and lowlands, where water is stored during the rainy season and released gradually during the dry season.

The net result of this chain of events is that useful water production from the state's watersheds is lower than it would be if the forests were more natural. This loss includes water for human consumption and environmental water for river and delta ecosystems. In other words, an effective, sustained thinning program for forested watersheds would probably increase useful water supplies and would require no further development of water supply infrastructure. Several experimental programs currently are under way to prove this connection, and to provide data on the amounts of water production that will result from thinning and other watershed improvement operations (Cal. Dept. of Water Resources 1994). A great deal of work remains to be done to understand the relationship between watershed improvement activities and the rate of watershed water production.

The production of power plant fuels from forest residues provides for the removal of some fuel loading in California forests. During the early 1990s, 800,000 to 1 million bdt/yr of in-forest residue fuels were produced in California and consumed by the biomass power industry. This represents a small fraction of the material that forest managers would like to see removed annually from the commercial forests. By 1996, projections showed that the amount of in-forest biomass fuels produced in the state will fall below 250,000 bdt, which will minimize the contributions that the biomass energy industry makes to forest fire risk mitigation.

California has approximately 16 million acres of commercial forest land, virtually all of which would benefit from periodic treatments such as thinning and removing culls. The California Department of Forestry estimates that residue harvesting operations would need to be rotated approximately every 15 years to achieve maximum fire reduction and forestry benefits. At the maximum level of in-forest residue fuel use of 2 million bdt/yr in the early 1990s, and an average harvesting density of 30 tons/acre (16.5 bdt/acre), approximately 60,000 acres/yr were being improved as part of the fuel-production process. On a sustainable basis with a 15-year rotation this would mean that approximately 6% of the state's forest land benefited from the operation of the biomass energy industry. By 1996, this percentage had dropped to approximately 1.5%.

The reduction in fuel use that the state would like to achieve involves a vast quantity of material, far more than could be used as fuel by the biomass power industry. The only other viable alternative for land managers is to perform prescribed burns, a form of open burning. This is cheaper than fuel production; however, it causes a heavy air pollution load, so only a limited amount of prescribed burning can be done each year. The state's forests and watersheds clearly would benefit from as much in-forest biomass fuel production as possible.

Environmental Impacts of Biomass Disposal in Landfills

More than 60% of the biomass fuel used in California during 1993 would have been landfilled without the fuel-use option. This represents a diversion of 3.3 million bdt of material, or more than 5.8 million green tons, from sanitary landfills, a major benefit to the state in its efforts to reduce landfilling and meet diversion goals. California's solid waste law, AB 939, passed in 1989, mandates a recycling rate for landfill diversion of 50%, to be achieved by the year 2000. A 25% diversion rate was to be achieved by 1995. This intermediate requirement was attained.

Recoverable wood waste represents approximately 15% by weight, and as much as 20% by volume, of the material that enters typical sanitary landfills in urban centers. Included in this resource are materials that enter the landfill gate separate from mixed household garbage. Separable urban wood waste includes:

- Construction and demolition wood waste
- Wood and brush waste from land clearing
- Wood and brush waste from public and private tree trimmers
- Wood waste from the manufacturing of cabinets and wood products
- Discarded pallets and drayage.

These materials enter the landfill in debris boxes, roll-offs, vans, and pickup truck loads. In the absence of a fuel use option, they are buried along with other wastes that enter the landfill gate. Some landfills segregate and grind inbound waste wood to use as daily landfill cover or for other applications, but this is a small fraction of the total recoverable resource statewide, and these applications would not likely expand significantly if the fuel market collapsed. Indeed, there is reason to believe that these nonfuel applications would actually decline if the fuel market collapsed, because the production of these products in most cases depends on the coproduction of fuel, and loss of the fuel market would make production of the other products infeasible.

Landfilling wood residues that can be recovered and converted into power plant fuel entails the same kinds of environmental impacts associated with disposing of all kinds of organic wastes in landfills. Compared with other types of organic wastes woody materials are slow to degrade, which means that landfill stabilization is delayed. Like all organic material in the landfill, waste wood can be a source of leachates. The material degrades, and produces emissions of methane and CO_2 in roughly equal quantities. Methane and CO_2 are both greenhouse gases, but methane is a much more reactive greenhouse gas, by a factor of some 25 times per unit of carbon, so emissions of the residue-bound carbon in the form of a 50:50 mix of methane and CO_2, rather than as pure CO_2, is far more damaging from the perspective of greenhouse gas buildup in the atmosphere (Morris 1992).

Large landfills are now required by EPA regulations to control their fugitive emissions by collecting and flaring some landfill gas. Approximately 60% of the landfills, which receive some 80%–95% of the state's solid waste, are covered by this regulation. In general, gas collection systems collect approximately 80% of the methane released by the landfill, which means that final emissions of the waste carbon to the atmosphere are approximately 90% CO_2 and 10% methane (compared with approximately 50:50 for an uncontrolled landfill). Emitting the carbon in the 90:10 mixture of CO_2 and methane results in an effective greenhouse gas emission 3.4 times more potent than emissions of the same amount of carbon in the form of 100% CO_2. For uncontrolled landfills,

the 50:50 mixture of the gases emitted leads to an effective greenhouse gas emission 13 times more potent than emissions of the same amount of carbon in the form of 100% CO_2. The only effective means of eliminating methane emissions from wood residues is to use the material as fuel.

Given that biomass power generation is more expensive than the conventional alternative (natural gas-fired generation), calculating the cost of greenhouse gas reduction by substituting biomass for natural gas is interesting. The cost of biomass power generation (see the section, The Future of the California Biomass Energy Industry) is approximately \$0.015 + \$0.02 kWh above market price, which is driven by the cost of power generation with natural gas. Based on the data in Table 3, the generation of 1 MWh of electricity from biomass, rather than natural gas, reduces net greenhouse gas emissions by 3.09 tons (6,179 lb/MWh in the table). Thus, if the entire above-market cost of biomass power generation is charged to greenhouse gas reduction, the cost of that reduction is approximately \$4.85 to 6.50/ton of CO_2 equivalent.

Environmental Impacts of Open Burning of Biomass Wastes

Open burning of biomass residues is a major source of air pollution in California's agricultural valleys, many of which are in nonattainment for criteria pollutants. It also is a significant source of air pollution in forests and urban areas. In fact, one of the early actions taken against air pollution in California was the phaseout of teepee burning of sawmill wastes. Decreasing the amount of open burning of agricultural residues in California has long been an objective of air quality regulators, but the imperative for farmers to dispose of their residues cost-effectively has prevented the banning of agricultural burning. The development of the biomass power industry during the 1980s helped mitigate the problem, but a great deal of residue continues to be open burned, even at the height of biomass fuel use from 1990 to 1993, when 1.2 million bdt/yr of agricultural residues were being used as fuel. The decrease in biomass fuel use since 1993 has led to a drop-off in the use of agricultural residue fuel of approximately 30% statewide, which means that more than 350,000 bdt/yr of agricultural residues that were being used as fuel as recently as 1993 are once again being open burned.

The state's air quality regulatory agencies recognized the potential contribution that the biomass power industry could make to eliminating open burning of agricultural residues during the early phases of the industry's development. In order to give the biomass power producers credit for the air quality benefits they provide, regulators developed the agricultural offset protocols, through which facilities that burn agricultural residues (which would otherwise be open burned) earn an offset for their emissions of pollutants at the power plant. Because emissions offsets are required only for pollutants for which the receiving basin is nonattainment, most agricultural offsets have been for NO_x emissions. For most facilities that have been permitted on the basis of the agricultural offset protocols, the permits require that one-half to two-thirds of the facility's fuel be obtained from agricultural residue sources.

Open burning of agricultural residues produces massive amounts of visible smoke and particulates. It also produces significant amounts of NO_x, CO, and hydrocarbons emissions, which contribute to the formation of atmospheric ozone, a particularly intractable problem for air quality control in the Sacramento and San Joaquin Valley air basins. Quantifying the emissions of open burning is difficult, as residues, burning practices, and conditions are extremely variable. Nevertheless, the use of these residues as power plant fuel greatly reduces the smoke and particulate emissions associated with their disposal, and reduces the amounts of CO, NO_x, and hydrocarbons.

A major effort to measure the emissions of open burning of biomass was undertaken by University of California, Riverside, researchers in 1979 (Darley 1979). The emissions factors reported from this study were used as the basis for the agricultural offset protocols, and remain the best, albeit limited, source of data on the open burning of biomass. The Darley emissions factors are shown in the first line of Table 3. The next line on the table shows

Table 3: Biomass Power Systems Emissions

Emissions Factors

		Part.	SOx	NOx	HC	CO	CO_2	CH_4	GHG *
Open Burning	lb/bdt	4.64	1.28	7.04	7.36	63.36	3080		3385
Landfill Burial	lb/bdt				2.93		2345	217.5	8871
Biomass Generation	lb/MWh	0.50	0.10	2.00	0.50	10.30	2904		2934
Nat. Gas Generation	lb/MWh	0.04	0.12	1.15	0.01	0.20	2326		2327

Emissions from Biomass Power Production

Biomass Cycle Only ♦	lb/MWh	(1.26)	(0.39)	(0.68)	(4.11)	(13.78)	280	(134.9)	(3,852)
Net of Fossil ✖	lb/MWh	(1.30)	(0.51)	(1.83)	(4.12)	(13.98)	(2,046)	(134.9)	(6,179)

% Open Burning	38%	
% Landfill Burial	62%	
Bdt/MWh:	1.0	
CH_4 Multiplier	10	(molar basis)

* GHG = green house gas emissions expressed as lb of CO_2 equivalents

♦ Biomass Cycle Only emissions are power plant less alternative disposal

✖ Net of Fossil emissions are Biomass Cycle Only less fossil generation

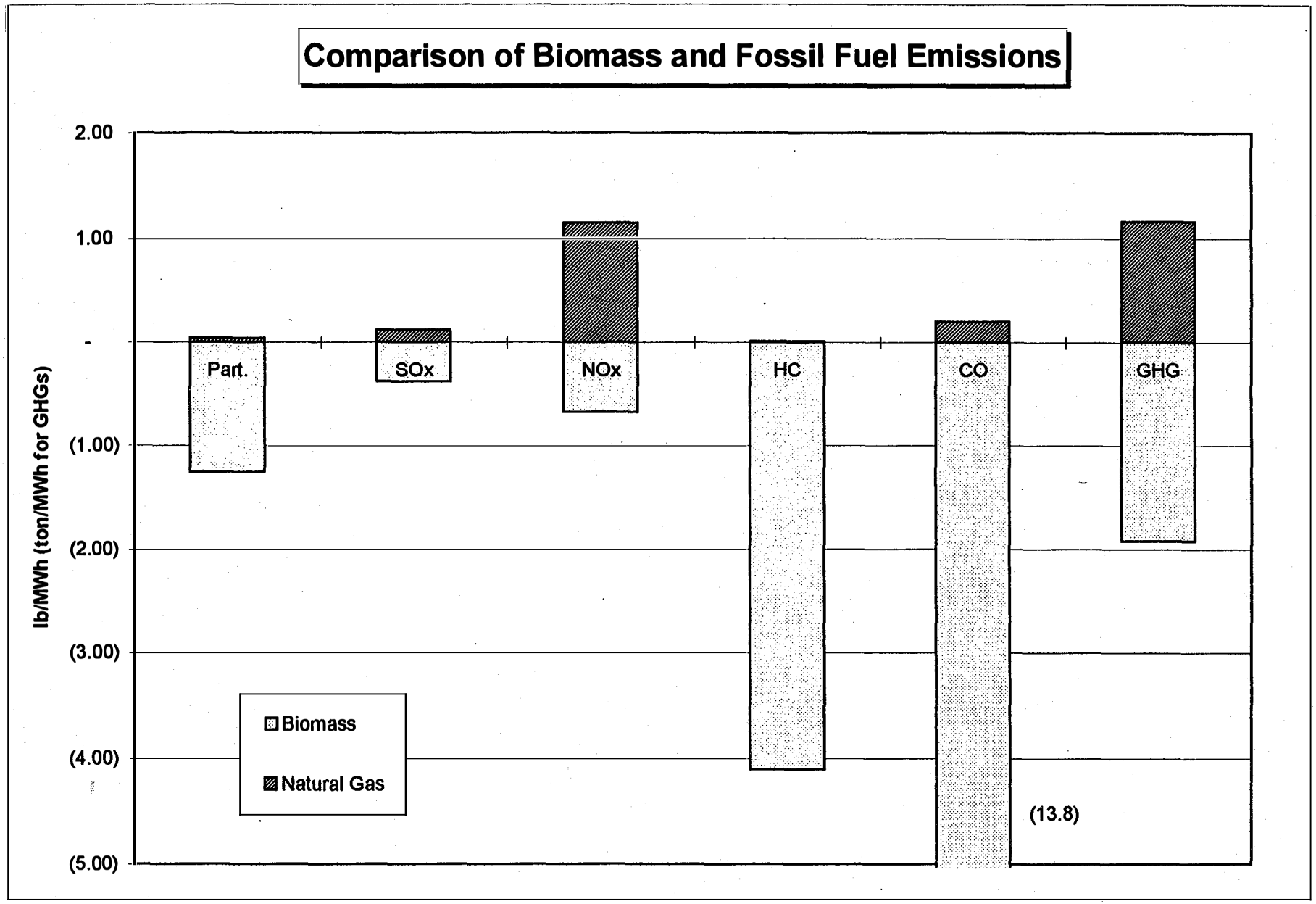
the airborne emissions factors associated with landfilling biomass residues, which are limited to hydrocarbons, methane, and CO_2, all of which are greenhouse gases. The table also shows emissions factors for biomass power plants (presented in greater detail in Table 2), and emissions factors for natural gas-fired steam power plants, which provide most of the utility base-load capacity in California.

The total emission of criteria air pollutants and greenhouse gases associated with biomass power production is calculated as the difference between the emissions associated with the fuel cycle, and the emissions that otherwise would be associated with the conventional disposal of the residue material. These emissions factors are shown on the fifth line of data in Table 3. The assumed mix of biomass fuels, 38% of which would otherwise be open burned, and 62% of which would otherwise be landfilled, is based on the fuel mix used during the watershed year of 1993. The data show that fuel use of the residues leads to large net benefits in terms of emissions reductions compared to conventional disposal. This reduction is achieved for every category of criteria pollutants, and for total emissions of greenhouse gases.

Some emissions associated with landfilling and in-forest fuel loading are delayed in time in comparison with the fuel use option. The analysis presented in Table 3 is static, and does not take these time lags into effect. This means that during the startup of the industry the benefits of the fuel use option are somewhat exaggerated, but in the longer term the system reaches an equilibrium that is very close to the results shown in the table.

The production of electricity by biomass power plants further reduces air pollution by displacing the power production via conventional sources. In California, the marginal generating source displaced by biomass generation is natural gas-fired power generation. Figure 8 compares graphically the net emissions reductions associated with biomass power production, with the emissions of an equivalent amount of fossil fuel-fired electricity generation. The full net emissions reductions associated with biomass power generation in California can be calculated as the difference between the net emissions associated with the biomass power cycle alone, and the emissions that would be produced by natural gas-fired generation if the biomass-generated power were not available. The full net emissions of biomass power generation in California are shown as the last line of data in Table 3. The full net emissions, which for all categories of pollutants are the total emissions avoided, are slightly better for the criteria pollutants, and much better for total greenhouse gases, in comparison with the consideration of the net emissions of the biomass fuel cycle alone. In either case, use of biomass residues as fuel leads to large net reductions in emissions of air pollution.

Figure 8


Comparison of Biomass and Fossil Fuel Emissions
lb/MWh (ton/MWh for GHGs)
2.00
1.00
-
(1.00)
(2.00)
(3.00)
(4.00)
(5.00)
Part.
SOx
NOx
HC
CO
GHG
(13.8)
Biomass
Natural Gas

The Impacts of Biomass Plant Closures after 1993

Since 1993, the operating capacity of the industry has shrunk by 26%, from 750 MW to 550 MW. Annual biomass fuel use in the state has decreased by 33% from 5.3 million bdt to 3.5 million bdt, representing a loss of 1.8 million bdt/yr of waste disposal services. Three of the four categories of biomass fuels have been affected by the drop in fuel demand. Only the use of mill residues has been largely unaffected by the loss of fuel demand. The result is that more material is being open burned in agricultural valleys and entering urban landfills. Also, the forest fire risk is not being reduced and watersheds are not being improved by removing residue from commercial forests.

The decreases in the use of biomass fuels in California between 1993 and 1996 are shown graphically in Figure 5, and numerically in Table 4. Mill residues continue to be the dominant source of fuel. The decrease in mill residue use during this period is attributable to a drop in wood products manufacturing, rather than to a loss in demand for this lowest-cost source of fuel. The consumption of mill residue fuel actually increased between 1995 and 1996 because (1) overall economic activity increased during this period; and (2) abnormally high prices for pulp chips in the Pacific Northwest during 1995 returned to more normal levels in 1996. Nevertheless, bet- ween 1993 and 1996, mill residue fuel use shrank 13%, from 1.9 million bdt/yr to 1.65 million bdt/yr. This did not represent a loss in environmental services, as the loss in fuel use resulted mainly from a loss in residue production.

Table 4. Loss in California Biomass Fuel Demand, 1993–1996 (thousand bdt per year)

	1993	1996	Change
Mill Residue	1,900	1,650	-13%
In-Forest Residue	800	240	-70%
Agricultural Residue	1,210	860	-29%
Urban Residue	1,365	785	-42%
Total	5,275	3,535	-33%

The use of forest residue fuels has been particularly hard hit by the plant closures since 1993. Forest residue fuels are the most expensive source of biomass fuels, (mostly because of the remote location of the resource) and this is the first source to be abandoned as overall demand for biomass fuels shrinks. Between 1993 and 1996 forest residue fuel use decreased by 70%, from 800,000 bdt/yr to 235,000 bdt/yr. The current level is more than 75% lower than its peak use during 1990 and 1991 (about 1 million bdt/yr).

Agricultural and urban residue fuel use have lost ground since 1993. Agricultural fuel use declined 29%, from 1.2 million bdt/yr to 865,000 bdt/yr. Urban fuel use declined by 43%, from 1.4 million bdt/yr to 785,000 bdt/yr. The loss in fuel use of these types of residues has led directly to an increase in agricultural burning and urban landfill loading, at a time when California is already having difficulty achieving air quality standards and complying with solid waste diversion mandates.

The buyouts and shutdowns since 1993 appear to have reached a plateau, and have allowed biomass fuel use to stabilize at about 3.5 million bdt/yr. In 1996, mill residues will contribute approximately 47% of the total, agricultural residues, 24%, urban wood wastes, 22%, and in-forest residues, 7%. The future stability of the

market, however, is in doubt, as the recently passed restructuring legislation may provide new incentives for the utilities to seek buyouts from their SO#4 PPAs, and some facilities that reach the 11-year cliff may decide to shut down. Furthermore, some operating plants that are reaching the 11-year cliff and continuing to operate are curtailing their operations to minimize fuel consumption during off-peak hours when the power purchase rate is at its lowest. This practice, if it becomes widespread, will further depress the demand for biomass fuels, even in the absence of any further loss of industry operating capacity.

Environmental Costs and Benefits

Most lost biomass power production in California has probably been replaced by gas-fired power generation. Because the emissions of criteria pollutants for both technologies are similar in magnitude, the loss of biomass power generation does little to alter the emissions of criteria pollutants associated with power production. The dominant environmental consequence of the industry shrinkage results from the loss of the waste disposal services provided by the biomass power industry: Of the 1.8 million bdt/yr of residues no longer used as power plant fuel, 1.25 million bdt/yr are returning to solid waste streams (0.58 million bdt/yr go to landfills, and 0.35 million bdt/yr re-enter agricultural burning), and 0.55 million bdt/yr add to fuel loading in forests.

Wood processing residues continue to be used as fuel according to their availability. The loss of biomass generating capacity since 1993 has not been enough to depress the demand for mill residue fuels. The decrease in the use of this fuel source, which began in 1991, is entirely related to the level of activity in the wood products manufacturing sector, so the closures of biomass power generating facilities have had no impact on the disposal of wood processing residues that require landfilling.

In contrast, the loss of biomass power generation in the state since 1993 has had a devastating impact on the contribution the industry made to removing fuel from forest lands. From 1990 through 1994, the biomass power industry provided the means for an annual harvest of 800,000 to 1 million bdt/yr of in-forest residues, a fraction of the total amount of fuel harvesting forest managers would like to see. Because of supply and demand pressures, the industry shrinkage that began in 1994 led to a significant decrease in the price that biomass fuel producers could obtain for their product. This has had the greatest impact on the highest cost-of-production fuels, and in California, in-forest residues are among the highest-cost sources of biomass fuels. Less than 240,000 bdt/yr of in-forest residue fuels are expected to be used during 1996, and the trend could continue even if biomass fuel demand remains the same and wood products manufacturing increases, which would make more mill residues available to the market. Thus, the closures in the California biomass power industry have almost eliminated the industry as a significant contributor to better forestry management and forest fire risk reduction.

The closures have also limited the extent to which the biomass power industry contributes to the avoidance of agricultural burning, and to the diversion of solid wastes from landfilling. The closures have led to a decrease in the use of agricultural residue fuels of more than 25%. About 350,000 bdt/yr of agricultural residues that were being used as fuel during 1993 are again being open burned, mostly in the San Joaquin and Sacramento Valleys. These valleys are out of compliance with federal and state air quality standards for pollutants such as ozone and NO_x, and the open field burning of agricultural residues is a major source of air pollution. During 1993, the biomass power industry made a significant contribution to better air quality in the agricultural valleys. The return of 350,000 bdt/yr of material to the burden of open burning exacerbates efforts to improve air quality in major agricultural regions.

The post-1993 closures have led to a decrease in urban waste wood fuel use of more than 40%. During the early 1990s, the biomass power industry provided an alternative use for approximately 1.4 million bdt/yr of segregatable clean wood residues that otherwise would have been landfilled. In fact, very little of this type of material was being landfilled near the major urban centers during the watershed period. For landfills that were producing

biomass fuel, fuel production reduced the amount of material needing to be landfilled by approximately 15%, and profits from the sale of biomass fuel when fuel prices were about $40/bdt helped underwrite the costs of recycling other components of the urban solid waste stream. The drop in demand for this material as a fuel has led to the return of 600,000 bdt of waste wood to landfills, and the drop in fuel prices has limited the ability of the remaining production of urban biomass fuels to underwrite other recycling activities.

Investment and Employment

The biomass power industry development in California required the investment of an enormous amount of capital. The average capital investment required for a biomass power facility, including project development and financing costs, was $2.4 million/MW of capacity. Approximately $2.3 billion was invested in the development of the 965 MW of biomass generating capacity built in California between 1980 and 1995. During the early 1990s the 750 MW of biomass generating capacity then operating represented an investment in place of approximately $1.8 billion. The shutdown of 200 MW of capacity that began in 1994, as the utility companies bought out the PPAs of 16 facilities, means that nearly $0.5 billion worth of installed capital investment has been removed from service. Some facilities have been physically dismantled; most sit idle and could be returned to service if enough revenues could be generated by their operation.

Because of their size and the nature of their operations, biomass power plants require more operators per unit output than utility fossil-fuel fired power plants. Based on an extensive survey of biomass power facilities in the United States and Canada, biomass power facilities require 0.6 to 2.1 man-years of annual labor per MW of capacity (Morris 1994). Thus, the 750 MW of capacity that operated during 1993 provided approximately 940 full-time equivalent employment positions in power plant operations. The number of full-time equivalent jobs needed to support the industry in fuel production and transportation is approximately twice as large as the number of power plant operators, so the total direct employment attributable to the industry during 1993 was approximately 2,800 jobs. The biomass generating facility closures since 1993 have entailed the loss of 250 power plant operator positions, and 750 total jobs. Nearly all these losses have occurred in rural areas, where employment opportunities are especially scarce.

The Value of the Biomass Power Sector in California

The biomass power industry in California provides valuable services in the forms of environmental benefits, rural employment opportunities, and energy source diversity and security. Like other renewable generating sour- ces, biomass avoids fossil fuel-fired power generation. But of much greater significance, biomass power genera- tion substitutes a beneficial use for a disposal burden for biomass residue. This includes major reductions in emissions of criteria air pollutants and greenhouse gases associated with biomass disposal, reductions of material that enters sanitary landfills, and decreases in the amount of fuel loading in forests. These services have already been diminished by the losses in generating capacity since 1993, and they will be further eroded if the industry cannot compete in the coming competitive market. There are no known disposal alternatives for waste biomass that can match the environmental performance of the biomass power industry.

Biomass power production also provides important economic benefits to California's large agricultural and forestry sectors, and to its solid waste recycling industry. The agricultural and forestry industries are major producers of biomass residues, and their profitability depends in no small part on their success in turning these residues into useful resources. Similarly, when fuel prices were high, urban biomass fuel producers were subsidizing many of their unprofitable recycling activities with the income available from the fuel market. The biomass power industry provides a large market for the disposal of biomass residue materials, and in the past has been able to make this an income source for those who generate and handle these materials. Efforts to drive down or shift the cost of biomass fuels, which are under consideration as one way the industry can become more competitive in the future deregulated power market, would make the biomass fuels alternative less economically appealing to residue generators and handlers. This will cause some of them to divert their biomass residue materials to disposal alternatives that are less attractive environmentally.

Biomass power production provides important rural economic benefits and generating source diversity benefits. Rural employment is offered in the areas of fuels production and transportation, and power plant operations and administration. In many cases, biomass power plants are the single largest payers of property taxes in their local school and municipal services districts. Virtually all biomass fuels used by California power plants are residue materials produced within the state that require some form of disposal operation, or, in the case of in-forest residues, present an environmental liability if left untreated. In addition, biomass power plants generally store enough fuel on site for at least 1 month of operation. This makes biomass power generation a very secure and dependable source of energy. During the massive power outages in the West during the summer of 1996, most of California's operating biomass power plants remained on line and provided important voltage stabilization services and power that were crucial in restarting the large utility power plants, most of which tripped off line.

The Future of the California Biomass Energy Industry

The electric utility industry in the United States is on the verge of a radical makeover, as deregulation spreads across the country. Predicting the kinds of market opportunities that will become available for biomass power in the future is difficult, but most experts believe that biomass generating sources will have trouble competing. Even in today's regulated market environment the biomass power industry is barely treading water. There is virtually no new project development activity in progress anywhere in the country, and no realistic prospect of a significant pickup. In the meantime, the industry has taken some significant losses during the past couple of years, as facilities throughout the country have accepted buyout agreements. In California, more than 25% of the operating biomass power generating capacity has disappeared since 1993, and many operating facilities are nearing the 11-year operating cliff in their PPAs when their power sales price reverts to the current SRAC (~ $0.03/kWh) from the SO#4 fixed-price schedule level (> $0.12/kWh in 1996).

In considering the future of biomass energy, we must understand the economic needs of biomass power generation. Conventional biomass power plants in the United States are based on steam-turbine technology. Because of the size range of biomass generating facilities, and the moisture content of biomass fuel, biomass power generators cannot achieve the same kind of heat rates that modern utility fossil-fuel generators do. Modern biomass power generators average about 15,000 Btu/kWh, which translates into a fuel-price contribution to the cost of electricity production of about $0.01/kWh for each $10/bdt of fuel cost. In other words, delivered fuel that costs $25/bdt contributes $0.02.5/kWh to the cost of electricity production. The most efficient biomass generators can do about 20% better than this and reduce the fuel-cost contribution to $0.02/kWh for $25/bdt fuel.

Nonfuel operating costs for biomass power generators in the United States average about $0.025/kWh (Morris 1994). This covers labor, supplies, parts, maintenance, services, regulatory, insurance, overhead, and administrative costs. It does not include costs related to capital, or any provision for profits. The turnkey construction cost for a modern, emissions-controlled biomass generating facility that uses steam-turbine technology is about $1,500 to $2,000/kW of capacity. Financing costs and development expenses increase the total cost to about $2,000 to $2,500/kW of capacity. This translates into a capital cost contribution to the cost of electricity production of about $0.03 to $0.05/kWh, which includes a return on investors' capital.

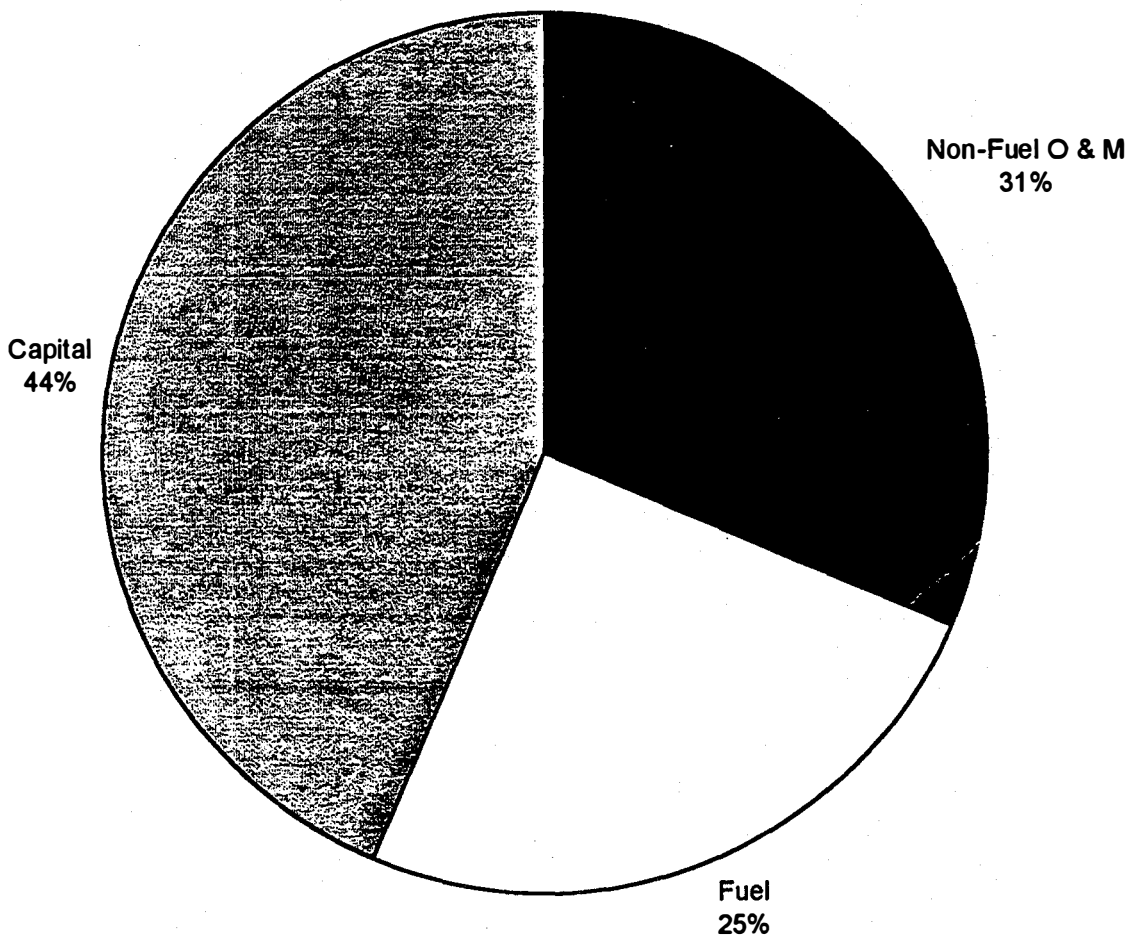
Biomass power facilities that purchase their fuel in a competitive market have operating costs in the range of about $0.035 to $0.06/kWh, depending on their efficiency characteristics and regional biomass fuel costs. Most biomass power generators in California rely on market sources for some or all their fuel supply. When capital costs are figured in, the cost of power production in a new biomass power plant that purchases fuel is in the range of about $0.065 to $0.11/kWh. This cost includes all capital-related costs, including a reasonable return on investment. Table 5 summarizes the cost of electricity production in a new biomass power plant in the United States. This is the level of compensation that will be necessary to motivate substantial new development of biomass power plants that use conventional steam turbine technology. Figure 9 illustrates the cost distribution of biomass power generation by major categories.

Table 5. Cost of Electricity Production from Biomass

	$/kWh
Nonfuel O&M	$0.022–$0.028
Fuel	$0.012–$0.035
Capital	$0.030–$0.050
Total	$0.064–$0.113

Figure 9

Cost of Biomass Power Production



Current SRAC rates in California are less than $0.03/kWh, and no utility offers capacity payments for new projects. During the next several years competitive markets for electricity generation will be established, and the prices for power sales that will be available to biomass generators is difficult to predict. In California, utilities currently report to the CPUC that their average cost of power generation is $0.06 to $0.07/kWh. On the other hand, for estimating their stranded costs, the same utilities project market prices for power purchases in the restructured market will be $0.025 to $0.035/kWh. If these estimates are correct, fully amortized biomass power facilities would require above-market support of about $0.015 to $0.03/kWh in order to remain in operation, and new facilities would require about $0.035 to $0.08/kWh in above-market support in order to motivate their development.

AB 1890, California's landmark electricity restructuring legislation, provides transition funding that is intended to allow renewables to achieve market competitiveness by January 1, 2002, when full restructuring will be in effect. The legislation, which acknowledges the special benefits associated with biomass, also directs the Cal/EPA to report to the legislature on the benefits of biomass energy use, and on strategies to shift some of the cost of biomass power generation away from the power market and onto other beneficiaries to maintain the viability of biomass power generation in the restructured market. The industry points out that if it can shift the cost of fuel procurement away from the electric rate payer, that would be enough to ensure its long-term viability. Sev- eral cost-shifting strategies are under consideration, all of which will require a good deal of effort and political will to implement. The future of the biomass power industry in California probably depends on it.

References

California Department of Forestry, *California Fire Plan: A Framework for Minimizing Costs and Losses from Wildland Fires*, March 1996.

California Department of Water Resources, *Bulletin 160-93, California Water Plan Update*, October 1994.

Darley, E. *Hydrocarbon Characterization of Agricultural Waste Burning*, Cal/ARB Project A7-068-30, University of California, Riverside, April 1979.

Morris, G. *Fuel Use and Other Characteristics of Biomass Power Plants in the U.S. and Canada*, FRA report, December 23, 1994.

Morris, G. *Greenhouse-Gas Emissions from Wastewood Disposal*, FRA report, May 11, 1992.

REPORT DOCUMENTATION PAGE

Form Approved
OMB NO. 0704-0188

'ublic reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, ıathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this :ollection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

. AGENCY USE ONLY (Leave blank)	2. REPORT DATE May 1997	3. REPORT TYPE AND DATES COVERED NREL Subcontract Report

I. TITLE AND SUBTITLE 'he Environmental Costs and Benefits of Biomass Energy Use in California	5. FUNDING NUMBERS Task #: BP711010
;. AUTHOR(S) G. Morris	
'. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) 'uture Resources Associates, Inc. :039 Shattuck Ave., Suite 402 Berkeley, CA 94704	8. PERFORMING ORGANIZATION REPORT NUMBER DE97000254
). SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Iational Renewable Energy Laboratory 617 Cole Boulevard Golden, CO 80401-3393	10. SPONSORING/MONITORING AGENCY REPORT NUMBER NREL/SR-430-22765
1. SUPPLEMENTARY NOTES	
12a. DISTRIBUTION/AVAILABILITY STATEMENT Iational Technical Information Service J.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161	12b. DISTRIBUTION CODE UC-600

3. ABSTRACT *(Maximum 200 words)* Responding to two oil crises during the 1970s, and to burgeoning environmental concerns, California developed a strong ›rogram to promote the development of its renewable energy sources. By the early 1990s California led the world in the production of power that uses a 'ariety of renewable resources, including biomass, geothermal, solar, and wind. But world energy markets had also undergone radical change, and California vas awash in cheap natural gas. Moreover, the technology for converting natural gas to electricity was improving dramatically. With deregulation of the California electricity industry looming on the horizon, the future commercial viability of renewable energy production was in doubt.

4. SUBJECT TERMS ›iomass generating facilities, waste disposal, restructuring proposal, PURPA	15. NUMBER OF PAGES 38 16. PRICE CODE

7. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT

SN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102