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In-state Biomass Resources for Biogas and Hydrogen

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University of California, Davis &

California Biomass Collaborative

The California Energy Commission

Sacramento / January 30, 2017

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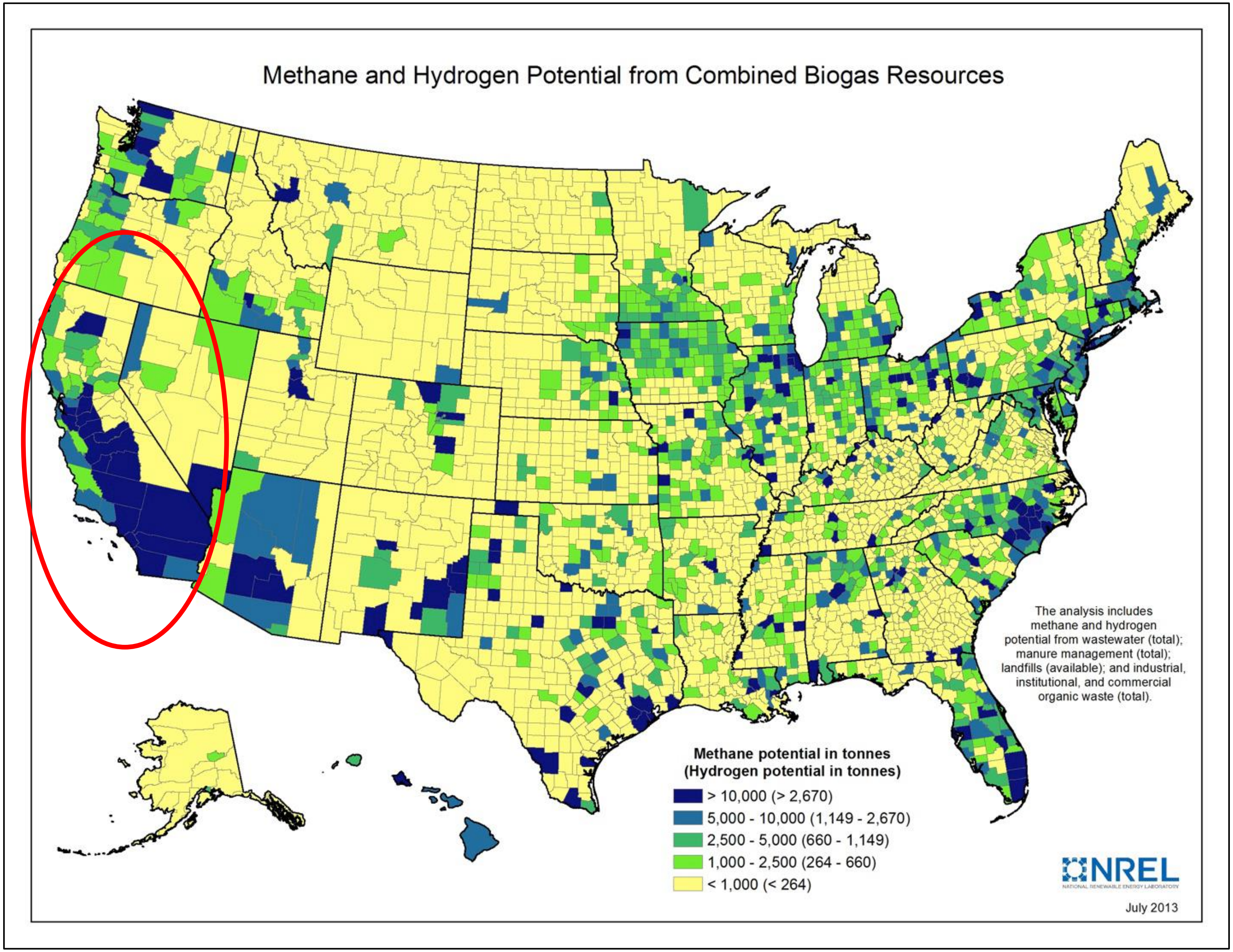
In-state biomass resources for biogas and hydrogen

Recent NREL/BETO estimates

California Biomass Collaborative estimates

Technologies

Policy Issues



Renewable Hydrogen Potential from Biogas in the United States; G. Saur and A. Milbrandt. *National Renewable Energy Laboratory;* Prepared under Task No. HT12.2010-2017

In-state biomass resources for biogas and hydrogen

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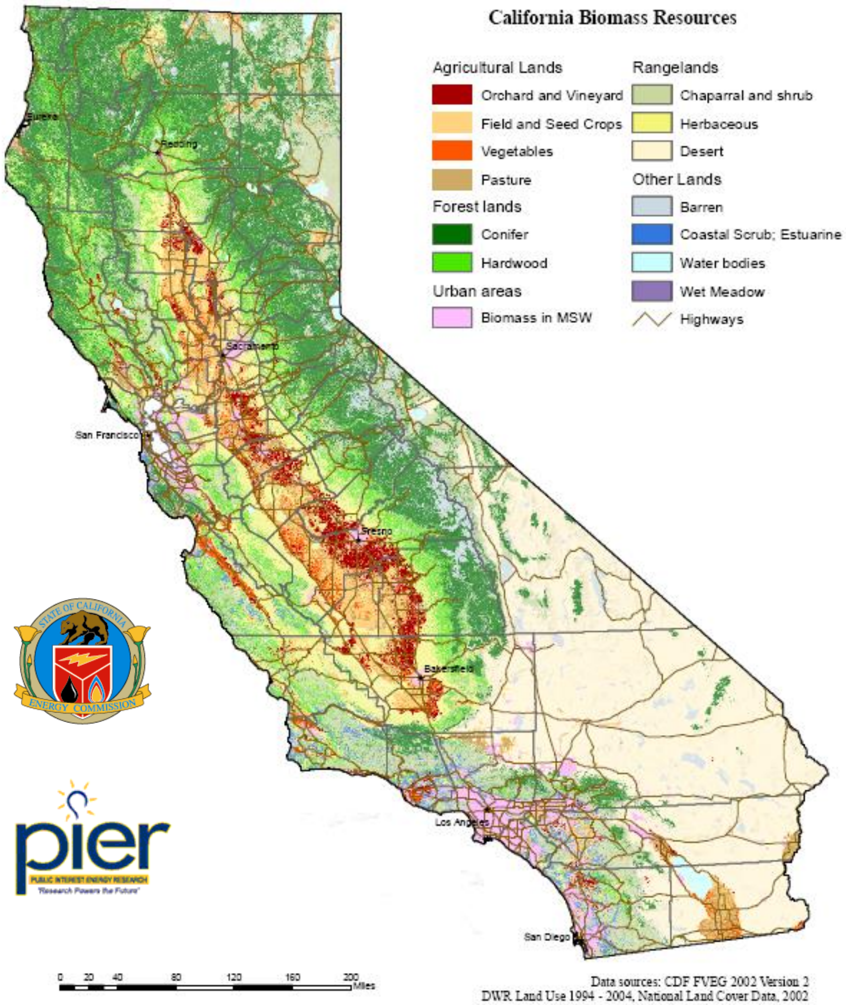
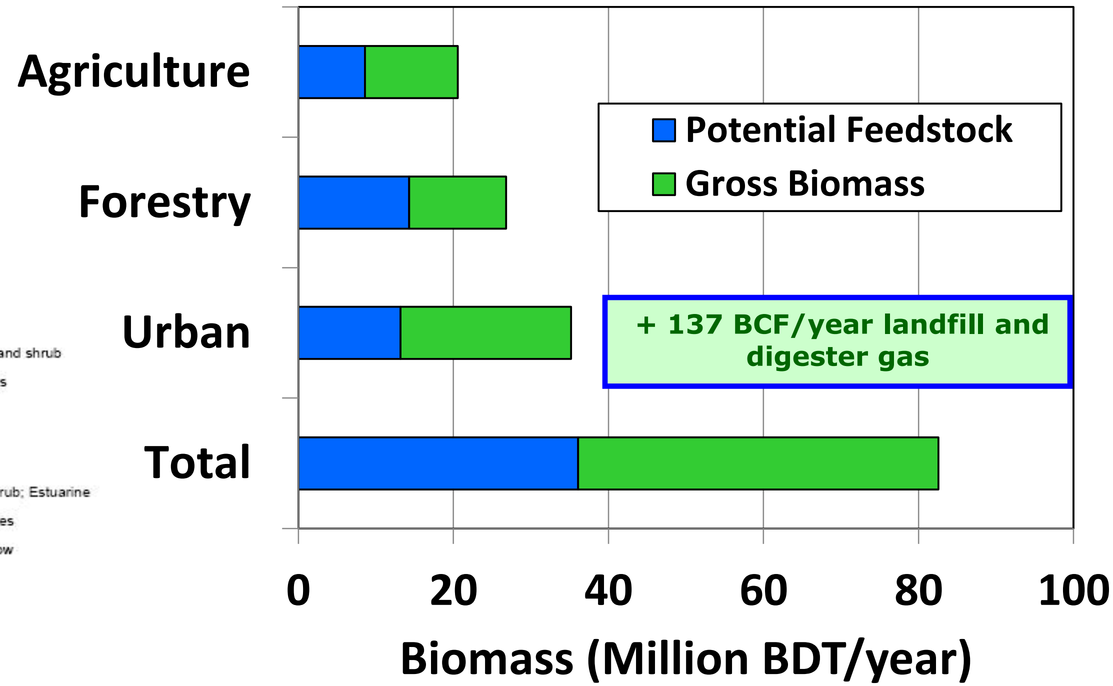
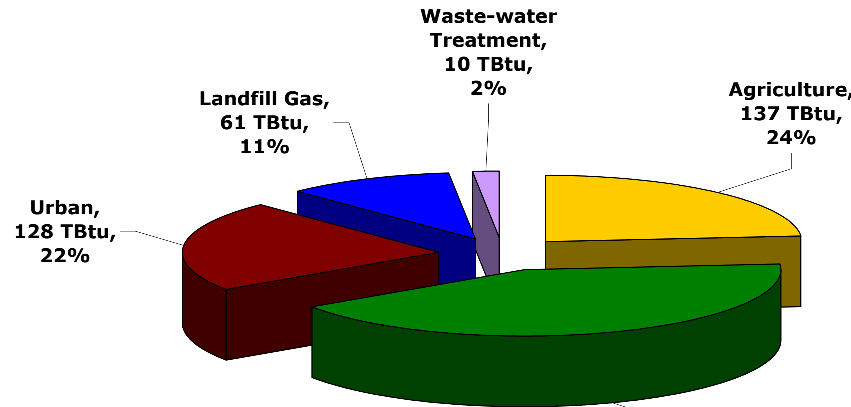
California Biomass Resources Are Diverse: http://biomass.ucdavis.edu/







Potential Feedstock Energy in Biomass 507 Trillion Btu/year

Jenkins et al. (2006) A roadmap for the development of biomass in California

Biomass is complicated. There are many possible feedstocks and biomass conversion pathways

- Production
- Collection
- Processing
- Storage
- Transportation

- Thermochemical Conversion
  - Combustion
  - Gasification
  - Pyrolysis
- Bioconversion
  - Anaerobic/Fermentation (AD)
  - Aerobic Processing
  - Biophotolysis
- Physicochemical
  - Heat/Pressure/Catalysts
  - Refining
  - Makes e.g. Esters (Biodiesel), Alkanes

- Energy
  - Heat
  - Electricity
- Fuels
  - Solids
  - Liquids
  - Gases
- Products
  - Chemicals
  - Materials

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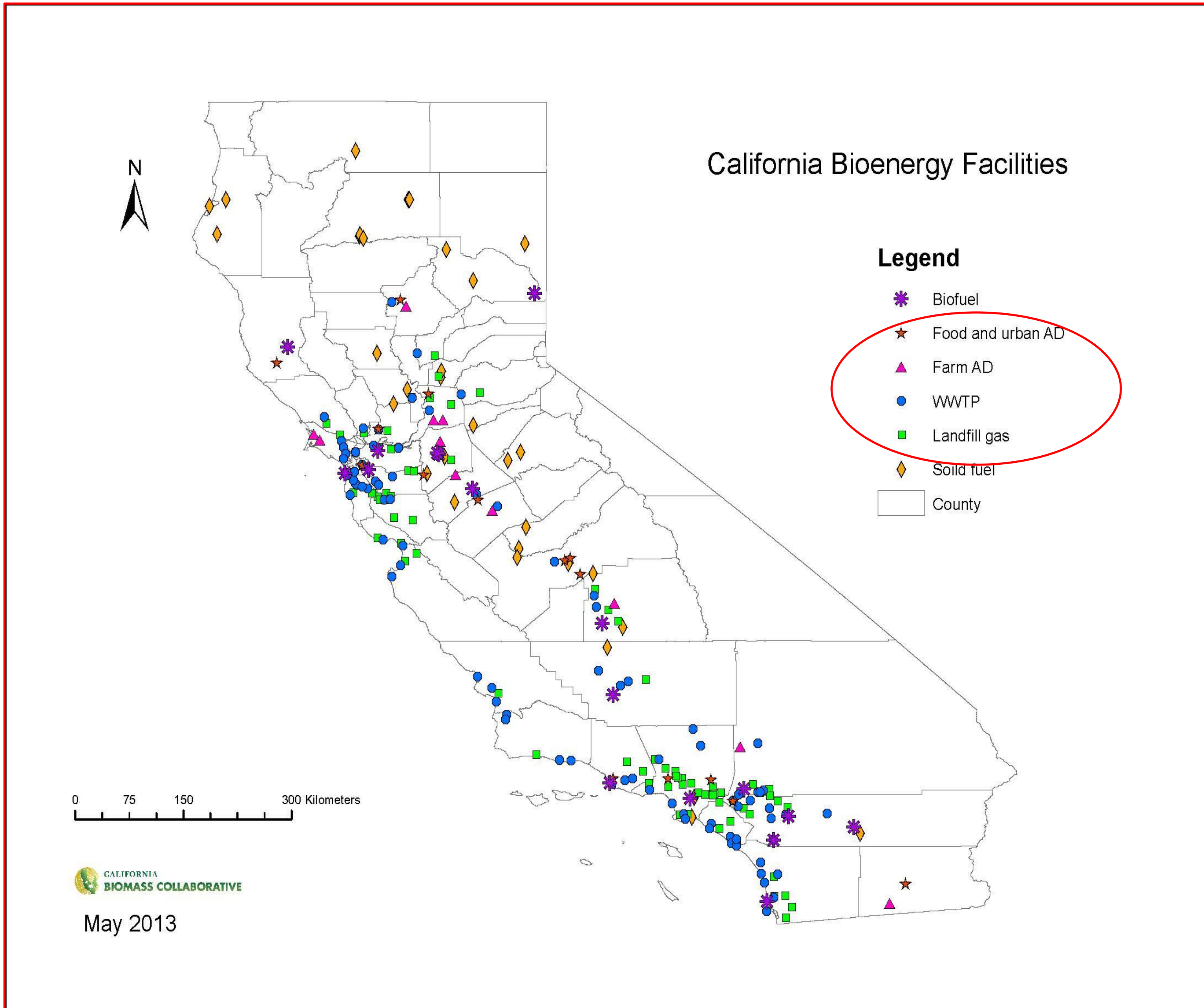

California Bioenergy Facilities
N
Legend
Biofuel
Food and urban AD
Farm AD
WWTP
Landfill gas
Solid fuel
County
0
75
150
300 Kilometers
CALIFORNIA
BIOMASS COLLABORATIVE
May 2013

California Biomass Energy Facilities
California Biomass Collaborative (CBC)
March, 2015 update‡ (Original release December 1, 2011)

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Facilities that are known to be converting biomass feedstocks into heat, power, or fuels are collected in this file. These specifically include datasets of solid fuel power plants (SolidFuel), landfill gas projects (LFGProjects), wastewater treatment plants with anaerobic digesters (WWTP-AD), liquid biofuels (Biofuels), farms using manure in anaerobic digesters (Farm-AD), and facilities that use food processor and/or Urban residues (FoodProcess&Urban-AD).

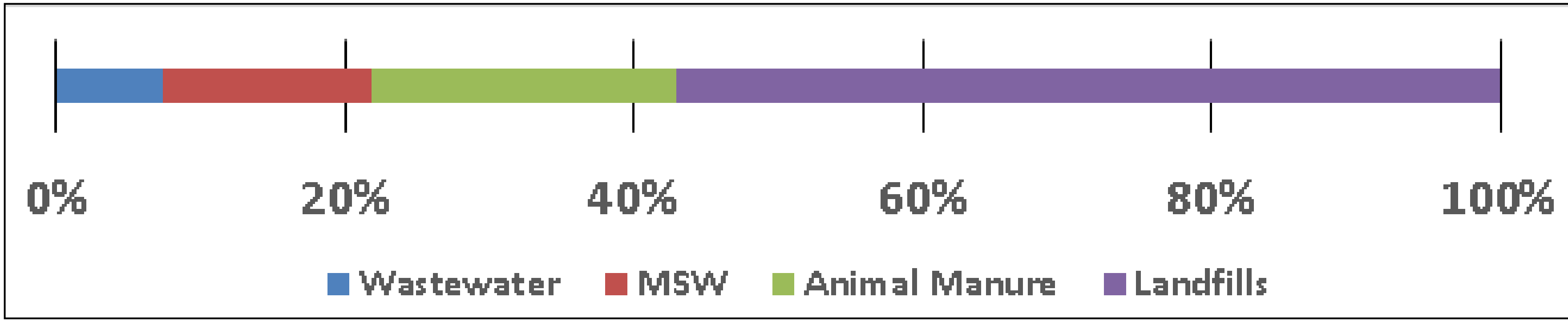
This collection is based on data generally assembled in cooperation with others.* The CBC standardized the formats and filled in occasional fields that were left blank. Numerous datasets and sources were used to supplement each worksheet, including the CBC historical datasets, but the foundation files listed generally formed the base information.

* We especially thank and acknowledge Peter Tittmann (UC Berkeley), Gareth Mayhead (formerly of UC Berkeley), Charlotte Ely (USEPA 9), Scott Walker (formerly of CalRecycle), Kim Carr (Sierra Nevada Conservancy), and Jacques Franco (formerly of CalRecycle) from whose work we've drawn extensively.

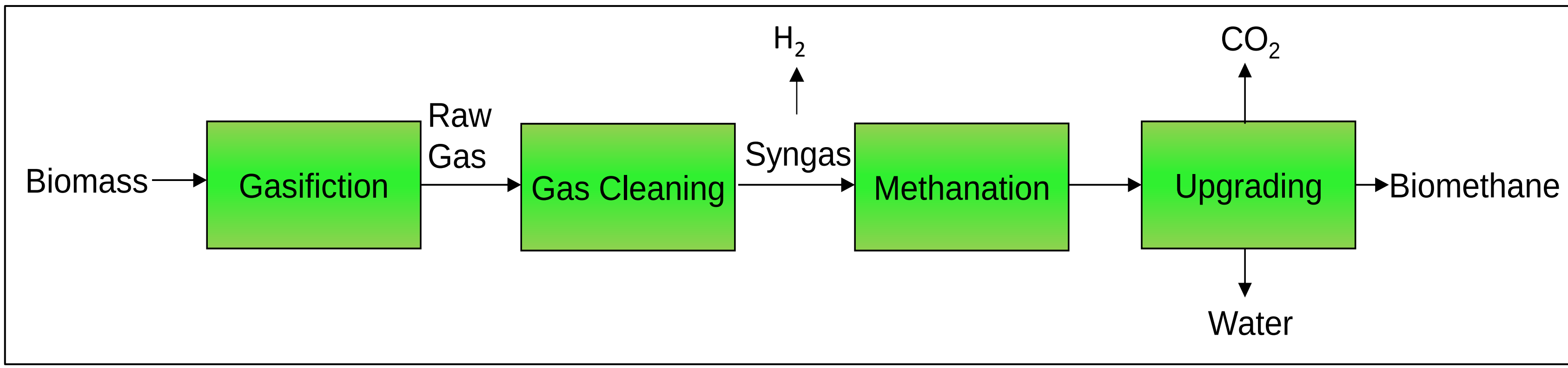
The foundation source for each dataset listed by dataset worksheet:

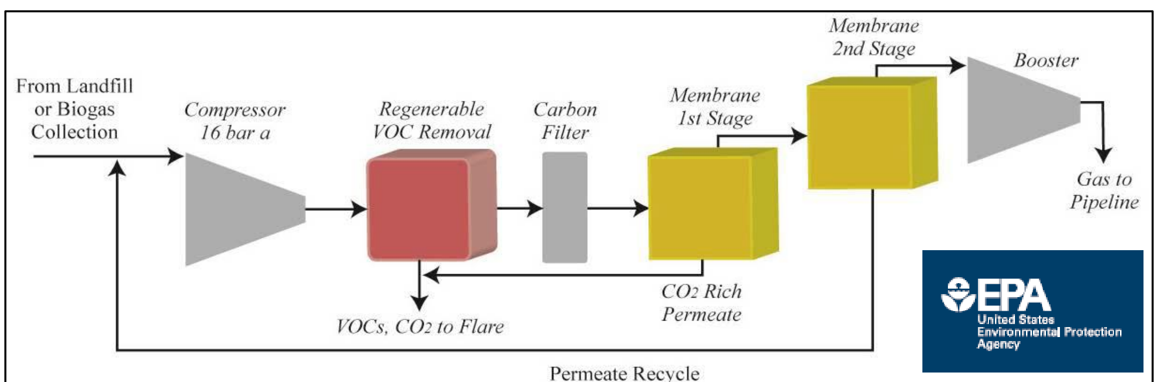
Worksheet	**Foundation dataset**
SolidFuel	Mayhead, Gareth J and Tittmann, Peter and Shelly, John R and Satomi, Rick, Woody Biomass Utilization, UC Berkeley, California http://ucanr.edu/sites/WoodyBiomass/Technical_Assistance/California_Biomass_Power_Plants/ Kim Carr, Sierra Nevada Conservancy (community scale bioenergy updates)
LFGProjects	Gino Yekta, California Department of Resources Recycling and Recovery (CalRecycle) Gino.Yekta@calrecycle.ca.gov CalRecycle, Solid Waste Information System (SWIS) http://www.calrecycle.ca.gov/SWFacilities/Directory/ US EPA, Landfill Methane Outreach Program (LMOP) http://epa.gov/lmop/
WWTP-AD	Charlotte Ely, Region 9, U.S. Environmental Protection Agency http://134.67.99.137/myenvtools/biogas/index.html Note: This dataset represents the known locations of WWTP digesters. Blank fields represent unknown quantities.
Biofuels	Renewable Fuels Assocation, Industry ethanol facilities http://www.ethanolrfa.org/bio-refinery-locations/ National Biodiesel Board and Celia DuBose (Biodico), biodiesel facilities http://www.biodiesel.org/buyingbiodiesel/plants/showall.aspx
Farm-AD	California Air Resources Board (CARB) http://www.arb.ca.gov/ag/manuremgmt/manuremgmt.htm US EPA, AgSTAR Program http://www.epa.gov/agstar/projects/index.html
FoodProcess&Urban-AD	California Food Processing Industry Organic Residue Assessment, Appendix B, Ricardo Amon, et al. CBC 2011 Jacques Franco, (formerly) CalRecycle

http://biomass.ucdavis.edu/tools/california-biomass-facilities-reporting-system/



California biogas production potential by source (AD). Ong et al., 2015.
http://biomass.ucdavis.edu/publications/





CALIFORNIA BIOMASS COLLABORATIVE

Estimated Annual Biomass Residue Amounts and Equivalent RNG Potential for California‡

Feedstock	Amount Technically Available	Biomethane (or RNG) Potential	
		(billion cubic feet)	(million gge*) [i]
Agricultural Residue (Lignocellulosic)	5.3 MM BDT [a]	51.8 [h]	446
Animal Manure (Dairy & Poultry)	3.4 MM BDT [a]	19.5 [a]	168
Fats, Oils and Greases	207,000 tons [b]	1.9 [j]	16
Forestry and Forest Product Residue	14.2 MM BDT [a]	139 [h]	1200
Landfill Gas	106 BCF [a]	53 [f]	457
Municipal Solid Waste (food, leaves, grass fraction)	1.2 MM BDT [c]	12.7 [g]	109
Municipal Solid Waste (lignocellulosic fraction)	6.7 MM BDT [c,d]	65.9 [h]	568
Waste Water Treatment Plants	11.8 BCF (gas) [e]	7.7 [k]	66
Total		351	3,030

Compiled by Rob Williams, University of California, Davis. April 2014, Oct., 2015, Feb., 2016. Source material: Williams, R. B., B. M. Jenkins and S. Kaffka (California Biomass Collaborative). 2015. ***An Assessment of Biomass Resources in California, 2013.*** Contractor Report to the California Energy Commission. PIER Contract 500-11-020. RevA., April 2016. Revised biomethane column titles. http://biomass.ucdavis.edu/publications/

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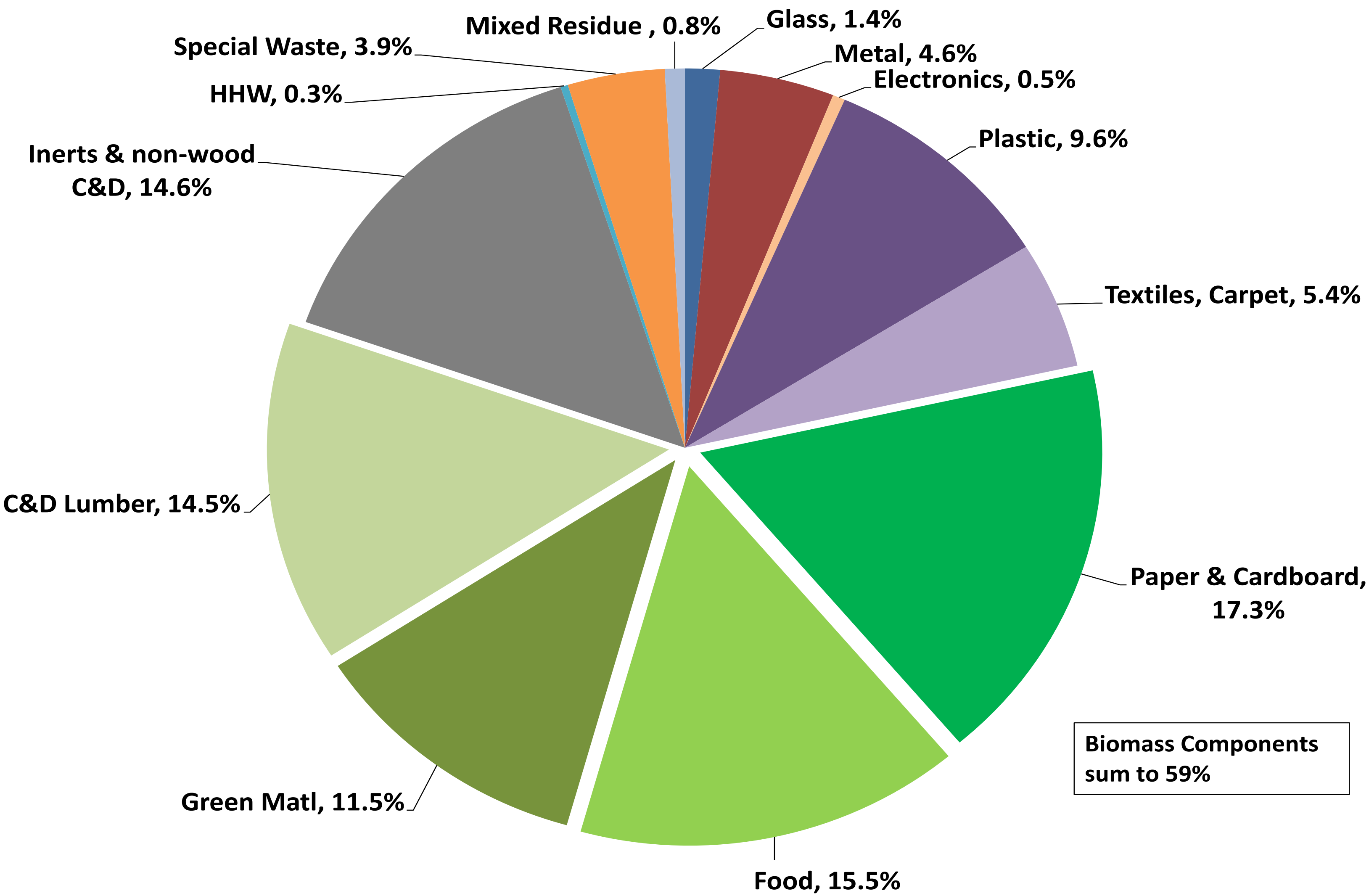
California landfilled waste stream by material type, post recycled (ADC not included)



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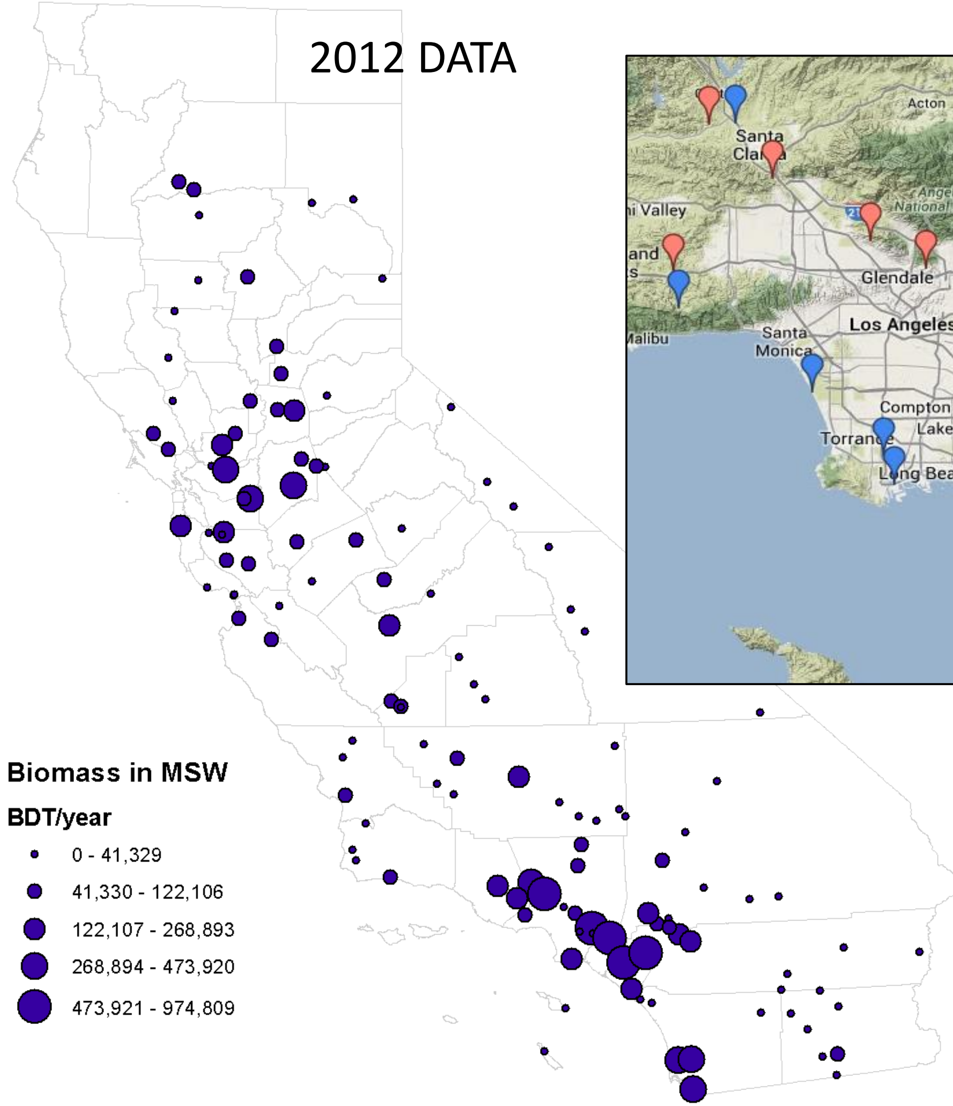
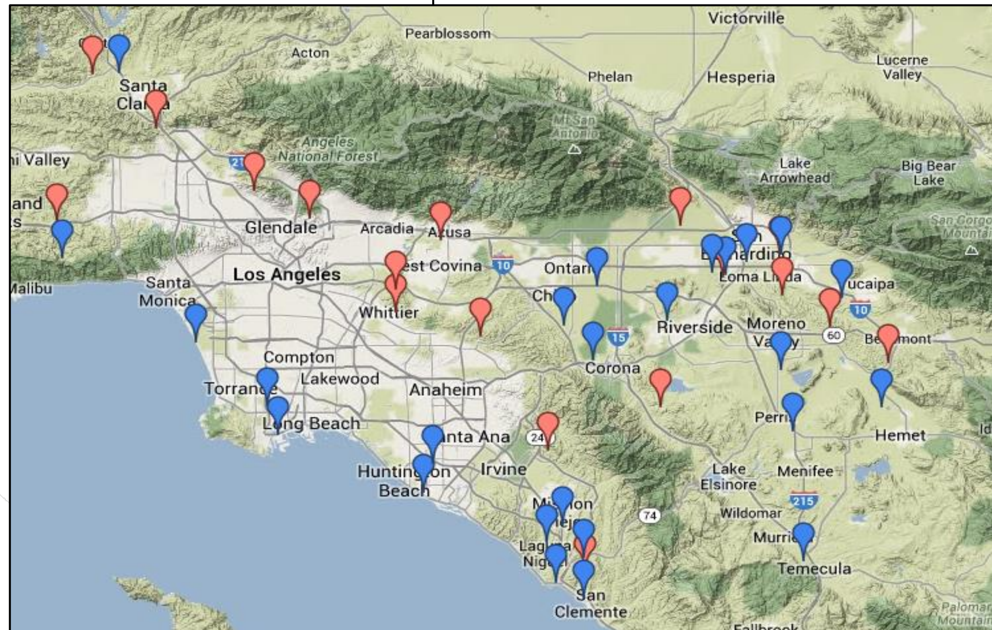
(adapted from 2008 characterization: (Cascadia 2009))

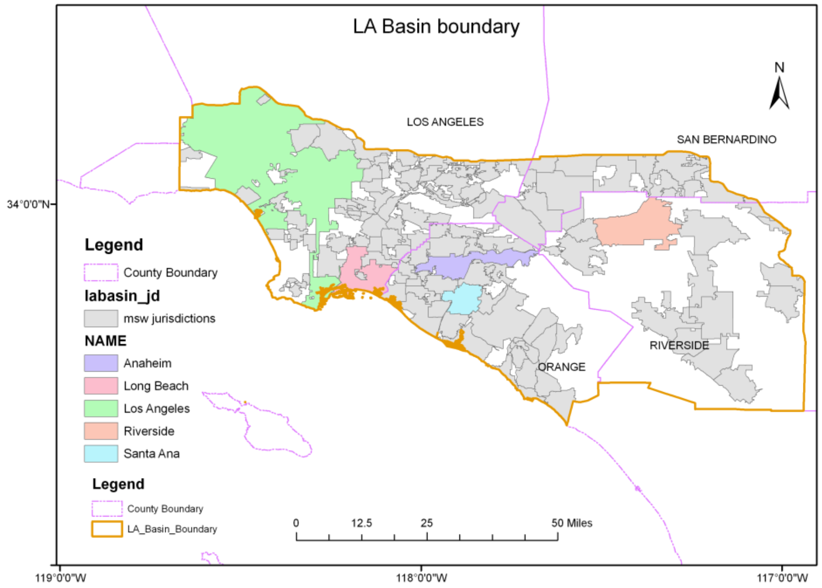
2012 DATA

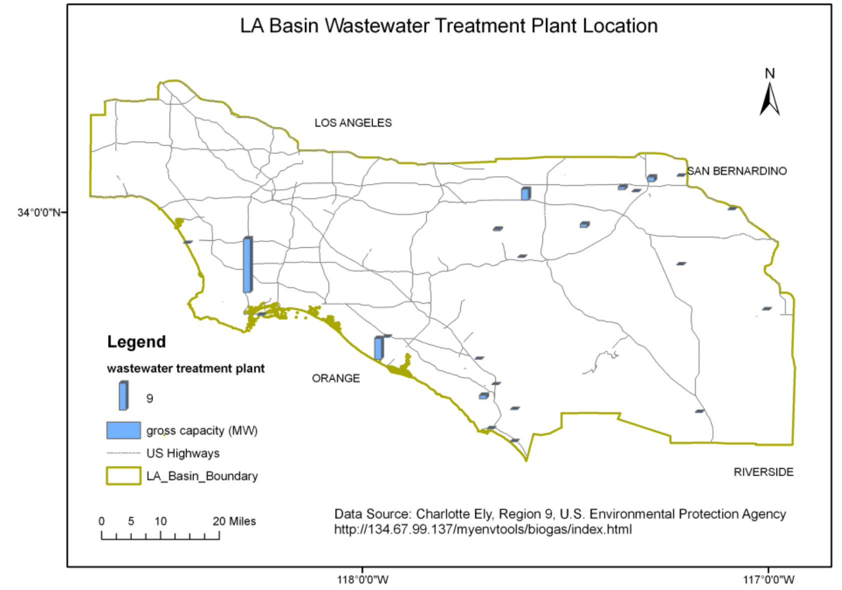


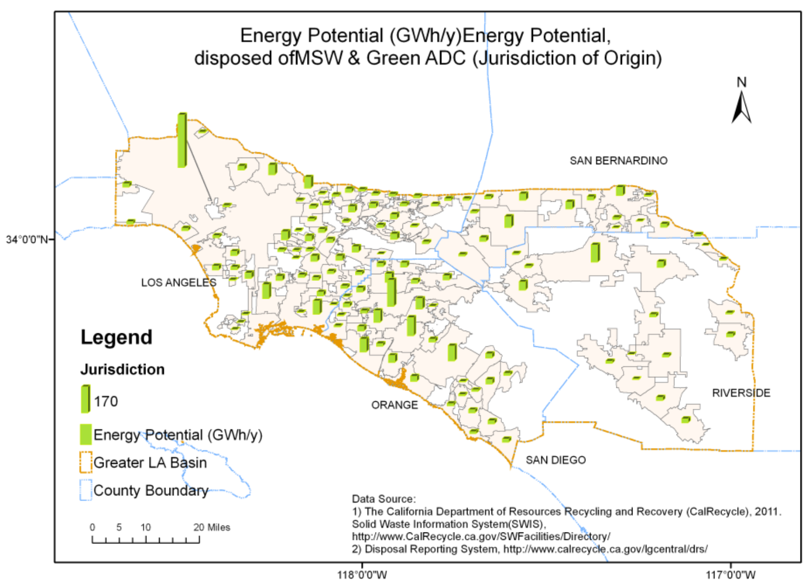


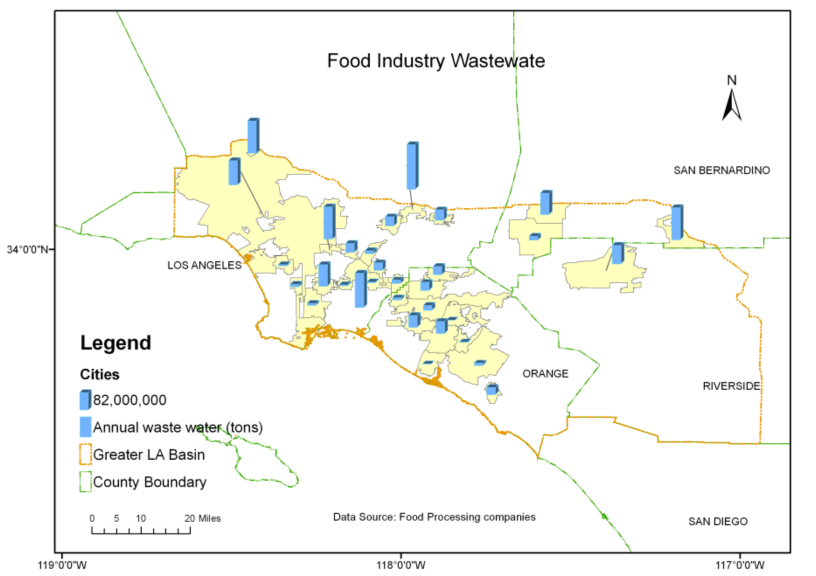
LA Basin map showing water treatment facility (blue) and landfill (red) locations.

CALIFORNIA BIOMASS COLLABORATIVE









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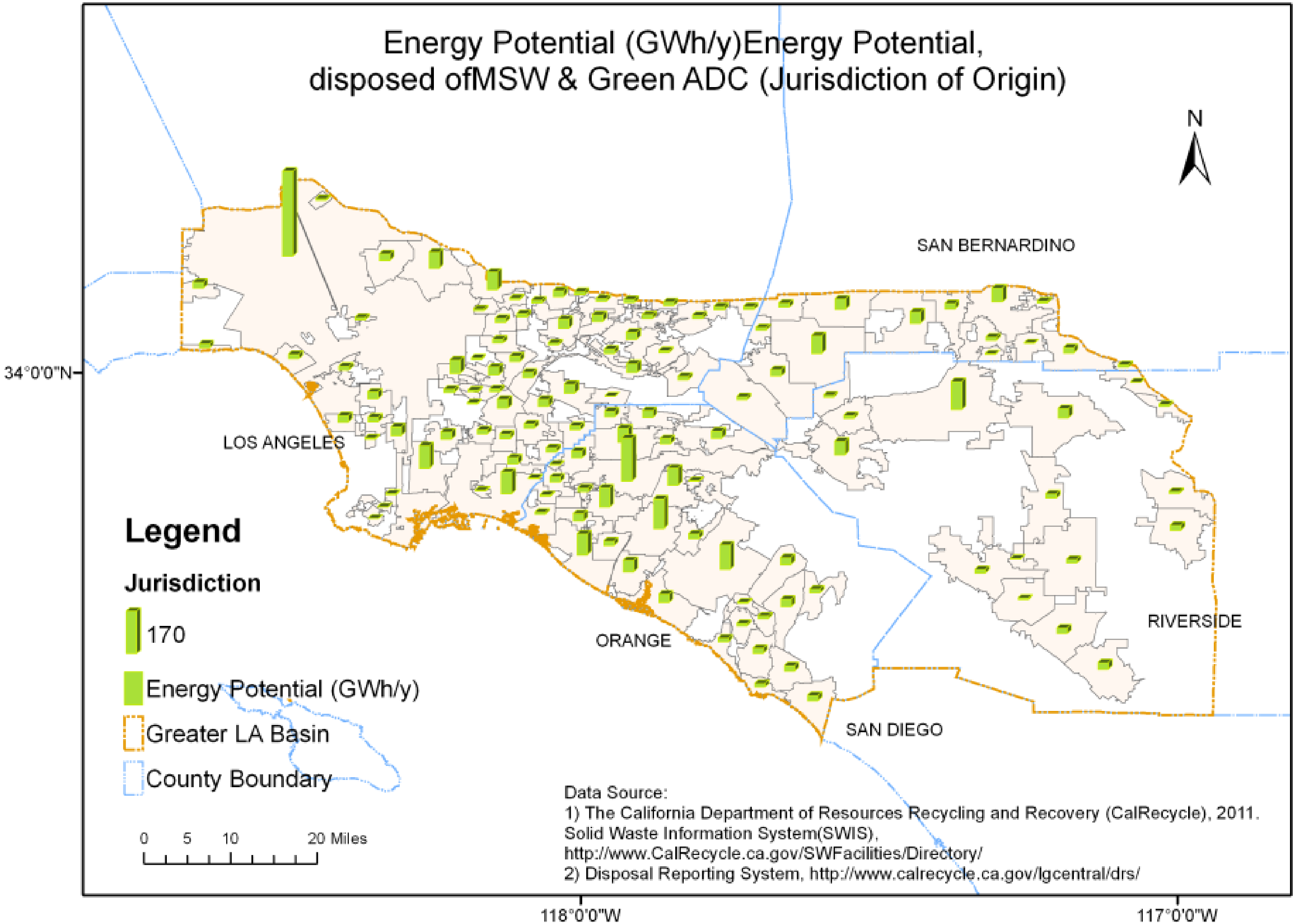

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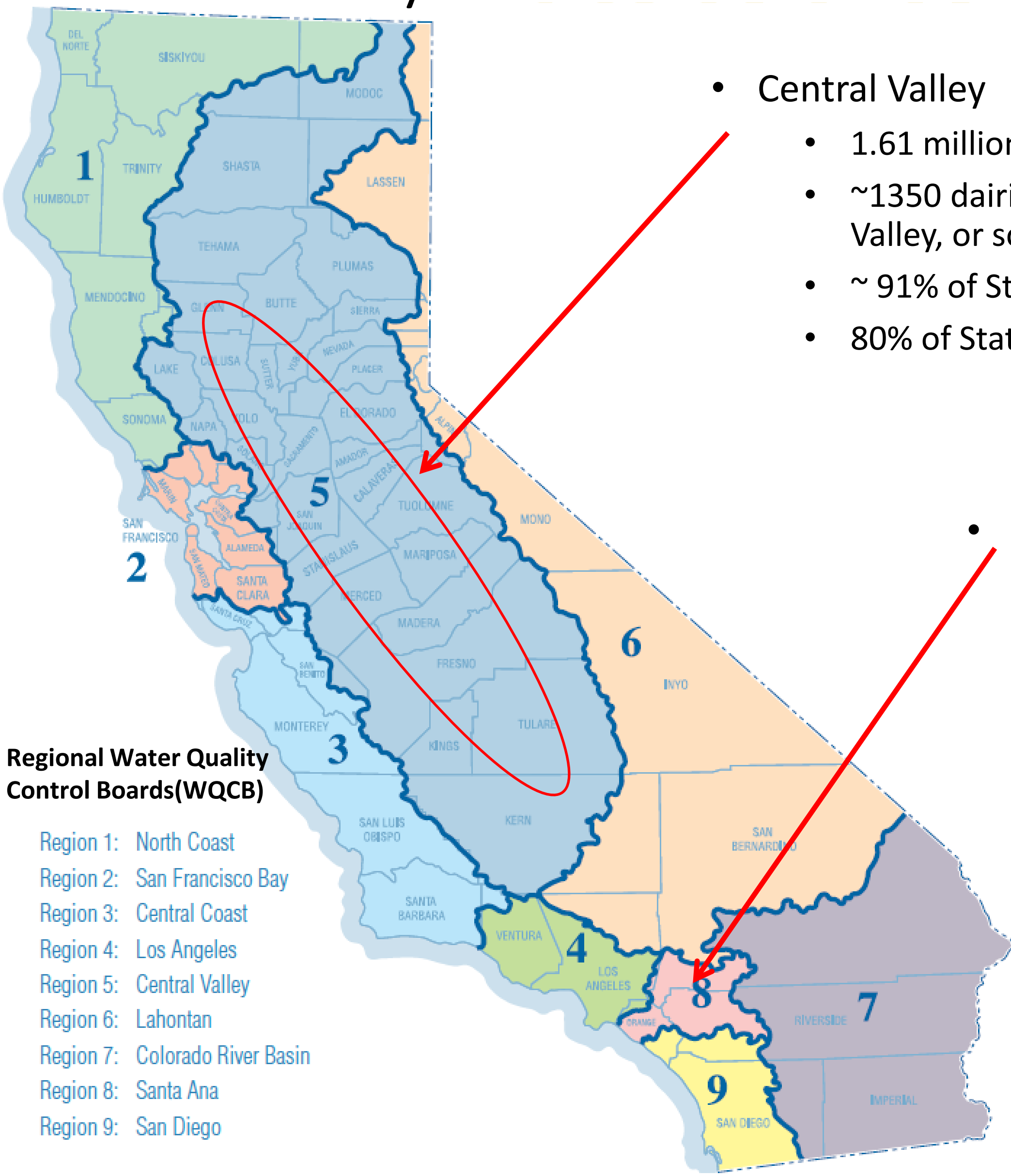
Cost of energy from solid waste AD facilities was calculated using a standard revenue requirement model for a range of tip fees (30, 50 and 70 $/ton). Depending on facility size and tip fee, LCOE ranged from a high of $400/MWh to a low of minus $87/MWh (Table 3 and Figure 23)

Table 3. MSW AD LCOE

Feedstock Capacity (1000 t/y)	Power Generation Potential (MW)	Tip Fee		
		30 $/ton	50 $/ton	70 $/ton
		LCOE ($/kWh)		
20	0.57	0.402	0.311	0.219
35	1	0.264	0.173	0.082
50	1.43	0.196	0.104	0.013
75	2.1	0.132	0.041	-0.05
100	2.9	0.095	0.004	-0.087

Dairy Location and Herd Size

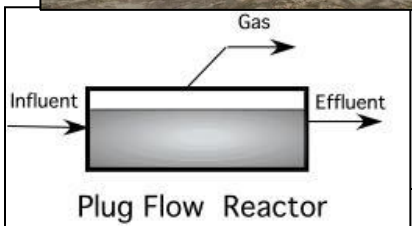


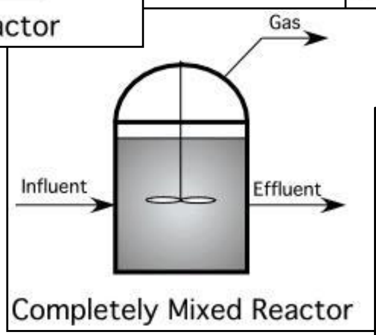
- Central Valley
  - 1.61 million dairy cows (milking & dry)
  - ~1350 dairies (primarily concentrated in San Joaquin Valley, or south of Sacramento)
  - ~ 91% of State's dairy cows
  - 80% of State's dairies

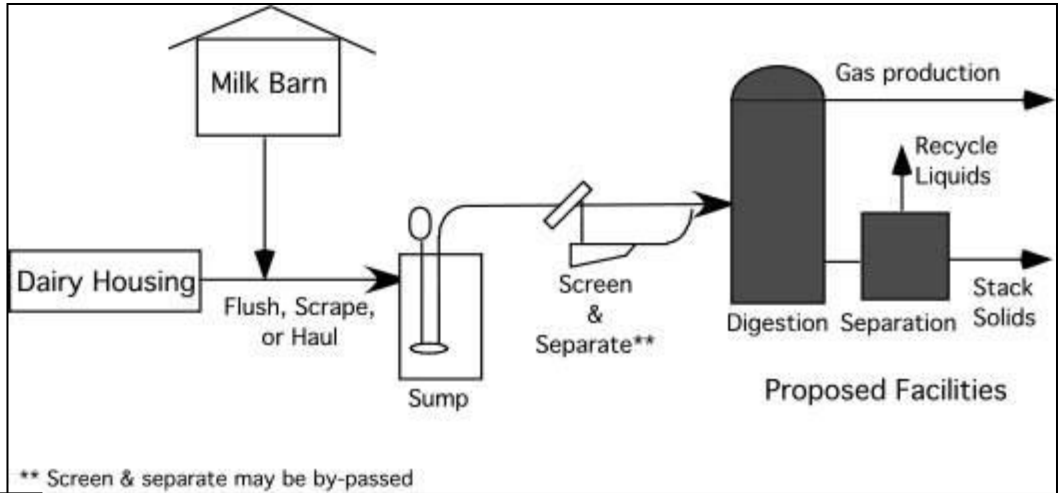
- Santa Ana RWQCB (essentially Inland Empire)
  - 93,500 dairy cows (milking & dry)
  - ~125 dairies
  - ~ 4% of State's dairy cows
  - 8% of State's dairies

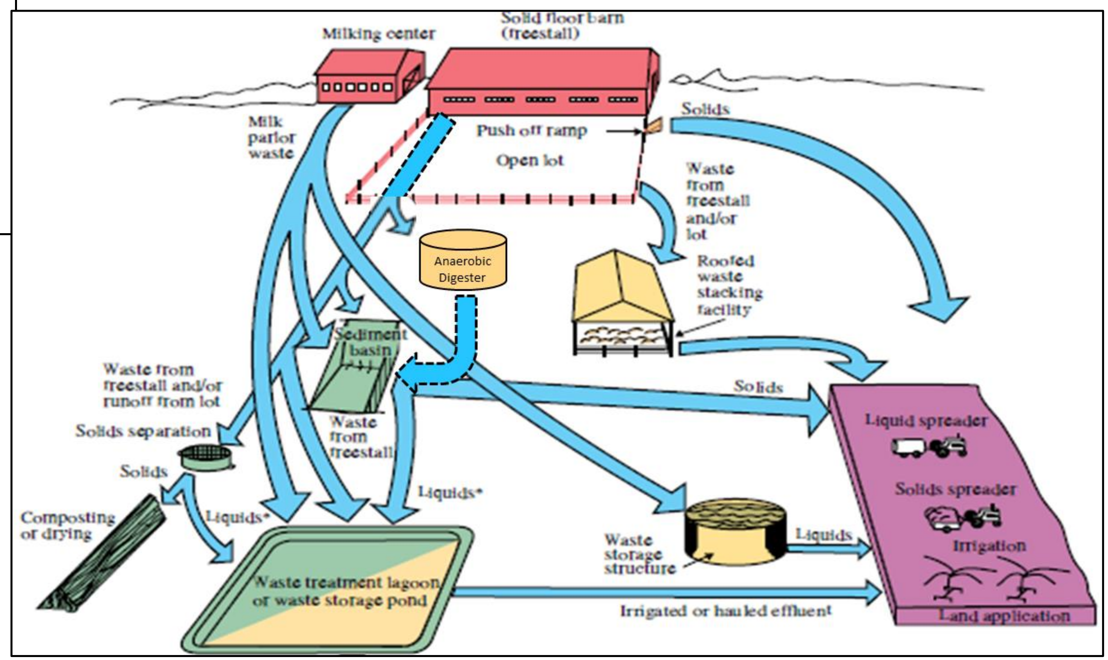
California has
- ~ 1.78 million dairy cows
- ~ 1650 active dairies

Anaerobic Digesters



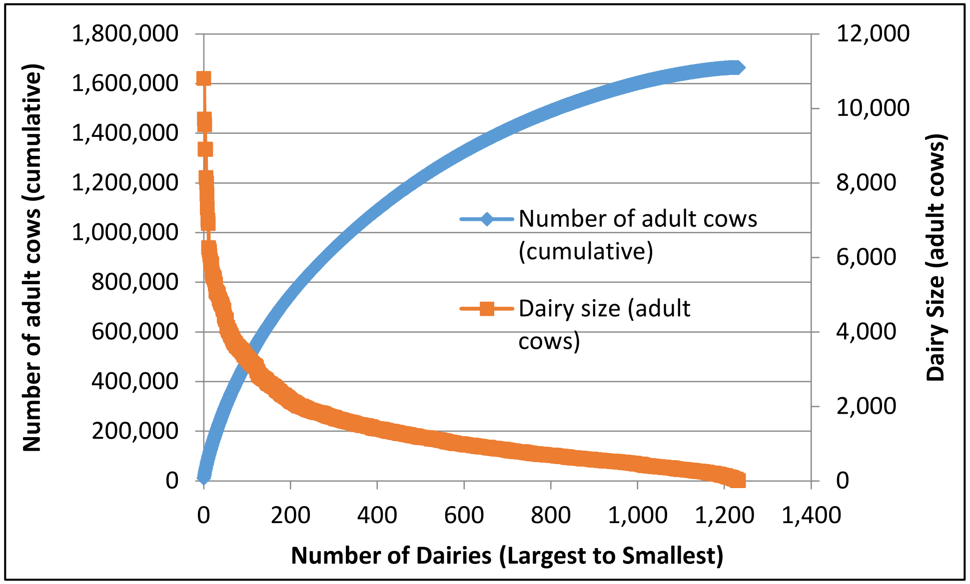


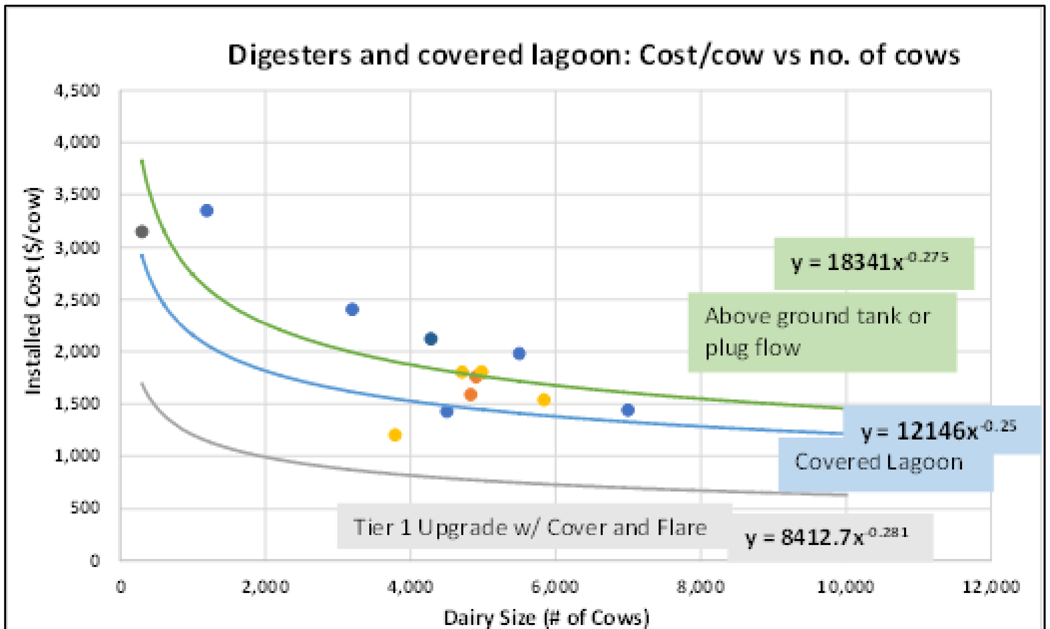




Evaluation of Dairy Manure Management Practices for Greenhouse Gas Emissions Mitigation in California. **DRAFT TECHNICAL REPORT to the State of California Air Resources Board, Contract # 14-456. September 30, 2015. Stephen Kaffka,** Department of Plant Sciences, University of California, Davis; and California Biomass Collaborative (Principal Investigator); 530-752-8108; srkaffka@ucdavis.edu; **Tyler Barzee,** Department of Biological and Agricultural Engineering, University of California, Davis; **Hamed El-Mashad,** Department of Biological and Agricultural Engineering, University of California, Davis; **Rob Williams,** Department of Biological and Agricultural Engineering, University of California, Davis and California Biomass Collaborative; **Steve Zicari,** Department of Biological and Agricultural Engineering, University of California, Davis; **Ruihong Zhang,** Department of Biological and Agricultural Engineering, University of California, Davis (Co-Investigator)/*California Air Resources Board.* *http://biomass.ucdavis.edu/publications/*

Typical Dairy Manure Management Handling Options.



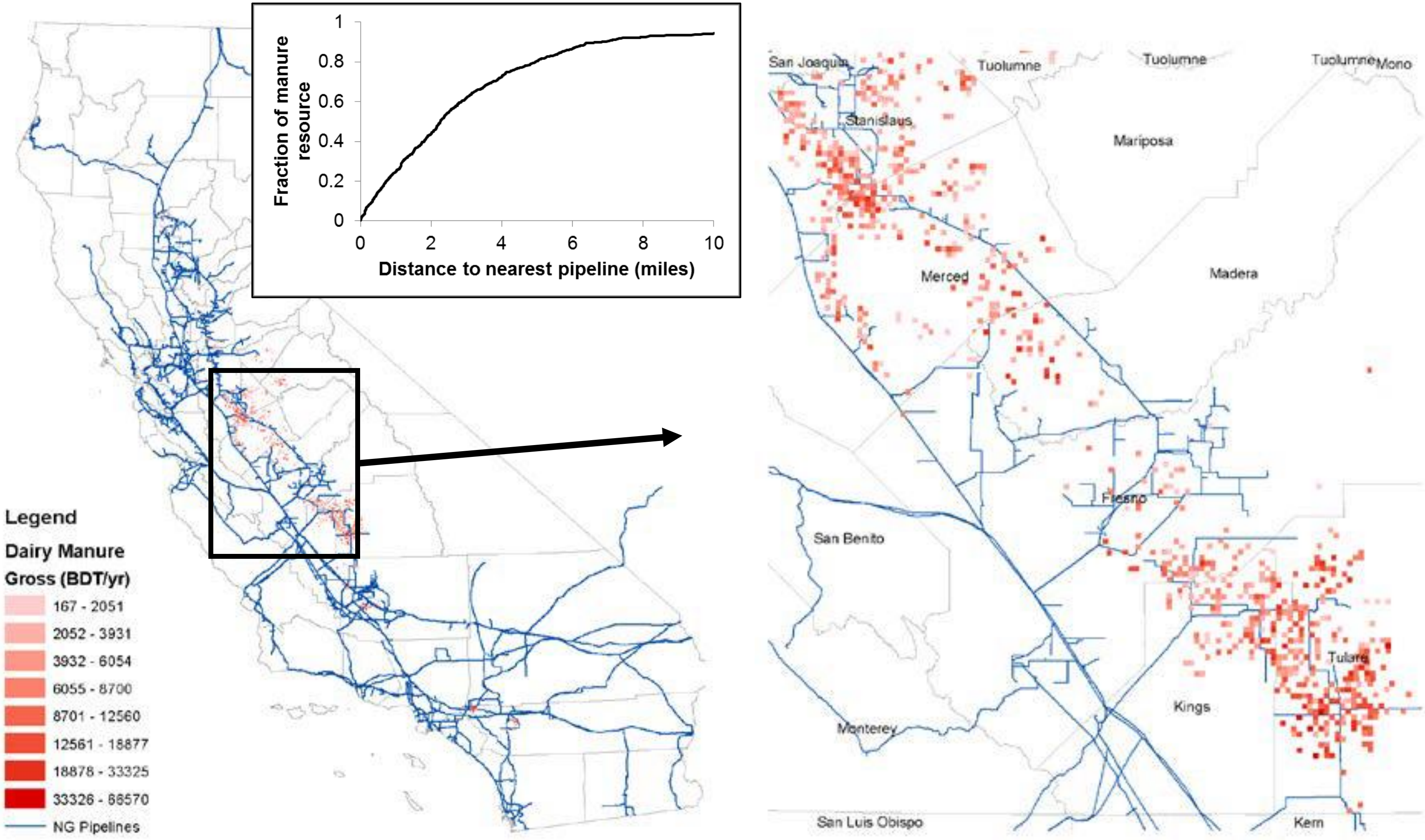


Digester and cover-and-flare installed cost curves Note: Orange/yellow data represent covered Tier 1 lagoon digesters. Dark Blue/Brown data are above ground tank or plug-flow systems. Data are from Black & Veatch, 2013; Summers and Williams, ICF 2013; ICF, 2013; CDFA, 2015.

Table 1.2. Cumulative energy and NOx from Anaerobic Digestion Scenarios

Scenario Description		≥ 300 milk cows/dairy or 1110 dairies (~1.65 million cows)		≥ 2000 milk cows/dairy or largest 225 dairies (~800,000 cows)	
		Energy Potential (MW)	**NOx (tons/y)**	**Energy Potenti al (MW)**	**NOx (tons/y)**
Lagoon Digester - Uncovered Effluent. Pond	Recip. Engine	190	382	92	186
	Microturbine	145	153	71	74
	Fuel Cell	316	28	154	13
	RNG fuel	**(million gde/y)**	**Tailgas flare (tons NOx)**	**(million gde/y)**	**Tailgas flare (tons NOx)**
		93	71	45.1	34.5
Tank / Plug Flow Digester -Covered Effluent Pond		**(MW)**	**NOx (tons/y)**	**(MW)**	**NOx (tons/y)**
	Recip. Engine	222	447	108	217
	Microturbine	170	179	83	87
	Fuel Cell	370	32	180	16
	RNG fuel	**(million gde/y)**	**(tons/y)**	**(million gde/y)**	**(tons/y)**
		108	83	52.7	40.3

Evaluation of Dairy Manure Management Practices for Greenhouse Gas Emissions Mitigation in California. DRAFT TECHNICAL REPORT to the State of California Air Resources Board Contract # 14-456. September 30, 2015. Stephen Kaffka, Department of Plant Sciences, University of California, Davis; and California Biomass Collaborative (Principal Investigator); 530-752-8108; srkaffka@ucdavis.edu; **Tyler Barzee,** Department of Biological and Agricultural Engineering, University of California, Davis; **Hamed El-Mashad,** Department of Biological and Agricultural Engineering, University of California, Davis; **Rob Williams,** Department of Biological and Agricultural Engineering, University of California, Davis and California Biomass Collaborative; **Steve Zicari,** Department of Biological and Agricultural Engineering, University of California, Davis; **Ruihong Zhang,** Department of Biological and Agricultural Engineering, University of California, Davis (Co-Investigator)/*California Air Resources Board.* *http://biomass.ucdavis.edu/publications/*



Concentration of Dairy Manure Production in California; Jaffee, Faust et al., 2016. page 25., "The Feasibility of Renewable Natural Gas as a Large-Scale, Low Carbon Substitute" by the STEPS Program, Institute of Transportation Studies, UC Davis under the sponsorship of the California Air Resources Board. contract 13-307

Draft Report: Potential for Biofuel Production from Forest Woody Biomass; **Authors:** Katherine A. Mitchell, California Biomass Collaborative, UC Davis, Nathan C. Parker, Institute of Transportation Studies, UC Davis, Benktesh Sharma, Center for Forestry, UC Berkeley, Stephen Kaffka, Director, California Biomass Collaborative, UC Davis.
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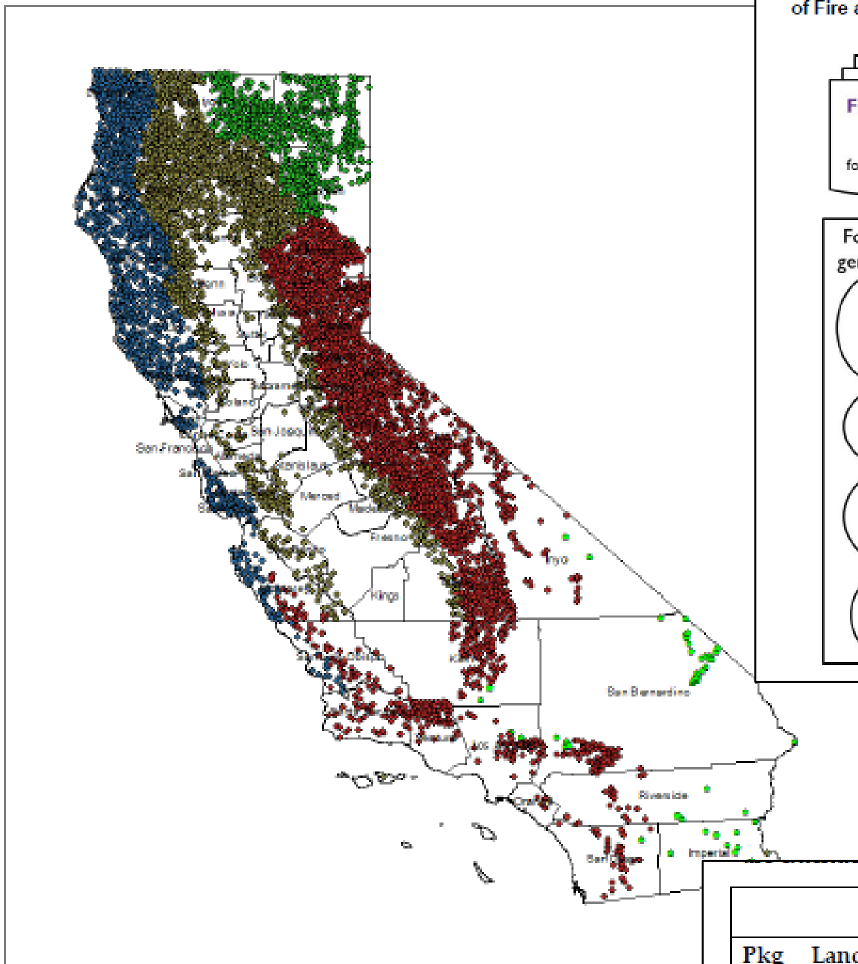
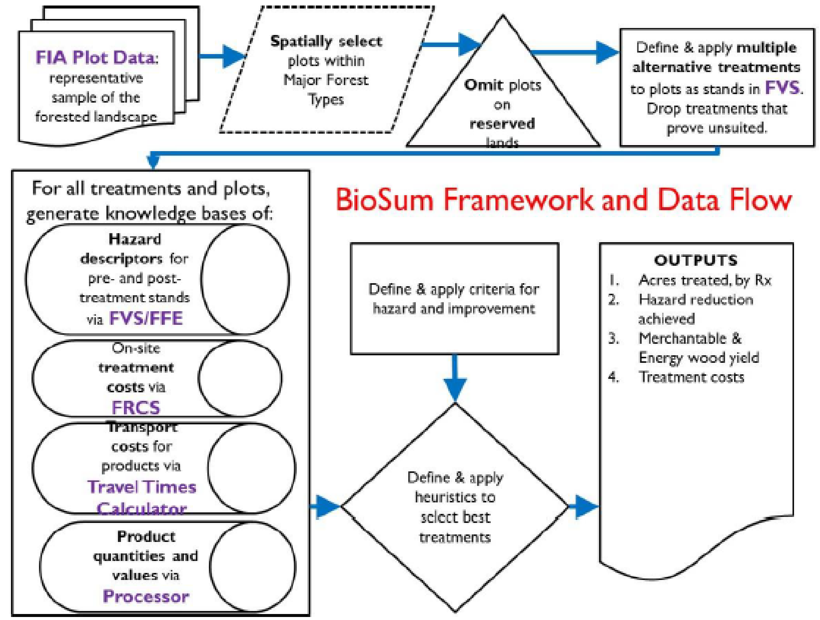


▲	CA	Inland California
▲	NC	North Coast
▲	SO	Southern Oregon
▲	WS	Western Sierra
▲	CR	Central Rockies (not included in model)

Figure 5. BioSum Model Process Flow Diagram. FIA plot data parameterize the Forest Vegetation Simulator (FVS), a dynamic growth and yield model. FVS output parameterizes additional models of Fire and Fuels (FFE) and forest treatment costs (FRCS). BioSum output results are input to the GBSM model.



Scenario 1: The goal of this research was to estimate forest residual biomass amounts under forest management as commonly practiced by the two major land ownership entities; public lands and private owners.

Table 3. Forest management prescriptions Scenario 1

Pkg No.	Land ownership on which applied	Style	Timing (Yrs)	Criteria for each entry	Max DBH (in.)	Min DBH recovered (in.)	Residual BA
17	Federal Private	Thin DBH	Depends on test	BA≥115	36 pvt 21 pub	4	33.33% less
30	Private	CC & plant yr 0; thin later	Year 0, + 30 or 40 or test	NA, BA >75	NA	4	NA
31	All[1]	Grow Only	NA	NA	NA	NA	NA

[1] All forest lands are processed in the simulation. Exclusions do not receive any prescription or active management and are 'Grow Only'. Also, plots that do not meet the BA entry criteria are left to grow.

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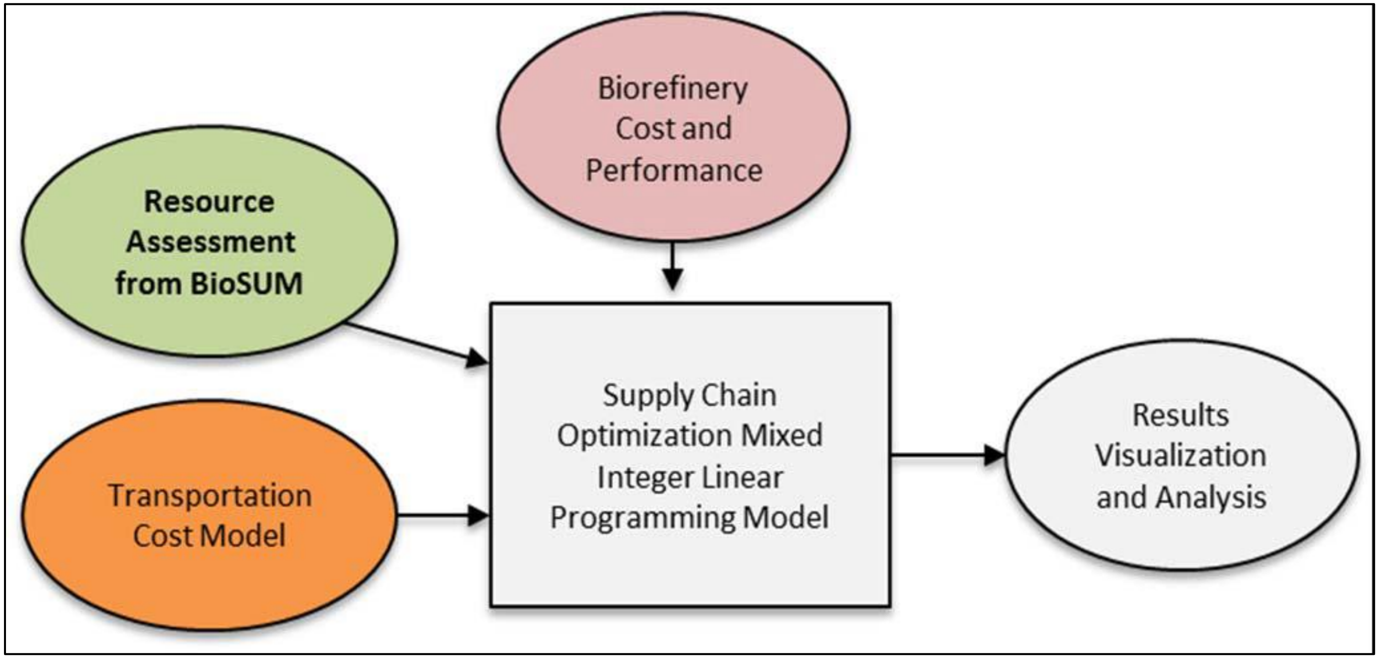

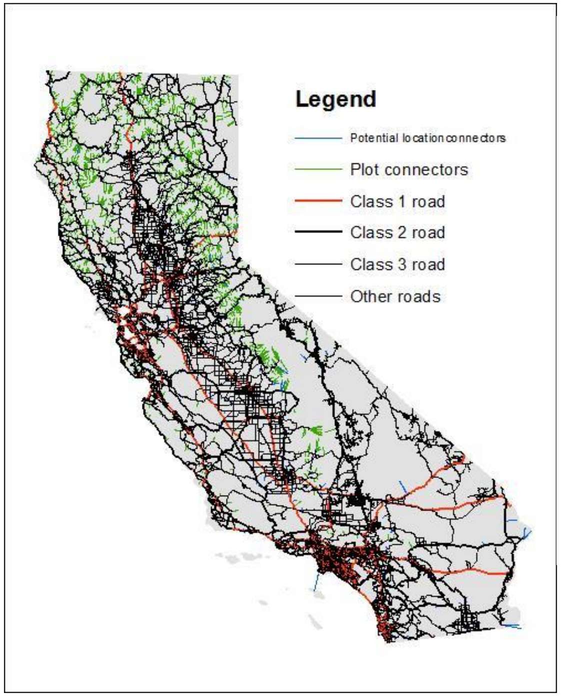

Table 5. Conversion technology cost and performance.

	Cellulosic ethanol (LCE)	Gasification and F-T Synthesis (FTD)
Yield (gge/ton)	41	57
Capital Cost (million $)	125	125
Operating Cost ($/gge)	2.01	1.48
Scaling factor	0.8	0.76
Levelized cost ($/gge)[1]	4.25-4.75	3.75 – 4.60

[1] Range over relevant scales of levelized cost assuming $50/dry ton of feedstock, 20 year economic life, 10 percent internal rate of return and $0.06 per kWh of co-product electricity.

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**Figure 13. Scenario 2 Forest Residue Amounts and Distribution.
Left side. BioSUM resource availability. Right side. GBSM resource availability at less than $50/BDT at the forest**

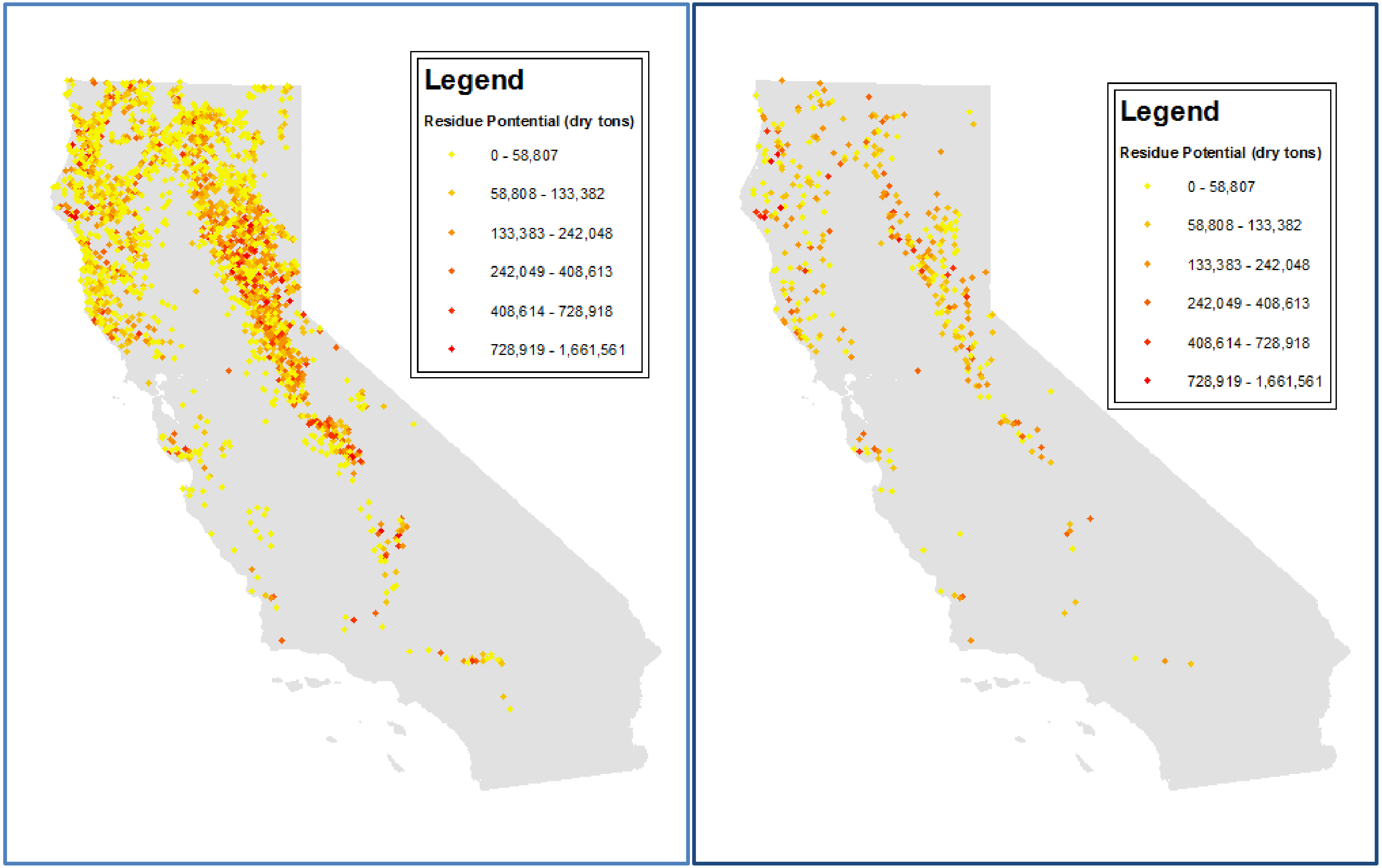


Figure 17. Scenario 2 Biorefinery Siting of a Potential Drop-In Fuel Industry. Left: biorefinery location and feedstock shed for ten biorefineries. Right: the quantity of biomass supply available and the average price at delivery to the biorefinery.

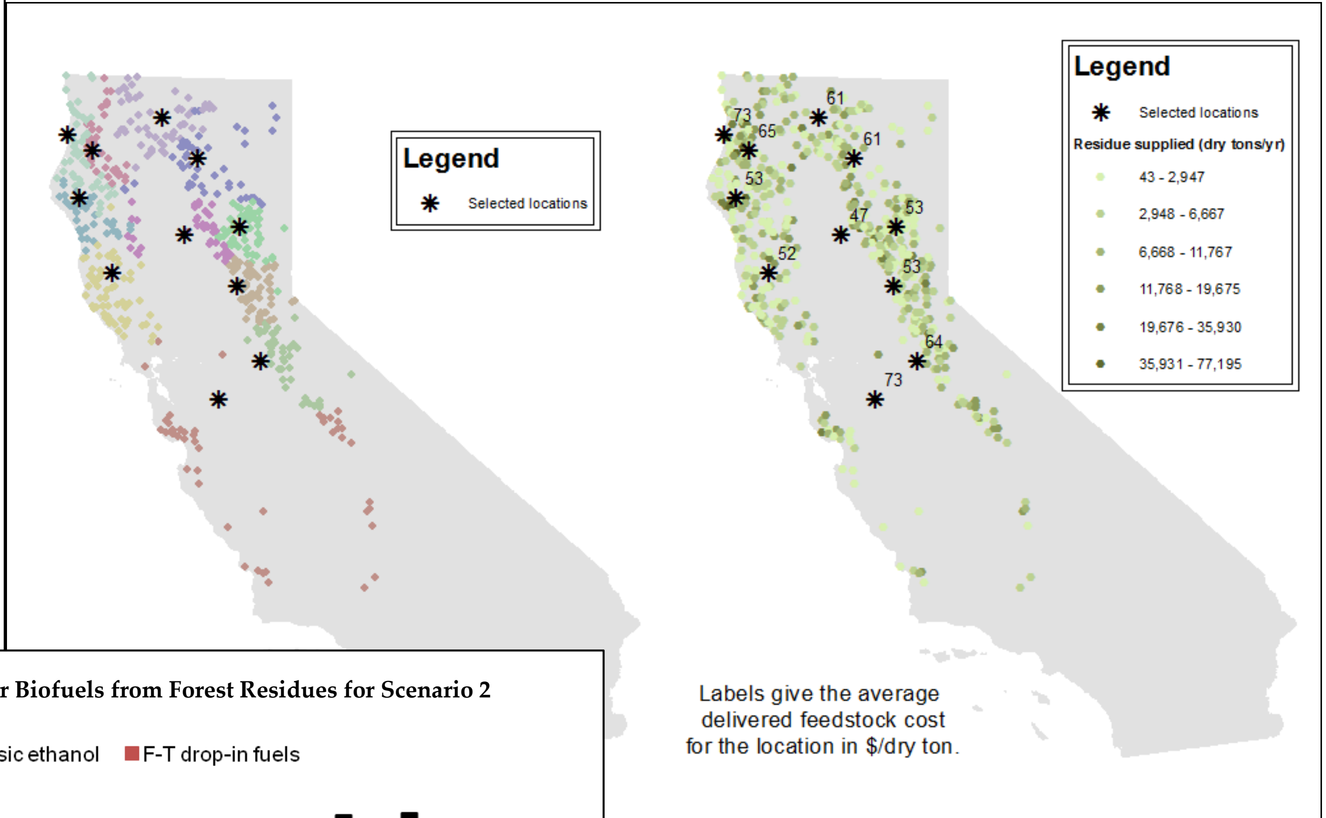
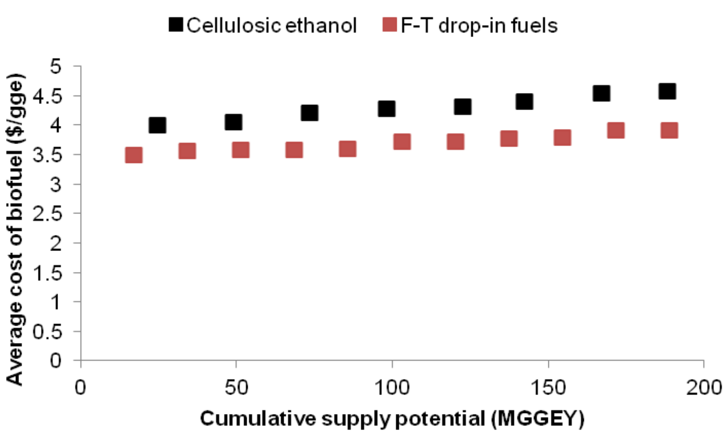


Figure 16. Supply Curve for Biofuels from Forest Residues for Scenario 2



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In-state biomass resources for biogas and hydrogen

Recent NREL/BETO estimates

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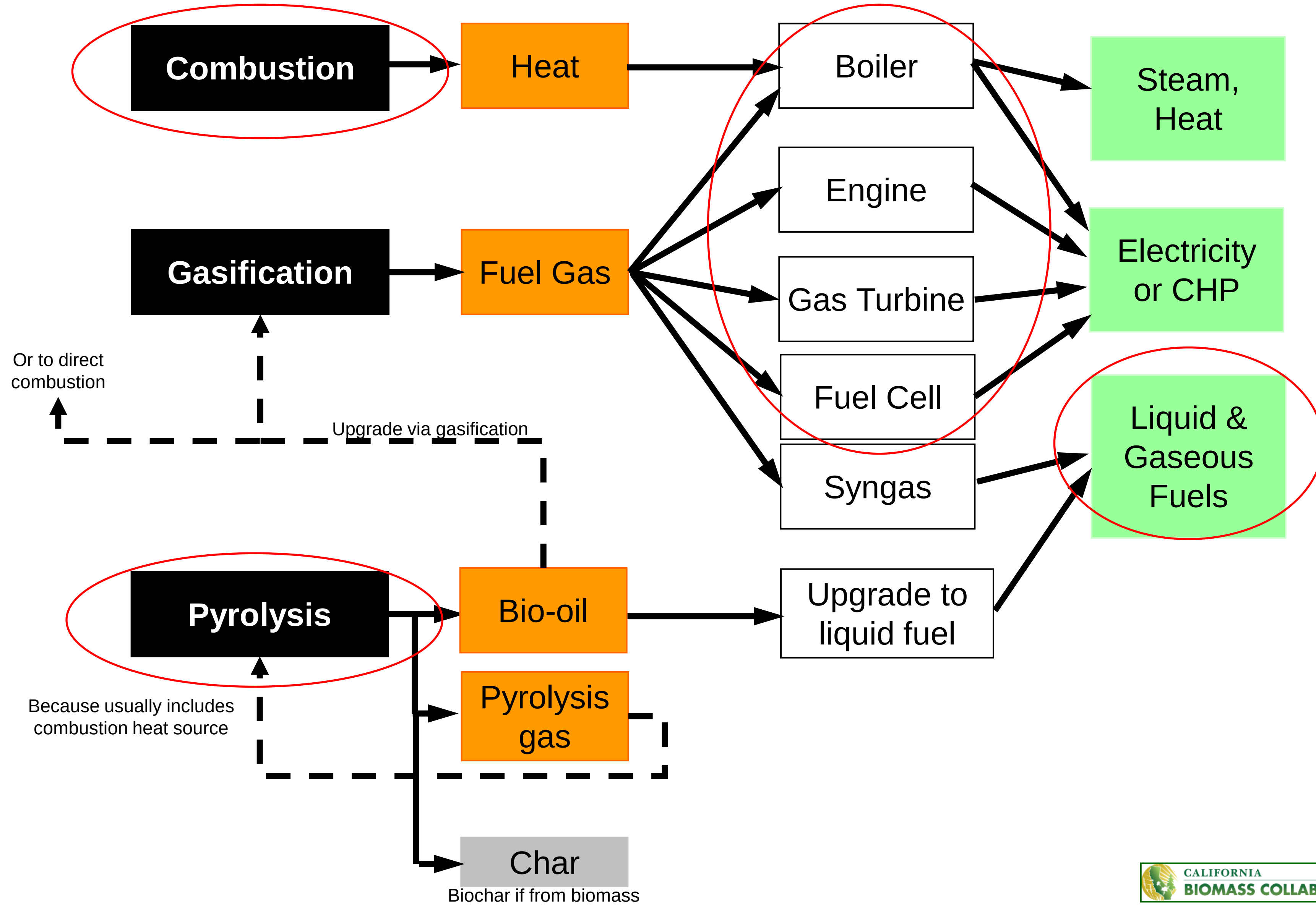
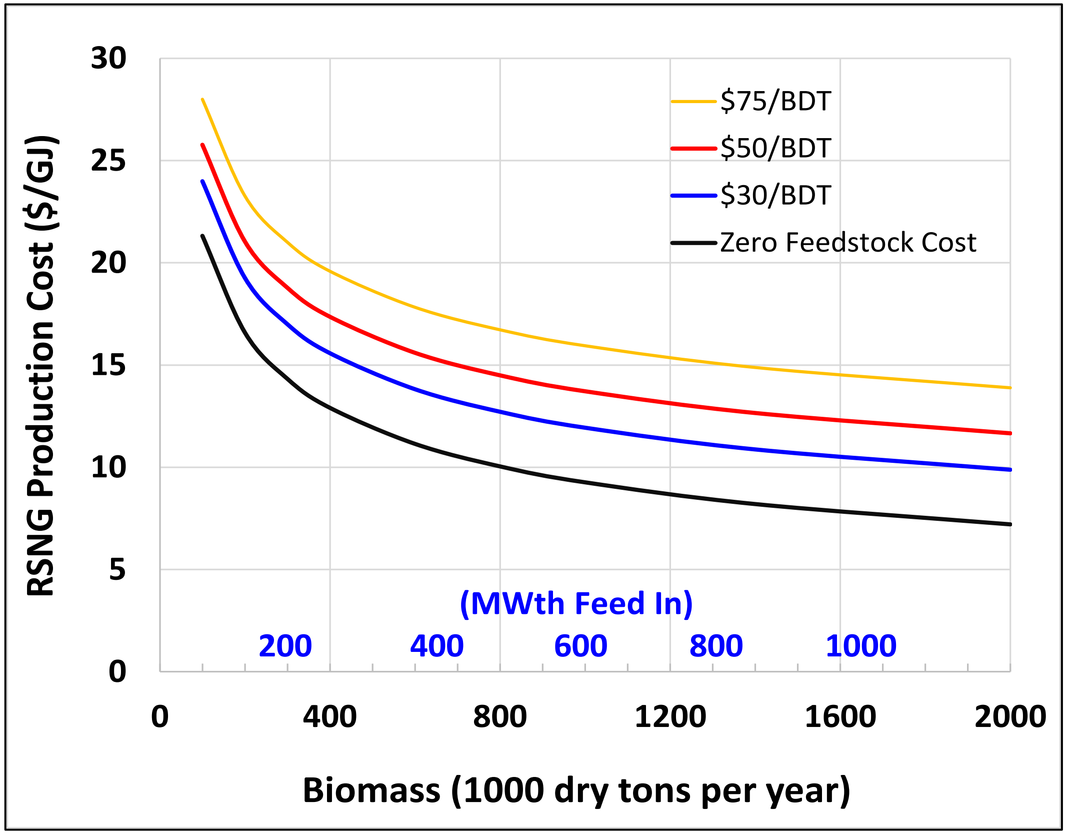
Basic Thermal Technologies – Components with air emissions





Using 65% biomass-to-RSNG conversion efficiency, gas production costs were calculated for three feedstock costs ($30, $50, and $75 per dry ton) (Figure 42). RSNG cost ranges from $10-$14 / GJ for GWth scale facilities (GWth input) to $23 - $28 per GJ for small (100 MWth) facilities.

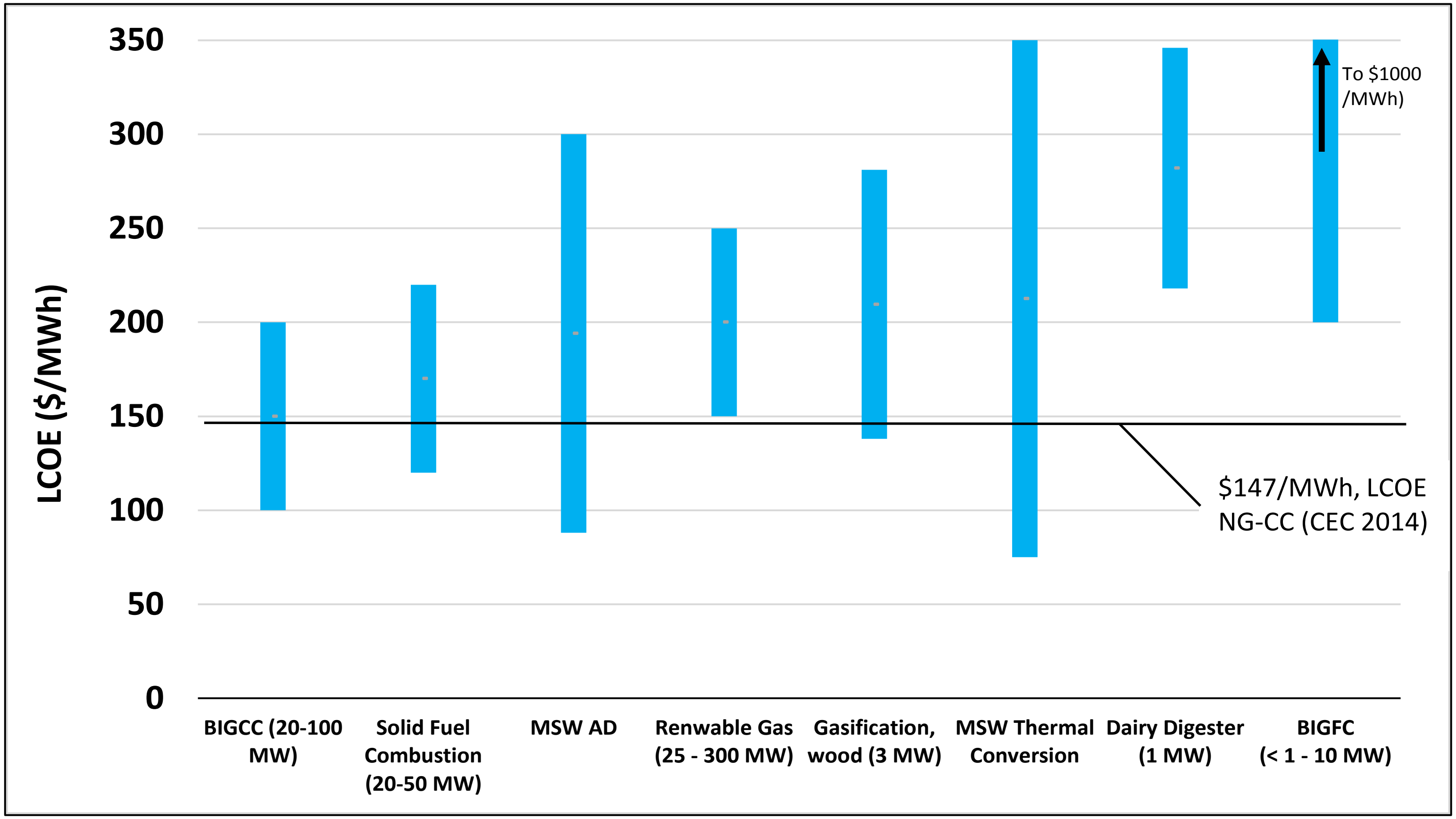


Fig. 45. The range of estimated LCOE for advanced biopower systems are displayed in figure 45. The LCOE for new conventional solid fuel combustion technology is also displayed. **BIGCC**: biomass integrated gasification combined cycle; **BIGFC**: biomass integrated gasification fuel cell.

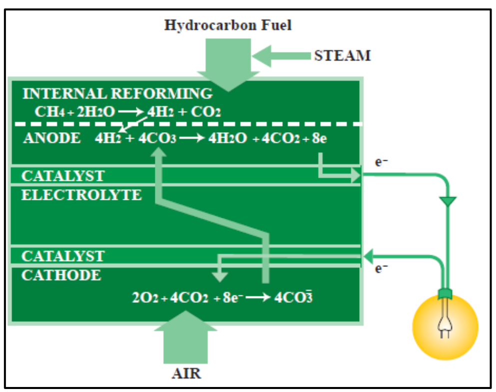
Evaluating the Air Quality, Climate & Economic Impacts of Biogas Management Technologies ***(***EPA/600/R-16/099 September 2016 ***);*** UC Davis Biomass Collaborative (Davis, CA); U.S. EPA Region 9 (San Francisco, CA); & National Risk Management Research Lab Office of Research and Development (Cincinnati, OH). Robert B. Williams, Development Engineer, University of California, Davis (UCD) California Biomass Collaborative; Charlotte Ely, Life Scientist, U.S. Environmental Protection Agency (EPA) Region 9 Pacific Southwest; Trina Martynowicz, Environmental Protection Specialist, EPA Region 9; and Michael Kosusko, Chemical Engineer, EPA Office of Research and Development (ORD). https://nepis.epa.gov/Exe/ZyPDF.cgi/P100QCXZ.PDF?Dockey=P100QCXZ.PDF

The focus of the research described in this report was to evaluate the impacts associated with biogas management technologies; specifically, to **evaluate the emissions and costs associated with using biogas in particular end-use applications.** Seven different technologies were evaluated in terms of their individual cost, efficiency and emissions — both greenhouse gas (GHG) and criteria air pollutant emissions. The technologies examined include: combustion in a reciprocating engine; combustion in a gas turbine; combustion in a microturbine; **conversion in a fuel cell**; processing for pipeline injection; processing to create Compressed Natural Gas (CNG); and flaring…. The analysis was narrow in that the system boundary began with already-produced biogas and ended with on-site use or upgrading.

United States Environmental Protection Agency

Summary: Costs required to process biogas varied from less than $1/MMBtu (input flow basis) for flare systems to $7-$25/MMBtu or more for upgrading the biogas for injection into the natural gas pipeline. Flaring appeared to be the lowest cost management option but would likely not be if energy savings, sales, or subsidies were included in a future analysis.

Fuel cell costs were similar to those of upgrading for pipeline injection. Costs for engines, microturbines and processing for CNG each fell below $5/MMBtu (input) for the upper end of the technology capacity range. Combustion turbine costs were relatively flat ($3-$4/MMBtu). **Fuel cells**, microturbines, processing to CNG and pipeline injection showed particularly strong economies of scale due to a combination of lower per-unit capital and operating costs, and higher efficiencies at larger scale. …**The LCOE for fuel cells** ranged from ~$0.16/kWh at a small size (200 kW) to about $0.09/kWh at the 3 MW size. …The CNG pathway was generally less costly than upgrading the gas for pipeline injection, which ranged upwards from $25/MMBtu at small scale to about $7/MMBtu at very large scale.



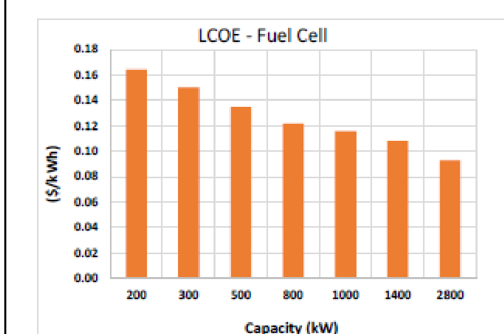
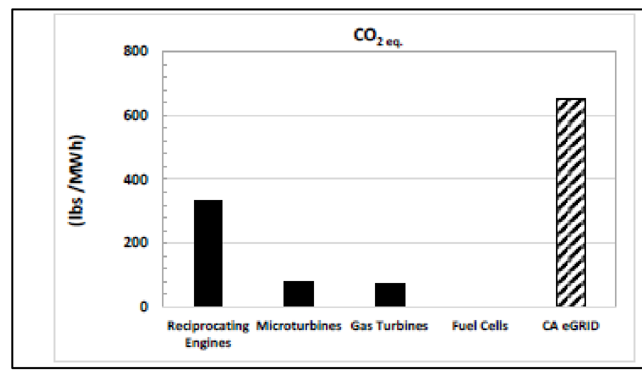


Figure 21. LCOE - fuel cell.



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EPA United States Environmental Protection Agency

In-state biomass resources for biogas and hydrogen

Recent NREL/BETO estimates

California Biomass Collaborative estimates

Technologies

Policy Issues

CALIFORNIA BIOMASS COLLABORATIVE

Policy Considerations:

Climate change effects and optimal policies are subject to deep uncertainty.

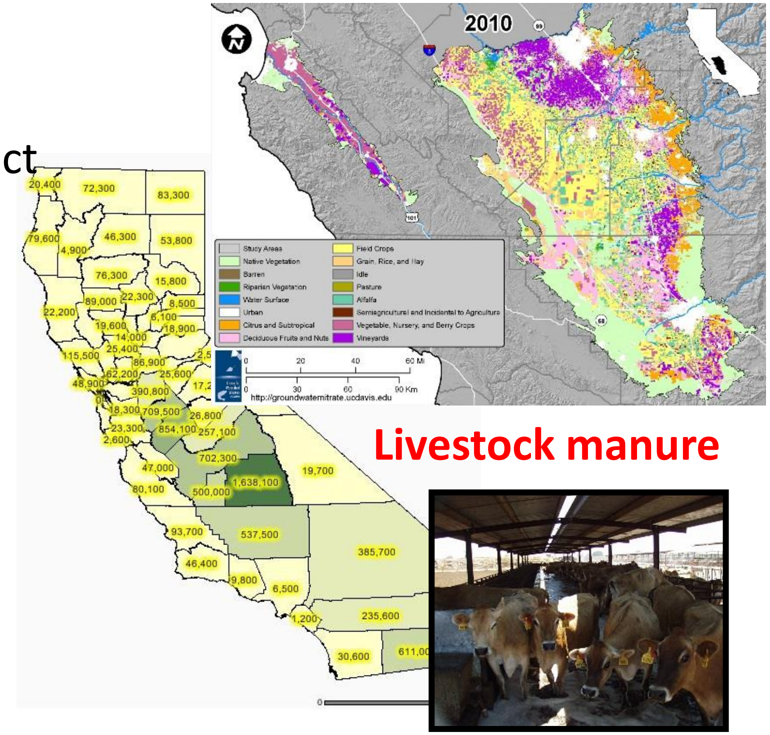
Biomass is abundant in California.

Biomass energy, including biomass conversion to hydrogen, tends to be more expensive than other alternative energy sources.

But the use of biomass for energy includes potential benefits at the landscape scale that correspond to socially desirable and commonly agreed upon goals.

These include (among others): improved protection against wildfires and the preservation of forest health, and improved means to manage surplus nutrients in manures, and protect groundwater, and job creation in rural areas and among disadvantaged populations.

Even under policy uncertainty, achieving these co-benefits are worthwhile goals.



Supplemental Slides

Biomass Resource Update:

- 2015 Update (2013 data) completed in March
- Estimates Annual Gross and Technical Biomass Resource
  - Bone-dry tons per year (BDT/Y)
  - Electric capacity and energy generation potential (MW, TWh/y)
  - Statewide biogas potential
- Resource Categories: Urban, Agriculture & Food Processing, Forest / Forest Products
- Residues and forest "over growth" – energy crops not modeled here
- Aggregated at County Level

Gross vs. Technical Resource

- Gross Resource
  - Total mass of residue/forest biomass estimated for each category
- Technical Resource
  - Practical to recover and in a
  - "Sustainable" manner
    - Excludes steep slope & riparian zones in forest
    - Portion of agricultural residue left in field for organic matter in soil, erosion mitigation,
    - etc.
- No economic filter applied
    - Amount that can be recovered economically is less than the technical resource (much less for forest based material)
    - Depends on use and markets

CALIFORNIA BIOMASS COLLABORATIVE

Notes and Sources:

MM BDT = million bone dry (short) tons,

BCF = billion cubic feet

gge = gallons gasoline equivalent

a. Williams, R. B., B. M. Jenkins and S. Kaffka (California Biomass Collaborative). 2015. ***An Assessment of Biomass Resources in California, 2013.*** Contractor Report to the California Energy Commission. PIER Contract 500-11-020.

b. From: Wiltsee, G. (1999). Urban Waste Grease Resource Assessment: NREL/SR-570-26141. Appel Consultants, Inc. 11.2 lbs./ca-y FOG and California population of 36.96 million. Biodiesel has ~9% less energy per gallon than petroleum diesel.

c. Technical potential assumed to be 67% of amount disposed in landfill (2012).

d. 67% of mixed paper, woody and green waste and other non-food organics disposed in landfill (2013), (waste characterization and disposal amounts are from: http://www.calrecycle.ca.gov/Publications/Detail.aspx?PublicationID=1346 and http://www.calrecycle.ca.gov/lgcentral/GoalMeasure/DisposalRate/Graphs/Disposal.htm)

e. From EPA Region 9; Database for Waste Treatment Plants

f. Assumes 50% methane in gas

g. Assumes VS/TS= 0.83 and biomethane potential of 0.29g CH_4/g VS (food waste) & VS/TS = 0.9 w/ BMP= 0.143g CH_4/g VS (leaves. Grass)

h. Assumes 19MJ/kg HHV for ligncellulosic feedstock and 60% conversion efficiency to synthetic RNG via gasification followed by methane: Mensinger, M., R. Edelstein and S. Takach (2011). The Potential for Renewable Gas: Biogas Derived from Biomass Feedstocks and Upgraded to Pi peline Quality. American Gas Foundation & Gas Technology Institute. Aranda, G., A. van der Drfit and R. Smit (2014). The Economy of Large Scale Biomass to Substitute Natural Gas (bioSNG) plants. **ECN-E-14-008**.

i. ~116 ft^3 methane is equivalent to 1 gge (983 Btu/scf methane and 114,000 Btu/gallon gasoline, lower heating value basis)

j. Assumes FOG biomethane potential of 400 litre CH_4/kg VS, 100% VS in Fog and practical digester conversion eff. Of 70%. BMP from: Allen, E., D. M. Wall, C. Herrmann and J. D. Murphy (2016). "A detailed assessment of resource of biomethane from first, second and third generation substrates." Renewable Energy **87, Part 1**: 656-665.

k. Assumes 65% methane in gas. http://biomass.ucdavis.edu/publications/

Table 8. Cumulative and annual forest residue amounts in Scenario 2

Forest Variant Code and Ownership (Fig. 10b-4)	Total area treated (acres)	Forest residue cumulative total 40 yrs (BDT)[1]	Forest residue annual (BDT/yr)	Forest residue cumulative per acre over 40 yrs (BDT tons/acre)	Merchantable timber cumulative per acre over 40 yrs (cu ft/acre)
Private					
WS	1,054,207	72,510,650	1,812,766	68.78	4,606
CA	1,153,266	77,275,857	1,931,986	67.01	4,865
NC	3,383,091	121,015,980	3,025,400	35.77	2,178
SO	417,248	13,496,585	337,415	32.35	2,804
Subtotal	6,007,813	284,299,072	3,787,982	Average=47.32	14,448

Table 8. Cumulative and annual forest residue amounts in Scenario 2

Public					
WS	2,322,899	71,180,570	1,779,514	30.64	2,314
CA	1,054,928	22,785,055	569,626	21.60	1,664
NC	2,208,784	44,306,378	1,107,659	20.06	3,091
SO	939,613	13,274,269	331,182	14.10	802
Subtotal	6,526,244	151,519,273	7,107,477	Average=23.22	7,871
Total	12,534,037	435,818,345	10,895,459	Average = 35.27	

Scenario 2 investigates the use of BioSum to estimate forest residual biomass amounts under a hypothetical forest management policy that maximizes wildfire risk reduction. For each FIA plot every package was modeled and the package was selected that was most able to reduce wildfire hazard risk. Determining which package most reduces fire risk was done by the development of a Hazard Score. The Hazard Score was the sole criteria for selection of a forest management prescription (package) and acres were not treated if there was no improvement in the Hazard Score.

	Air-blown Producer Gas (vol. %)	Oxygen-blown Synthesis Gas (vol. %)	Indirect-fired-steam gasification Synthesis Gas (vol. %)
CO	22	38	19
H_2	14	20	20
CH_4	5	15	8
C_2H_2 and higher	low	5	3
H_20	2	4	38
CO_2	11	18	11
N_2	46	trace	trace
	Plus tars, PM, and other		

Air-blown gasifiers produce a low energy gas (~ 150 Btu ft-3) composed of CO, H_2, CO_2, CH_4, higher light hydrocarbons, H_2O, PM, alkali vapors, nitrogen and sulfur compounds, and 40-50% N_2. The N_2 is a diluent and is from the air gasification medium (Table 7.1). **Oxygen-blown gasifiers** produce a medium energy gas (~ 350 Btu ft-3) composed of similar compounds but much less nitrogen. An air separation plant is needed to create a pure or enriched oxygen stream to use for the gasification medium. Properly designed and operated **air-blown indirect gasifiers** produce a medium energy gas because the combustion reactor is separate from the gas producing reactor. The products of combustion and the air borne nitrogen are therefore separate from the synthesis gas stream. Sources: Gebhardt, Wang et al., 1994; Proll, Siefert et al., 2005).