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Biomass for power, fuels (and bio-products) in California

SB100 Technologies & Scenarios Workshop

November 18, 2019 CPUC-San Francisco

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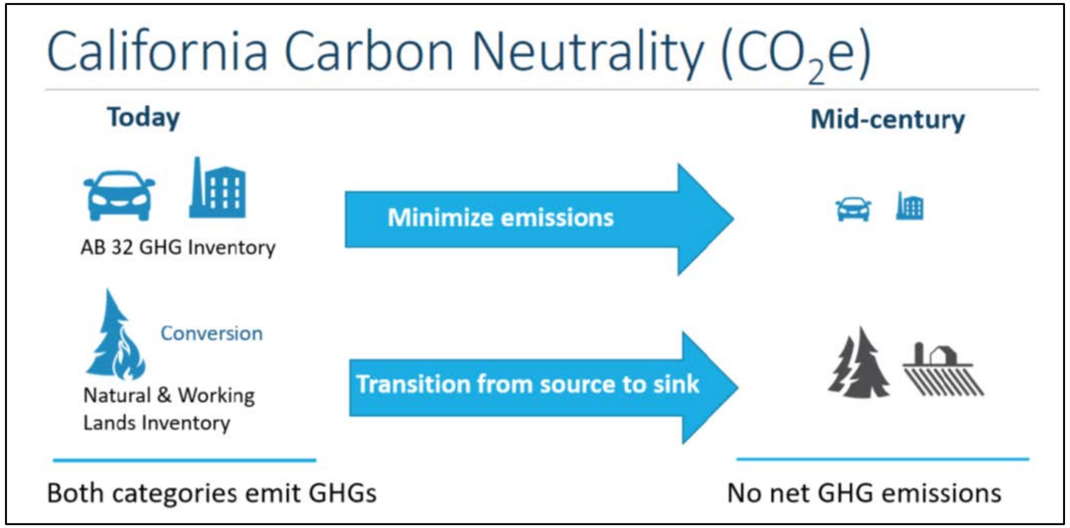
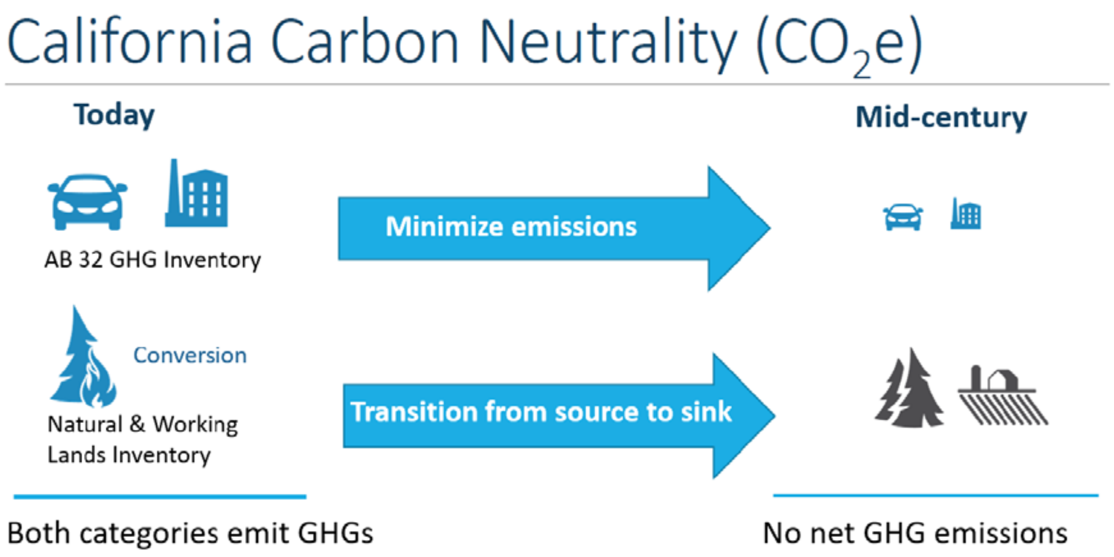


Under the SB 100 policy, California's renewable energy and zero-carbon resources supply 100 percent of electric retail sales to end-use customers and 100 percent of electricity procured to serve state agencies by December 31, 2045. The policy requires the transition to a zero-carbon electric system does not cause or contribute to increases of greenhouse gas emissions elsewhere in the western electricity grid.

UCDAVIS DEPARTMENT of PLANT SCIENCES

CALIFORNIA BIOMASS COLLABORATIVE



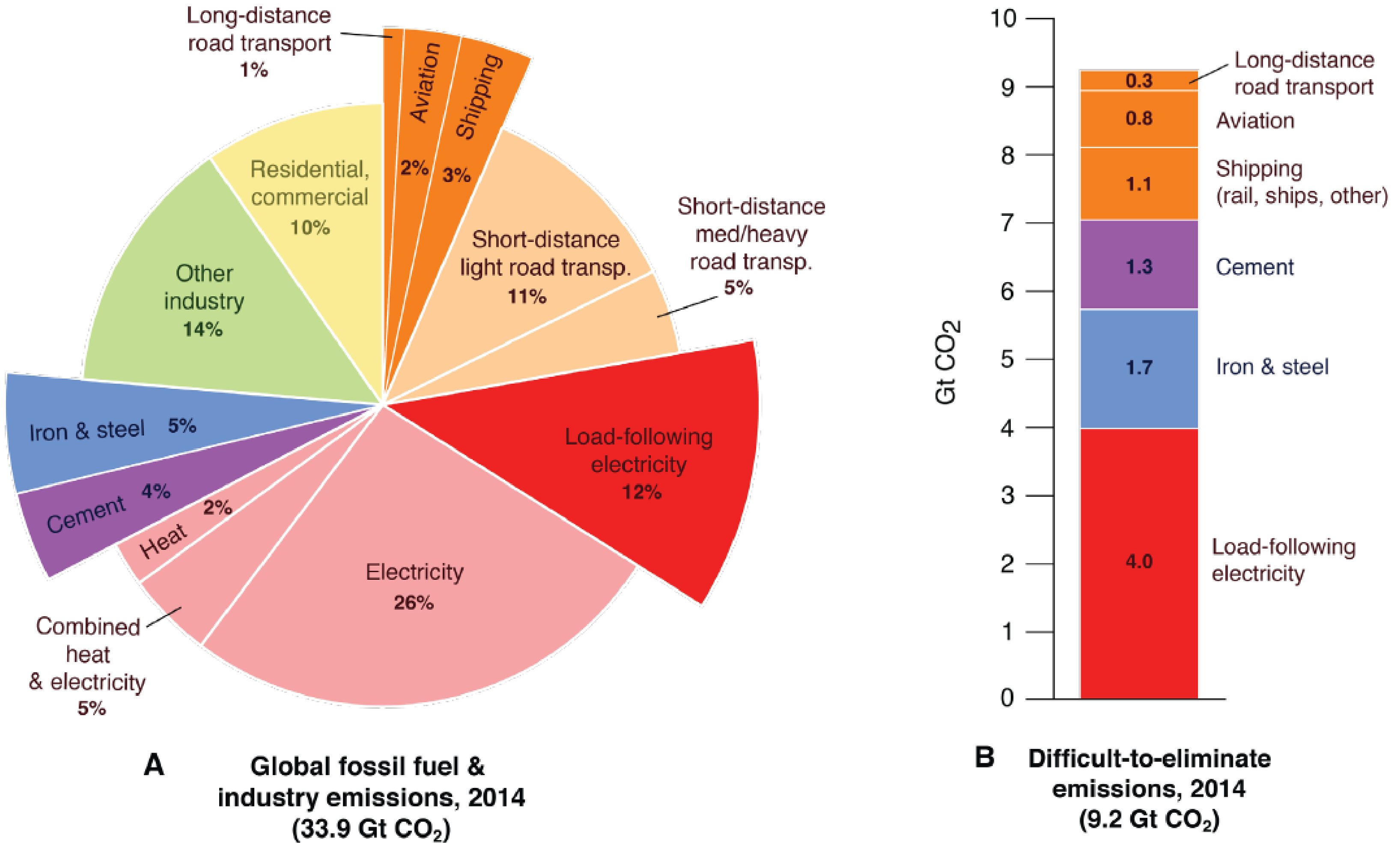
Physical and techno-economic characteristics make a net-zero emissions system challenging, especially for: **Aviation and long-distance transport, industrial materials, and highly reliable electricity**.

Energy-dense liquid fuels… **Biofuels** or other advanced (as yet unrealized) synthetic processes

To achieve high reliability in a power sector with a large share of variable, uncertain renewables, the **system needs storage or flexible generators** that have low fixed costs and/or alternate products are needed.

Nathan Lewis 2019/CARB presentation

How much "difficult" CO_2 are we talking about?

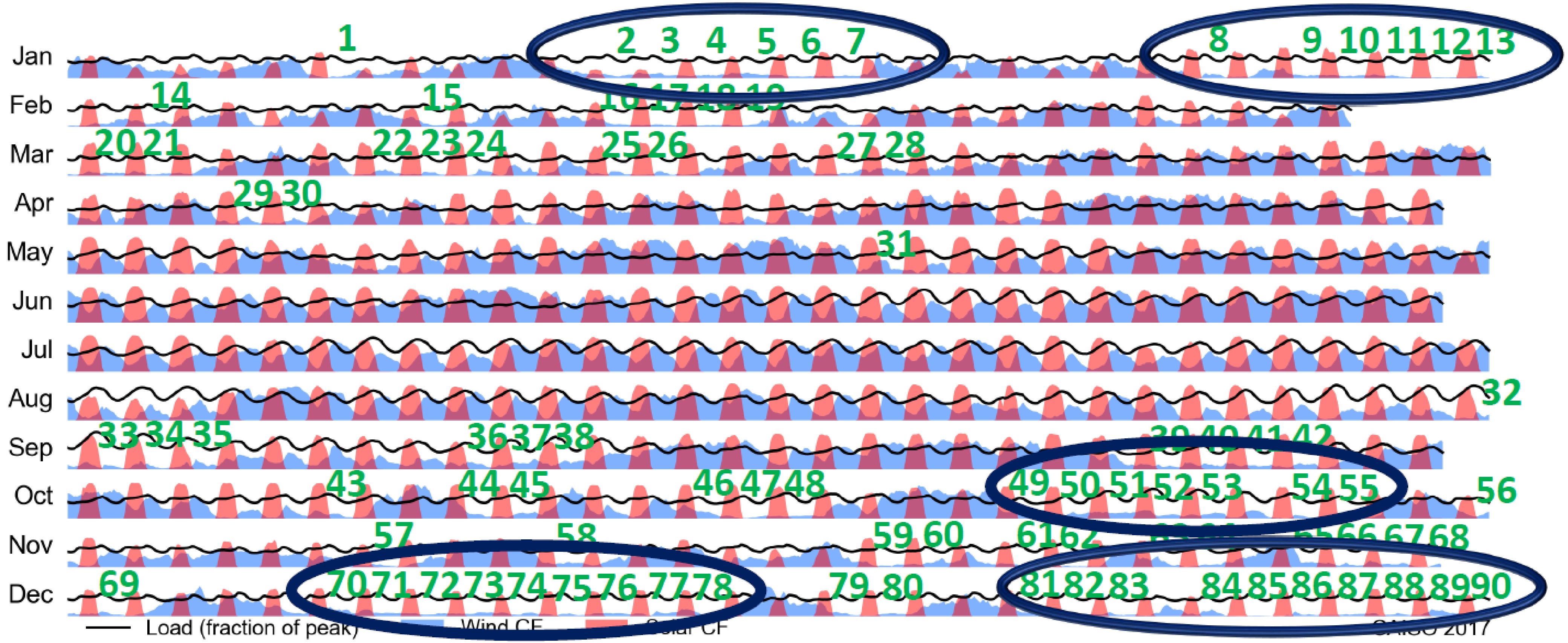


All these have a role for biomass

Davis et al. *Science*, 2018

Source: Nathan Lewis, August 19, 2019-CARB workshop on carbon neutrality

EFI analysis: relying on intermittent sources will require very large scale backups---CARB August 2019



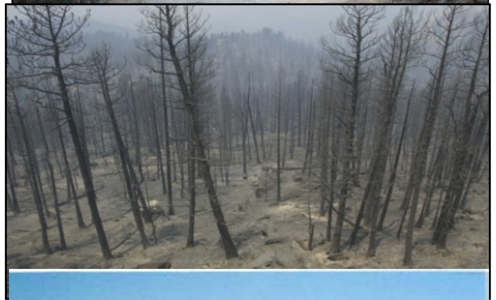
Source: CAISO data, EFI analysis

Hourly trends in solar and wind capacity factors in CA for 2017 aligned to normalized variation in hourly load relative to peak daily load

Biomass is stored solar energy, can help with load following and peak use.

What roles for biomass in a low or zero carbon future?

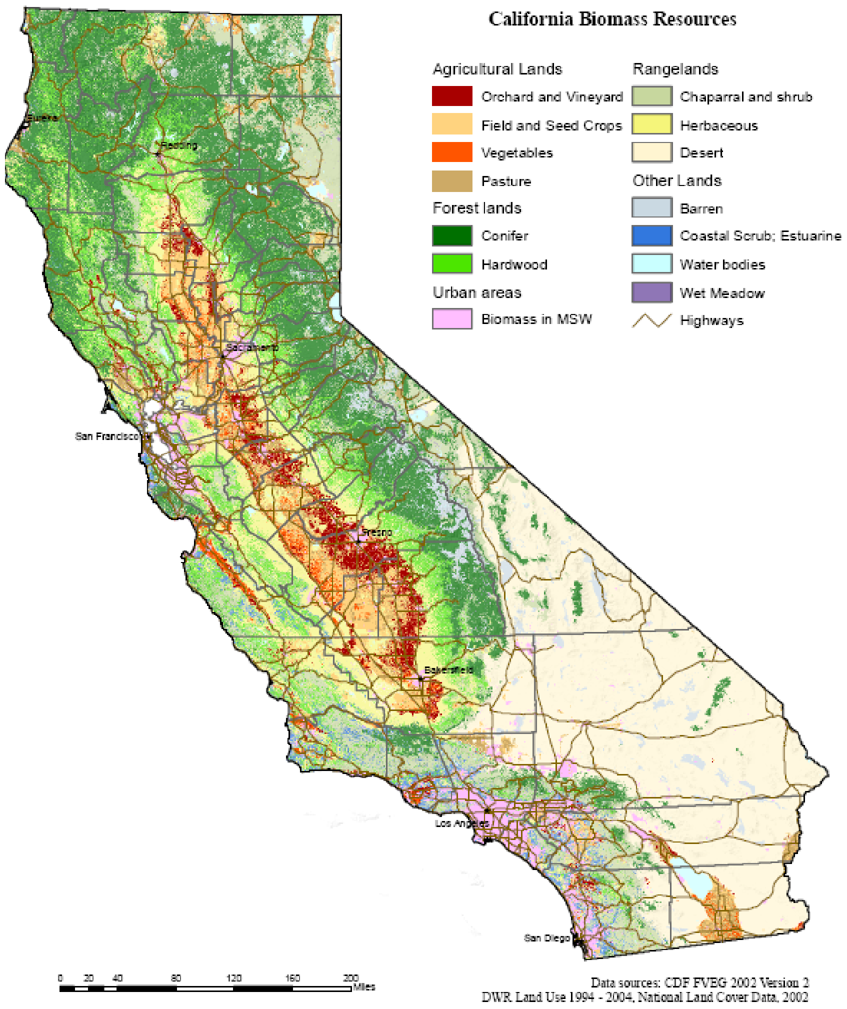
- **Biomass resources in California: Forest, Urban and Agricultural**
- **Transformation pathways and opportunities for power, fuels and bioproducts. These can be integrated.**
- **No regret uses for biomass**

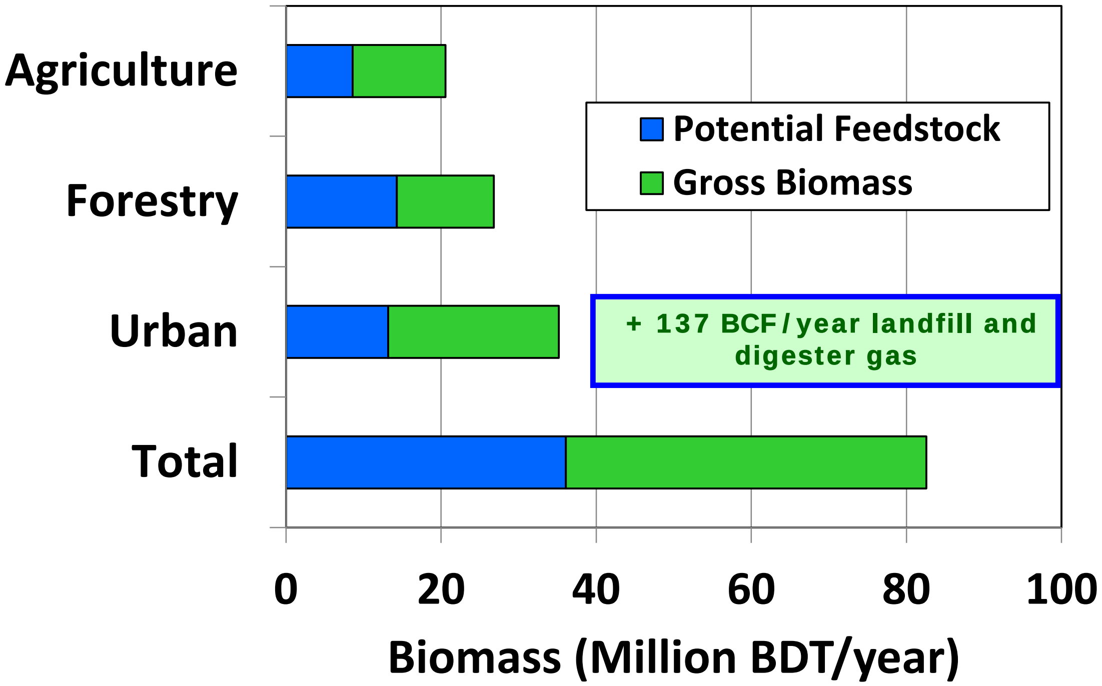



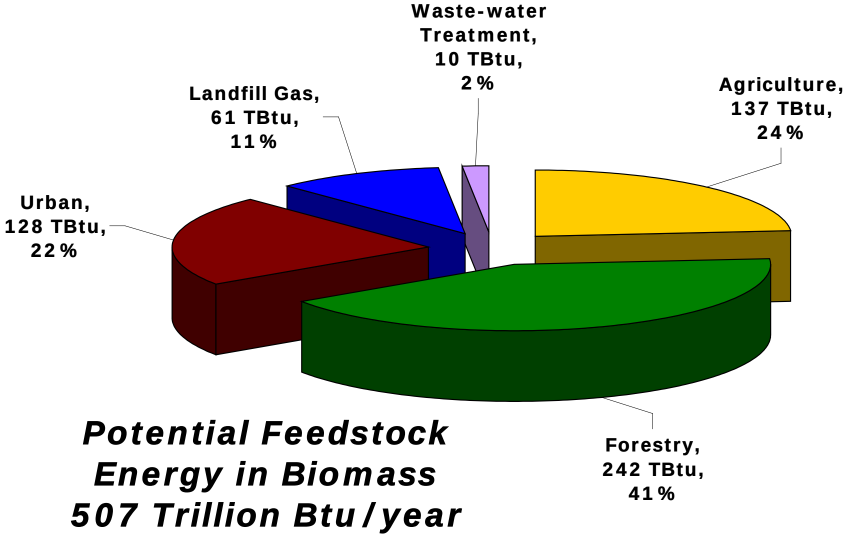





California Biomass Resources Are Diverse

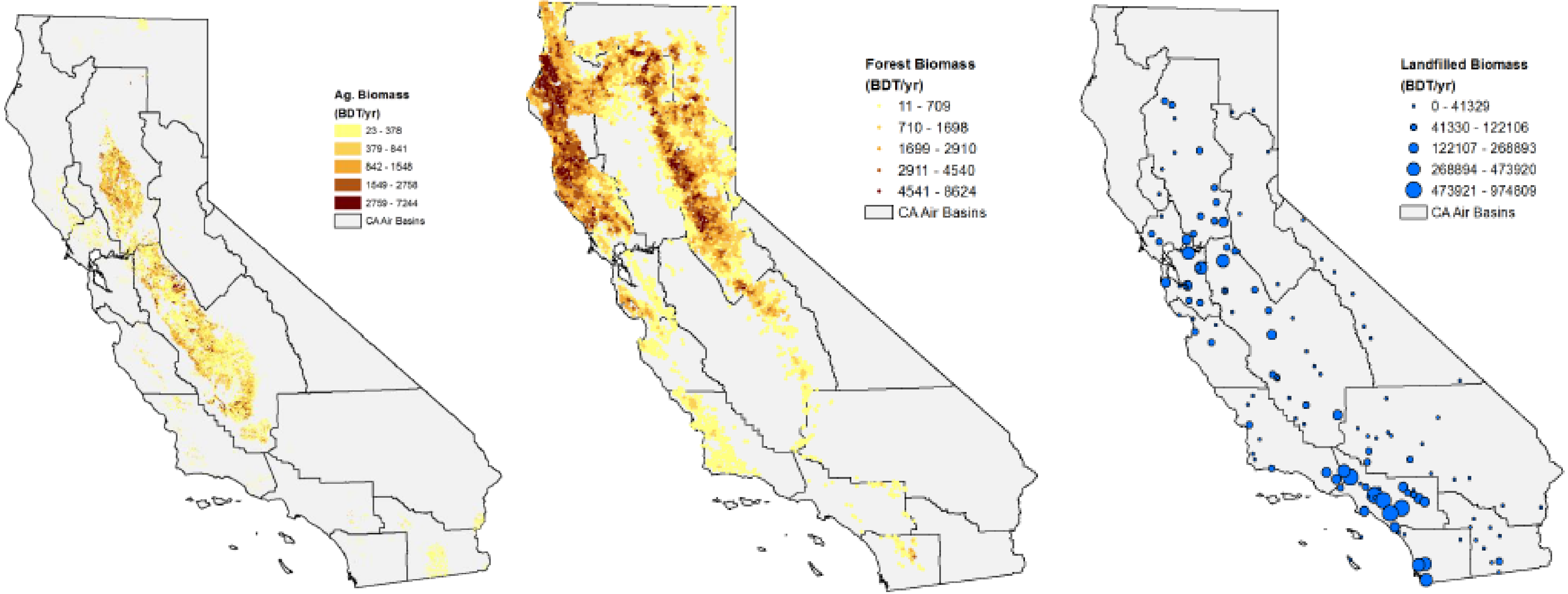






Jenkins et al. (2006) A roadmap for the development of biomass in California

CALIFORNIA BIOMASS COLLABORATIVE



Samuelsen, Scott; Bryan Jenkins, Donald Dabdub, Jack Brouwer, Alejandra Cervantes; Brendan Shaffer; Marc Carreras-Sospedra; Robert Williams; Nathan Parker. (Advanced Power and Energy Program). 2016. ***Air Quality and Greenhouse Gas Emissions Impact Assessment from Biomass and Biogas Derived Transportation Fuels and Electricity and Heat Generation.*** California Energy Commission. Publication number: CEC-500-2016-022.

Some objections to the use of biomass:

1. Biopower is expensive, polluting, and no longer needed
2. Biomass use may not be (or is not) carbon neutral
3. Accounting methods for biomass are difficult and compromised by unavoidable epistemic error
4. Biofuels compete with food production and lead to secondary pollution
5. Other ?

Principal Biomass Conversion Pathways

Bioenergy is complicated.

- Production
- Collection
- Processing
- Storage
- Transportation

- Thermochemical Conversion
  - Combustion
  - Gasification
  - Pyrolysis
- Bioconversion
  - Anaerobic/Fermentation
  - Aerobic Processing
  - Biophotolysis
- Physicochemical
  - Esters
  - Alkanes

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

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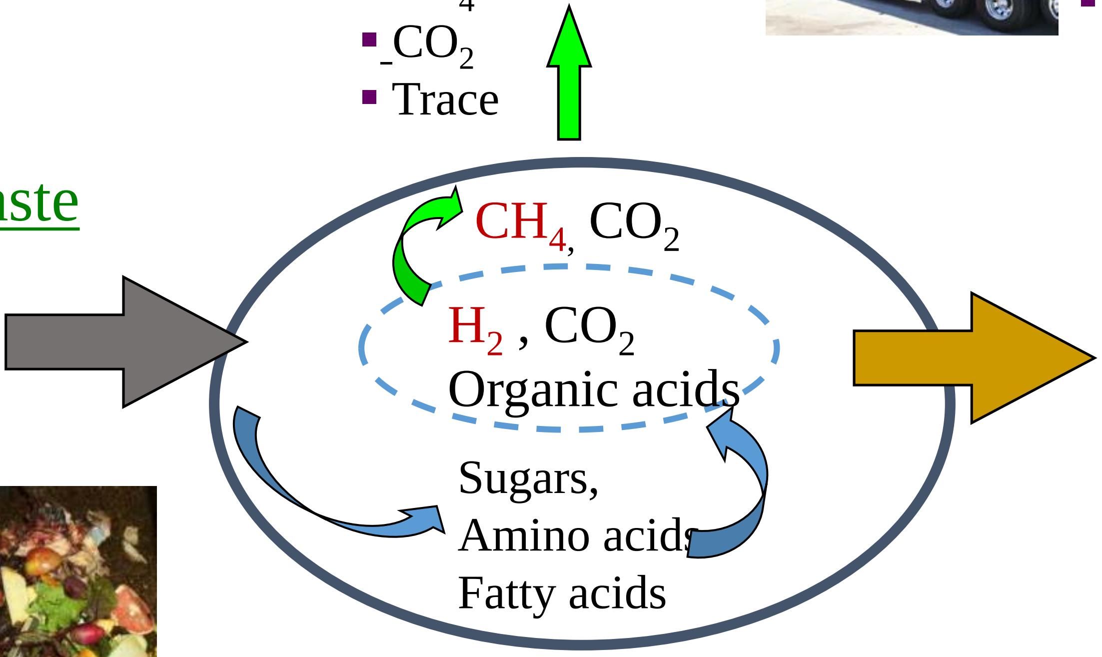
Anaerobic Digestion for high moisture solids

Biogas
- CH_4
- CO_2
- Trace

Biogas Energy
- Electricity and heat
- Renewable natural gas

Organic Waste
- Food
- Green
- Agricultural



Digestate for Water and Fertilizer
- Fibers/Lg Solids
- Suspended Solids
- Dissolved Solids
- Water


Anaerobic Digestion

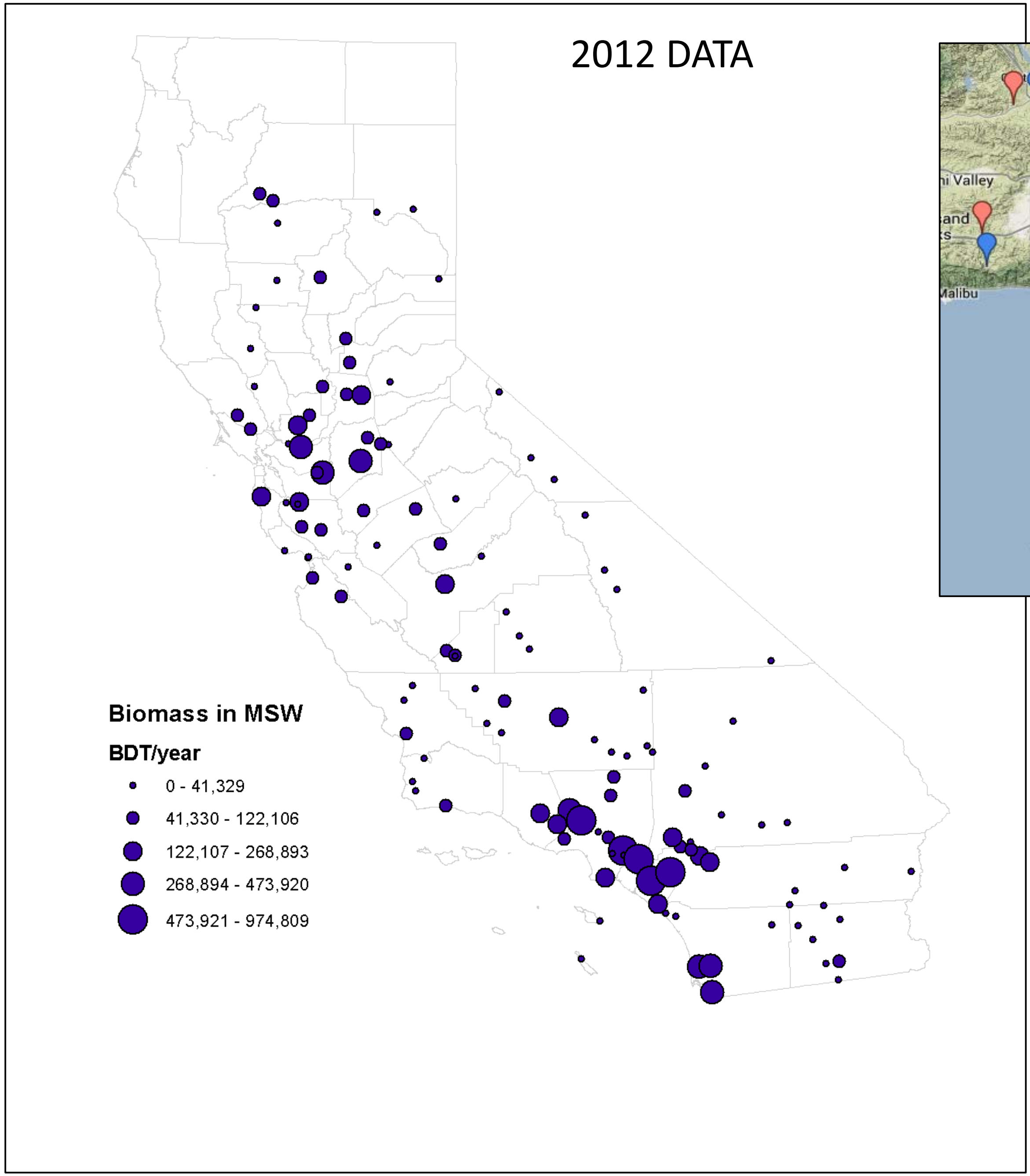
R. Zhang

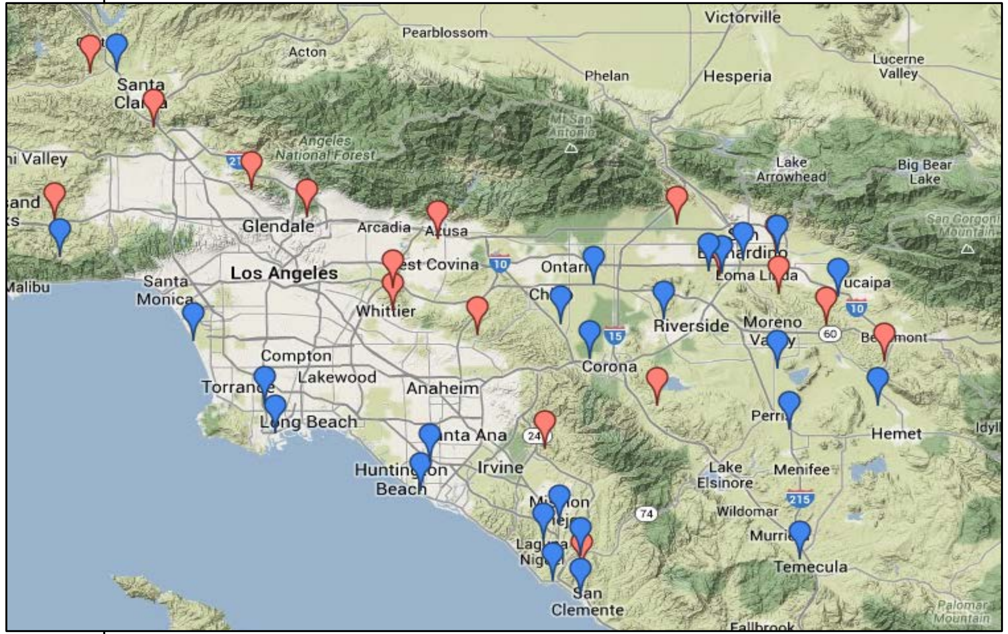
Biochemical pathways-Statewide Biogas Potential

Most, but not all, urban MSW may best be converted biochemically to renewable natural gas. The same is true for energy recovery from WWTF and manures.

Feedstock	*Biomethane Potential (million m^3 per year)*		Technical Energy (PJ, HHV basis)	* Technical Factor Assumption
	Gross	Technical or Recoverable Amount*		
Dairy Manure	943	472	17	50% of manure is recovered
Poultry Manure	174	87	3	50% of manure is recovered
Landfill Gas	2,006	1,505	56	75% recovery of gas produced
Waste Water Treatment Plants	218	196	7	90% recovery of gas produced
Municipal Solid Waste (food & grass / leaves fraction)	519	348	13	67% of feedstock is recovered

Technical Potential Total = 2,600 (million m^3 per year methane)
CBC estimate (Williams; https://biomass.ucdavis.edu/)





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

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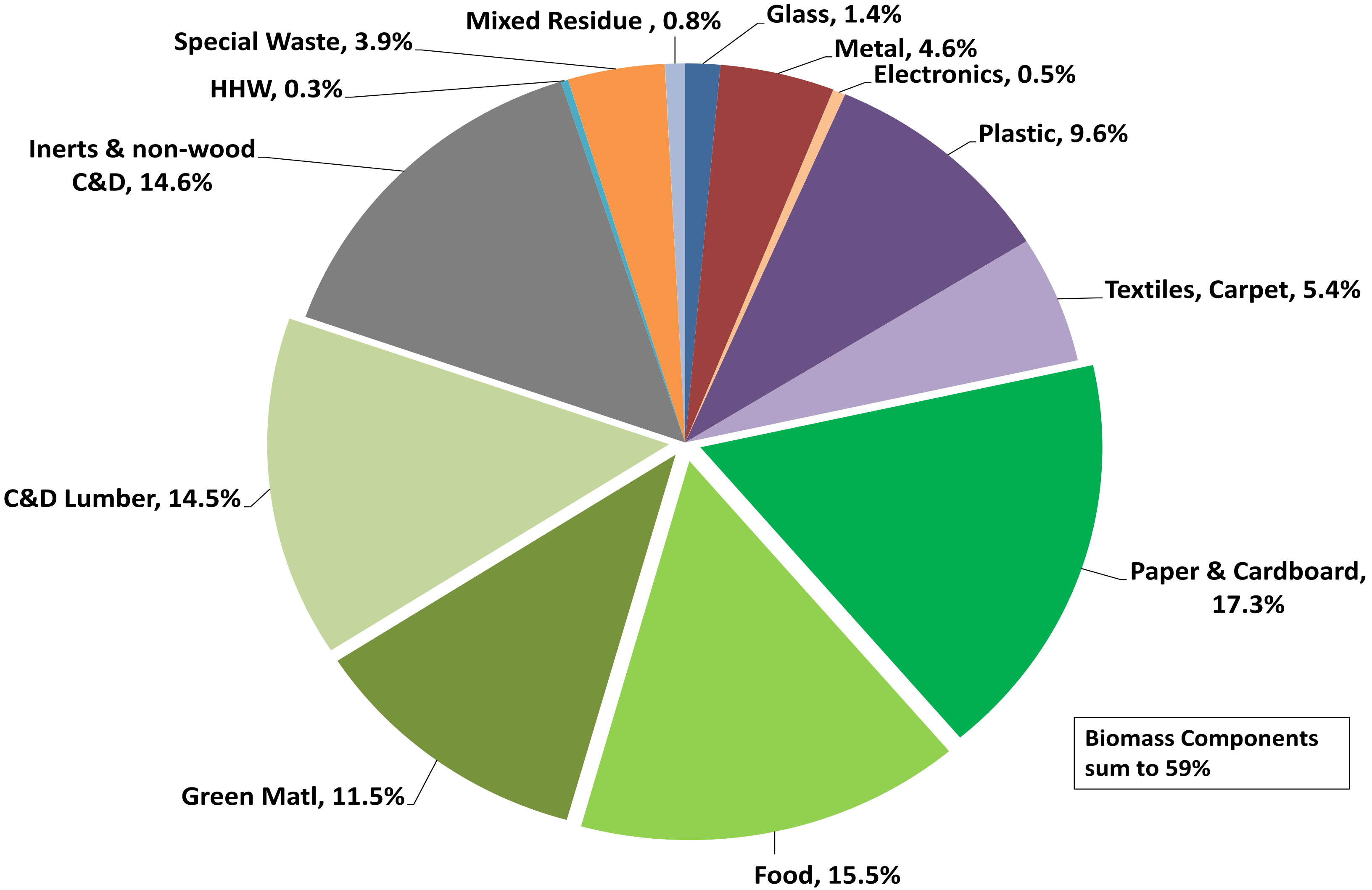
California landfilled waste stream by material type



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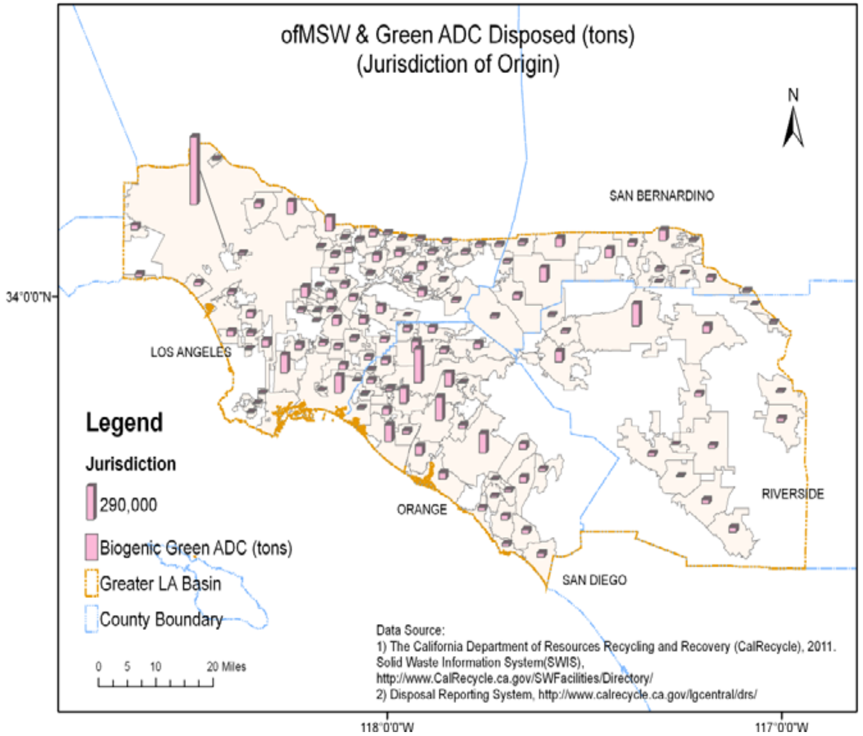
(adapted from 2008 characterization, Cascadia 2009)



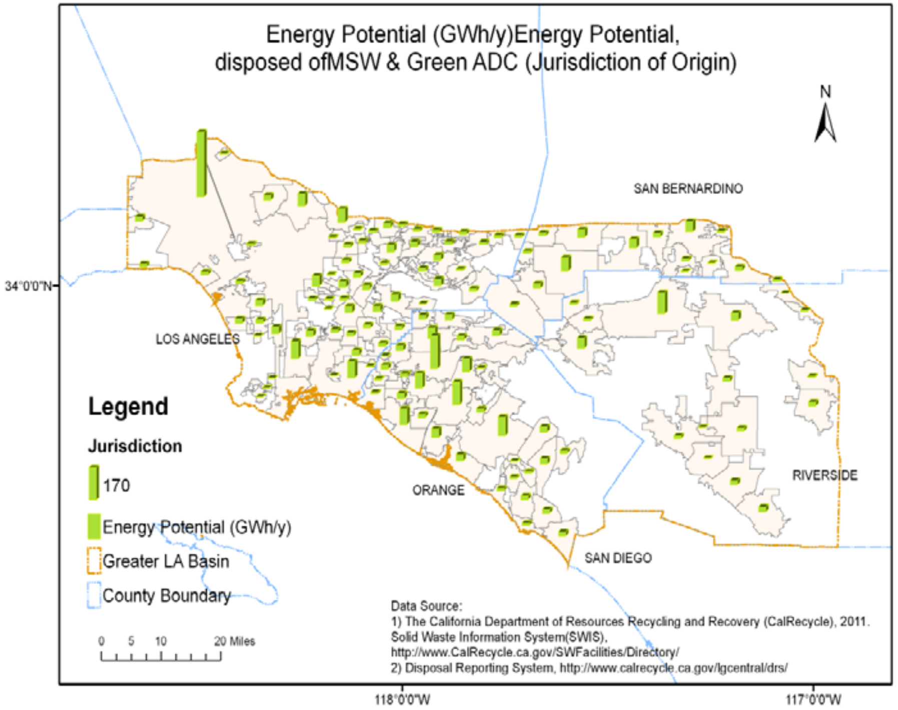
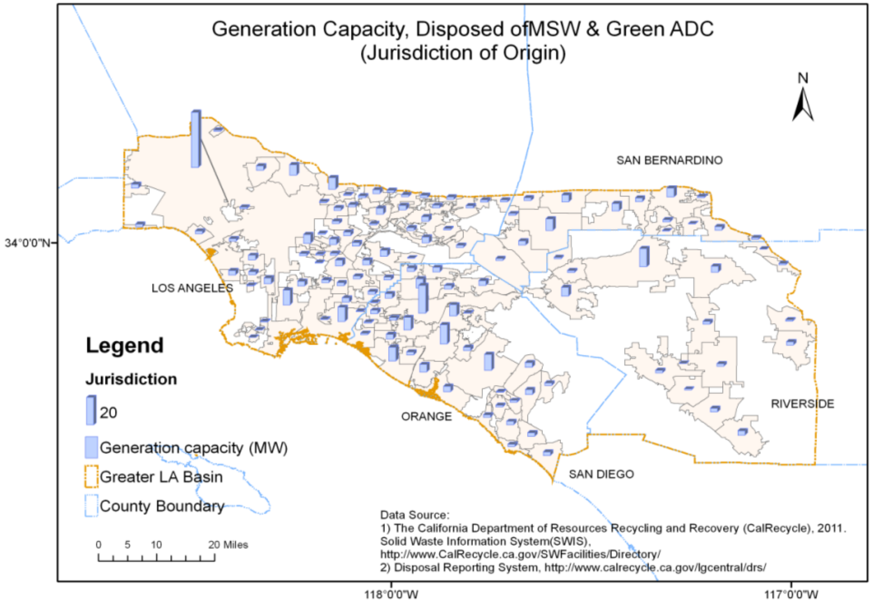
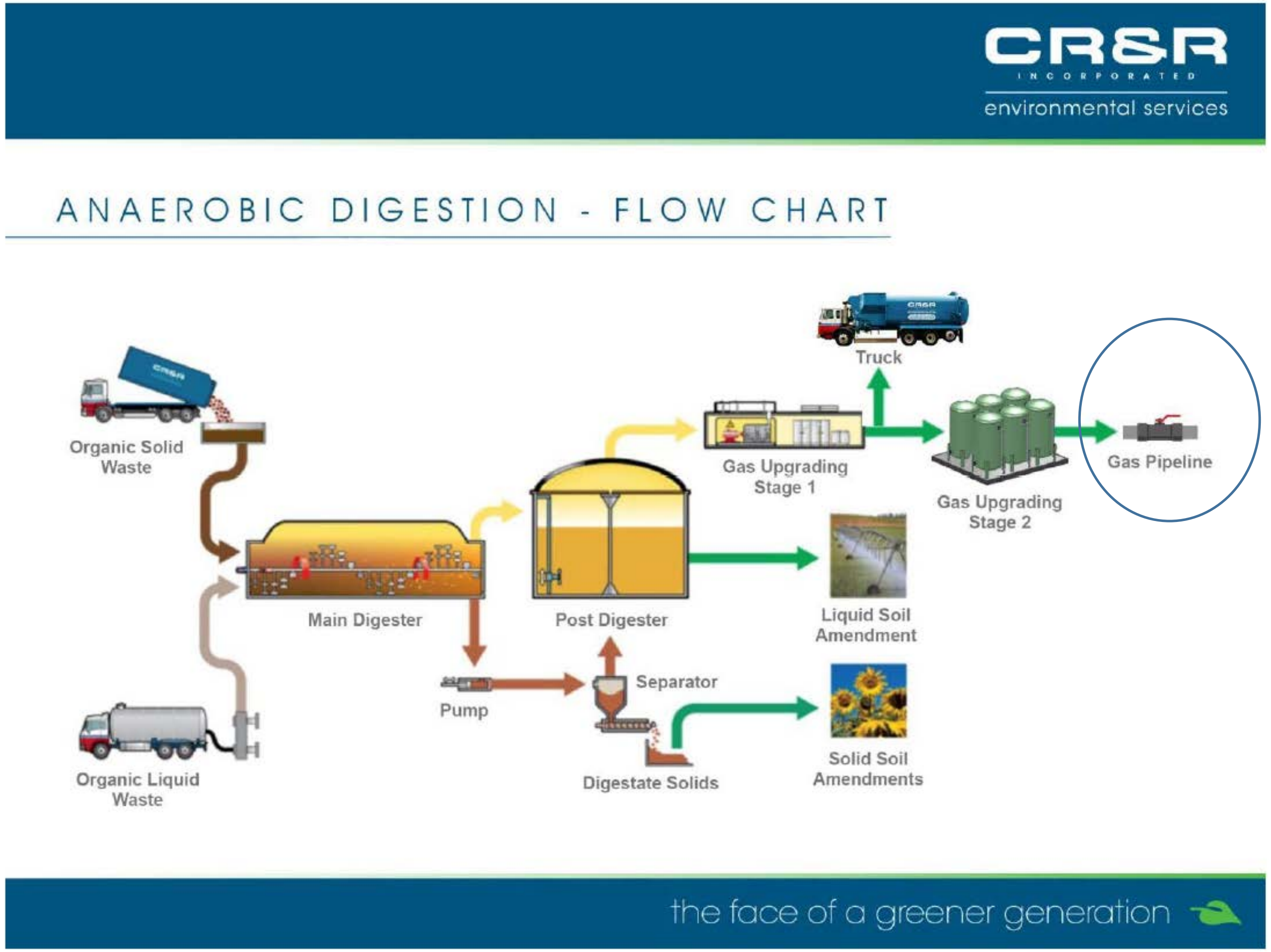


Fig A Sum of Biogenic disposal and Green ADC tons (jurisdictions of origin)
Fig B Energy potential of MSW of each jurisdiction in the Greater LA Basin (Gigawatt Hour/year)
Fig C Generation Capacity of MSW of each jurisdiction in the Greater LA Basin (MWs)



Source: Glassley, W., H. Shiu, **R. B. Williams**, M. Rahman, J. Delplanque, J. Kleissl, **S. R. Kaffka**, E. Brown, C. P. van Dam and **B. M. Jenkins**. 2014. Costs and Benefits of Co-Located Renewable Resources in the Greater Los Angeles Basin - DRAFT. PIER Contract CEC 500-11-020, California Renewable Energy Center, UC Davis.



A residual carbon recovery and processing facility has been added (not shown here) and used for cement production. This is an example of a circular economy process that reduces GHGs while adding value to urban residuals.

Comparing Waste Hierarchies

USEPA and EU incorporate energy recovery as a policy objective but California does not.

CA Waste Hierarchy
1. Source reduction
2. Recycling and composting
3. Environmentally safe transformation and land disposal

EPA/EU Waste Hierarchy
1. Source reduction
2. Reuse
3. Recycling and composting
4. Energy Recovery
5. Landfill

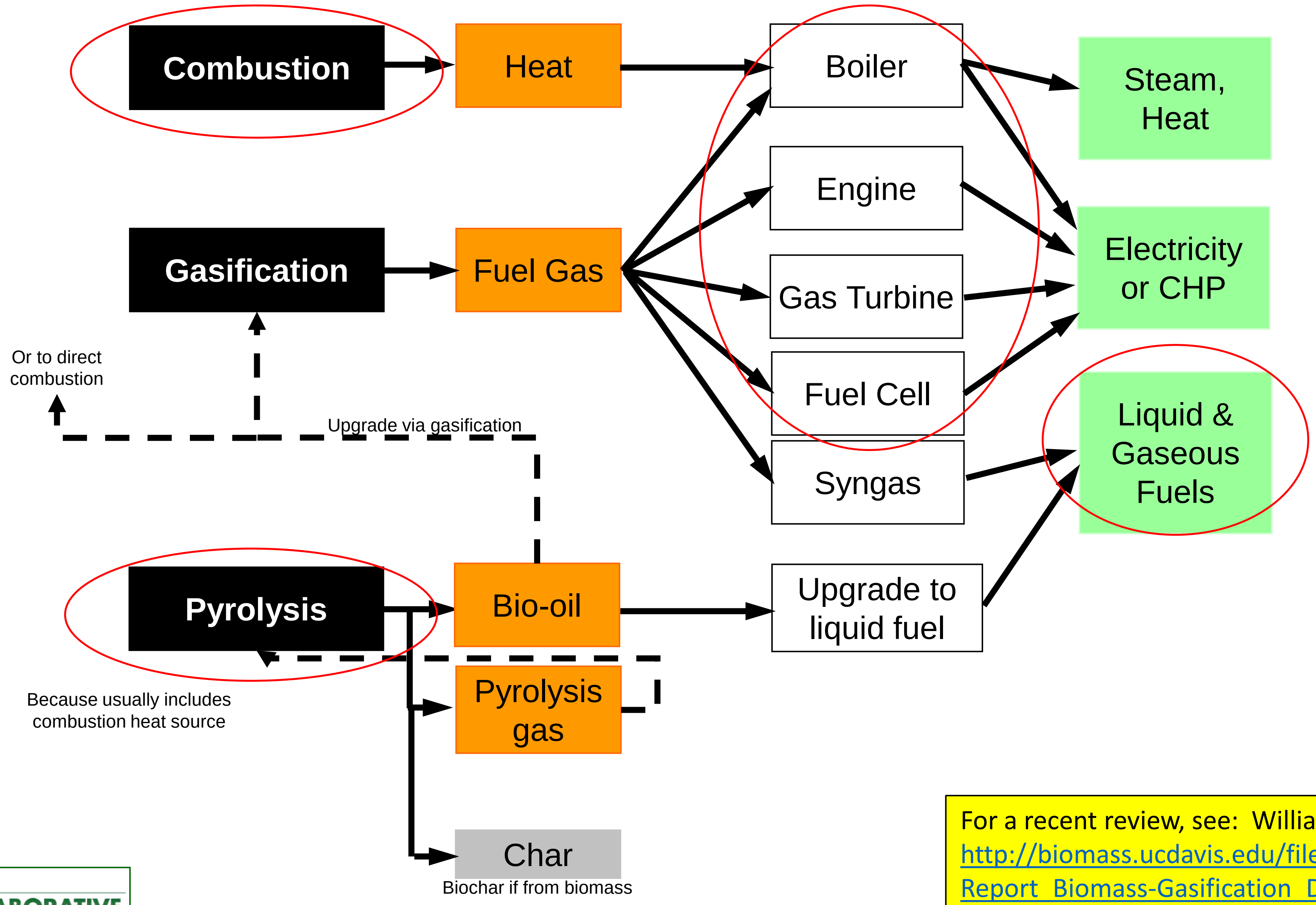
AB 939 (Sher), Statutes of 1989, established the California Waste Hierarchy

Open Issues/Barriers

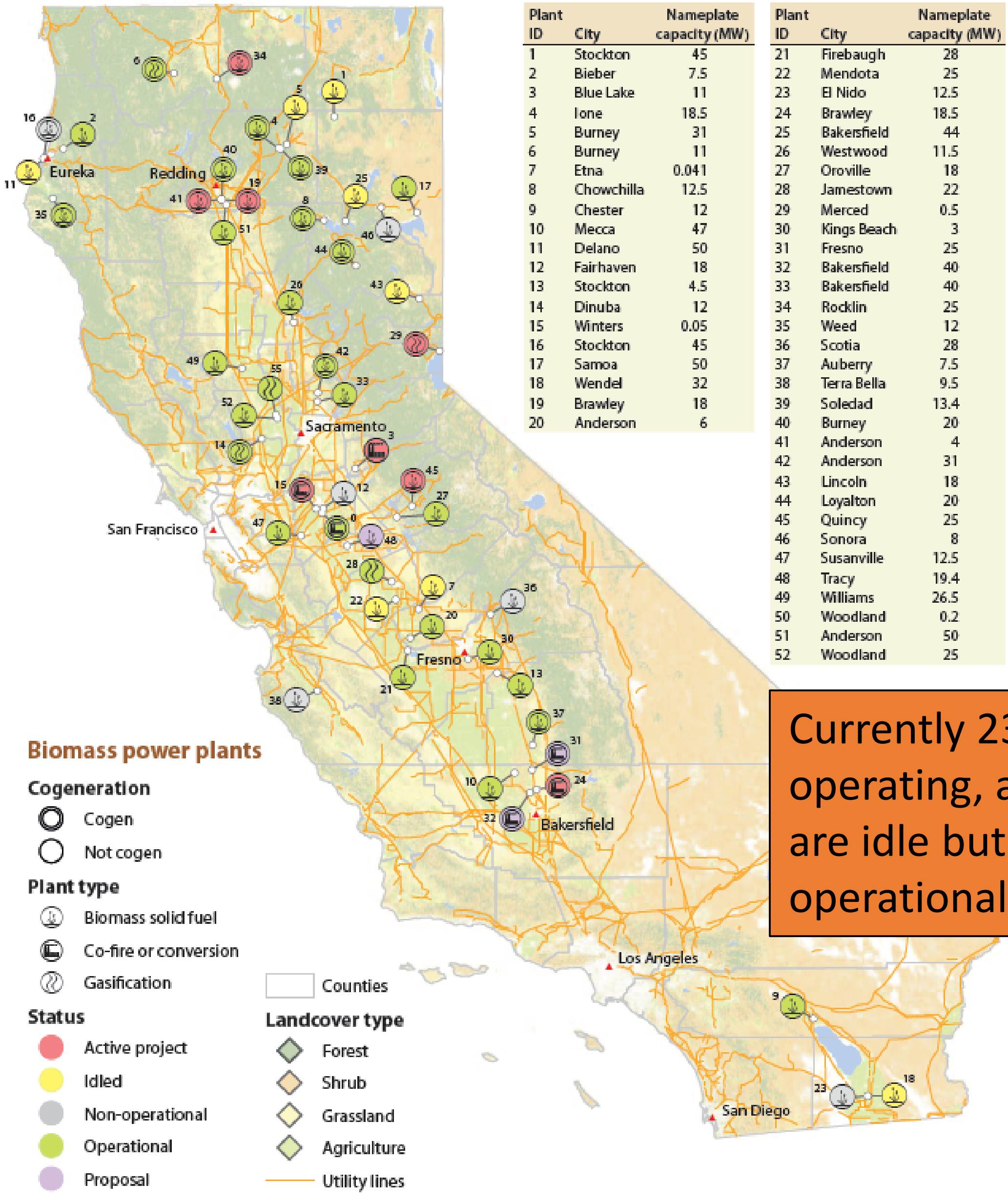
- Transformation (in statute)
  - means incineration, pyrolysis, distillation, or biological conversion other than composting [no mention of energy recovery].
  - Limited diversion credit
  - No RPS eligibility for the biogenic fraction for new facilities*
- Problematic statutory definition for gasification
  - no air “emissions, including greenhouse gases”
  - Disagreement on interpretation of definition for real projects
  - Policy basis for proscribing technology (rather than performance standards) is not clear, out of date, and a barrier.

*** The Covanta-Stanislaus facility has RPS status per statute (even for fossil components of feedstock). The facilities in Long Beach and Commerce do not.**

Basic Thermal Technologies – Components with air emissions



For a recent review, see: Williams and Kaffka, 2015. http://biomass.ucdavis.edu/files/2015/10/Task7-Report_Biomass-Gasification_DRAFT.pdf



Plant ID	City	Nameplate capacity (MW)
1	Stockton	45
2	Bieber	7.5
3	Blue Lake	11
4	Ione	18.5
5	Burney	31
6	Burney	11
7	Etna	0.041
8	Chowchilla	12.5
9	Chester	12
10	Mecca	47
11	Delano	50
12	Fairhaven	18
13	Stockton	4.5
14	Dinuba	12
15	Winters	0.05
16	Stockton	45
17	Samoa	50
18	Wendel	32
19	Brawley	18
20	Anderson	6
21	Firebaugh	28
22	Mendota	25
23	El Nido	12.5
24	Brawley	18.5
25	Bakersfield	44
26	Westwood	11.5
27	Oroville	18
28	Jamestown	22
29	Merced	0.5
30	Kings Beach	3
31	Fresno	25
32	Bakersfield	40
33	Bakersfield	40
34	Rocklin	25
35	Weed	12
36	Scotia	28
37	Auberry	7.5
38	Terra Bella	9.5
39	Soledad	13.4
40	Burney	20
41	Anderson	4
42	Anderson	31
43	Lincoln	18
44	Loyalton	20
45	Quincy	25
46	Sonora	8
47	Susanville	12.5
48	Tracy	19.4
49	Williams	26.5
50	Woodland	0.2
51	Anderson	50
52	Woodland	25

Currently 23 are operating, and 10 are idle but operational.

Fig. 1. Current status of California biomass power plants, 2011

Solid fuel biomass currently used in California includes various agricultural residues (mainly orchard and vineyard prunings or whole tree removals), food processing residues (fruit and olive pits, some nut shells, rice hulls), clean urban wood and forest product residues and forest thinnings. At this time, no purpose-grown energy crops are used in California for electricity generation to our knowledge. **These systems were first built in part to reduce pollution from open burning**.

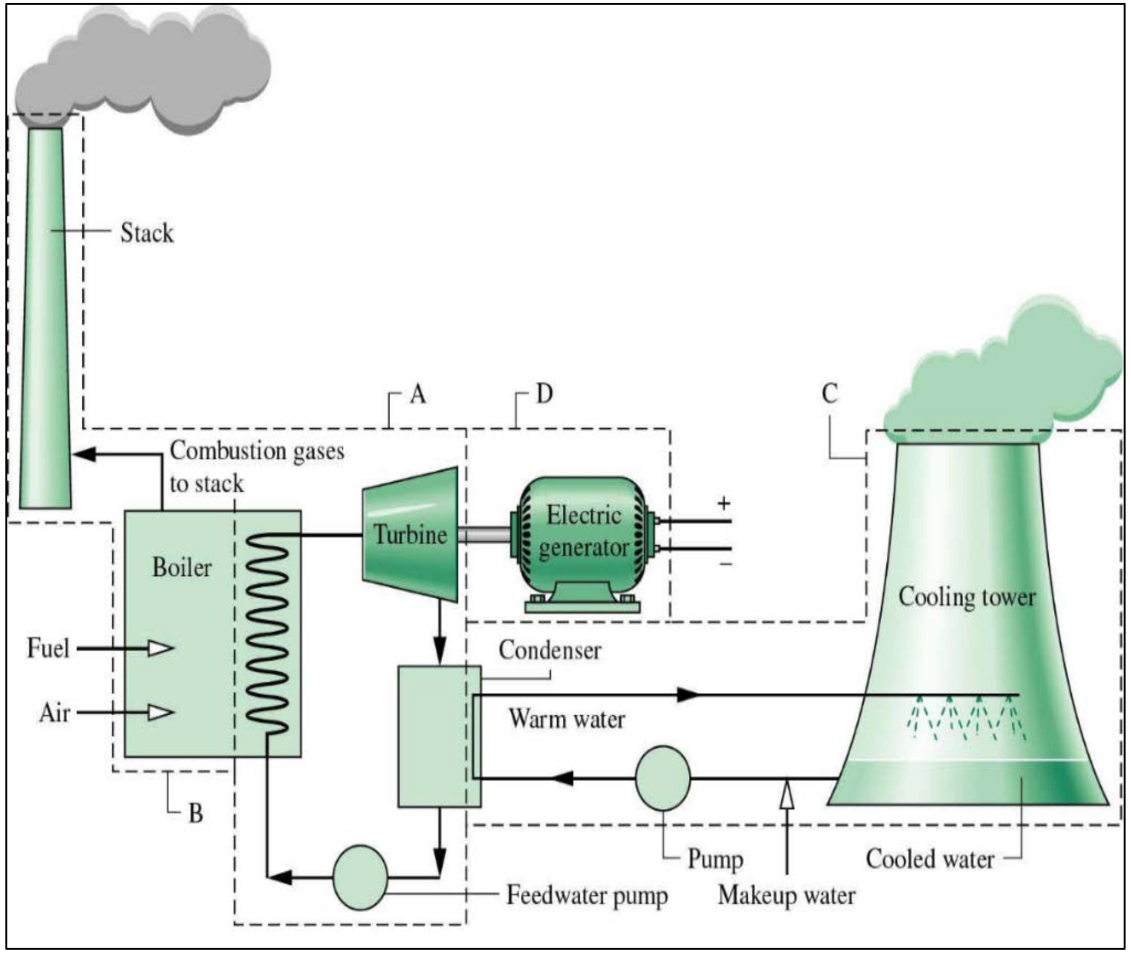
Table 2: Summary of Biopower in California

Facility Type	Net (MW)	Facilities
Solid Fuel (woody& ag.)	575	27
Landfill Gas Projects	270	79
Wastewater Treatment Plant Facilities	88	56
Farm Anaerobic Digestion (AD)	3.8	11
Food Process/Urban AD	0.7	2
Solid Fuel (MSW)	63	3
Totals	1001	178

2016 or older data. There are additional farm and urban AD facilities that have been added since.

Source; Samuelsen, Scott; Bryan Jenkins, Donald Dabdub, Jack Brouwer, Alejandra Cervantes; Brendan Shaffer; Marc Carreras-Sospedra; Robert Williams; Nathan Parker. (Advanced Power and Energy Program). 2016. ***Air Quality and Greenhouse Gas Emissions Impact Assessment from Biomass and Biogas Derived Transportation Fuels and Electricity and Heat Generation.*** California Energy Commission. Publication number: CEC-500-2016-022.

California's biomass to energy systems



Rankine cycle biomass to energy system.

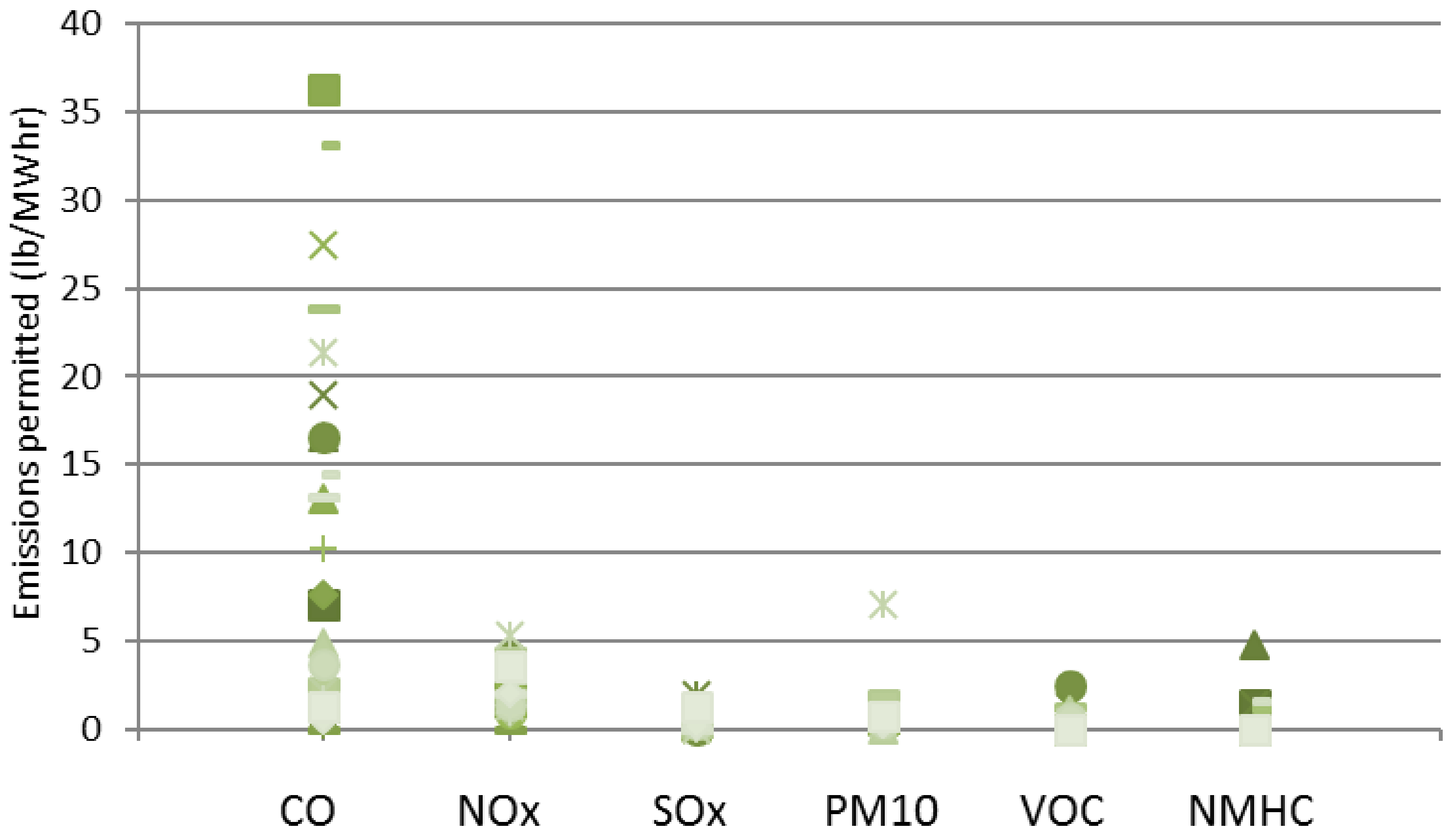
Table 4: Biomass Steam Cycle Efficiency by Boiler Type

Boiler Type	Efficiency (%, HHV basis)	Heat Rate (Btu/kWh)
Stoker	21.7	15724
Circulating Fluidized Bed	22.2	15369
Bubbling Fluidized Bed	26	12827

Current biomass steam plants typically were installed for $2,000-2,800/kWe; current installed costs are $5000-6000/KWe; net efficiencies are from 15-25%; Fuel costs range from 0 - $50/dry ton. Current prices range from approximately $0.08 to 0.12/kWh. These systems are considered by utilities to be expensive, polluting and unnecessary.

Table 4 from Samuelsen, Scott; Bryan Jenkins, Donald Dabdub, Jack Brouwer, Alejandra Cervantes; Brendan Shaffer; Marc Carreras-Sospedra; Robert Williams; Nathan Parker. (Advanced Power and Energy Program). 2016. ***Air Quality and Greenhouse Gas Emissions Impact Assessment from Biomass and Biogas Derived Transportation Fuels and Electricity and Heat Generation.*** California Energy

Commission. Publication number: CEC-500-2016-022.



Permitted emissions at 33 California solid fuel bioenergy facilities

Most air permits regulate emissions of nitrogen oxides (NOx), particulate matter (PM), volatile organic compounds (VOC, or sometimes reactive organic gases, ROG or non-methane hydrocarbons, NMHC), carbon monoxide (CO), and hazardous air pollutants (HAPs) such as hydrogen chloride (HCl). Permits obtained through requests for public information from: Shasta, Tuolumne, Northern Sierra, South Coast, San Joaquin, North Coast Unified, Placer, Monterey Bay, and Yolo-Solano Air Quality Management Districts. (33 facilities). J Button et al, 2012.

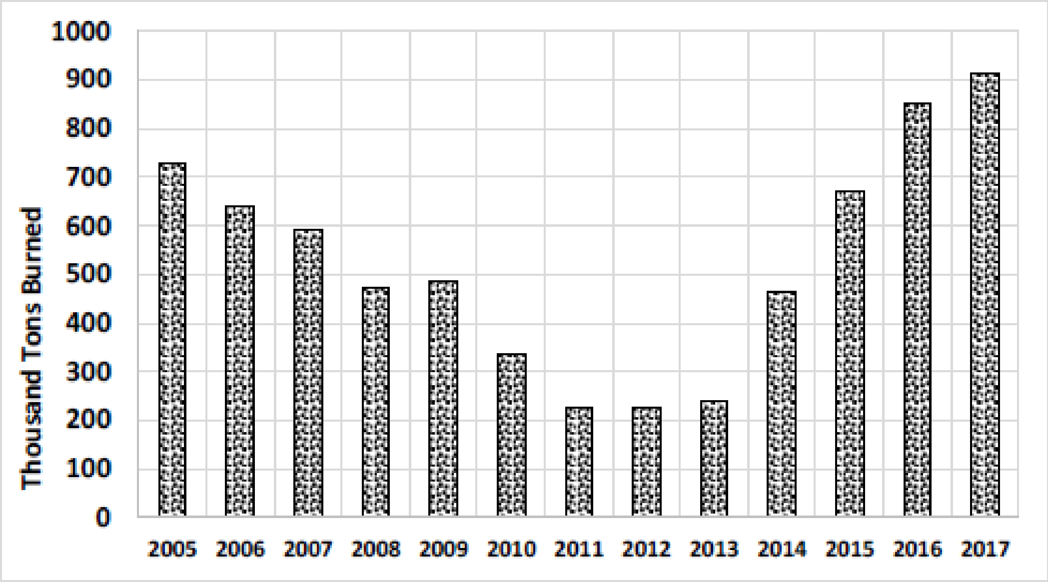


Figure 7. Agricultural residue burn totals for the San Joaquin Valley (thousand tons)

Table 11. Criteria pollutants and GHG open-burn emissions factors (lbs per dry ton consumed).

Fuel Type	Fuel Loading (tons/acre)	Criteria Pollutants (lbs/ton) ‡							GHG (lbs/ton) ‡			GHG (lbs CO2eq/ton)**				Mg CO2eq/ BDT
		PM10	PM25	NOX	SO2	VOC	CO	NH3	CH4	N2O	BC*	CH4	N2O	BC*	Total	
Almond Prunings	1.0	7.00	6.70	5.90	0.10	5.20	52.2	0.82	2.34	0.40	0.35	65.5	106	315	487	0.22
Citrus Prunings	1.0	5.90	5.60	5.20	0.10	6.80	81.0	1.28	2.81	0.40	0.30	78.7	106	266	450	0.20
Walnut Prunings	1.2	4.20	4.00	4.50	0.20	4.80	67.0	1.06	3.28	0.40	0.21	91.8	106	189	387	0.18
Pistachio Prunings	1.7	7.80	7.30	5.20	0.10	6.30	66.0	1.04	3.28	0.40	0.39	91.8	106	351	549	0.24
Orchard Removal	30.0	7.80	7.30	5.20	0.10	6.30	66.0	1.04	2.81	0.40	0.39	78.7	106	351	536	0.25
Vineyard Removal	15.0	7.80	7.30	5.20	0.10	6.30	66.0	1.04	2.81	0.40	0.39	78.7	106	351	536	0.24

Notes:

‡ Jenkins, B. M., I. M. Kennedy, D. P. Y. Chang, O. G. Raabe, S. Q. Turn, R. B. Williams, H. S.G. and S. Teague (1996). Atmospheric Pollutant Emissions Factors from Open Burning of Agricultural and Forest Biomass by Wind Tunnel Simulations, UC Davis. California Air Resources Board contract A932-126.

* Assumes black carbon (BC) is 5% of the PM10 emission (Reid et al., (2005))

** Using 100-year GWP values of 28, 265, and 900 for CH2, N2O, and BC respectively (IPCC AR5, 2013)

Biomass to power facilities reduce these emission levels by up to 98%.

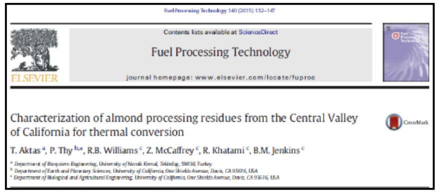
Source: Williams and Kaffka, 2019; Projected biomass availability from tree nuts in the central valley. (in prep)

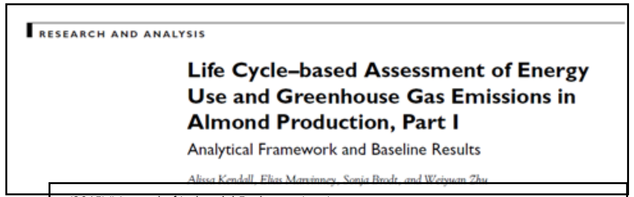
Tree nuts and deciduous fruits and vines: GHG & Energy

With the rapid expansion of tree and vine acreage in California, a significant amount of woody biomass is available when older orchards and vineyards are removed. This biomass has potential for power, liquid fuel or biogas production. Open burning increases SLCPs and GHG emissions and wastes valuable biomass resources.

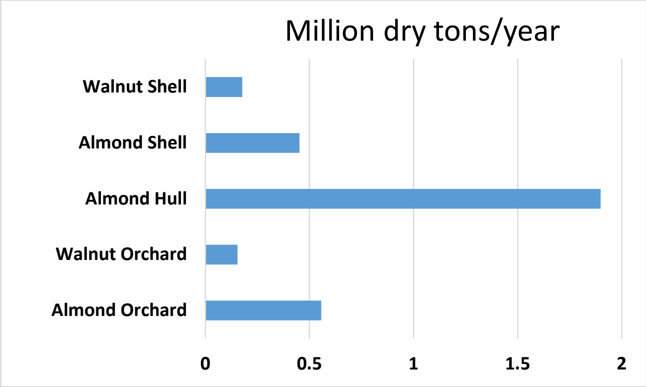
California Almond Industry

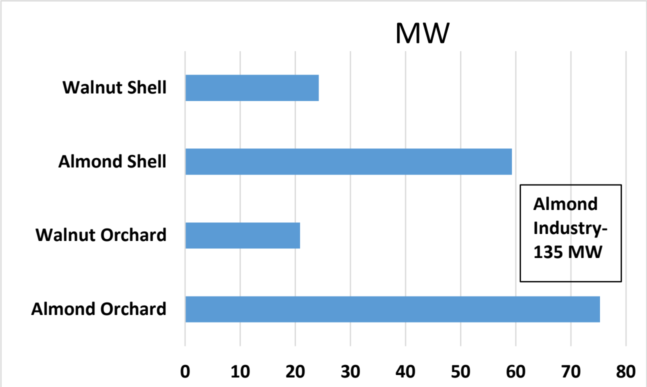
- Significant resource from residues : hulls, shells and orchard prunings/removals
- Electricity : 135 MW potential
- Renewable Natural Gas:
  - 8.7 million MMBtu
  - 75 million gallons gasoline equiv.

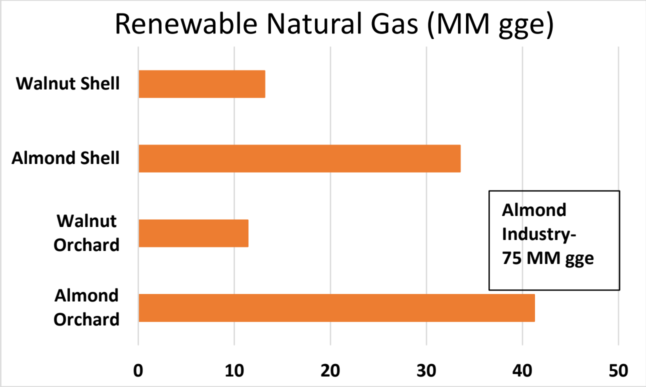

Fuel Processing Technology 140 (2015) 132–147
Contents lists available at ScienceDirect
Fuel Processing Technology
journal homepage: www.elsevier.com/locate/fuproc
Characterization of almond processing residues from the Central Valley of California for thermal conversion
T. Aktas [a], P. Thy [b,*], R.B. Williams [c], Z. McCaffrey [c], R. Khatami [c], B.M. Jenkins [c]
[a] Department of Biosystem Engineering, University of Namik Kemal, Tekirdag, 59030, Turkey
[b] Department of Earth and Planetary Sciences, University of California, One Shields Avenue, Davis, CA 95616, USA
[c] Department of Biological and Agricultural Engineering, University of California, One Shields Avenue, Davis, CA 95616, USA


RESEARCH AND ANALYSIS
Life Cycle–based Assessment of Energy Use and Greenhouse Gas Emissions in Almond Production, Part I
Analytical Framework and Baseline Results

(2015)." Journal of Industrial Ecology: n/a-n/a.
http://onlinelibrary.wiley.com/doi/10.1111/jiec.12332/abstract







Williams et al., (2015)

LCA estimates of tree nut carbon production costs were reduced by energy recovery. GHG emissions from CA agriculture increase with the loss of this pathway.

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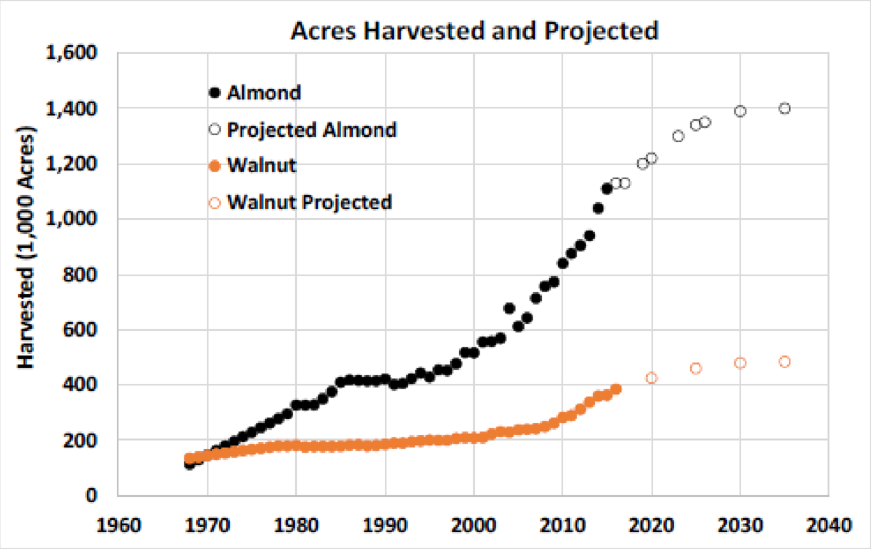

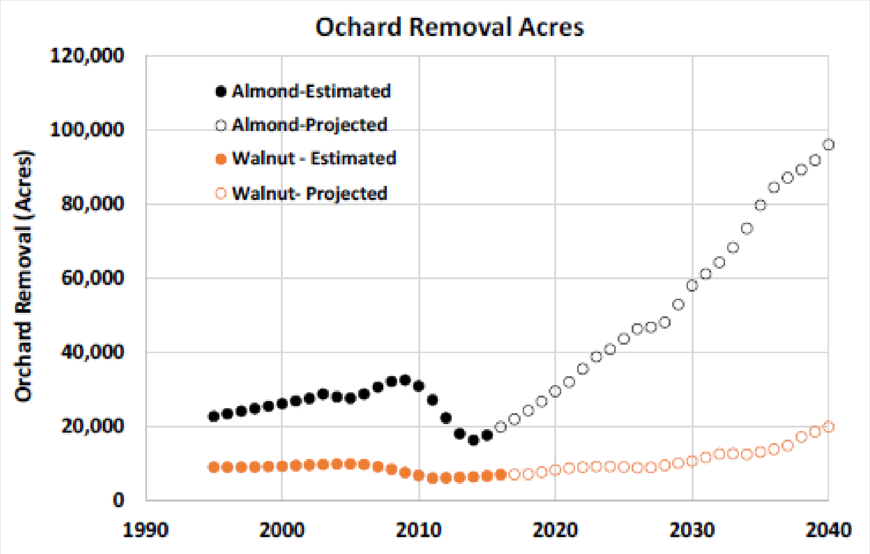

Biomass to power facilities were estimated to consume 700K BDT/y of orchard residuals. **The amount available is expected to increase significantly in the next two decades** due to aging orchards and increased acreage of tree nuts.

Table 8. Projected gross biomass (current to 2035), 1000 BDT.

Gross Biomass (1000 BDT)	Almond Shell	Almond Orchard Removals and Prunings	Walnut Shell	Walnut Orchard Removals and Prunings	Pistachio Shell	Total
Current	628	435	354	159	16	1593
2020	691	669	414	204	-	1977
2025	759	950	448	223	-	2380
2035	793	1641	472	318	-	3224

Table 9. Projected available biomass (current to 2035), 1000 BDT.

Technically Available (1000 BDT)	Almond Shell	Almond Orchard Removals and Prunings	Walnut Shell	Walnut Orchard Removals and Prunings	Pistachio Shell	Total
Current	539	25	303	9	16	893
2020	601	259	363	53	-	1277
2025	669	540	397	73	-	1680
2035	703	1232	421	168	-	2524

Note: Assumes no change in fuel demand from biomass power (i.e., 700,000 BDT/y is subtracted from "Gross" amount.

Source: Williams and Kaffka, 2019; Projected biomass availability from tree nuts in the central valley. (in prep)

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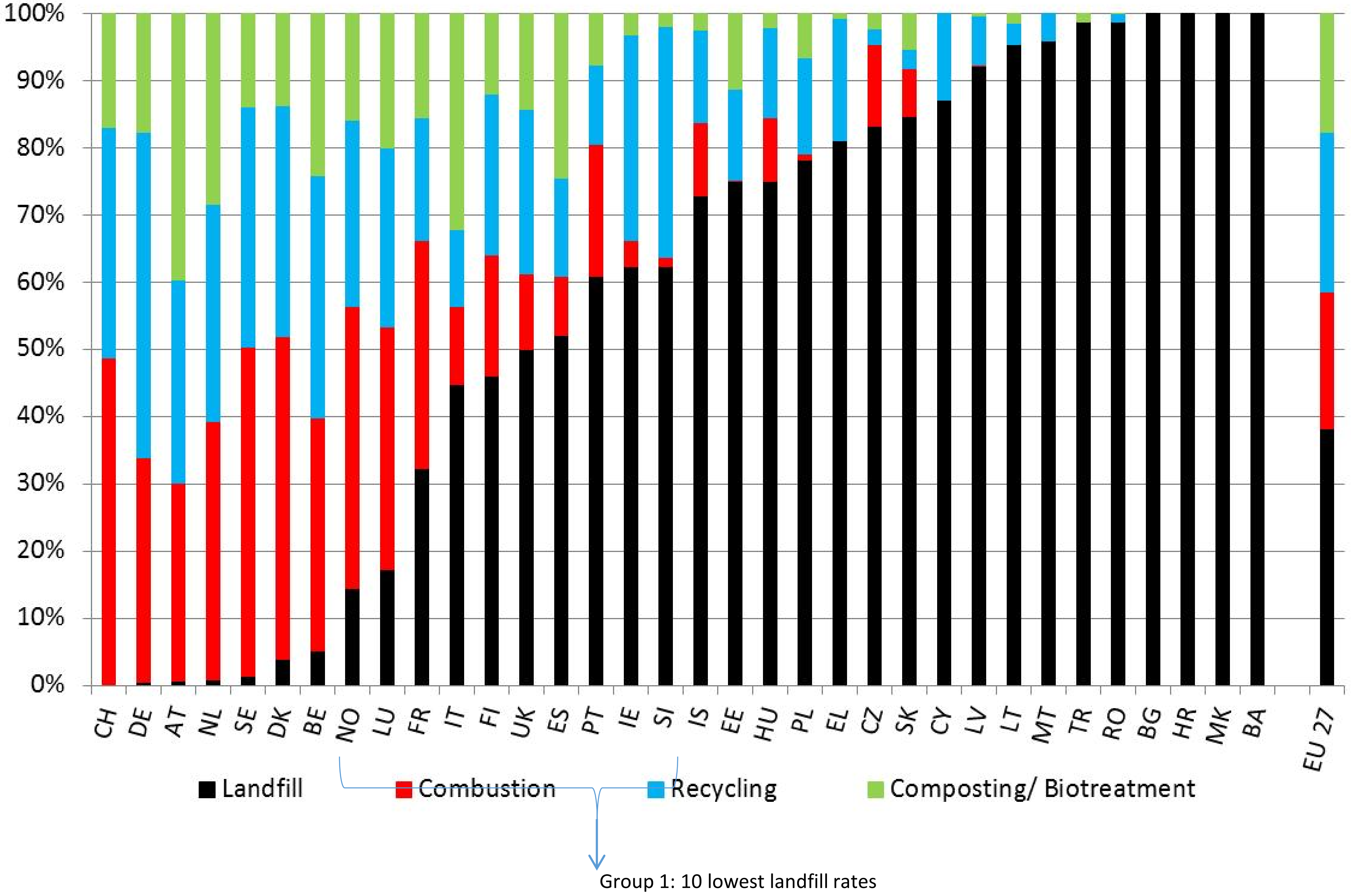
Disposition of MSW in Europe



Group 1: Switzerland, Germany, Austria, Netherlands, Sweden, Denmark, Belgium, Norway, Luxembourg, France;

Composting, AD, recycling and combustion are all accommodated.

Eurostat (2011)

Stockholm CHP system

Bioenergy's role in balancing the electricity grid and providing storage options – an EU perspective: IEA Bioenergy 2017

The EU is committed to the use of biomass as a fuel source for power, primarily through co-firing with coal or natural gas. Many systems there capture waste heat for community uses. Properly sourced biomass is considered carbon-neutral.

Another recommended approach is to treat biomass as a solar storage system that can be used for load balancing and priced as a peak supply source.

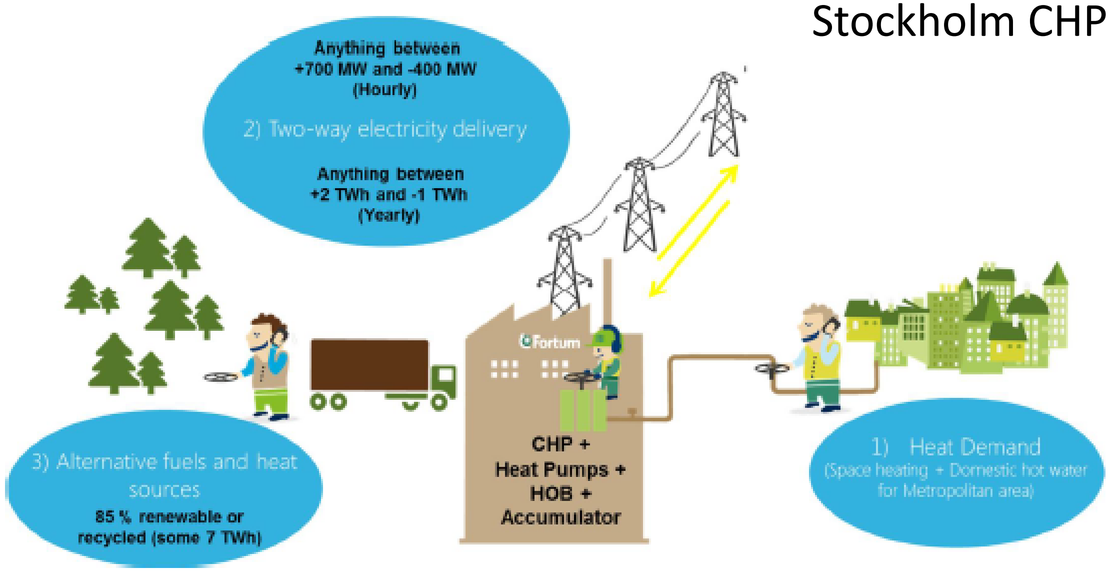


Figure 31. Characteristics and technologies utilized in Stockholm CHP system

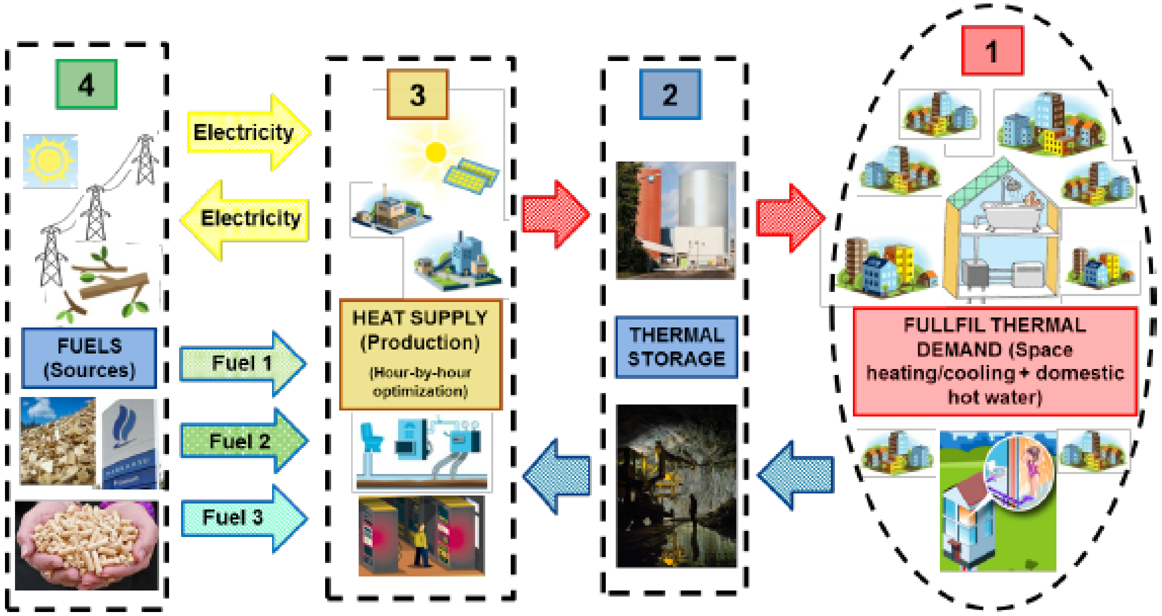


Figure 32. Customer need being satisfied by the smart energy system operator

Advanced Thermal Pathways:

(Combustion, Gasification, Pyrolysis)

- Characterized by high temperature and high rates of conversion,
- Ability to covert all or most of biomass feedstock (cellulose, hemicellulose & lignin)
- Dryer (lower moisture) feedstocks preferred

Thermal Gasification

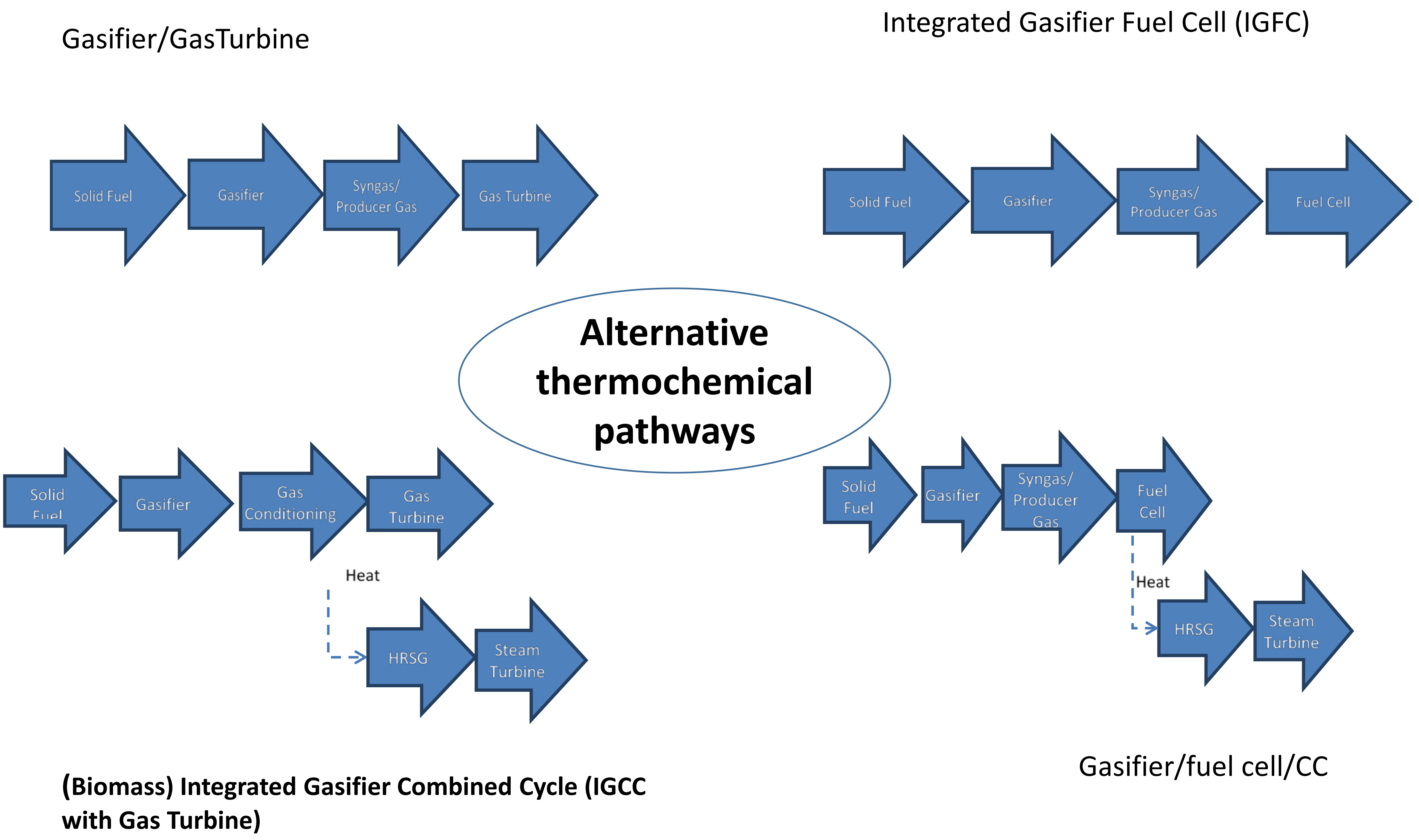
Fuel + Oxidant/Heat

$\downarrow$

Partial Oxidation/Air or Oxygen
Steam/Carbon Dioxide/Hydrogen
Indirect Heating

CO + H_2 + HC + CO_2 + N_2 + H_2O + Char + Tar + PM + H_2S + NH_3 + Other + Heat

B. M. Jenkins


Gasifier/GasTurbine
Solid Fuel
Gasifier
Syngas/ Producer Gas
Gas Turbine
Integrated Gasifier Fuel Cell (IGFC)
Solid Fuel
Gasifier
Syngas/ Producer Gas
Fuel Cell
Alternative thermochemical pathways
Solid
Gasifier
Gas Conditioning
Gas Turbine
Heat
HRSG
Steam Turbine
Solid Fuel
Gasifier
Syngas/ Producer Gas
Fuel Cell
Heat
HRSG
Steam Turbine
(Biomass) Integrated Gasifier Combined Cycle (IGCC with Gas Turbine)
Gasifier/fuel cell/CC




Presentation of Research Findings by the California Renewable Energy Center

Rob Williams
California Biomass Collaborative, UC Davis

Research Results Forum for Renewable Energy Technology and Resource Assessments

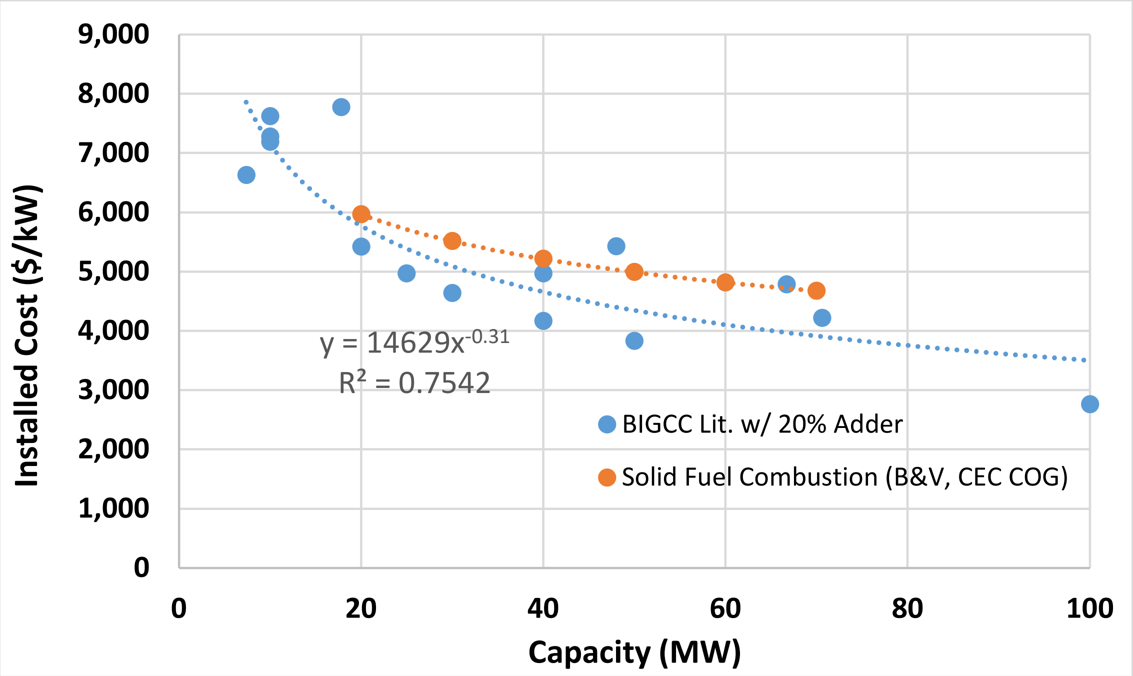
Public Workshop at the California Energy Commission (CEC)

September 3, 2014

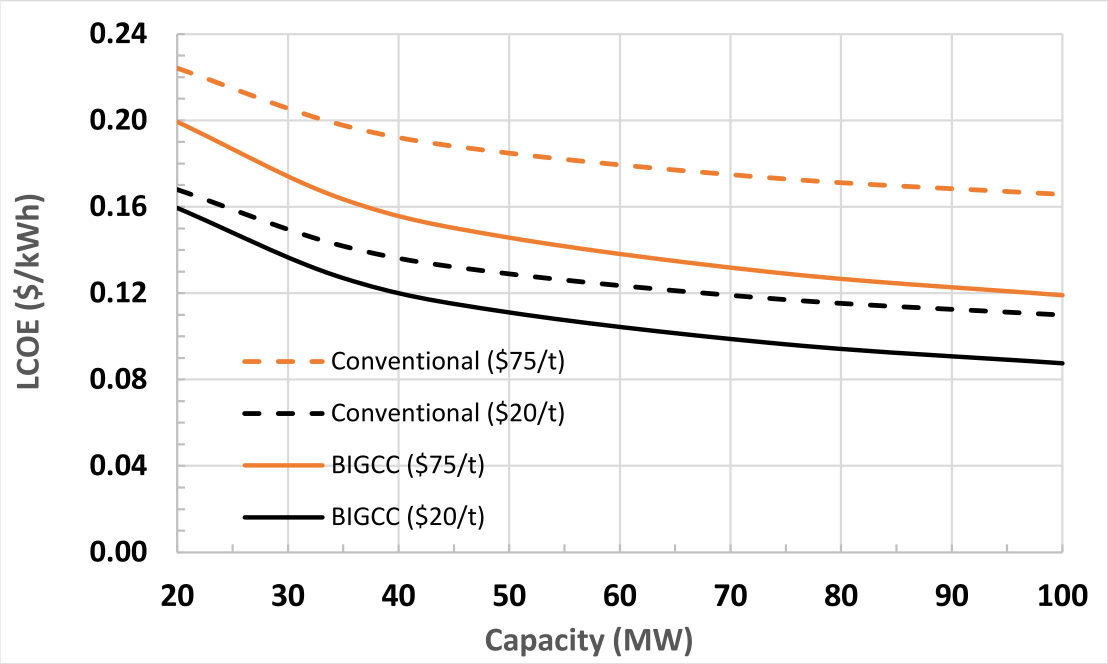
UC DAVIS
UNIVERSITY OF CALIFORNIA

California Renewable Energy Center

Biomass Integrated-Gasification- Combined-Cycle (BIGCC)- Williams 2014



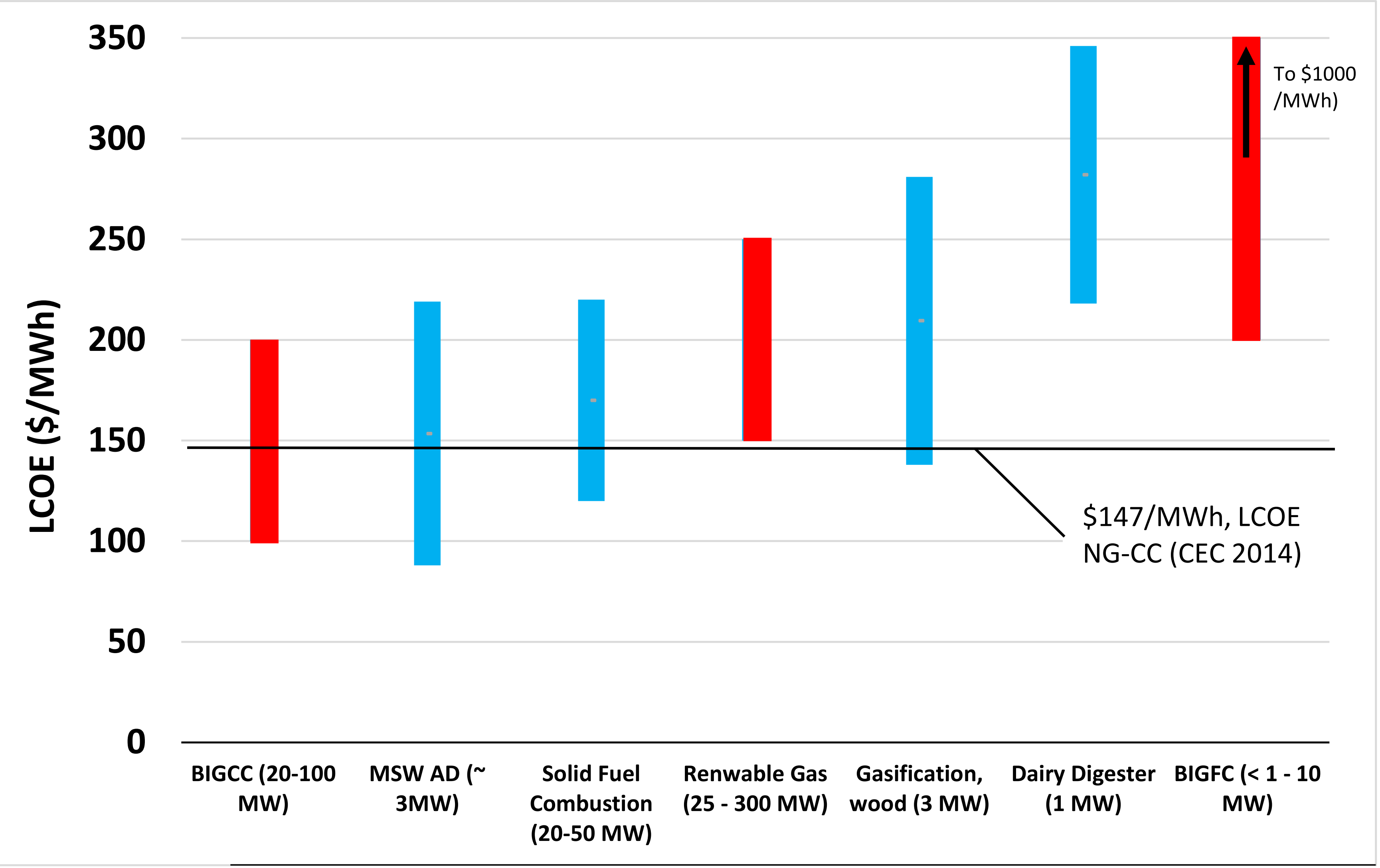
Installed cost estimates from techno-economic modeling literature* (year 2014 with CPI price inflator)



LCOE, Conventional & BIGCC for two fuel costs ($20/BDT and $75/BDT)

LCOE Summary

- LCOE Summary:
  - RED bars : Advanced systems reviewed in project
  - BLUE bars: Conventional systems



Williams, 2014/CREC report

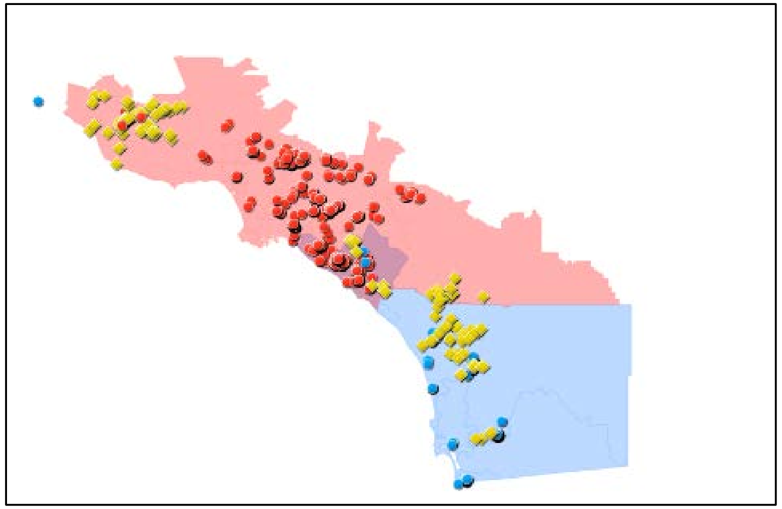
An invasive beetle is prompting removal of trees on the UC Irvine campus…

http://news.uci.edu/research/regional-beetle-infestation-prompts-removal-of-uci-trees/

Polyphagous Shot Hole Borer (PSHB) at UC Irvine: Tuesday, November 1, 2016– "The Polyphagous Shot Hole Borer (PSHB) and plant disease known as Fusarium dieback persist within UCI's urban forest and natural areas and continue to spread across the region. A recent survey at UCI identified 1,500 trees with PSHB and Fusarium dieback within the campus core and student housing areas. Approximately 1,000 trees have also been identified with the beetle-disease complex in University Hills**. Shot Hole Borers … have now spread throughout Orange, San Diego, Los Angeles, Riverside, San Bernardino, and Ventura counties and their occurrence has been recently confirmed in Santa Barbara County**. **The beetle-disease complex has caused severe damage to a wide variety of trees within both urban forests and natural areas."**

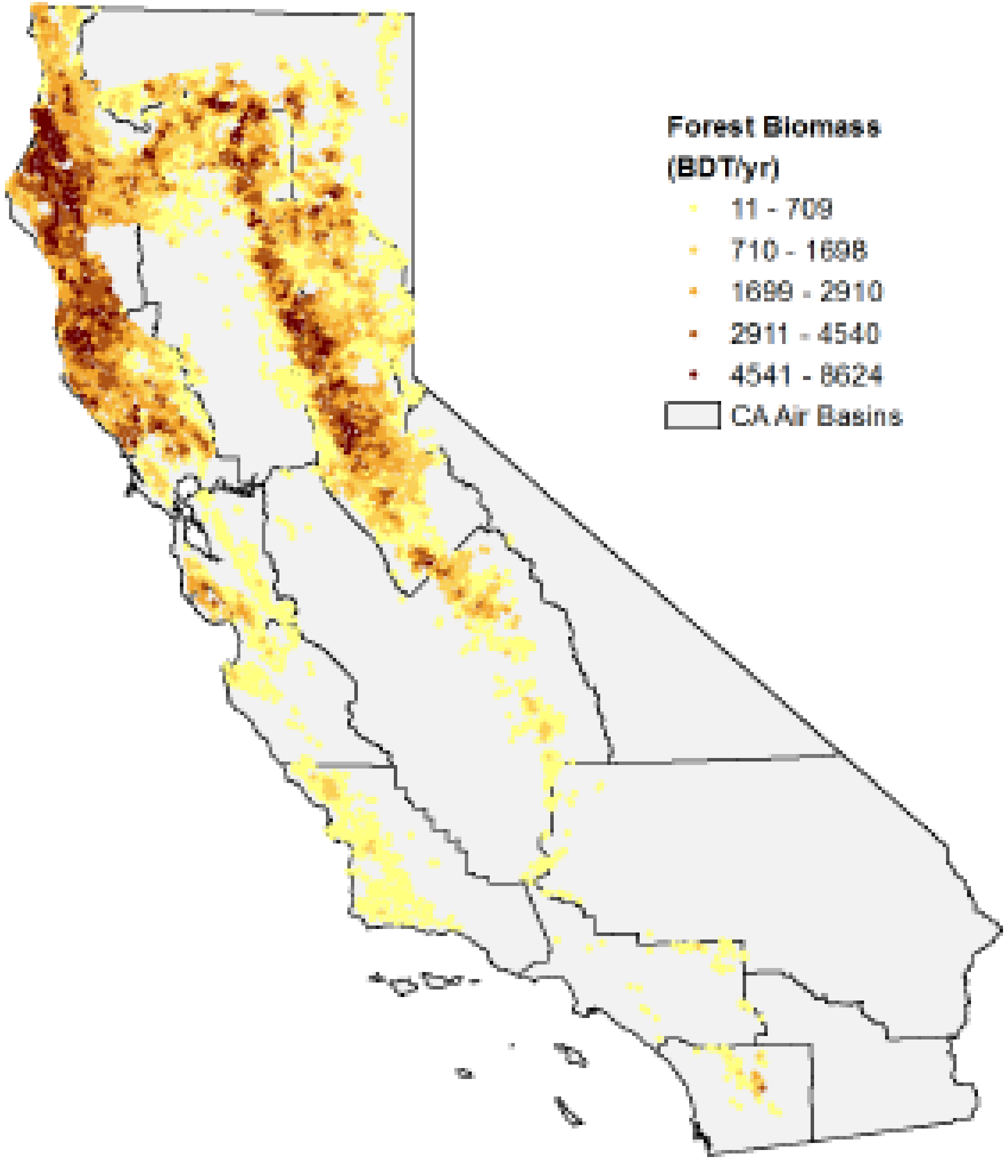
The Polyphagous Shot Hole Borer (PSHB) is a new pest in Southern California. This boring beetle, from the group of beetles known as ambrosia beetles, drills into trees and brings with it a pathogenic fungus (*Fusarium euwallacea*), as well as other fungal species that may to help establish the colonies. **The PSHB attacks many species of trees**, …including box elder, **California sycamore**, London plane, **Coast live oak**, Avocado, White alder, Japanese maple, Liquidambar, and Red willow …
http://ucanr.edu/sites/socaloakpests/Polyphagous_Shot_Hole_Borer/

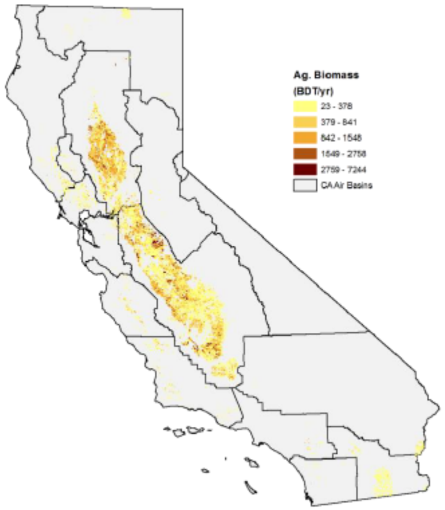
Chipping disperses this dangerous, invasive pest. Landfilling is not viable. Thermal gasification would be an ideal way to deal with this biomass and may become an urgent need in Southern California. No viable alternative is currently available.

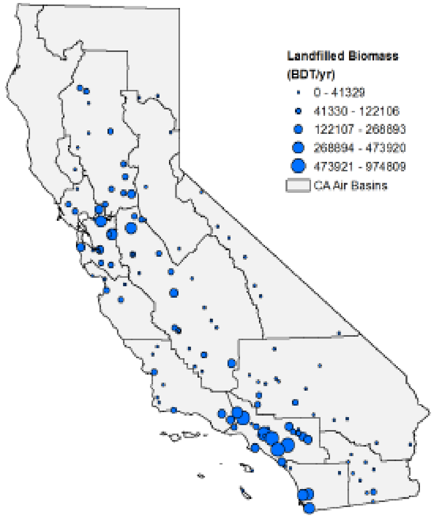


Advanced combustion (gasification) systems. These are not commercially available yet to our knowledge. An exception: **National Carbon Technologies** (https://national-carbon.com/) which produces power, but also valuable, 'high-performing" carbon bio-products including metallurgical carbon, activated carbon, energy carbon (similar to torrefied biomass) and biochar from hardwood and softwood residues at scale in Michigan. They use a high temperature pyrolysis system (details are proprietary).

Primarily bioproducts from large-scale pyrolysis, but also creates power







Samuelsen, Scott; Bryan Jenkins, Donald Dabdub, Jack Brouwer, Alejandra Cervantes; Brendan Shaffer; Marc Carreras-Sospedra; Robert Williams; Nathan Parker. (Advanced Power and Energy Program). 2016. ***Air Quality and Greenhouse Gas Emissions Impact Assessment from Biomass and Biogas Derived Transportation Fuels and Electricity and Heat Generation.*** California Energy Commission. Publication number: CEC-500-2016-022.

SF Chronicle (11-230-18): “Butte County’s Camp Fire not only claimed a staggering amount of lives and property, **it spewed out a whole lot of greenhouse gases - about as much as all of California’s cars and trucks produce in a week,** according to new state estimates. …

Last year, **the cumulative amount of greenhouse gases released by California fires was equal to about 9 percent of the total generated by human activity statewide**. And the problem doesn’t end there. **These fires are burning down forests that, when healthy, absorb heat-trapping gas and help stabilize the Earth’s temperature**. That absorption is being lost.

Whether California’s forests are now taking in more greenhouse gases, or giving off more, remains in dispute. **But climate scientists agree that the balance is heading in a bad direction**.”

Is the state loosing ground?

Potential for Biofuel Production from Forest Woody Biomass/ Mitchell et al., 2015 (STEPS/ITS) for CEC
https://biomass.ucdavis.edu/

Bioenergy from Forest Woody Biomass

What is the effect of forest management and policy on woody biomass availability for the bioenergy industry in California?

What are the optimal locations and size of potential biorefineries based on forest biomass feedstock supply chain optimization?

A spatially explicit modeling approach:

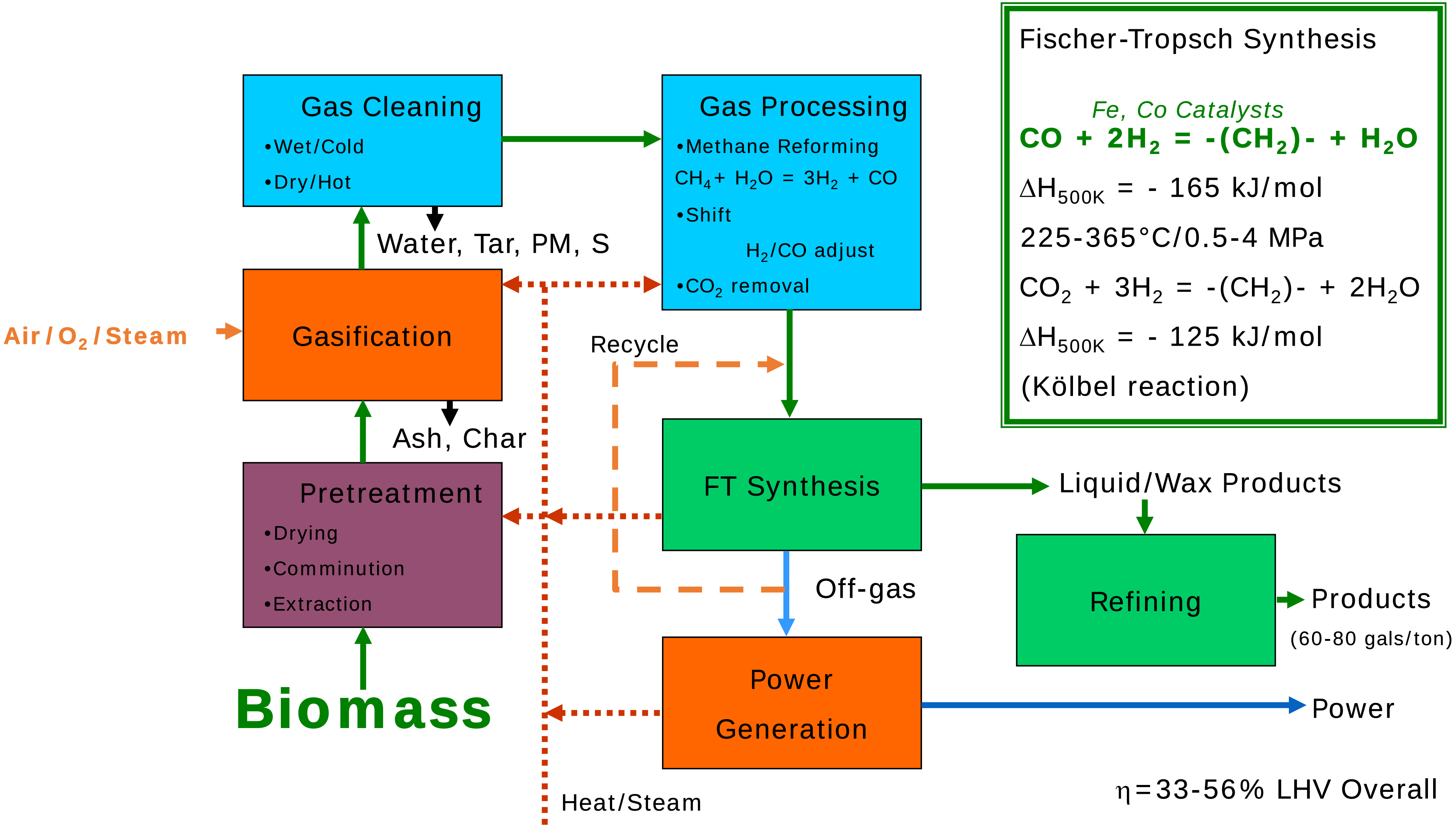
1. Potential forest residuals resource assessment using **BioSUM 5.2** model developed by USDA Forest Inventory Analysis (FIA) unit and co-developed for California by UC Berkeley.
2. Optimal siting and size of biorefineries in CA using the **Geospatial Biorefinery Siting Model (GBSM)** developed by UC Davis.

USDA FIA
BioSUM 5.2

UC Davis
GBSM

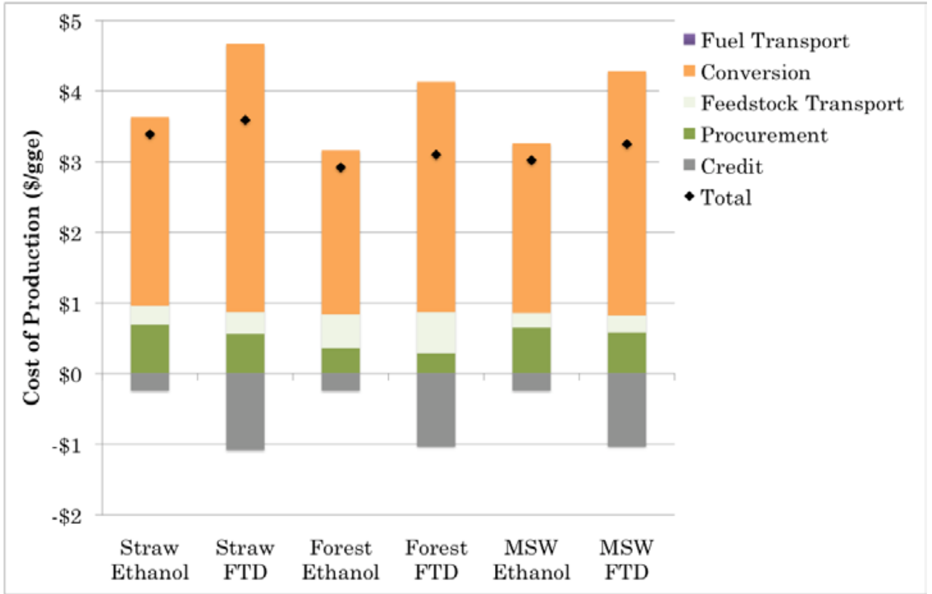
CALIFORNIA BIOMASS COLLABORATIVE

BTL: Biomass To Liquids

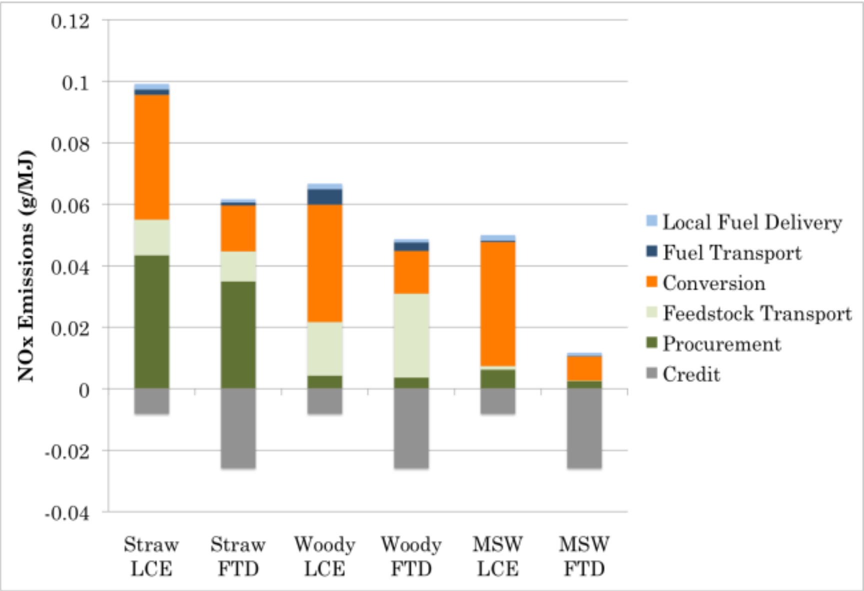


Sample Results BioSUM and GBSM

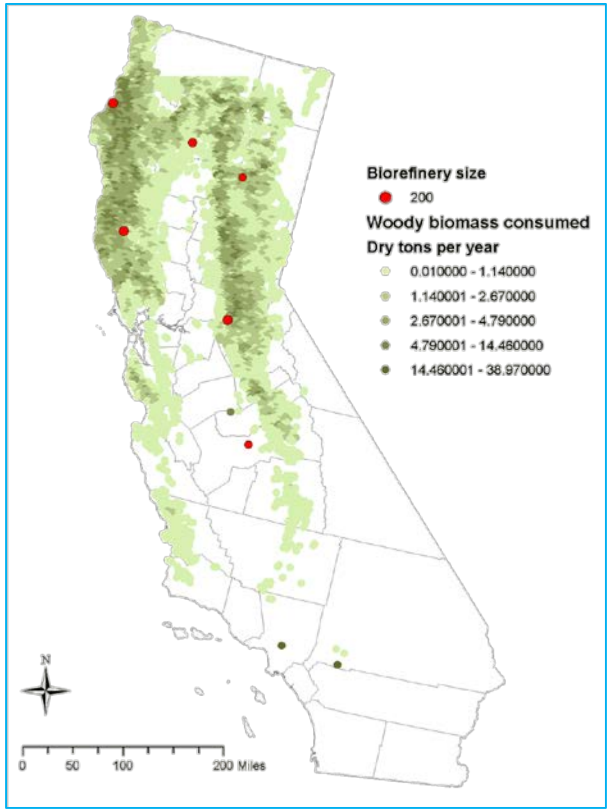
What are the optimal locations and size of potential biorefineries based on forest biomass feedstock supply chain optimization?



Breakdown of costs for optimally sited biorefineries



Breakdown of NOx emissions for optimally sited biorefineries



Example of optimal biorefinery locations

CALIFORNIA BIOMASS COLLABORATIVE

Over the **40-year simulation period**, *California forests generate forest residue of about 177 million bone-dry-tons (BDT) on private land, and 100 million BDT on federal land, for a total of 277 million BDT. On average, this is about 7 million BDT of forest woody biomass per year across the state.*

The largest total cumulative amount of woody biomass comes from North Coast private lands, with over 74 million BDTs. Standardized on a per acre basis, Western Sierra private lands have the greatest output, 34 BDT/acre, and the Southern Oregon/Northeast California public lands have the least output, 12 BDT/acre.

GBSM was run for two conversion technologies; biochemical cellulosic ethanol and gasification-synthesis of drop-in fuels (Fischer-Tropsch, FTD). *Cellulosic ethanol biofuel production ranged from 45 million gasoline gallon equivalents per year (MGGEY) to 154 MGGEY with minimum selling prices from \$3.85/gge to \$4.85/gge. FTD production estimates ranged from 17 MGGEY to 241 MGGEY with minimum selling prices from \$3.40/gge to \$4.80/gge.*

The value of biofuels would need to be greater than those observed in the current market to make the system profitable. However, prices of \$20.00 per Low Carbon Fuel Standard credit and \$0.75 per Renewable Fuel Standard cellulosic RIN would provide residue-based biofuels an additional value of roughly \$1.25/gge. The best performing biorefineries analyzed here are economic with the \$1.25/gge subsidy.

Figure 11. Biorefinery Siting of a Potential Drop-In Fuel Industry. Left: biorefinery location and feedstock shed for ten biorefineries.[1] Right: the quantity of biomass supply available and the average price at delivery to the biorefinery.[2]

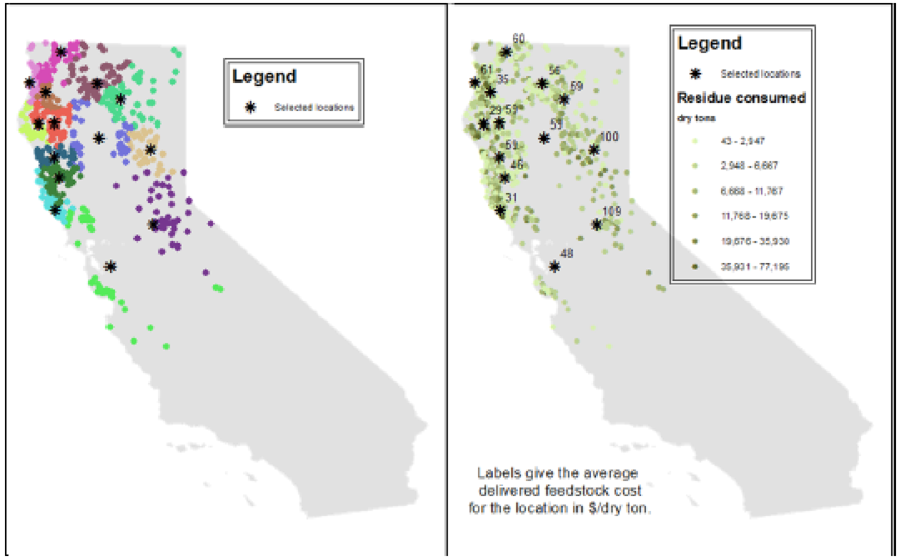
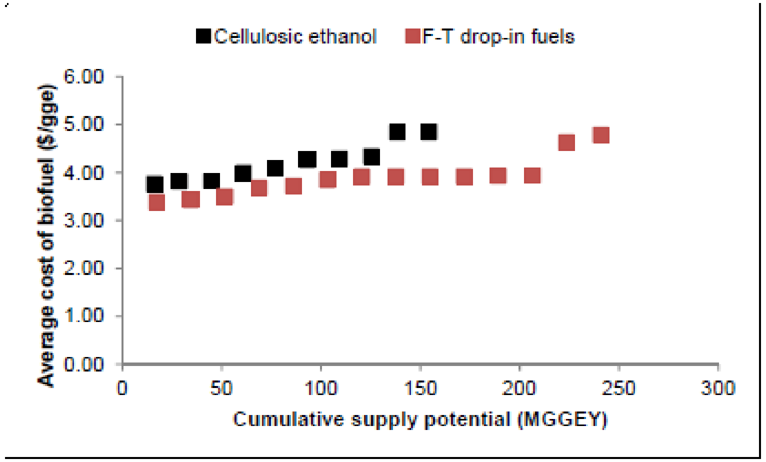
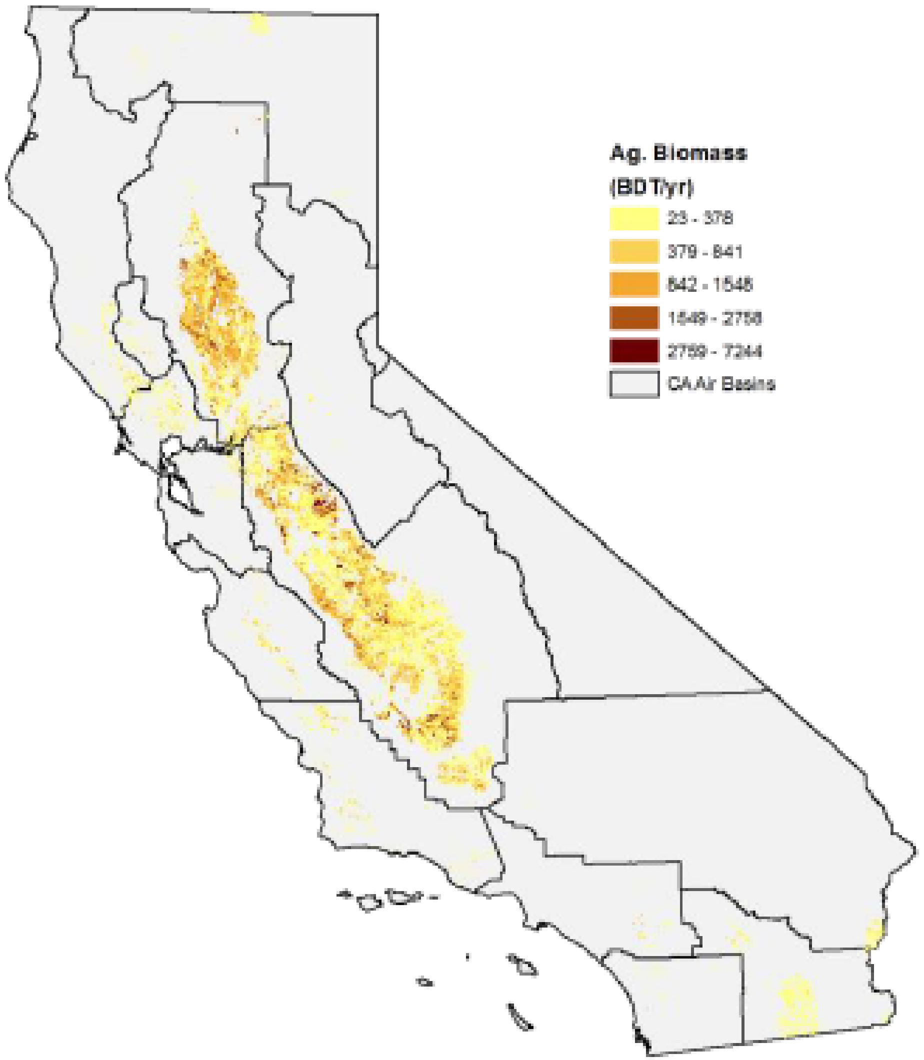
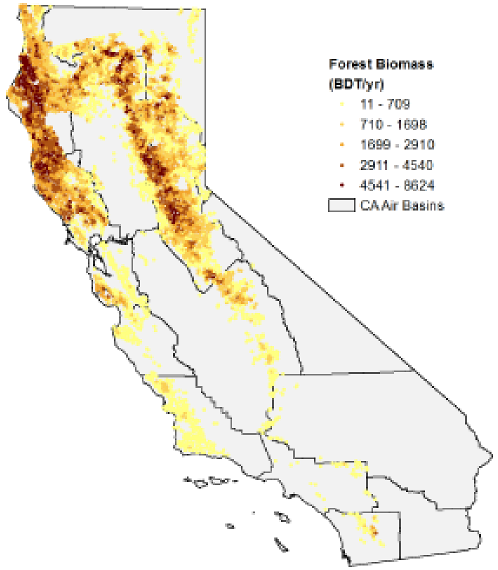


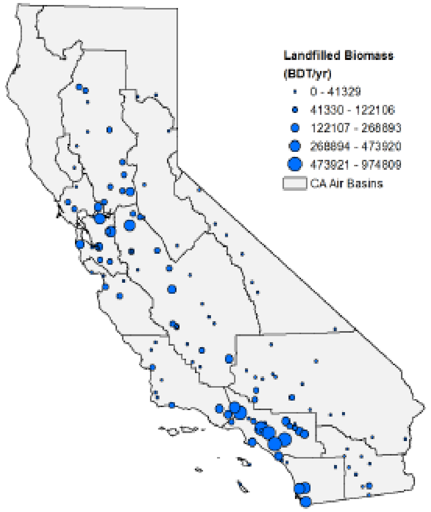
Figure 10. Supply Curve for Biofuels from Forest Residues[1]



[1] MGGEY is million gallon gasoline equivalent per year







Samuelsen, Scott; Bryan Jenkins, Donald Dabdub, Jack Brouwer, Alejandra Cervantes; Brendan Shaffer; Marc Carreras-Sospedra; Robert Williams; Nathan Parker. (Advanced Power and Energy Program). 2016. ***Air Quality and Greenhouse Gas Emissions Impact Assessment from Biomass and Biogas Derived Transportation Fuels and Electricity and Heat Generation.*** California Energy Commission. Publication number: CEC-500-2016-022.

"**Transportation is the single largest emitting sector in California** … California's plans for addressing emissions from this sector rely on deploying alternative fuel vehicles, including electric vehicles; increasing vehicle fuel efficiency; **decreasing the carbon intensity of fuels**; and reducing vehicle-miles traveled."

"**Clean fuels** (e.g., **renewable natural gas [RNG], hydrogen, biofuels**) **are critical clean energy pathways due to the enormous value of fuels to flexible operations of energy systems. Fuels that are durable, storable, and easily transportable play a fundamental role**."

"**The development of RNG in California has multiple tangible benefits**: RNG is a carbon neutral fuel; RNG diverts methane from being released into the atmosphere, **enabling major emissions reductions from the difficult-to-decarbonize Industry and Agriculture sectors**; and it leverages existing carbon infrastructure, potentially **avoiding the costly stranding of these established systems and their associated workforces**, as well as their time-consuming and costly replacement."

Optionality, Flexibility, & Innovation: Pathways for Deep Decarbonization in California. Energy Futures Initiative, April 2019

The San Joaquin Valley is home to more than 1,000,000 dairy cows, primarily in Tulare, Kern and Merced Counties

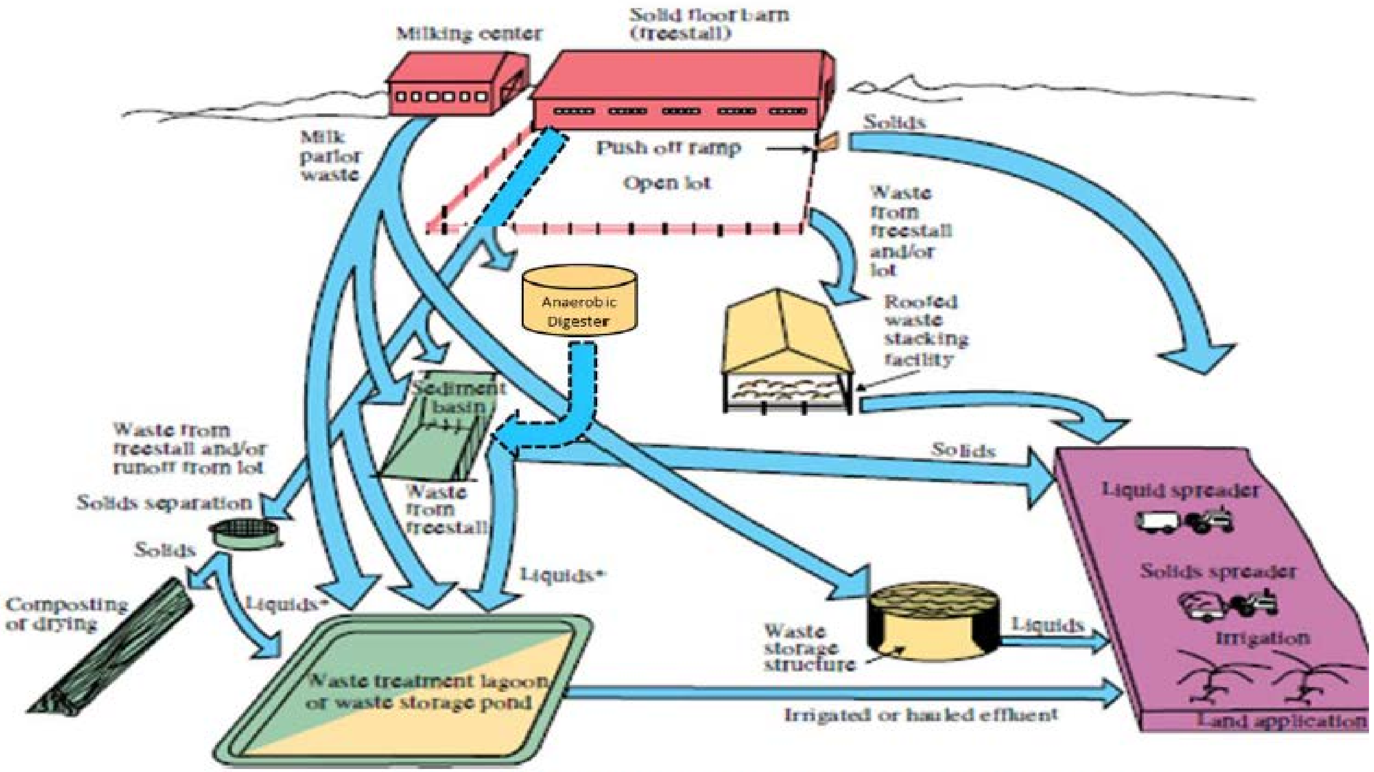


Figure 2.1: Typical Dairy Manure Management Handling Options. Adapted from Figure 9-3 of AWMFH (USEPA, 1992)
http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=31493.wba
(Slurry manure from free stall barn and anaerobic digester added)

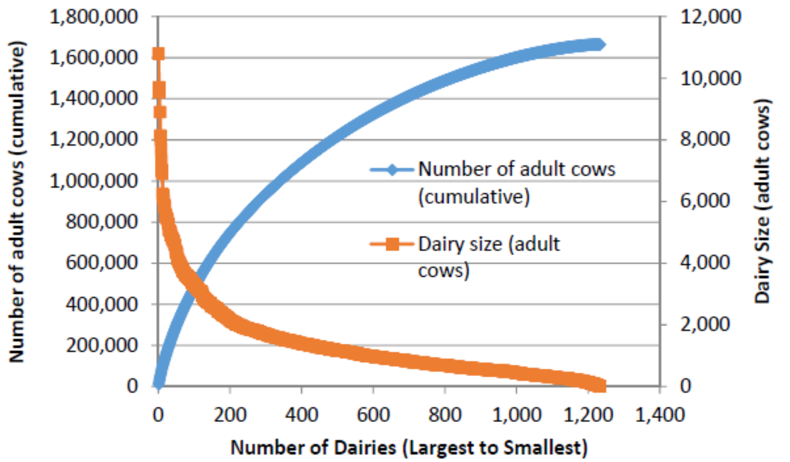


Figure 2.2: Dairy sizes and numbers included in statewide full report database used

Table 2.1: California Dairy and Agriculture Sector GHG Emissions

Activity	2012 GHG Emissions ($Tg\ CO_{2eq}$)	Fraction of State Total (%)
Dairy Manure - Anaerobic Lagoon	9.04	2.0
Dairy Manure – Other	2.36	0.5
Dairy Enteric Fermentation	8.22	1.8
Dairy Total	19.6	4.3
All Agriculture	34.1	7.4

State Total GHG emissions are ~459 Tg Co_{2eq}.
*Source: http://www.arb.ca.gov/cc/inventory/data/data.htm , March 2014 update. Accessed Feb., 2015

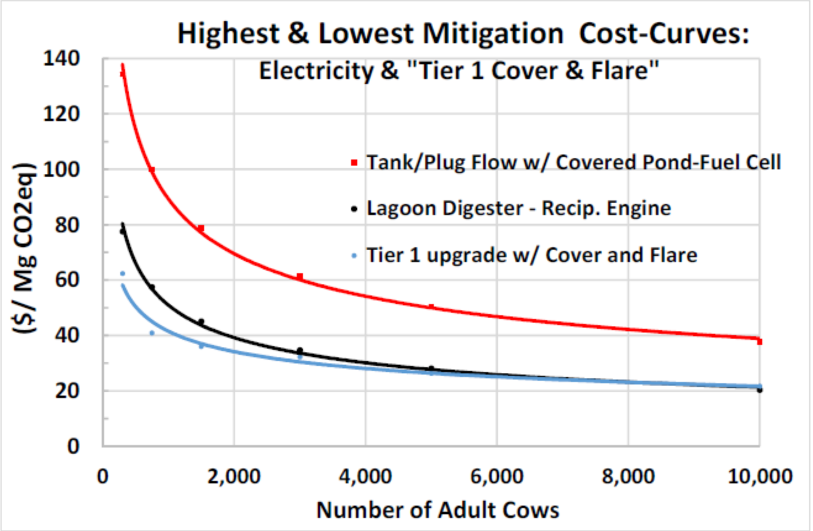


Figure 3-3: Highest and lowest mitigation cost curves; digester-electricity and cover and flare

Source: Evaluation of Dairy Manure Management Practices for Greenhouse Gas Emissions Mitigation in California1 FINAL TECHNICAL REPORT to the State of California Air Resources Board Contract # 14-456 February 26, 2016

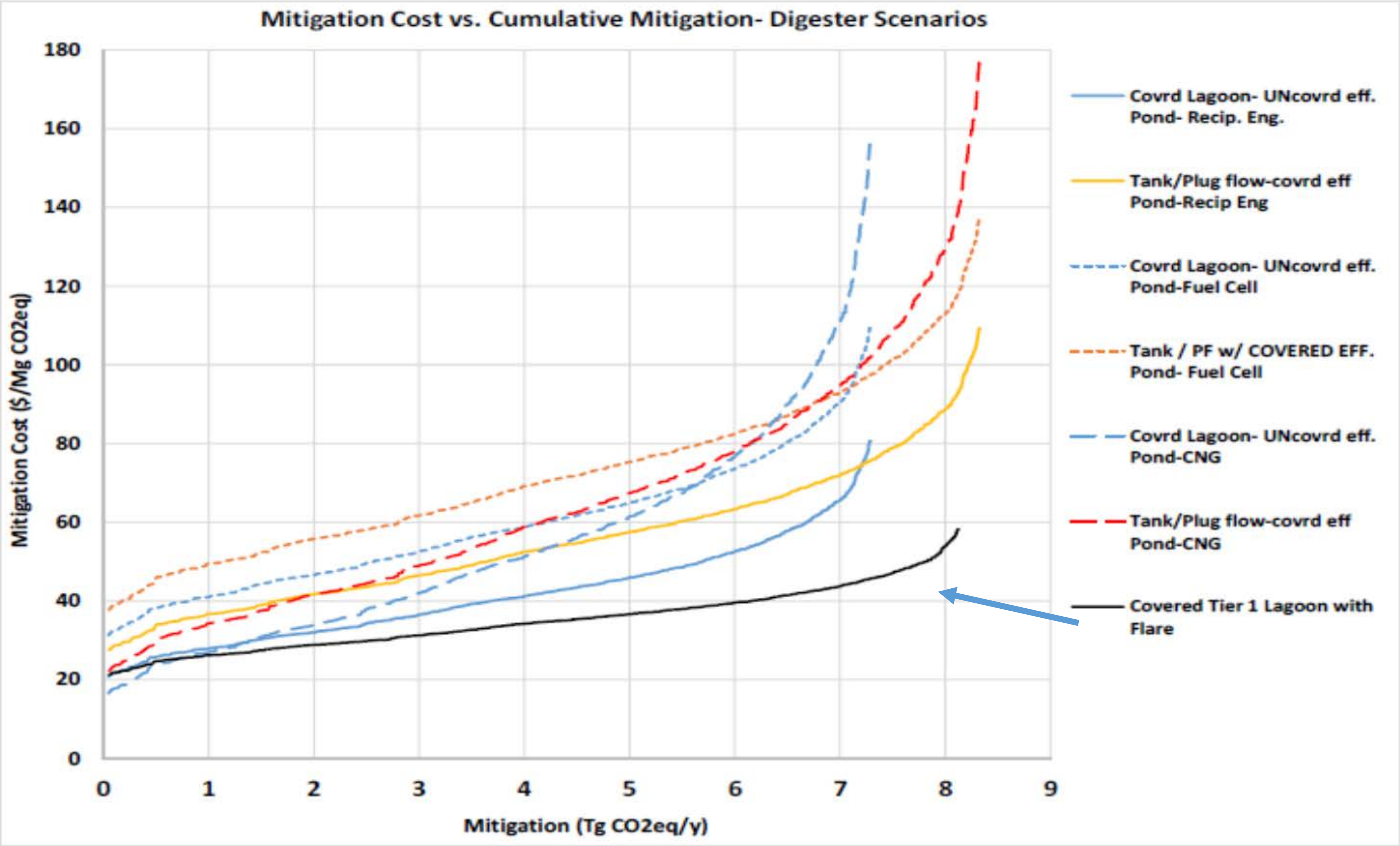


Figure 3.5: Anaerobic Digestion Mitigation cost supply curve, largest to smallest dairies ($/Mg CO_{2eq} vs. Cumulative Mitigation)

Each of the current ethanol refineries in California are evolving into integrated biorefineries. The LCFS and RFS support investments in innovative technologies and alternative feedstock uses.

Aemetis, Keyes, CA; 55mgy

Calgren, Pixley CA; 60 mgy

Biofuel Facilities

	(MGY)	Facilities
Ethanol	179	4
Biodiesel	62.1	13
Totals	241.1	17

Stockton; 60 mgy

Madera; 40 mgy

Pacific Ethanol

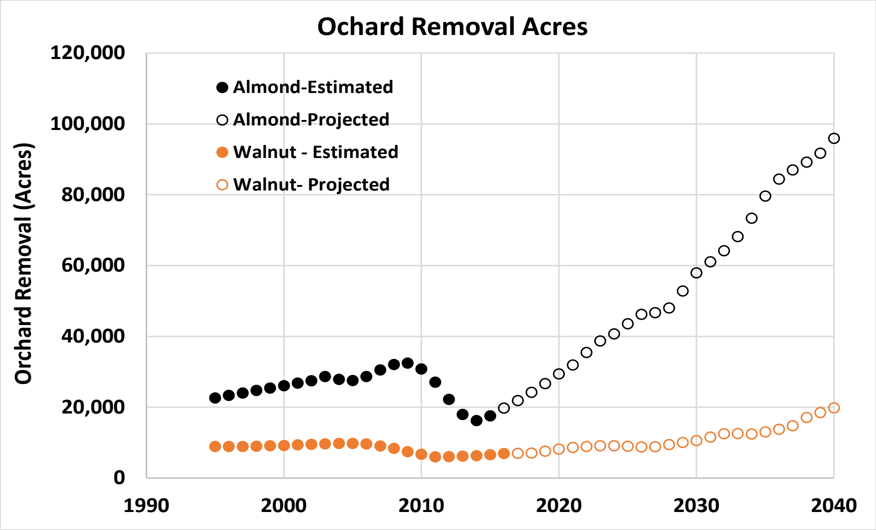
Aemetis, Keyes, CA; 55mgy

Calgren, Pixley CA; 60 mgy

Stockton; 60 mgy

Madera; 40 mgy

Pacific Ethanol

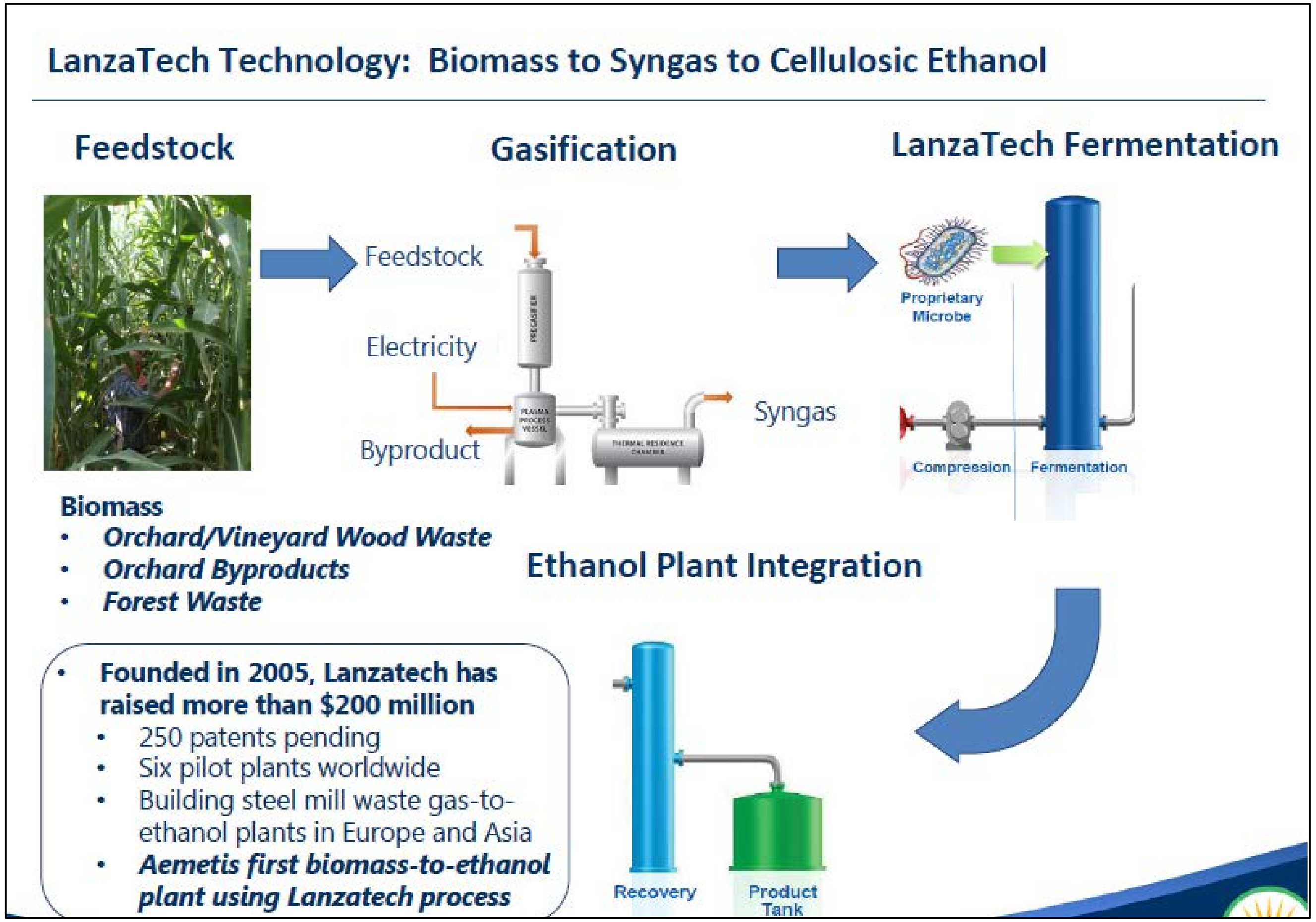


Tree nut plantings in California have increased and hardened water demand reducing supplies for other crops.

Expansion of tree nut plantings driven by changing tastes and Asian demand has altered the state’s agricultural economy and landscape in an unprecedented way.

Aemetis is building a woody biomass to ethanol facility in cooperation with Lanza Tech using a combined thermochemical/ biochemical process already operating at scale in China. To use woody biomass from retired orchards. This is made possible by the existence of the core corn ethanol facility. New fuels will be carbon negative.

They will also produce biodiesel from corn oil and other feedstocks.

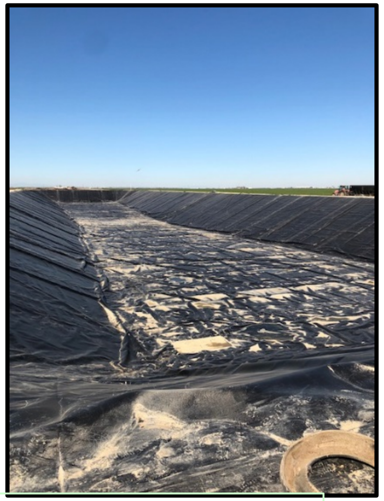


Older biomass to energy plants have closed in the Central Valley leading to unacceptable levels of open burning.

Calgren and Aemetis Biogas Project Supported by LCFS/RFS Value Creation

Dairy

Pipeline



Local Customer

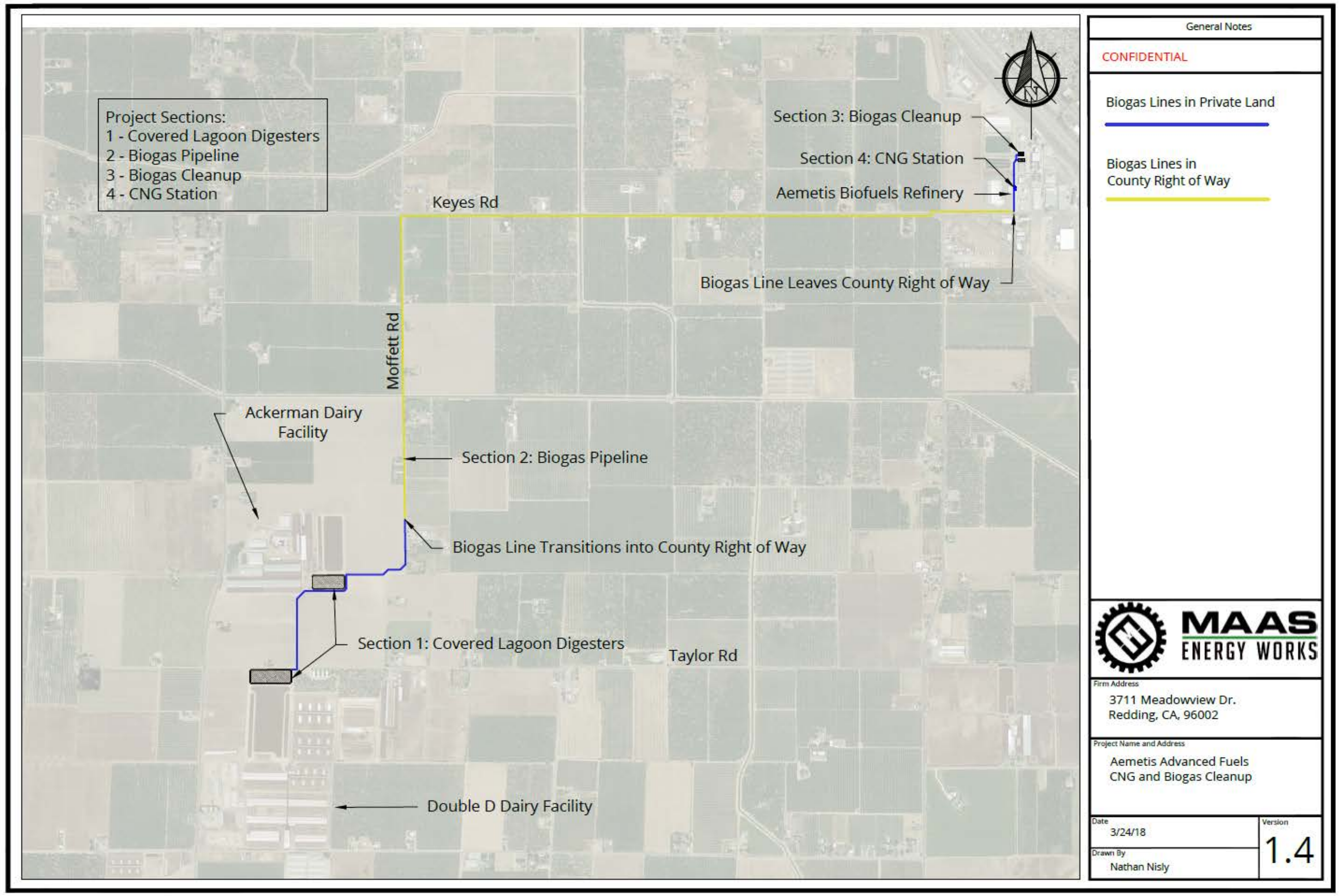
Dairy Waste to Biogas: Aemetis estimates importing raw biogas from approximately 20 nearby dairies ((400K cows), and producing RNG for diverse uses

<u>Aemetis Biogas to Ethanol Plant Project</u>:

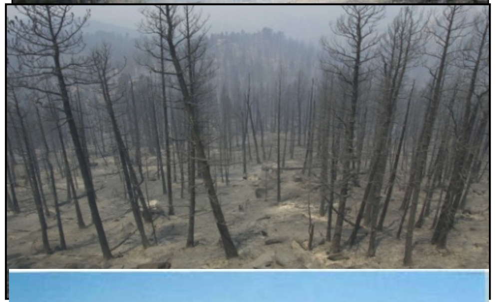
- $30 million in funding secured from existing lender 2018
- $3.1 million in CDFA funds awarded for the project in July 2018
- Engineering/ Permitting Underway
- First operations Q4 2019

Biogas used to offset natural gas use, for CNG, and for pipeline injection.

CCS is also being evaluated.



How should we think about in-state feedstock production and use for biopower, biofuels (and bioprducts)?






How should we think about in-state feedstock production and use for biopower and biofuels?

- Important public goods (**healthy forests**, **methane reduction from dairy farming, reduction in open burning of ag residues, Delta preservation**, and others), **are linked to biopower and biofuel production**, directly or indirectly. In particular, biomass use can help achieve the state's short-lived climate pollution (SLCP) goals.
- In-state biopower/biofuel production produces needed jobs, especially in rural areas---a rural justice, but non-carbon goal.
- Prudent biomass use for energy is part of the sustainable management of the state's landscape.
- Biomass use is the key to a circular economy, necessary for wide-scale decarbonization.

How should we think about in-state feedstock production and use for biopower and biofuels?

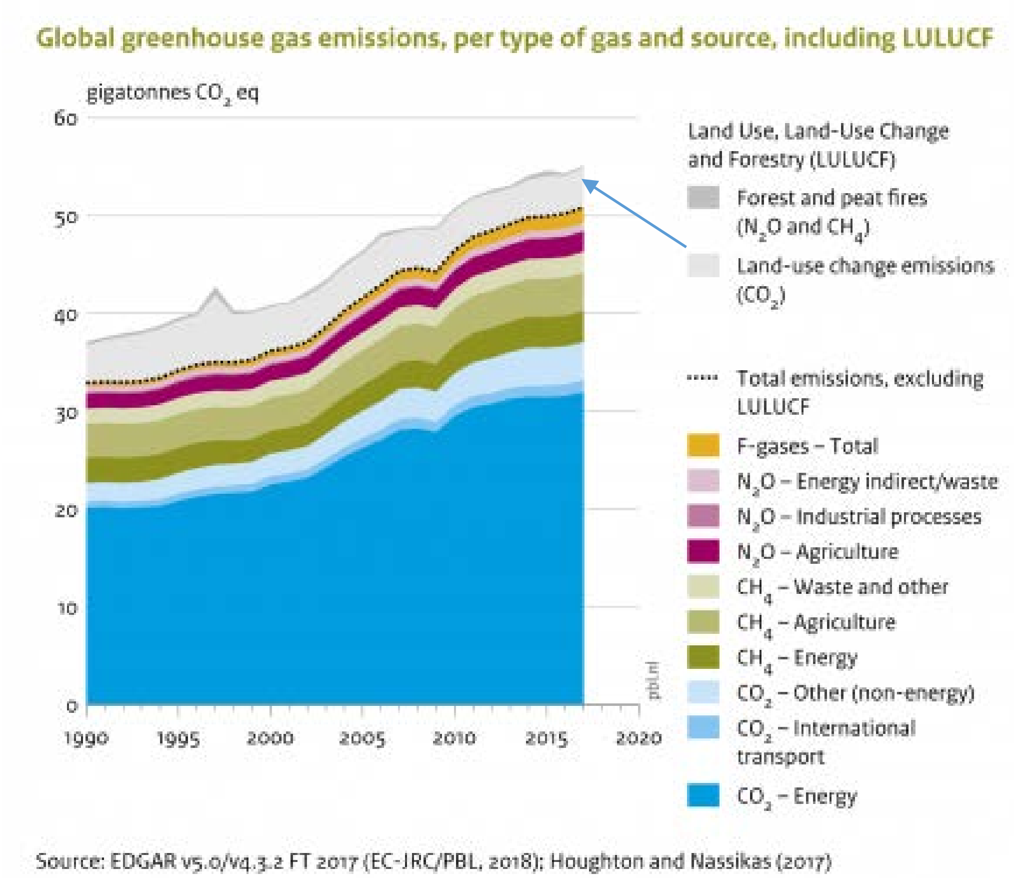
We should not isolate our energy policies, siloing them from the achievement of a wider set of important public goods that are, or can be integrated with energy use and GHG reductions.

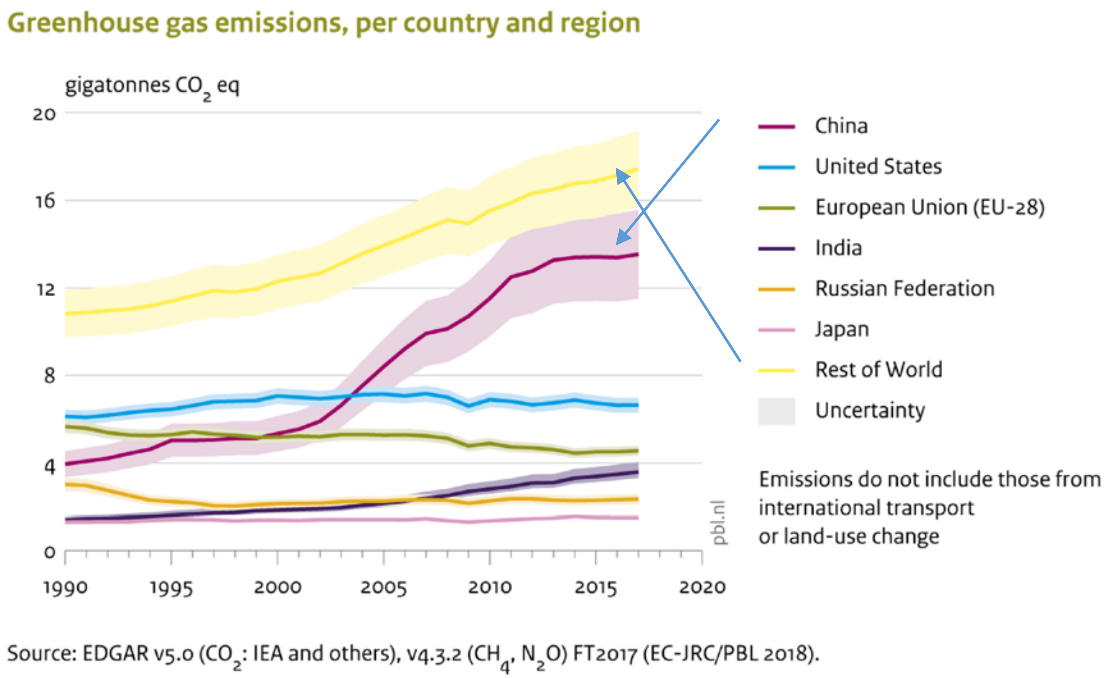
Supplemental slides

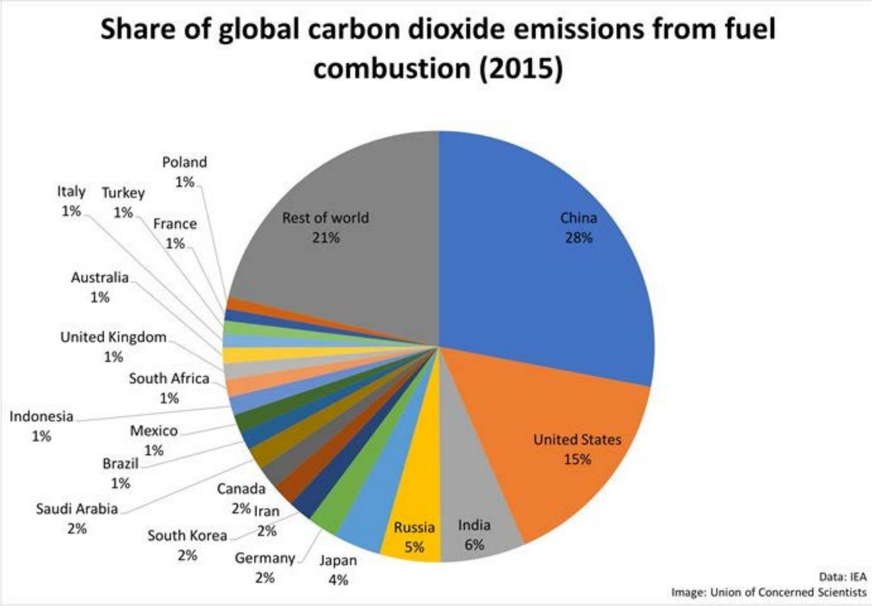
UC DAVIS DEPARTMENT OF PLANT SCIENCES

CALIFORNIA BIOMASS COLLABORATIVE

De-carbonization is an unprecedented challenge

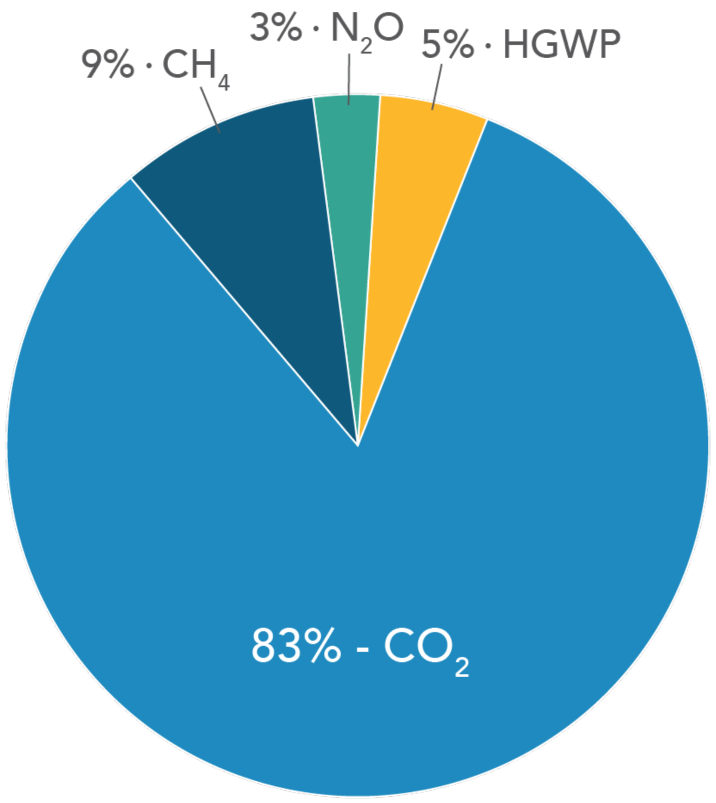




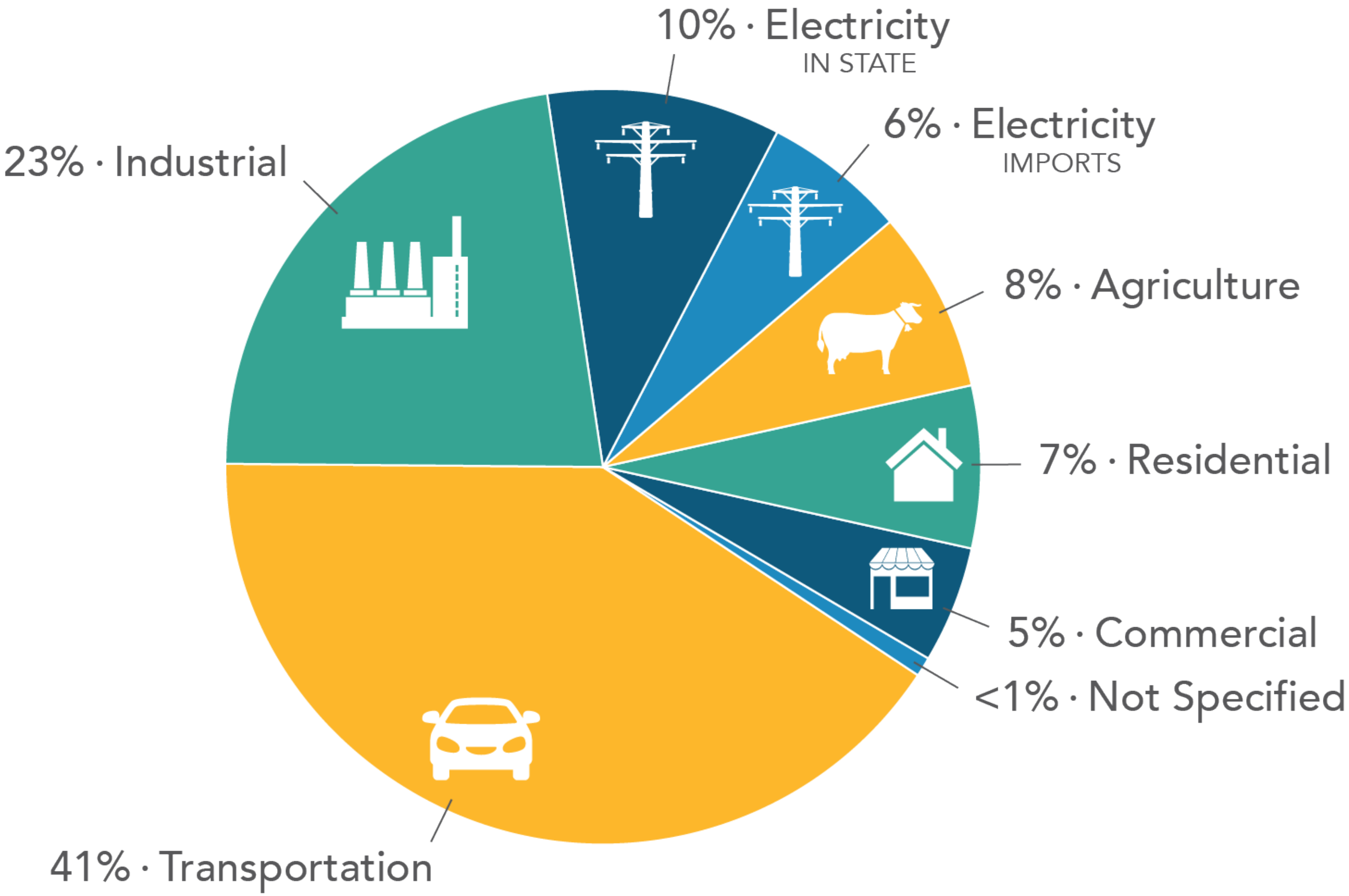


GHG emissions on a world-wide basis seem to be increasing at an increasing rate. Increases are dominated by China, India and developing countries in general.

https://www.pbl.nl/en/infographic/global-greenhouse-gas-emissions-per-type-and-gas-and-source-including-lulucf



429.4 $MMTCO_2e$
2016 TOTAL CA EMISSIONS



429.4 $MMTCO_2e$
2016 TOTAL CA EMISSIONS

https://www.arb.ca.gov/cc/inventory/data/data.htm

SB100

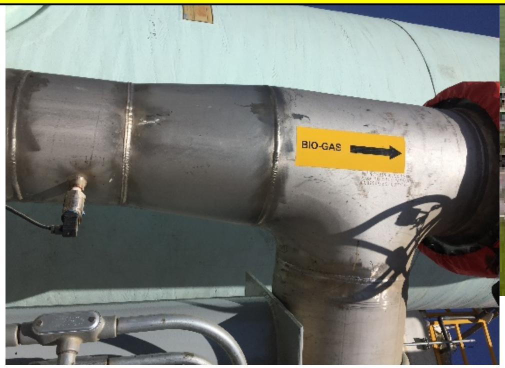
- Under the policy, California's renewable energy and zero-carbon resources supply 100 percent of electric retail sales to end-use customers and 100 percent of electricity procured to serve state agencies by December 31, 2045. The policy requires the transition to a zero-carbon electric system does not cause or contribute to increases of greenhouse gas emissions elsewhere in the western electricity grid.
- SB 100 requires the CEC, CPUC, and CARB to complete a joint agency report to the Legislature evaluating the 100 percent zero-carbon electricity policy, as described below. The report will be developed using a public process and qualitative and quantitative analyses to address the requirements and intent of the statute.

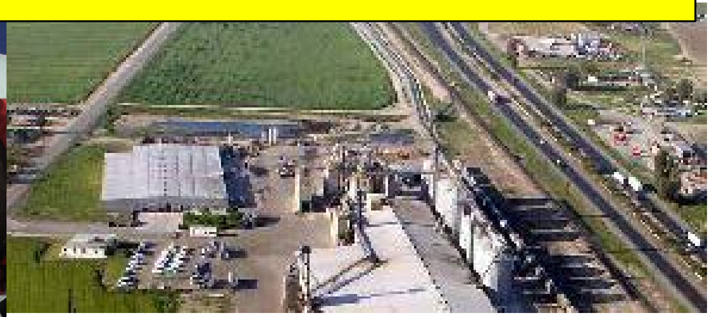
Examples of other legislation and regulations that **encourage using biomass and biogas resources in California** include:

- **AB 32**: Requires carbon reduction in all sectors; the proposed cap and trade system may elevate demand for biogas credits
- **RPS**: Renewable Portfolio Standard requires 33% renewable electricity generation by 2020
- **LCFS**: Low Carbon Fuel Standard requires carbon intensity of vehicle fuels to be reduced over time with specific goals in 2020
- **CAFE**: Corporate Average Fuel Economy requires automakers to improve the average fuel economy of their fleets
- **SB 1505**: Requires 33% of hydrogen vehicle fuel to be generated renewably
- **SB 1122**: Requires investor owned utilities to procure 250 MW of new small biopower
- **ZEV**: Zero Emission Vehicle Mandate requires automakers to market zero emission vehicles; one compelling option is the hydrogen fuel cell vehicle. Combined with SB 1505, this is potentially a large end-use of biogas
- **EPA NAAQS**: National Ambient Air Quality Standards require improvements in air quality in several regions of California

Samuelsen, Scott; Bryan Jenkins, Donald Dabdub, Jack Brouwer, Alejandra Cervantes; Brendan Shaffer; Marc Carreras-Sospedra; Robert Williams; Nathan Parker. (Advanced Power and Energy Program). 2016. ***Air Quality and Greenhouse Gas Emissions Impact Assessment from Biomass and Biogas Derived Transportation Fuels and Electricity and Heat Generation.*** California Energy Commission. Publication number: CEC-500-2016-022.

Calgren: integrated biorefinery based on imported corn grain, also now produces biodiesel and CNG, based on biogas from nearby dairies and sale of DDGS to those dairies.





Also has RNG pipeline injection

and planning for CCS.

Calgren is processing its own corn oil into biodiesel (with brown grease), otherwise exported to China and burned. This is a robust pathway for new biodiesel production in CA. It will integrate biogas from 20 nearby dairies to produce RNG.