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ICF Study: Re-Assessment of Renewable Natural Gas

Additional submitted attachment is included below.

MEMORANDUM

To: Allison Smith, SoCalGas

From: Philip Sheehy

Date: February 2016

Re: Re-Assessment of Renewable Natural Gas

Introduction

Renewable natural gas (RNG) is produced over a series of steps – namely collection of a feedstock, delivery to a processing facility for biomass-to-gas conversion, gas conditioning, compression, and injection into the pipeline. In this memo, ICF focuses on the availability of various feedstocks at the California state-level and at the national level for conversion to RNG. ICF's resource assessment focused on the following four studies:

- BAC/University of California, Davis (UC-Davis), White Paper (November 2014). Note that the BAC white paper draws from an analysis performed by UC-Davis.[1]
- National Petroleum Council (NPC), An Overview of the Feedstock Capacity, Economics, and GHG Emission Reduction Benefits of RNG as a Low-Carbon Fuel (March 2012)
- American Gas Foundation (AGF), The Potential for Renewable Natural Gas: Biogas Derived from Biomass Feedstocks and Upgraded to Pipeline Quality (September 2011).
- U.S. Department of Energy (DOE), Billion Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry (DOE BT) (August 2011).

Feedstocks Considered

RNG can be produced from a variety of renewable feedstocks, including the following:

[1] Data from this study are a mix of publicly available documents regarding UC Davis's assessment a draft version of UC Davis's 2013 resource assessment, recently published by the California Energy Commission (CEC).

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Table 1. Renewable Natural Gas Feedstocks

Feedstock for RNG	Description
Agricultural residue	The material left in the field, orchard, vineyard, or other agricultural setting after a crop has been harvested. Inclusive of unusable portion of crop, stalks, stems, leaves, branches, and seed pods.
Animal manure	Manure produced by livestock, including dairy cows, beef cattle, swine, sheep, goats, poultry, and horses.
Energy crops	Energy crops are inclusive of perennial grasses, trees, and some annual crops that can be grown specifically to supply large volumes of uniform, consistent quality feedstocks for energy production.
Fats, oils, and greases (FOGs)	Long chain fatty compounds that are byproducts of cooking, such as fryer grease (yellow grease) and grease traps (brown grease).
Forestry and forest product residue	Biomass generated from logging, forest and fire management activities, and milling. Inclusive of logging residues (e.g., bark, stems, leaves, branches), forest thinnings (e.g., removal of small trees to reduce fire danger), and mill residues (e.g., slabs, edgings, trimmings, sawdust). Includes materials from public forestlands (e.g., state, federal), but not specially designated forests (e.g., roadless areas, national parks, wilderness areas) and includes sustainable harvesting criteria as described in the U.S. Department of Energy *Billion Ton Update* (see below).
Landfill gas (LFG)	The anaerobic digestion of biogenic waste in landfills produces a mix of gases, including methane (40-60%).
Municipal solid waste (MSW) (compost or lignocellulosic)	Refers to the organic fraction of waste which is typically landfilled, such as food waste and some yard trimmings. Does not include portion that is used in other industries, such as composting. Refers to the organic fraction of waste which is typically landfilled, such as paper products, certain yard trimmings (e.g., branches), and construction and demolition debris. Does not include portion that is used in other industries.
Wastewater treatment (WWT) gas	Wastewater consists of waste liquids and solids from household, commercial and industrial water use. In the processing of wastewater, a sludge is produced, which can be anaerobically digested to produce methane.

Feedstocks are generally harvested and/or collected for delivery to a centralized facility for pre-processing and/or treatment before being converted to natural gas (and other reaction products).

Conversion Technologies

RNG production is largely produced via two conversion technologies: anaerobic digestion or thermal gasification.

- **Anaerobic digestion (AD)** is the process whereby microorganisms break down organic material in an environment without oxygen. In the context of RNG production, the process generally takes place in a controlled environment, referred to as a digester or reactor. When organic material is introduced to the digester, it is broken down over time (e.g., days) by microorganisms, and the gaseous products of that process contain a large fraction of methane and carbon dioxide.

- **Thermal gasification (TG)** describes a broad range of processes whereby a carbon-containing feedstocks are converted into a mixture of gases referred to as synthetic gas or syngas, including hydrogen carbon monoxide, steam, carbon dioxide, methane, and trace amounts of other gases (e.g., ethane, hydrogen sulfide, and nitrogen). The process occurs at high temperatures (650–1350°C) and varying pressures (depending on the gasification system. There is limited commercial-scale deployment of TG technologies.

After conversion, the product gases require other processes which may include methanation, conditioning, clean-up, and compression prior to being injected into the pipeline for delivery to the end-user. In many cases, RNG projects require some investment in interconnection e. g., distribution pipelines that connect to a natural gas transmission pipeline network.

RNG Resource Assessment

The table below highlights the scope of each study in terms of a) feedstocks and b) geography.

Table 2. Scope of Biogas Resource Assessments Considered by ICF by a) Feedstock and b) Geography

Study	Feedstock								Geography	
	Ag Residue	Animal Manure	Energy Crops	FOGs	Forestry Residue	LFG	MSW	WWT Gas	US	CA
BAC/UC Davis										
NPC 2012										
AGF 2011										
DOE BT 2011										

California Biogas Resource Assessment

The table below includes California's biogas production potential, broken down by feedstock in units of trillion Btu (tBtu) for each of the studies considered; the table also includes ICF's recommended range of biogas production based on our review of the studies and their respective methodologies.

Table 3. ICF RNG Resource Assessment, California (in units of tBtu)

Feedstock	BAC / UC DAVIS	AGF[1]		DOE BT[2, 3]		ICF Assessment of Existing Studies	Notes/Comments
		low	high	low	high		
Agricultural Residue	31.0	4.2	10.6	30.7	33.7	30.7–33.7	Significant competition likely with liquid biofuel sector.
Animal Manure	19.4	8.7	29.0	2.3	10.3	12.8–19.4	Recommend the UC Davis as a high value, scaling down the AGF study slightly.
Energy Crops[4]	73.5	0.0	0.0	0.0	0.0	n/a	The most recent version (Mar 2015) of "An Assessment of Biomass Resources in California" did not assess dedicated biomass energy crops.
Fats, Oils and Greases	6.4	n/a	n/a	n/a	n/a	n/a	The BAC report links FOGs to biodiesel conversion. And since it is not included in any other study, we exclude it from consideration here.
Forestry and Forest Product Residue	80.9	4.9	12.2	9.2	15.0	15.0–46.6	Significant competition likely with liquid biofuel sector. The UC Davis study likely over-estimates the potential of forest residue based on ICF review of DOE BT updated approach.
Landfill Gas	52.1	28.4	56.8	n/a	n/a	22.8–56.8	ICF recommendation based on combination of *high Btu* LFG projects in California and the assumption that other landfill gas capture projects can be converted over time.
MSW (food, leaves, grass)	12.1	7.8	23.3	12.1	14.1	23.3–52.0	Although the UC Davis numbers are higher than other studies considered, ICF does not have sufficient reasoning for a reduced high potential.
MSW (lignocellulosic)	39.9			10.3	17.7		
WWT Gas	7.5	0.3	0.8	n/a	n/a	4.2–7.5	UC Davis has much higher estimates than AGF; however, it is unclear why. Insufficient reasoning to revise potential downward.
Total Potential (tBtu)	*322.8*	*54.3–132.7*		*67.2–98.6*		*108.8*–216.0	ICF's range of recommended values reflects variation in studies reviewed and consideration of potential competition for feedstocks; however, these estimates were not developed using a comparative cost-benefit analysis or techno-economic assessment of feedstock and conversion technologies.

1. The low and high values in the AGF study represent what the study refers to as *non-aggressive* and *aggressive* scenarios. The low/non-aggressive scenario assumes roughly 5-25% (depending on resource) of biomass is processed into RNG. The high/aggressive scenario assumes 15-75% (depending on resource) of biomass is processed into RNG.
2. The DOE BT study did not estimate yields of biogas. The focus of the study is on the *feedstock* rather than the *finished fuel*. ICF used conversion efficiencies from the UC Davis work to estimate the tBtu of finished fuel (in this case, biogas) based on the feedstock potential reported in the DOE BT study.
3. The low and high values from the DOE BT study represent the available feedstock assuming a price of $40/ton in 2015 and a price of $80/ton in 2030.
4. Energy crops were not identified in the BAC White Paper; nor were they included in the most updated UC Davis report available.

Feedstock Competition

It is important to note that one cannot assume that any of these feedstocks are freely available for biogas production. Many of these feedstocks are currently used for other purposes and therefore the price of the feedstock will largely depend on the cost of replacing the feedstock with another material. For example, animal manure is widely used as an alternative to chemical fertilizers. The cost of the animal manure will largely depend on the current market price of synthetic fertilizer. A brief list of feedstock competitors is included in the table below and discussed in more detail in the subsequent sub-sections.

Table 4. Competition for RNG Feedstocks

Feedstock	Competition
Agricultural Residue	Animal feed; livestock bedding (e.g., straw from grains); liquid biofuels (e.g., POET-DSM); carbon sequestration, and; benefits to agricultural land such as reduced soil erosion, soil nutrient recycling, and maintenance of soil organic matter and fertility.
Animal Manure	Fertilizers and compost materials; electricity production (e.g., poultry litter), and; manure being diverted for existing anaerobic digestion systems.
Energy Crops	Electricity production and liquid fuels production.
Fats, Oils and Greases	Animal feed; liquid biofuels production (e.g., biodiesel), and; cosmetics and soaps.
Forestry and Forest Product Residue	Electricity production; fuel for boilers, kilns, dryers; pulp-and-paper; pellet and briquette manufacturing; landscaping (e.g., bark chips); fertilizer for forest land; particleboard manufacturing, and; animal bedding (e.g., shavings and sawdust).
Landfill Gas	Electricity production; industrial process heat; existing LFG contracts for biogas.
Municipal Solid Waste (food, leaves, grass, lignocellulosic)	Recycling; fertilizer production through composting (e.g., food scraps, yard trimmings), and; waste-to-energy (i.e., heat, electricity).
WWT Gas	Fuel for WWTP process heat, and; electricity production.

Many of these feedstocks are also being used to generate electricity to meet state Renewable Portfolio Standard (RPS) targets. The California RPS requires that in-state electric utilities have 33% of retail sales derived from eligible renewable energy resources by December 31, 2020 and all subsequent years, within incremental targets starting in 2013. Eligible renewable energy technologies include certain biomass resources, including "agricultural crops, agricultural wastes and residues, waste pallets, crates, dunnage, manufacturing, construction wood wastes, landscape and right-of-way tree trimmings, mill residues that result from milling lumber, rangeland maintenance residues, biosolids, sludge derived from organic matter, wood and wood waste from timbering operations, and any other materials under Public Resources Code Section 40106."[2] Other biomass including landfill gas, biomethane, and municipal solid waste conversion are also eligible.[3]

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[2] See "Renewables Portfolio Standard Eligibility" pg. 9 for a complete list: http://www.energy.ca.gov/2013publications/CEC-300-2013-005/CEC-300-2013-005-ED7-CMF-REV.pdf

[3] There are strict in-state requirements for tracking and verifying the quantities and sources of biomethane and deliveries from dedicated pipelines, common carrier pipelines, or certain on-site production facilities.

Feedstock-Specific Considerations in Resource Assessment

The following sub-sections highlight the key aspects ICF considered when developing our California in-state resource assessment. Broadly speaking, we considered a) methodological aspects of each study and b) potential competition for feedstocks. Where possible, we have provided current pricing data for feedstocks.

Agricultural Residue

ICF has no objections to the resource assessments for agricultural residues; however, ICF notes that the technically recoverably volumes of agricultural residue will be difficult to convert into biogas with high efficiency. For instance, the agricultural residues outlined in the UC Davis study include orchard and vineyard crops, field and seed crops, vegetable crops, and food and fiber residues. UC Davis assumed that 70% of orchard and vineyard crops, 50% of field and seed crops, 5% of vegetable crops, and 80% of food and fiber residues were technically recoverable for purposes of energy production. The UC Davis study does not account for existing competition for those feedstock sources: Many residues are currently plowed back in the soil to serve as fertilizer and recycle nutrients, reduce soil erosion, and maintain organic matter levels. Many residues are also used for animal feed and livestock bedding (e.g., straw from grains). Furthermore, there will likely be competition for residues from liquid biofuels. The numbers presented in the BAC White Paper, for instance, support this viewpoint, which assumes the lignocellulosic portion of residues converted into ethanol.

For illustrative purposes, we consider wheat straw as a potential feedstock. At the field-level, the farmer will likely consider the value of wheat straw as a soil enriching agent. Wheat straw has moderate levels of nitrogen and potassium, but low levels of phosphate. Using current pricing (as of Q1 2016) for these fertilizers and the amount of each in a ton of wheat straw, the economic value of the wheat straw as a fertilizer is around $10/ton. That price excludes any costs of removing that wheat straw from the field, delivering it to a facility, and other considerations. Regardless, our point is that this is the first step in the process of determining how these residues might be valued at the field- or farm-level.

Animal Manure

ICF recommends a more cautious approach to the resource assessment for animal manures outlined in the BAC report and the AGF Report. While ICF agrees with the methodology employed in both the AGF study and the UC Davis study, neither takes into account competing uses for the manure. As mentioned in the feedstock competition section previously, manure is typically land-applied as an alternative to synthetic fertilizers. Manure may also be used for electricity production, particularly from poultry litter which is largely composed of wood chips or sawdust used for bedding, or already dedicated to existing anaerobic digestion systems. However, it is reasonable to assume that manure not used for electricity or existing systems could capture a higher value as a biogas feedstock compared to fertilizer and therefore could be diverted depending on demand. This unmitigated manure could also generate carbon mitigation credits for programs like California’s Carbon Cap and Trade program and/or provide negative carbon intensities for programs like the LCFS due to the capture and utilization of methane that is currently being vented to atmosphere.

Energy Crops

ICF recommends excluding energy crops from consideration as a California-based resource. Both the AGF and DOE-BT studies indicated that there is no potential for energy crops in California. Further, in a previous report to the CEC, UC Davis writes (*emphasis* added):

> Dedicated biomass crops are not currently grown to any significant extent in California. There is some potential that they will develop in combination with phytoremediation efforts for contaminated lands such as salt-affected soils in the San Joaquin Valley. Sugar and starch crops may develop to support the production of ethanol and other biofuels and bioproducts. Residues from these crops could be used for

> power generation or the fuel products used directly. Dedicated crop production could lead to crop shifting on existing agricultural lands but might also be associated with more marginal lands. This analysis includes a dedicated biomass crop category producing 5 million BDT/y by 2017 with an availability of 90%, recognizing that *this constitutes a highly uncertain source of supply*. The production would likely occur logistically. The analysis here assumes an average yield of 5 BDT/acre. *Water may be a key limiting resource in this production.*

Furthermore, ICF notes that in the most recent resource assessment (2013), UC Davis excluded energy crops from consideration. Given the uncertainty associated with the potential for energy crops in California, the current drought conditions in California, and the exclusion of this resource from other studies, ICF recommends a conservative approach that assumes no potential for energy crops in California.

There are significant potential resources outside of California, however, with the DOE-BT study indicating that more than 600 MDT of energy crops could be available in 2030. For the other feedstocks considered, there was little variation between resource availability in 2020 compared to 2030. In the case of energy crops, however, the resource availability increases by a factor of two (2).

Fats, Oils, and Greases (FOGs)

The BAC report is the only study that we reviewed that included an estimate of FOGs. They estimated 207,000 tons of FOGs available in California for the production of 56 million gasoline gallon equivalent (GGE) of biofuels (specifically biodiesel). This analysis was based on a 1999 report commissioned by the National Renewable Energy Laboratory (NREL) and performed by Appel Consultants. The BAC report assumes each Californian produces 11.2 pounds (lbs) per person per year of FOGs among a California population of 36.96 million.[4] The FOGs documented in this study included yellow grease (primarily from restaurant fryers) and trap grease (grease from sinks and dishwashers that is trapped in a containment unit of a restaurant before entering the sewer system). This study was based on 30 randomly selected metropolitan areas in the United States. The only city in California included in the study was Sacramento, which had a yellow grease and trap grease production average of 3.04 and 11.2 lbs per person per year (lbs/person/yr) respectively.

Trap grease is typically not considered an optimal feedstock for biodiesel due to the high levels of contaminates. These contaminates are difficult to remove and may ultimately impact the quality of the biodiesel. ICF contends that only the yellow grease portion would realistically be available for biodiesel production. Using the Sacramento average of 3.04 lbs./person/yr and a revised California population of 38.33 million based on the 2013 census, the total resource would be closer to 58,000 tons of biodiesel. Using the BAC calculation of 7.5 lbs. FOG per gallon of finished biodiesel and one diesel gallon equivalent (DGE) equal to 1.12 GGE, the revised total would be closer to 17.4 M GGE.

It is possible that urban waste grease could be used in anaerobic digesters to produce biogas. However, with the high commodity price of yellow grease close to $400/ton (as of January 2016),[5] it is far more likely that yellow grease would be used in the biofuel or animal feed market. It is possible that trap grease could be used in anaerobic digesters as it has negligible value, but contaminants, including cleaning detergents, could kill microbes essential to biogas production making it an unlikely feedstock.

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4 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.

5 Jacobsen Report, Animal Fats & Oil: FOG West Coast, January 2016.

Forestry and Forest Product Residue

There are approximately 40 million acres of forest lands in California. Approximately 46% is national forest, 12% is other public forest, and 42% is private forest. ICF follows the recommendations from the U.S. Department of Energy (DOE) U.S. Billion Ton Study Update[6] in 2011, which estimated the in-state resource to be between 1.8 and 2.4 million bone dry tons per year (MBDT/yr) for biomass up to $80/ton with the low estimate without federal lands and the high estimate with federal lands. The estimate included integrated composite operations, other removal residues, conventional wood, logging residues, simulated thinnings from forestlands, and treatment thinnings (e.g., fire hazard thinnings).

These estimates contrast with those in the UC Davis report[7] commissioned by CEC and account for four main categories of forestry biomass: logging slash (e.g., branches, tops, bark); forestry thinnings (e.g., understory brush, small diameter trees, other non-merchantable materials); sawmill residues (e.g., bark, sawdust, planer shavings, trim ends), and; shrub or chaparral (e.g., shrub biomass obtained from habitat improvement activities like thinning, fuel treatment operations to reduce wildfire risk). The UC Davis resource estimates were based on information from the California Department of Forestry and Fire Protection (CAL FIRE)[8] Fire and Resource Assessment Program and sawmill residues were developed from the 2003 timber harvest and residue data.[9] The UC Davis study estimated the technical potential for forestry products to be approximately 14.2 MBDT/yr.

However, unlike the DOE BT study, the UC Davis study did not account for the overlap between forest materials that might be taken under a commercial harvest operation and forest materials that might be taken for fire threat reduction scenarios. This overlap has been estimated in the CAL FIRE report to be about 53,000 BDT/yr (about 26,000 BDT/yr merchantable timber and 27,000 BDT/yr of non-merchantable material), and is removed from the CALFIRE estimates for harvest potential. Revised CAL FIRE assessments were approximately 4.2 MBDT/yr.

The DOE Billion Ton study also altered the original methodology to include additional sustainability criteria. Some of the changes included:[10]

- Alterations to the biomass retention levels by slope class (e.g., slopes with between 40% and 80% grade included 40% biomass left on-site, compared to the standard 30%).
- Removal of reserved (e.g., wild and scenic rivers, wilderness areas, USFS special interest areas, national parks) and roadless designated forestlands, forests on steep slopes and in wet land areas (e.g., stream management zones), and sites requiring cable systems.

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[6] U.S. Department of Energy, "U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry," 2011. https://www.bioenergykdf.net/content/billiontonupdate.

[7] California Energy Commission, "An Assessment of Biomass Resources in California, 2007, 2010, and 2020," prepared by University of California, Davis, December 2008. http://www.energy.ca.gov/2013publications/CEC-500-2013-052/CEC-500-2013-052.pdf.

[8] California Department of Forestry and Fire Protection, "Biomass potentials from California forest and shrublands including fuel reduction potentials to lessen wildfire threat," Draft PIER Consultant Report, Contract 500-04-004, February 2005. See page 34 and Table 15. http://frap.fire.ca.gov/publications/BIOMASS_POTENTIALS_FROM_CA_FOREST_AND_SHRUBLANDS_OCT_2005.pdf.

[9] Yang, P. and B.M. Jenkins. 2005. Wood residue generation from sawmills in California. Draft report,

California Biomass Collaborative, University of California, Davis, CA.

[10] Bryce Stokes, Department of Energy, "2011 Billion Ton Update – Assumptions and Implications Involving Forest Resources," September 29, 2011, http://web.ornl.gov/sci/ees/cbes/workshops/Stokes_B.pdf.

- The assumptions only include thinnings for over-stocked stands and didn't include removals greater than the anticipated forest growth in a state.
- No road building greater than 0.5 miles.

ICF believes the additional sustainability criteria provide a more realistic assessment of available forestland. Unlike the UC Davis study, the DOE Billion Ton study also includes resource costs.

Another study performed by the Western Governors' Association estimate California's resource to be closer to 1.3-5.1 MBDT/yr ranging from $10/ton to $100/ton for forestry residues including fire hazard thinnings, logging residue, treatment of Pinyon Juniper woodland, thinnings on private timberland, and mill residues.[11] At a price of $50/ton the base case estimate was 4.1 MBDT/yr and the high case estimate was 4.9 MBDT/yr.

It is important to note that these estimates were developed for liquid biofuels, not biogas. It is possible that biogas could be generated from forestry resources using thermal gasification technologies. However, thermal gasification technologies are more expensive than anaerobic digestion, less efficient (range of 60% to 70% depending on the process), and typically produce undesirable by-products, such as tars and oils. According to the National Petroleum Council, thermal gasification of woody biomass to produce biogas is at the pre-commercial stage. Commercial-scale implementation is expected around 2020.[12]

Pricing for forest and forest product residues is complicated. For instance, in California, pricing is determined across 9 regions (see map in figure below) and for various types of products, including:

- Miscellaneous harvest: Includes special items such as Christmas trees, fuelwood, chipwood, poles and pilings, posts, split products, small sawlogs, cullogs and miscellaneous conifers.
- Green Timber: Defined as trees that are health and, in the opinion of a Registered Professional Forester (RFP) or Professional Arborist, have a high likelihood of surviving 12 months or more if not harvested.
- Salvage Timber: Includes only dead, dying, fatally damages, or downed trees removed from an area of salvage logging.

California's Board of Equalization posts prices by region and product time on a quarterly basis (for tax purposes). These prices are shown for harvested wood in units of thousand board feet (MFB, a board foot is 1ft x 1ft x 1in) or linear feet (LF). This is effectively untreated wood, and has not been dried or treated for biomass processing – regardless if it is a gasification or liquefaction. The tables

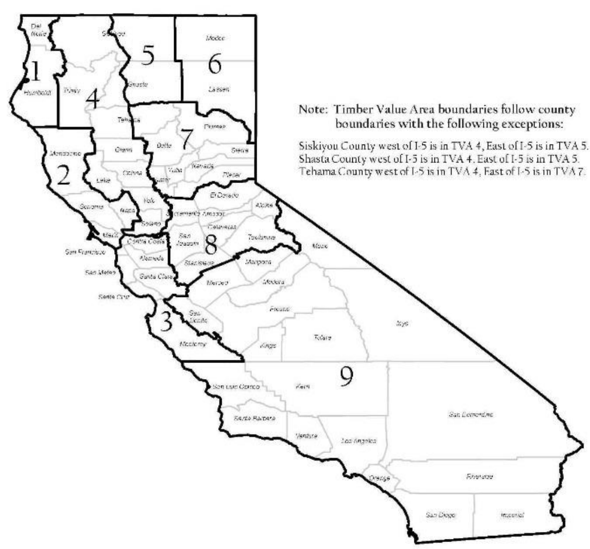

Figure 1. Timber Value Areas in California, BOE

[11] Western Governors' Association, "Strategic Assessment of Bioenergy Development in the West," September 2008. http://www.fpl.fs.fed.us/documnts/pdf2008/fpl_2008_gordon001.pdf. See Tables 8 and 9.

[12] Renewable Natural Gas for Transportation: An Overview of the Feedstock Capacity, Economics, and GHG Emission Reduction Benefits of RNG as a Low-Carbon Fuel, National Petroleum Council, March 2012: http://www.npc.org/FTF_Topic_papers/22-RNG.pdf.

below include the so-called Harvest Value Schedule for July 1, 2015 through December 31, 2015.[13]

Table 5. Miscellaneous Harvest Values in California, July-December 2015

Species or Product	UNIT	Harvest Value ($ per unit)
Christmas trees, Natural Misc.	Linear Feet	0.60
Christmas trees, Natural Red Fir	Linear Feet	1.40
Christmas trees, Natural White Fir	Linear Feet	0.60
Christmas trees, Plantation	Linear Feet	1.50
Cull logs	Adj. Gross M board feet	5.00
Fuelwood, hardwood	Cords	20.00
Fuelwood, miscellaneous	Cords	10.00
Pulp chipwood & hardwood logs	Green Tons	1.00
Woods-produced fuel chips	Bone Dry Tons	0.00
Poles & pilings, small DF (20'-50')	Net M board feet	270.00
Poles & pilings, large DF (51' - up)	Net M board feet	290.00
Poles & pilings, PP, TF (all sizes)	Net M board feet	190.00
Posts, round	8 Linear feet	0.20
Split products, redwood	Net M board feet	75.00
Split products, miscellaneous	Net M board feet	10.00
Small sawlogs, miscellaneous 1/	Net M board feet	90.00
Miscellaneous conifer species	Net M board feet	80.00

Table 6. Green Timber (via Tractor Logging), California July-December 2015

SPECIES	PER LOG	SIZE CODE	Time Value, By Area								
			1	2	3	4	5	6	7	8	9
Ponderosa Pine	Over 300	1	210	180	80	280	320	340	330	230	230
	150-300	2	160	170	60	230	290	310	260	200	190
	Under 150	3	110	110	30	140	240	280	250	190	80
Hem/fir	N/A	N/A	200	150	N/A	180	260	210	240	220	160
Douglas-fir	Over 300	1	380	270	120	350	390	370	380	300	N/A
	150-300	2	340	260	110	330	370	340	340	290	N/A
	Under 150	3	320	180	80	310	350	310	320	280	N/A
Incense Cedar	N/A	N/A	70	100	N/A	160	280	310	270	270	220
Redwood	Over 300	1	650	690	560	N/A	N/A	N/A	N/A	N/A	N/A
	150-300	2	540	630	550	N/A	N/A	N/A	N/A	N/A	N/A
	Under 150	3	500	480	500	N/A	N/A	N/A	N/A	N/A	N/A
Port-Orford Cedar	Over 125	1	350	N/A	N/A	350	N/A	N/A	N/A	N/A	N/A
	125 & Under	2	250	N/A	N/A	250	N/A	N/A	N/A	N/A	N/A

[13] California State Board of Equalization, Harvest Values Schedule, Effective July 1, 2015 Through December 31, 2015, BOE-401-HVS1-2H15.

Table 7. Salvage Timber (via Tractor Logging), California July-December 2015

SPECIES	PER LOG	SIZE CODE	Time Value, By Area								
			1	2	3	4	5	6	7	8	9
Ponderosa Pine	Over 300	1	160	140	60	210	240	260	250	170	100
	150-300	2	120	130	40	170	220	230	200	150	50
	Under 150	3	80	80	20	100	180	210	190	140	40
Hem/fir	N/A	N/A	150	110	N/A	140	200	160	180	160	60
Douglas-fir	Over 300	1	280	200	90	260	290	280	280	230	N/A
	150-300	2	260	190	80	250	280	260	260	220	N/A
	Under 150	3	240	140	60	230	260	230	240	210	N/A
Incense Cedar	N/A	N/A	50	80	N/A	120	210	230	200	200	60
Redwood	Over 300	1	490	500	420	N/A	N/A	N/A	N/A	N/A	N/A
	150-300	2	400	460	410	N/A	N/A	N/A	N/A	N/A	N/A
	Under 150	3	380	350	380	N/A	N/A	N/A	N/A	N/A	N/A
Port-Orford Cedar	Over 125	1	260	N/A	N/A	260	N/A	N/A	N/A	N/A	N/A
	125 & Under	2	190	N/A	N/A	190	N/A	N/A	N/A	N/A	N/A

Landfill Gas

BAC 2014 estimates that there are 53 billion cubic feet (BCF) of biomethane potentially available each year in California for RNG. This estimate is based on existing waste-in place (WIP) using a first order waste decay model (similar to US Environmental Protection Agency (EPA) LandGEM). The gross resource represents gas production from annual disposal since 1970 (1.2 billion tons WIP). The potential resource is based on an assumed 75% technical recovery factor for upgrading LFG to pipeline quality RNG.[14] This analysis assumes that RNG can be generated from all or most of California landfills, regardless of size, location and current use.

Other national biomass resource assessment studies from the NPC[15] and AGF[16] base their LFG biomethane estimates on data from EPA's Landfill Methane Outreach Program (LMOP).[17] Using LMOP data for California, ICF estimates a range for LFG RNG potential of 6.21 to 87.3 BCF per year (BCF/yr) based on varying assumptions on how much of the total LFG could be dedicated to producing RNG.

ICF's recommended range is based on the current state of high Btu landfill gas to energy projects in California. This includes biogas that is currently flared from 31 CA-LMOP candidate landfills and at least nine of the current LFG to electricity projects that could be repurposed into LFG to pipeline quality RNG given end-use

[14] UC Davis. 2014. Research Results Forum for Renewable Energy Technology and Resource Assessments, PPT from Public Workshop at the California Energy Commission Sept. 3rd 2014. http://energy.ucdavis.edu/files/09-16-2014-08_Biomass_Resource-and-Facilities-Database-Update.pdf

[15] National Petroleum Council. 2012. Topic Paper #22: Renewable Natural Gas for Transportation: An Overview of the Feedstock Capacity, Economics, and GHG Emission Reduction Benefits of RNG as a Low-Carbon Fuel. http://www.npc.org/reports/FTF_Topic_papers/22-RNG.pdf

[16] American Gas Foundation. 2011. The Potential for Renewable Gas: Biogas Derived from Biomass Feedstocks and Upgraded to Pipeline Quality. http://www.gasfoundation.org/researchstudies/agf-renewable-gas-assessment-report-110901.pdf

[17] EPA Landfill Methane Outreach Program – operational and candidate landfills. http://www.epa.gov/lmop/projects-candidates/index.html

competition, cost, and access to pipelines. These assumptions are in line with estimates from the Coalition for Renewable Natural Gas.[18] The high end of the range is representative of biogas currently flared or collected from 122 landfill sites (31 LMOP candidate landfills and 91 operational LMOP landfills).

Municipal Solid Waste

According to the UC Davis study an estimated 90 million wet tons of municipal solid waste (MSW) are generated each year in California, of which approximately half are disposed in landfills. The biomass portion of MSW includes construction and demolition wood (also known as urban wood waste), paper and paper products, grass and other yard trimmings, food waste, and other organic materials. The total biomass generated is around 35 million BDT/yr (both landfilled and diverted), or approximately 1 BDT of biomass per person per year. The UC Davis study assumes that none of the diverted portion of the material is technically available as it is being used for other purposes such as recycling, composting, and power generation. The study assumes that at least 50% of the landfilled materials would be technically available. Generally, ICF concurs with the estimates.

Wastewater Treatment Gas

UC Davis estimated the amount of available biosolids in wastewater treatment facilities based on influent waste water flow rate information provided by the EPA. UC Davis assumed a maximum biogas potential based on the flow rate and estimated biogas to be 67% recoverable. Though it is possible that the biogas produced by wastewater treatments plants could be used for other purposes, ICF generally agrees with the estimates from the UC Davis study.

US Biogas Resource Assessment

The table below includes a national-level biogas production potential, broken down by feedstock in units of trillion Btu (tBtu) for each of the studies considered. Unlike the California-focused estimates, we have not developed recommendations for the biogas production potential. This is in large part due to resource constraints i.e., it is time-consuming to conduct a state-by-state assessment given the range of studies and data sources considered. In the subsequent table, we summarize the assumptions utilized in each of the studies.

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[18] The Coalition for Renewable Natural Gas. 2013. Docket Number 13-IEP-1L, Transportation Energy Scenarios and the CEC Joint IEPR-Transportation Lead Commissioner Workshop. http://www.energy.ca.gov/2013_energypolicy/documents/2013-07-31_workshop/comments/Coalition_For_Renewable_Natural_Gas_Comments_2013-08-09_TN-71825.pdf

Table 8 Overview of RNG Feedstock / Resource Assessment, United States

Feedstock	NPC[1]	AGF[2]		DOE BT[3, 4]	
		low	high	low	high
Agricultural Residue	1,300	401	1,002	327	1,872
Animal Manure	140	148	493	72	336
Energy Crops	1,500	80	200	364	6,483
Fats, Oils and Greases	n/a	n/a	n/a	n/a	n/a
Forestry and Forest Product Residue	1,100	82	206	293	569
Landfill Gas	340	182	365	n/a	n/a
MSW (food, leaves, grass)	400	69	207	148	247
MSW (lignocellulosic)				53	64
WWT Gas	60	4	13	n/a	n/a
Total Potential (tBtu)	*4,840*	*966*	*2,486*	*1,256*	*9,572*

1. The NPC and AGF reports do not differentiate MSW feedstocks.
2. The low and high values in the AGF study represent what the study refers to as *non-aggressive* and *aggressive* scenarios. The low/non-aggressive scenario assumes roughly 5-25% (depending on resource) of biomass is processed into RNG. The high/aggressive scenario assumes 15-75% (depending on resource) of biomass is processed into RNG.
3. The DOE BT study did not estimate yields of biogas. The focus of the study is on the *feedstock* rather than the *finished fuel*. ICF used conversion efficiencies from the UC Davis work to estimate the tBtu of finished fuel (in this case, biogas) based on the feedstock potential reported in the DOE BT study.
4. The low and high values from the DOE BT study represent the available feedstock assuming a price of $40/ton in 2015 and a price of $80/ton in 2030.

Feedstock	NPC 2012	AGF 2011	DOE BT Update 2011
Overall	The aim of this 2012 white paper published by the National Petroleum Council (NPC) is to provide a broad assessment of the potential for RNG as a transportation fuel in terms of feedstock capacity, cost estimates, and lifecycle GHG emission reduction. Analysis of the practical and potential inventory of feedstock sources in the U.S. suitable for RNG production	The report presents three scenarios of total biomass utilization or market penetration available on an annual basis with varying levels of feedstock utilization: a) non-aggressive; b) aggressive; and c) maximum. The report acknowledges that the aggressive scenario would require a 'concerted national effort'. The maximum scenarios assumes 100% biomass utilization and represents the upper limit for RNG production.	The 2011 Billion-Ton Update addresses a number of the 2005 report shortcomings by providing a county-by-county inventory of primary feedstocks, prices and quantities for the primary feedstocks, and a more rigorous treatment and modeling of resource sustainability. The estimates do *not* represent the total cost or the actual available tonnage to the biorefinery; rather, it provides estimates of biomass to roadside or the farmgate. [19] There are additional costs to preprocess, handle, and transport the biomass.
Agricultural Residue	Potential: The 2005 BTS was used for agricultural waste Practical: National Academy of Sciences (NAS) study on liquid transportation fuels from biomass from 2009.[20]	Includes residues from corn, wheat, soybeans, cotton, sorghum, barley, oats, rice, rye canola, beans, peas, peanuts, potatoes, safflower, sunflower, sugarcane, flaxseed. The potential, annual quantity of agricultural residues is based on the data presented in Geographic Perspective.[21]	Includes primary crop residues from the major grains—corn, wheat, sorghum, oats, and barley Also includes other residues and processing wastes: sugarcane trash and bagasse, cotton gin trash and residues, soybean hulls, rice hulls and field residues, wheat dust and chaff, and orchard and vineyard prunings Many data sets employed, including soils, slope, climate, cropping rotations, tillage (i.e., conventional, reduced, and no tillage), management practices, and residue collection technology Many factors taken into account to estimate available crop residues: soil erosion and soil organic matter constraints, physical ability of machinery to harvest residues.

[19] Roadside price is the price a buyer pays for wood chips at a roadside in the forest, at a processing mill location in the case of mill residue, or at a landfill for urban wood wastes prior to any transport and preprocessing to the end-use location.

[20] National Academies of Sciences, Liquid Transportation Fuels from Coal and Biomass: Technological Status, Costs, and Environmental Impacts, 2009.

[21] A Geographic Perspective on the Current Biomass Resource Availability in the United States, A. Milbrandt, NREL/TP-560-39181, Dec 2005.

Feedstock	NPC 2012	AGF 2011	DOE BT Update 2011
Animal Manure	Potential: Employ data from EPA's AgStar[22] program to estimate the quantity of livestock manure Practical: Data from Cuellar and Webber (2008) is to estimate the livestock manure RNG yield[23]	Include waste from dairy cows, beef cattle, hogs, sheep, poultry, and horses. Animal population data are based on state inventories that generally span the years 2006-2009; for each animal, the most recent population data was selected.[24] For horses, the most recent data acquired was based on population inventories in 1999.[25]	The 2011 BTS report estimates recoverable and available dry tons of manure based on assumptions by Kellog et al. (2000) and Gollehon et al. (2001) on the quantity of manure phosphorus excreted, recoverable, and available in excess of farm use. Production identified for beef (cattle and calves), swine, poultry (broilers and layers), and turkeys. Total production of cattle, dairy, and swine was estimated as the product of total animal units (1,000 pounds of livestock) and the percentage of inventory produced on large farms (greater than 10,000 head for cattle; 1,000 head for dairy; 5,000 head for swine). Litter available from poultry production was estimated at 70% of total poultry production (chicken broilers, chicken layers, and turkeys).

[22] EPA AgSTAR, "Market Opportunities for Biogas Recovery Systems at U.S. Livestock Facilities," (November 2011): available at http://www.epa.gov/agstar/documents/biogas_recovery_systems_screenres.pdf.

[23] Cuellar, AD and Webber, ME. Cow Power: the energy and emissions benefits of converting manure to biogas. Environ Res. Lett, 3, 2008.

[24] Agricultural Statistics Annual, National Agricultural Statistics Service, available at http://www.nass.usda.gov/Publications/Ag_Statistics/2009/

[25] Equine, USDA, National Agricultural Statistics Service, available at http://usda.mannlib.cornell.edu/usda/nass/Equine/equi1999.txt

Feedstock	NPC 2012	AGF 2011	DOE BT Update 2011
Energy Crops	Potential: Used 2005 BTS, which includes biomass grown on Conversation Reserve Program (CRP), grains for biofuels, soybeans, and perennial crops. Practical: Based on NAS 2009	Derived from NREL report; based on estimated yield of unirrigated energy crops (switchgrass and short rotation woody crops – willow and hybrid poplar). The potential, annual availability of energy crops is based on the data presented in Geographic Perspective.[26]	Two scenarios considered: baseline and high yield. Considers perennial grasses, ,woody crops, and annual energy crops Used an agricultural policy simulation model (POLYSYS) to assess the economic competitiveness of energy crop production and determine how much cropland could shift to energy crops Detailed consideration of sustainability issues for each energy crop identified
Forestry & Forest Product Residue	Potential: Based on the 2005 Billion Ton Study (BTS) Practical: Based on a NAS 2009. Included significant recovery losses and incorporated sustainability criteria such as leaving nutrient rich residues in the forest to maintain soil fertility.	Includes forest residues, mill residues, urban wood residues. The potential, annual quantity of dedicated wood residues is based on the data presented in Geographic Perspective.[27]	Estimates potential supplies of forest biomass and wood wastes under different yield and feedstock farmgate prices Primary forest biomass supply is based on estimates of recent amounts of generated logging residues and simulated silvicultural treatments on overstocked timberland, as well as pulpwood and sawlogs 72%[28] less than the 2005 BTS due to the removal of unused resources, the decline in pulpwood and sawlog markets and more explicit accounting of resource sustainability

[26] A Geographic Perspective on the Current Biomass Resource Availability in the United States, A. Milbrandt, NREL/TP-560-39181, Dec 2005.

[27] Ibid.

[28] 2005 BTS forest resource potential was 368 MDT. This is compared to the total unused forest resource available at $60/ton in 2030 (including federal lands) from the 2011 BTS report – 102 MDT.

Feedstock	NPC 2012	AGF 2011	DOE BT Update 2011
Landfill Gas	EPA Landfill Methane Outreach Program (LMOP) is used as the total resource and the fraction that is captured in gas- to-energy projects or currently flared is treated as the practical resource.	2,402 landfills in database including EPA-designated operational, potential, candidate, construction, or shutdown (2000 or later); included landfills categorized as small, large, arid, and non-arid; assumed landfill gas composition was 60% methane	n/a
MSW	Employ 2009 EPA data and assumptions regarding waste generated per person per day, US population (via AEO2012, out to 2035), and percent of waste that can be collected. Potential/total resource assumes more than 75% of total waste; practical resource assumes about 10% of waste is suitable for gasification	Only included MSW directed to landfills; did not include MSW directed to energy projects; did not consider potential volume reductions through recycling	Employ 2008 EPA data and assumptions regarding total waste generated. Differentiate between agricultural sources of MSW (food wastes, textiles, and leather) and forest sources of MSW (newsprint, paper, containers, packaging, yard trimmings, and wood)
WWT Gas	Use data from EPA[29] to estimate how much methane can be produced per person per day from waste water.	Uses database of 436 wastewater facilities with capacity of 5 MGD or greater but biogas production would only occur with 17 MGD or greater capacity	n/a

[29] Environmental Protection Agency, "Opportunities for and Benefits of Combined Heat and Power at Wastewater Treatment Facilities," U.S. Environmental Protection Agency Combined Heat and Power Partnership (October 2011): available at http://www.epa.gov/chp/documents/wwtf_opportunities.pdf.