Case Studies in Alternate Uses of Biomethane from Wastewater Treatment Plants and Landfill Gas Facilities in California

Lori Smith Schell, Ph.D., ERP, Empowered Energy

Brendan Shaffer, M.S., UC-Irvine

Professor Scott Samuelsen, UC-Irvine

39th IAEE International Conference

Bergen, Norway

21 June 2016

Advanced Power and Energy Program

UCIrvine | University of California

Empowered Energy™

Motivation

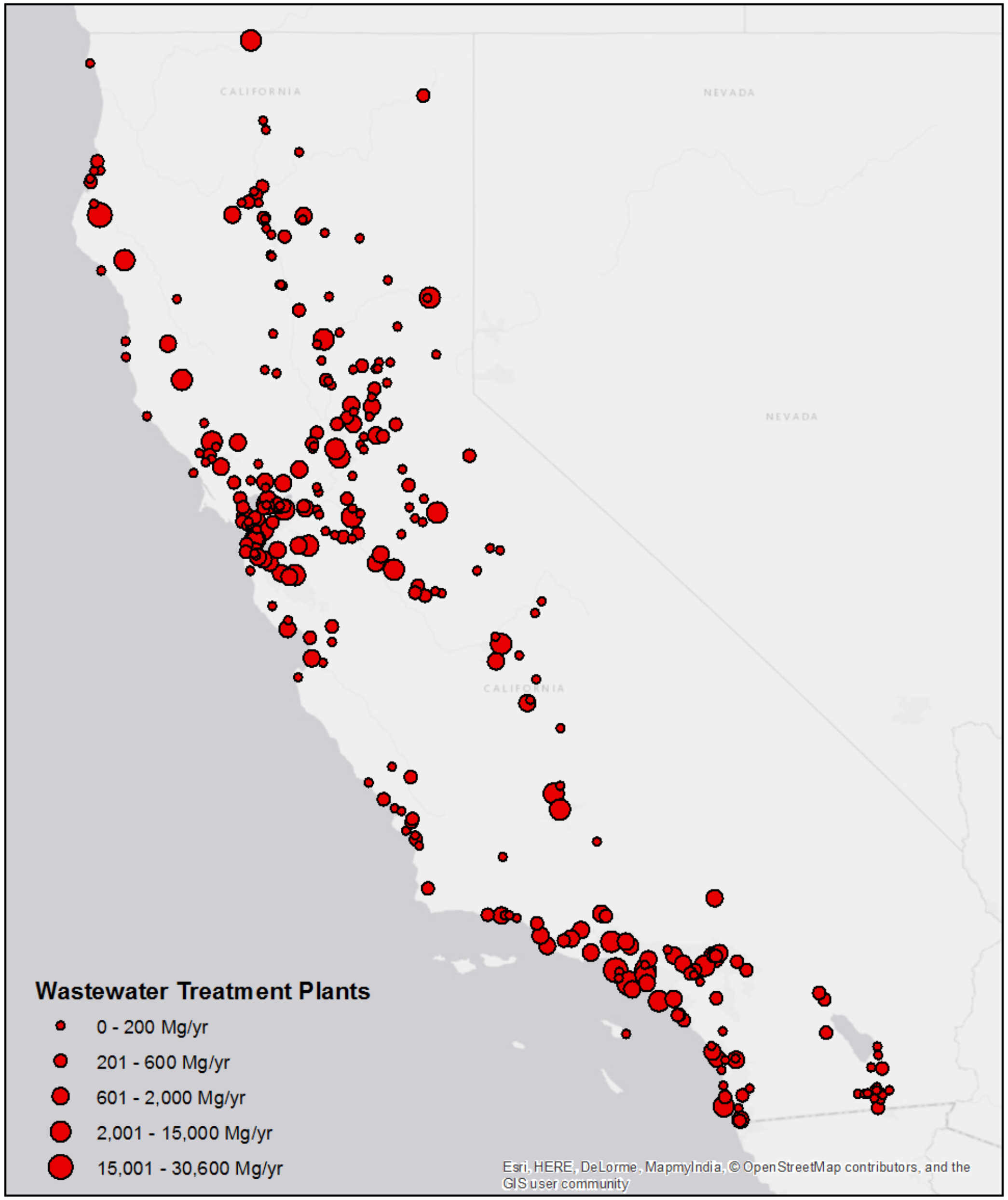
- Wastewater treatment plants (“WWTPs”) and landfill gas (“LFG”) facilities naturally produce significant quantities biogas (40-60% methane)
- Methane is a potent greenhouse gas (”GHG”) that has a 100-year Global Warming Potential (“GWP”) 21 times greater than carbon dioxide (“CO_2”)
- California committed to reduce CO_2 emissions to 1990 levels by 2020 under AB 32
  - By Executive Order, California further committed to 80% CO_2 reduction below 1990 levels by 2050
- California has 303 WWTPs & 314 LFG facilities
- Biogas capture and use from WWTPs and LFG facilities necessary to meet CO_2 reduction goals.

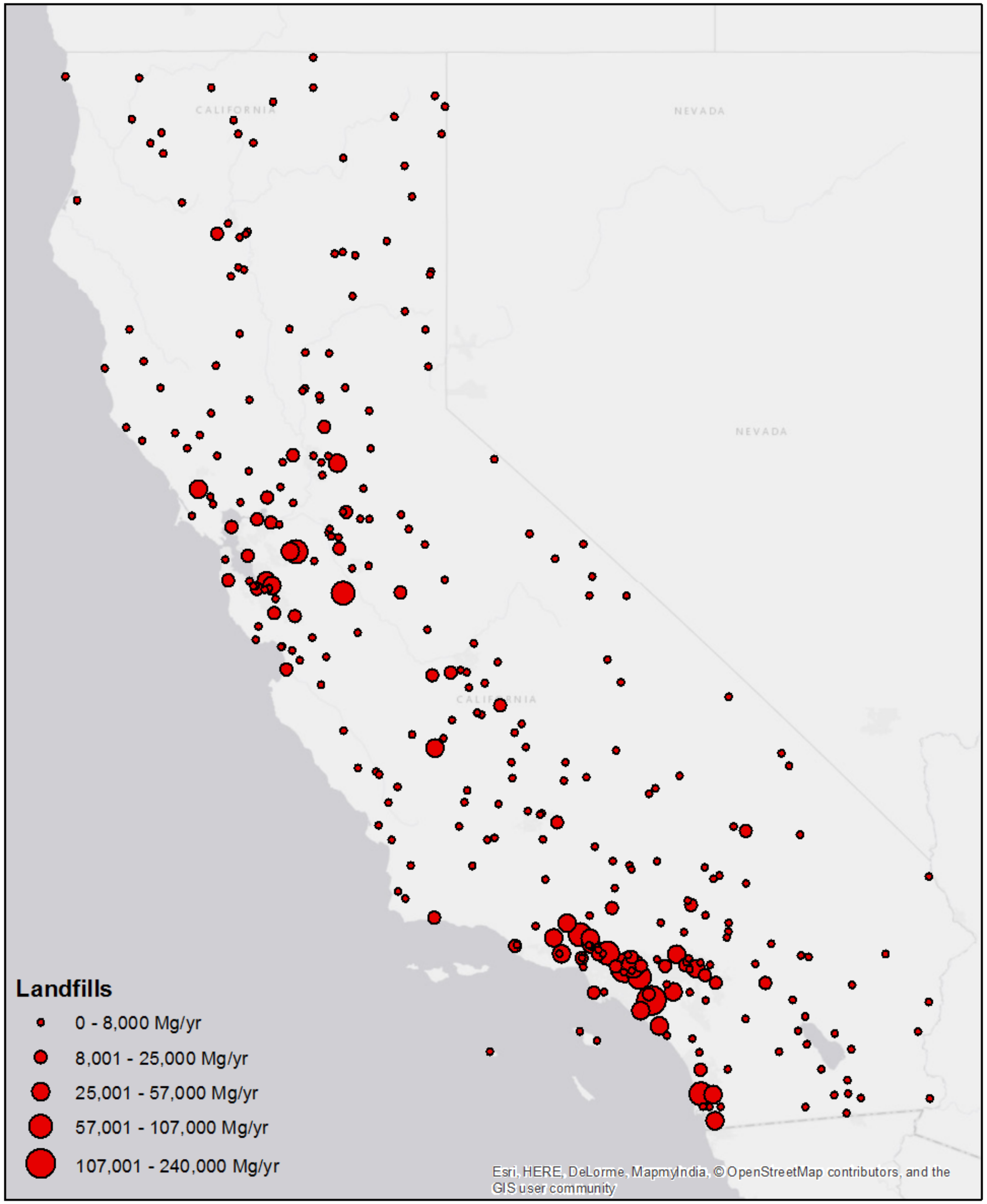
Strong Regulatory Support for Biogas Use

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

Source: California Energy Commission, March 2015, Air Quality and Greenhouse Gas Emissions Impact Assessment from Biomass and Biogas Derived Transportation Fuels and Electricity and Heat Generation, CEC-500-2016-022, Prepared by Advanced Power and Energy Program, p. 7.

California: 303 WWTPs & 314 LFG Facilities





Utilization Scenarios

Scenario 1	•	Onsite combined cycle combustion
Scenario 2	•	Onsite reciprocating engine
Scenario 3	•	Onsite reciprocating engine combined heat and power system or onsite combined cycle system if available biogas would support 3 MW of combined cycle capacity
Scenario 4	•	Onsite micro turbine combined heat and power system or onsite combined cycle system if available biogas would support 3 MW of combined cycle capacity
Scenario 5	•	Onsite fuel cell combined heat and power system
Scenario 6	•	Onsite fuel cell combined heat and power system or onsite combined cycle system if available biogas would support 3 MW of combined cycle capacity
Scenario 7	•	Onsite fuel cell tri-generation system (power, heat, and hydrogen production)
Scenario 8	•	Onsite Compressed Natural Gas (CNG) production
Scenario 9	•	Onsite Liquefied Natural Gas (LNG) production
Scenario 10	•	Pipeline injection of biomethane (Sized for 1 million scfd of available biomethane)
Scenario 11	•	Pipeline injection for central CNG production
Scenario 12	•	Pipeline injection for combined cycle electricity generation
Scenario 13	•	Onsite direct-fired boiler
Scenario 14	•	Onsite hydrogen production using steam methane reformation (SMR)
Scenario 15	•	Onsite microturbine
Scenario 16	•	Onsite gas turbine combustion

Economic Module: Input Parameters

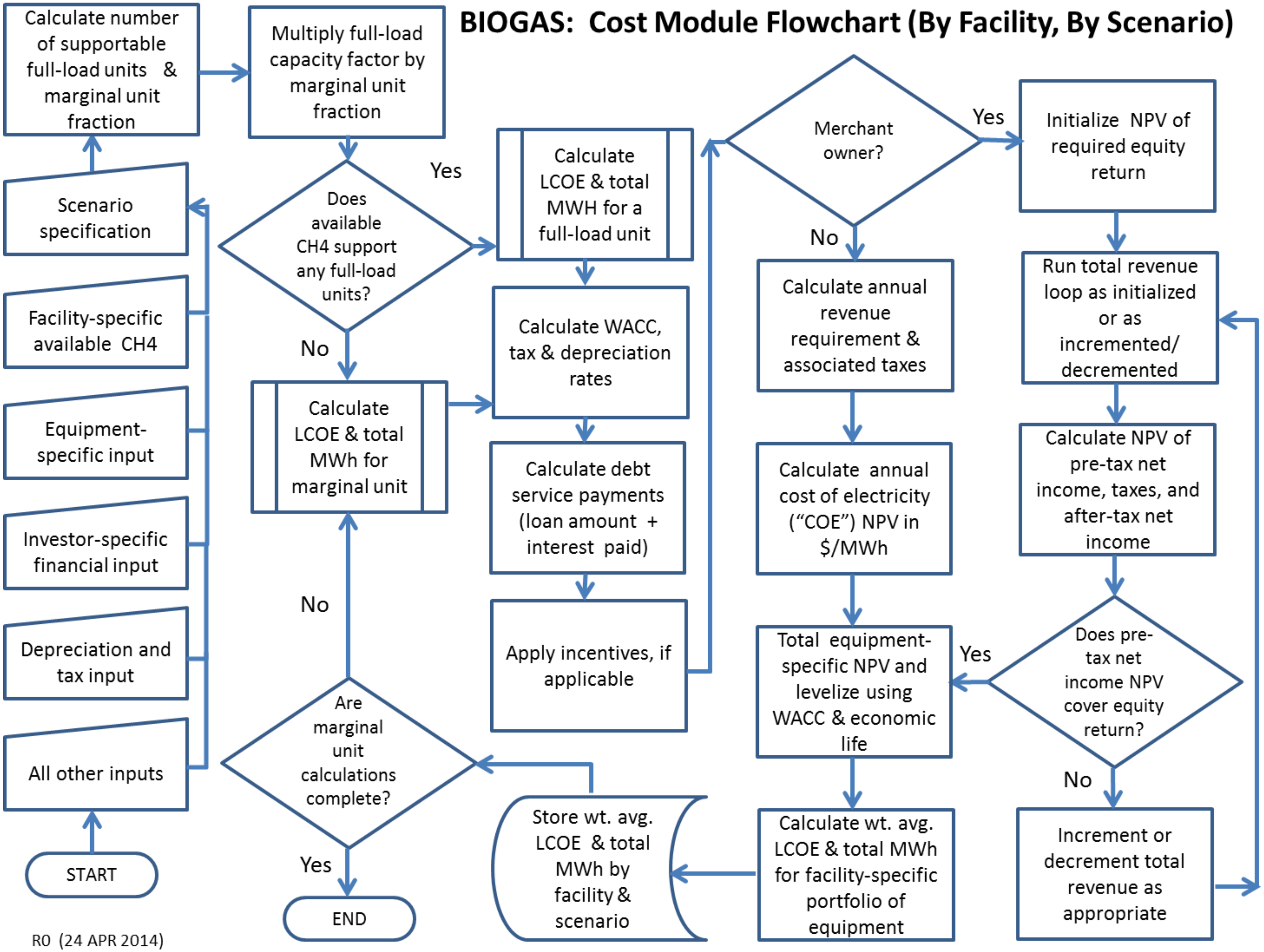
		48	49	50	51	52	53	54	55	56	57	58	59
		1.06 MW Recip	130 kW Microturbine	Small GT (5.5MW)	3 MW Conventional Combined Cycle (CC)	1.4 MW Fuel Cell	Heat Recovery Unit (Marginal	H2 Production (FC; Marginal Impact Only)	Natural Gas Boiler	Onsite CNG Production	Onsite LNG Production	Onsite SMR (500 kg H2/ day)	Pipeline Injection
1	Gross Capacity	1.06	0.13	5.5	3	1.4	1	0.2775	2.1	0.61	0.256	0.82	12.2
2	Annual Capacity Factor	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
3	Instant Cost ($/kW)	1900	3800	2400	1500	3300	50	1830	40	450	600	1450	305
4	FOM ($/kW-yr)	30	20	25	14.44	150	3	90	5	25	30	10	20
5	VOM ($/MWh)	18	22	12	15	10	1	0	1	15	20	25	20
6	HR (MMBtu/MWh)	11.221	13.5	12	7.85	8.06	0	5.2177	3.412	3.412	3.412	11.919	0
7	HR Degradation	0.0024	0.0024	0.001	0.0024	0.009	0.05	0.009	0.05	0.0024	0.0024	0.0024	0.0024
8	Capacity Degradation	0.0024	0.0024	0.001	0.0024	0.009	0.001	0.009	0.001	0.0024	0.0024	0.0024	0.0024
9	Debt Term (Yrs)	12	12	12	12	20	10	20	10	12	12	10	20
10	Economic Life (Yrs)	20	20	20	20	20	20	20	20	20	20	10	20
11	Federal Tax Life (Yrs)	20	20	15	20	10	10	10	15	20	20	20	20
12	State Tax Life (Yrs)	20	20	15	20	20	15	20	15	20	20	10	20
13	Ad Valorem Tax Rate	0.01098	0.01098	0.01098	0.01098	0.01098	0.01098	0.01098	0.01098	0.01098	0.01098	0.01098	0.01098
14	Annual Starts	25	25	150	25	4	0	0	0	0	0	25	0
15	Start-Up Fuel (MMBtu/MW)	2.8	2.8	2.8	2.8	10	0	0	0	0	0	2.8	0
16	Plant Losses	0	0	0.034	0	0.0693	0	0	0	0.0693	0.0693	0	0.0693
17	TX Losses	0	0	0	0	0	0	0	0	0.033	0.0925	0	0.033
18	Transformer Losses	0	0	0	0	0	0	0	0	0	0	0	0
19	TX Cost ($/MWh)	0	0	0	4.3	0	0	0	0	0	0	0	0
20	Fuel Type	1	1	1	1	1	7	0	8	1	1	1	6
21	GDA Eligibility	0	0	0	0	0	0	0	0	0	0	0	0
22	CSI PBI Eligibility	0	0	0	0	0	0	0	0	0	0	0	0
23	Ownership Type	0	0	0	0	0	0	0	0	0	0	0	0
24	Annual Starts	25	25	150	25	25	0	25	0	0	0	0	0
25	CO2 Emission factors (tons CO2/MMBTU fuel)	0.0585	0.0585	0.0585	0.058	0.0585	0	0.0585	0.0585	0.0585	0.0585	0.0585	0.0585
26	CO2 released (tons CO2)	0	0	0	0	0	0	0	0	0	0	0	0
27	Renewable Resource Percent	0	0	0	0	0	0	0	0	0	0	0	0

Power, Heat, Transportation Fuel Potential

Utilization Scenario	Landfills				Wastewater Treatment Plants				
	Additional MW_e Capacity	CNG (Mg)	LNG (Mg)	H2 (Mg)	Additional MW_e capacity	Heat Capacity (MW_{th})	CNG (Mg)	LNG (Mg)	H2 (Mg)
1	815				69				
2	590				69	76			
3	883				101	27			
4	917				132	45			
5	621				85	46			
6	875				104	16			
7	687			105,024	78	34			16,348
8		932,300					189,685		
9			862,341					178,013	
10	923				184				
11		918,317					186,839		
12	923				171				
13	579				94				
14				606,428					85,253
15	575				90	44			
16	258				24	28			

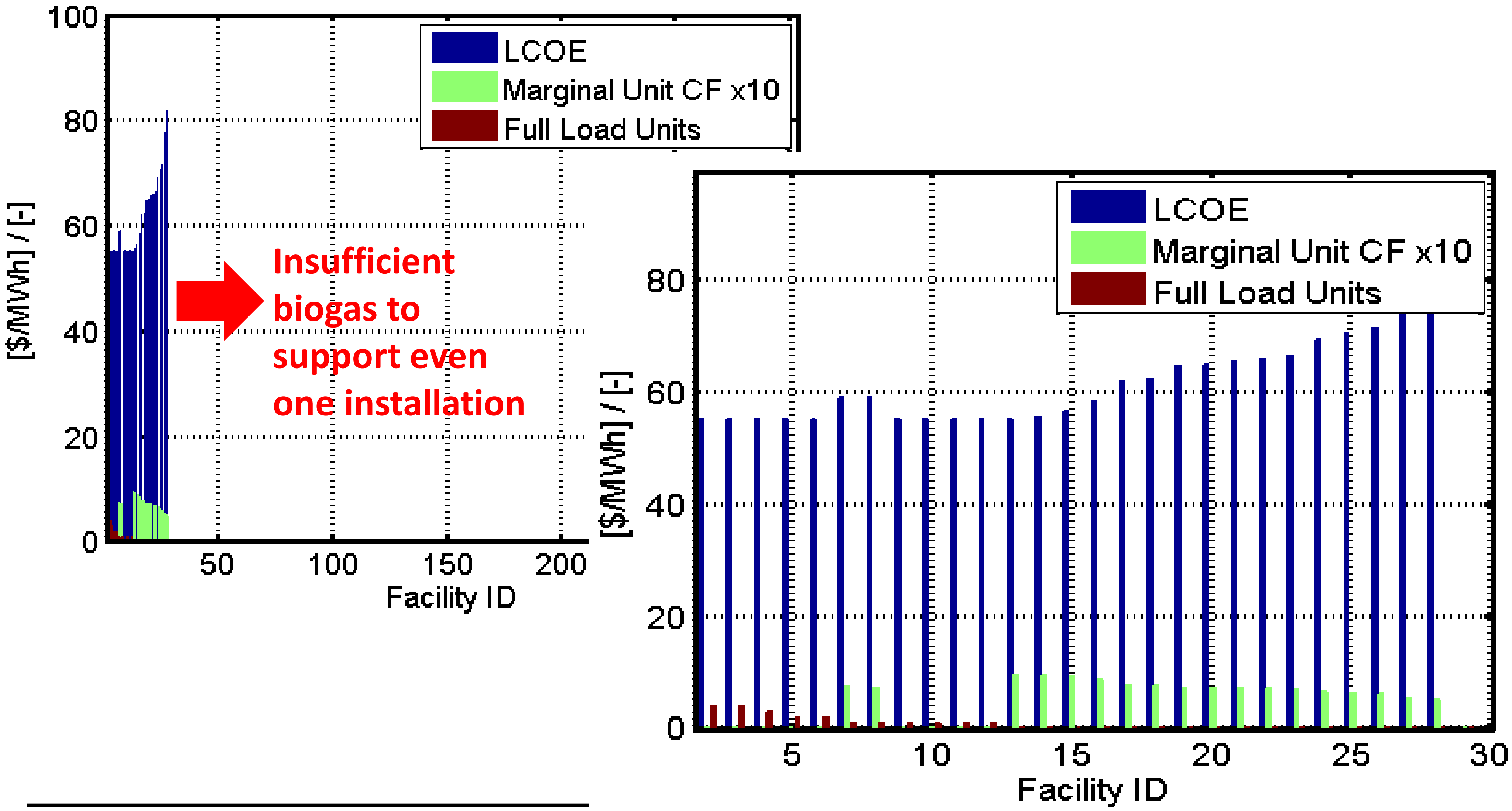
Mg = megagram = 1,000,000 grams = 1,000 kilograms = 1 metric tonne = 2,200 pounds.

Cost Module


BIOGAS: Cost Module Flowchart (By Facility, By Scenario)
Calculate number of supportable full-load units & marginal unit fraction
Multiply full-load capacity factor by marginal unit fraction
Scenario specification
Facility-specific available CH4
Equipment-specific input
Investor-specific financial input
Depreciation and tax input
All other inputs
START
Does available CH4 support any full-load units?
Yes
No
Calculate LCOE & total MWH for a full-load unit
Calculate LCOE & total MWh for marginal unit
Calculate WACC, tax & depreciation rates
Calculate debt service payments (loan amount + interest paid)
Apply incentives, if applicable
No
Are marginal unit calculations complete?
Yes
END
Store wt. avg. LCOE & total MWh by facility & scenario
Merchant owner?
Yes
No
Initialize NPV of required equity return
Calculate annual revenue requirement & associated taxes
Calculate annual cost of electricity ("COE") NPV in $/MWh
Total equipment-specific NPV and levelize using WACC & economic life
Calculate wt. avg. LCOE & total MWh for facility-specific portfolio of equipment
Run total revenue loop as initialized or as incremented/ decremented
Calculate NPV of pre-tax net income, taxes, and after-tax net income
Does pre-tax net income NPV cover equity return?
Yes
No
Increment or decrement total revenue as appropriate
R0 (24 APR 2014)

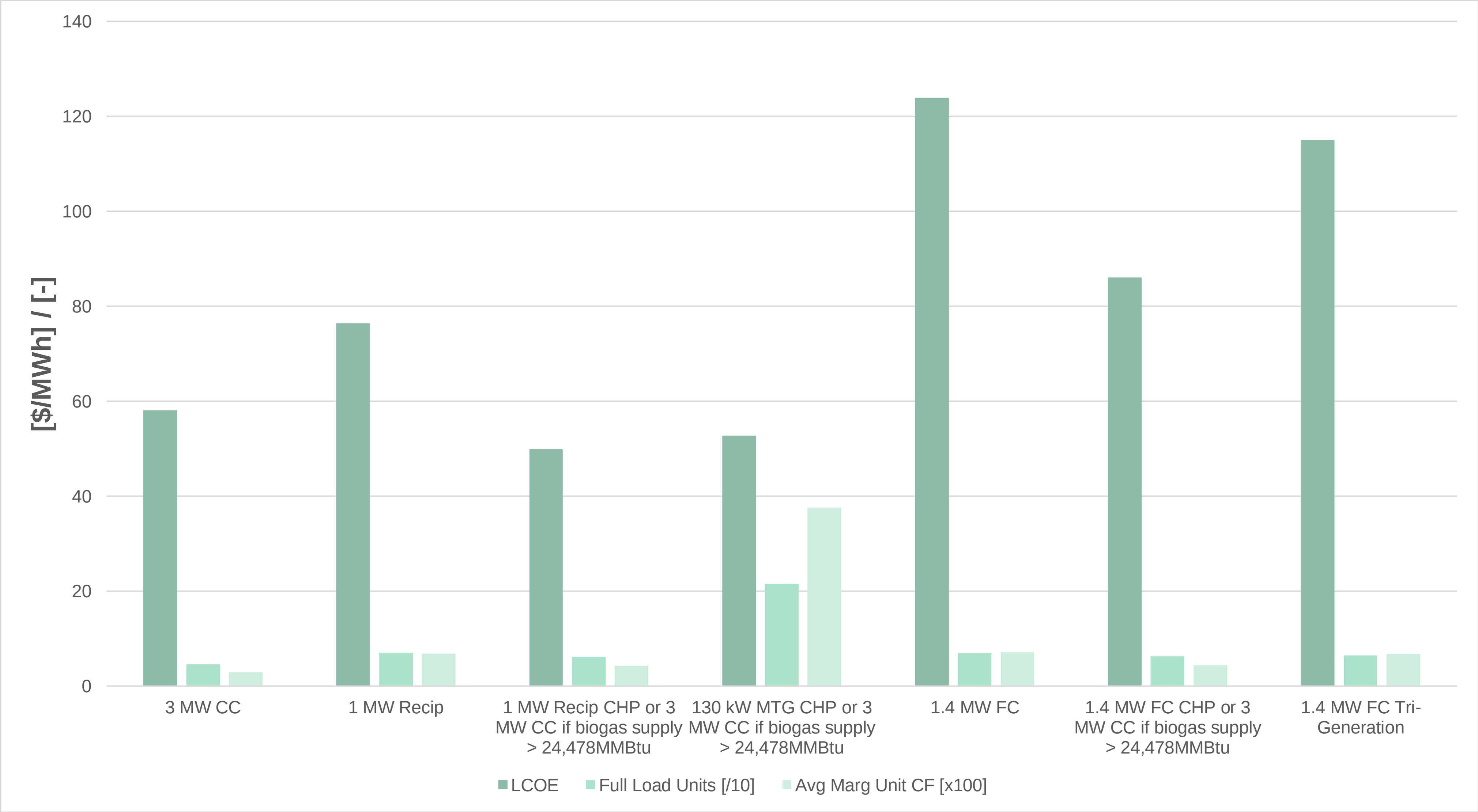
WWTPs: Power Generation Results

- **Utilization Scenario 1: 3 MW Combined Cycle**



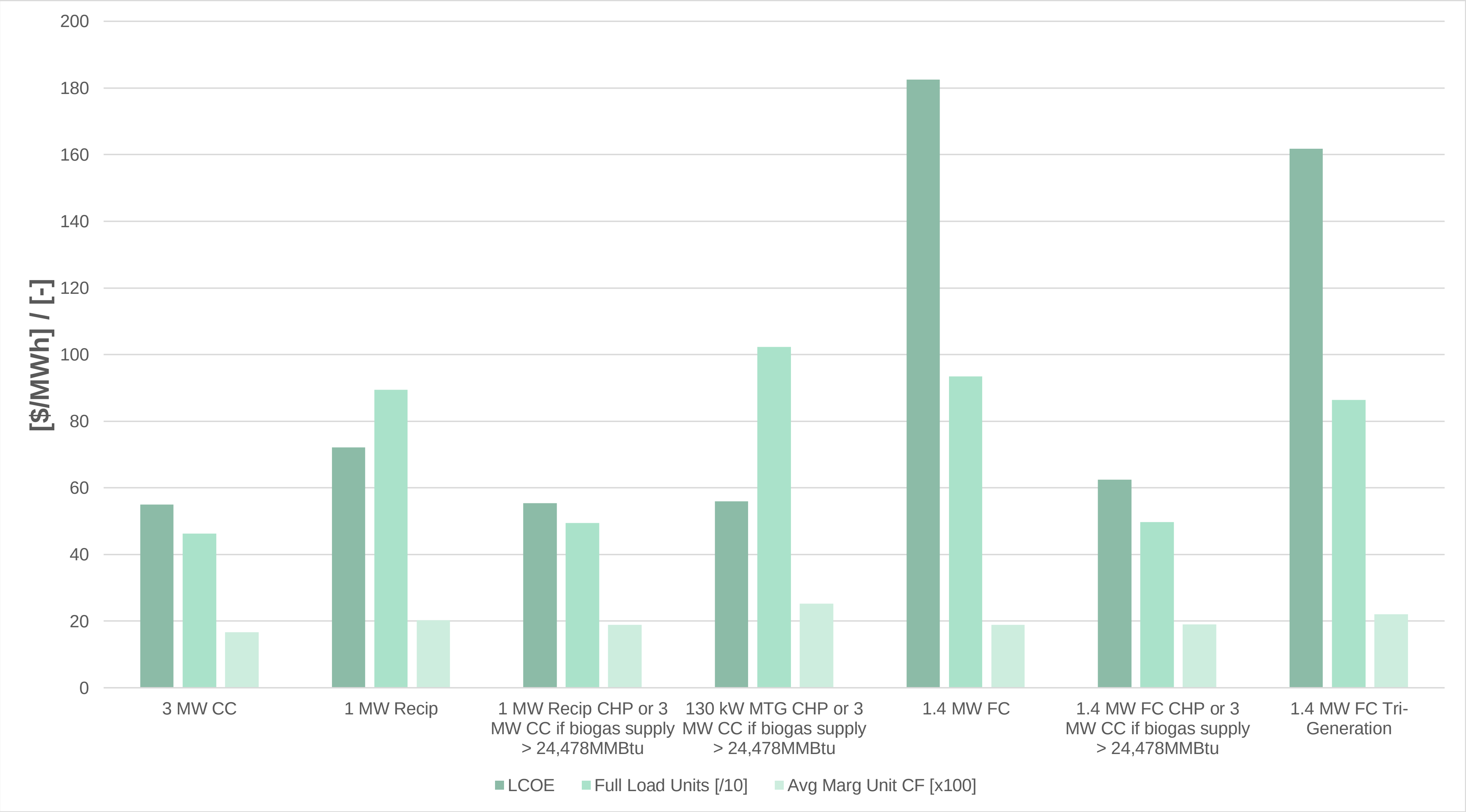
WWTPs: Power Generation Results

- No co-firing, no biogas cost



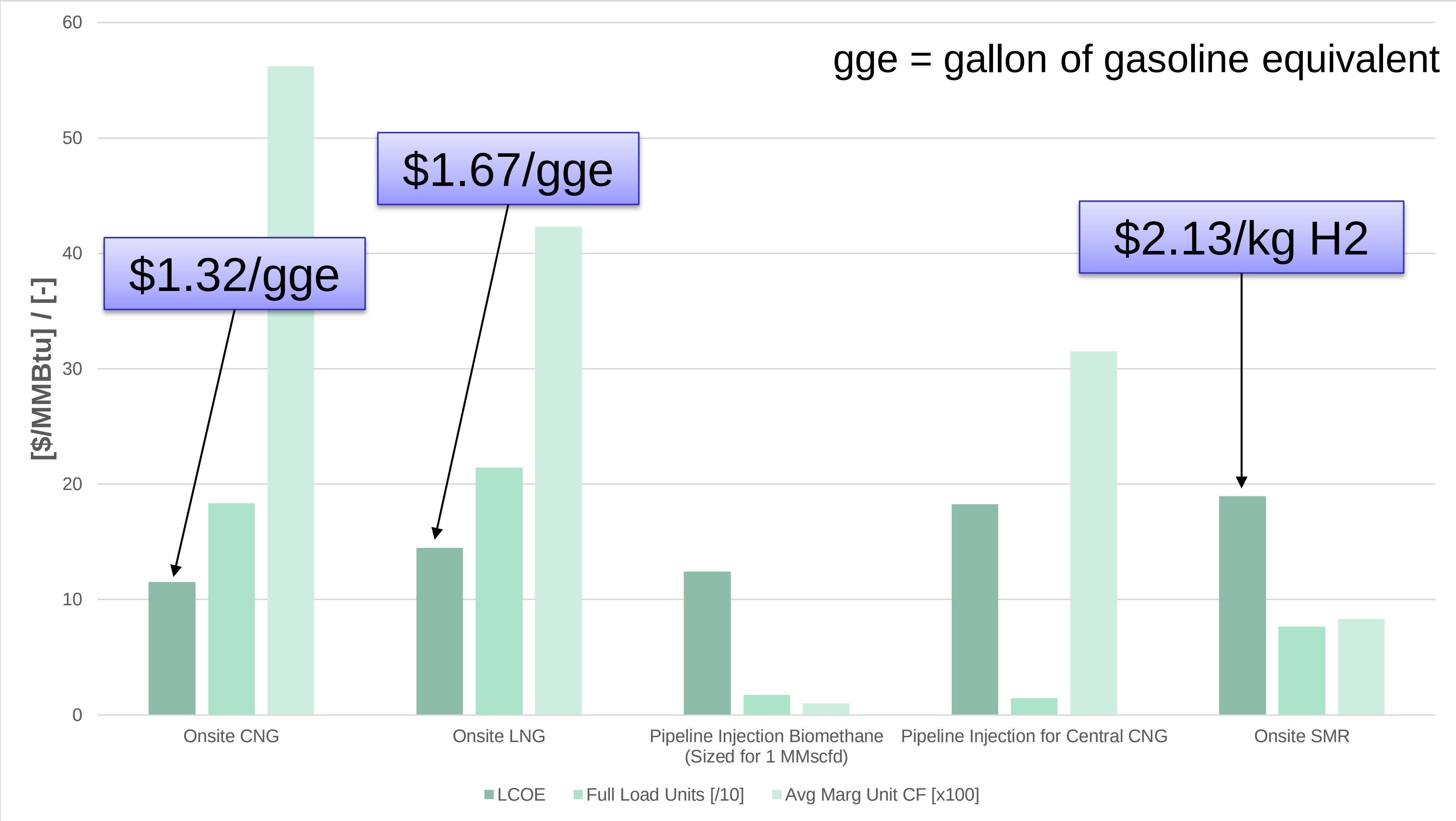
LFG Facilities: Power Generation Results

- No co-firing, no biogas cost



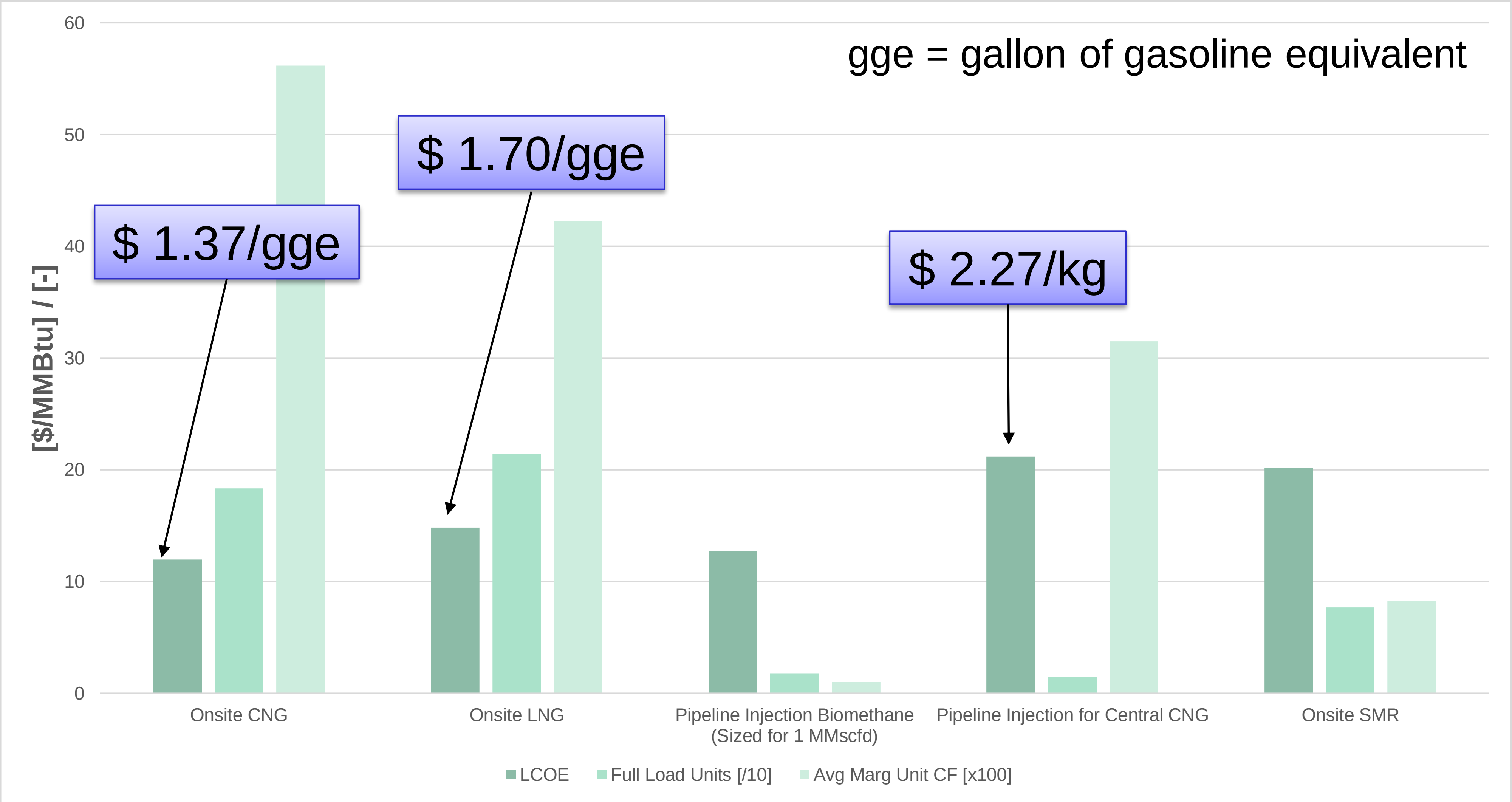
WWTPs: PL Injection & H2 Utilization

- No co-firing, no biogas cost

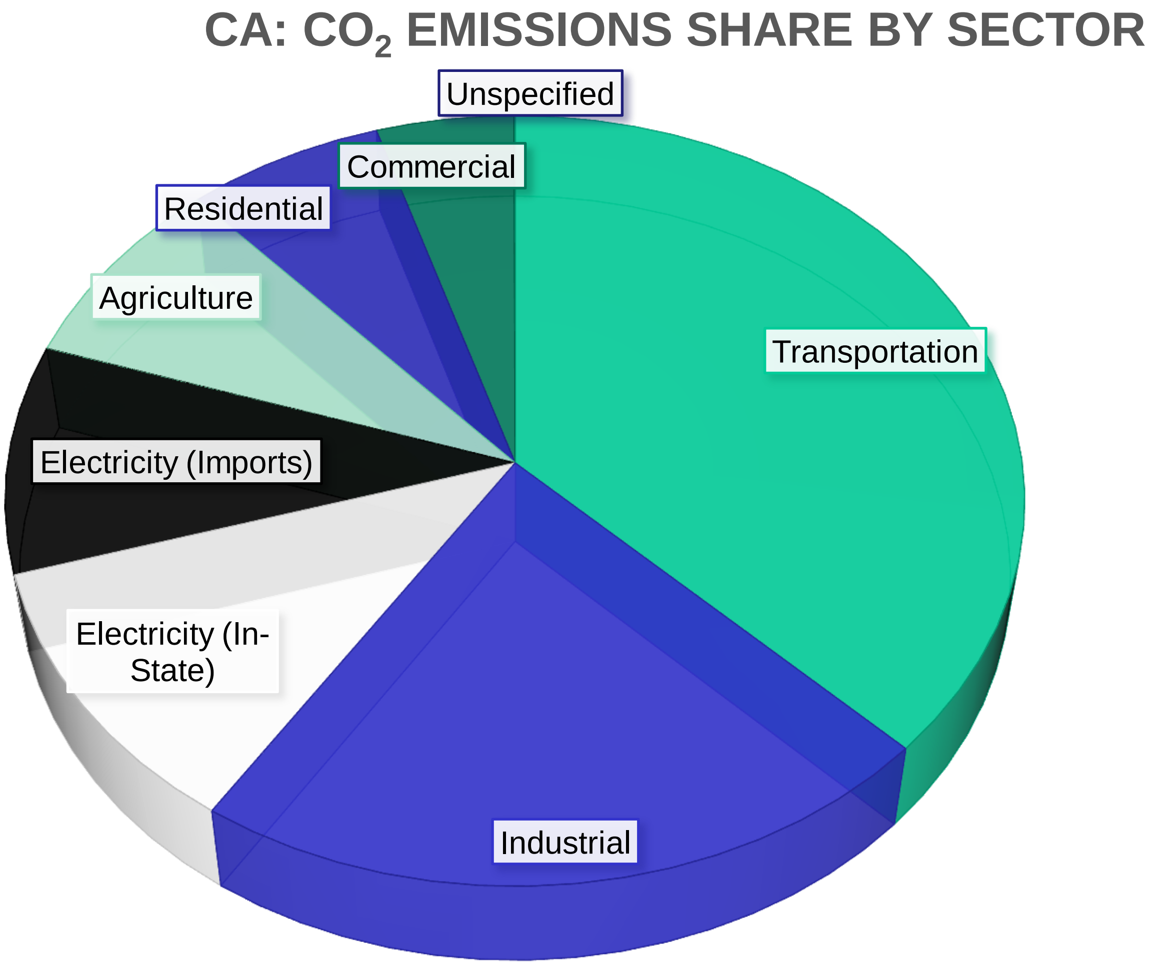


LFG Facilities: PL Injection & H2 Utilization

- No co-firing, no biogas cost

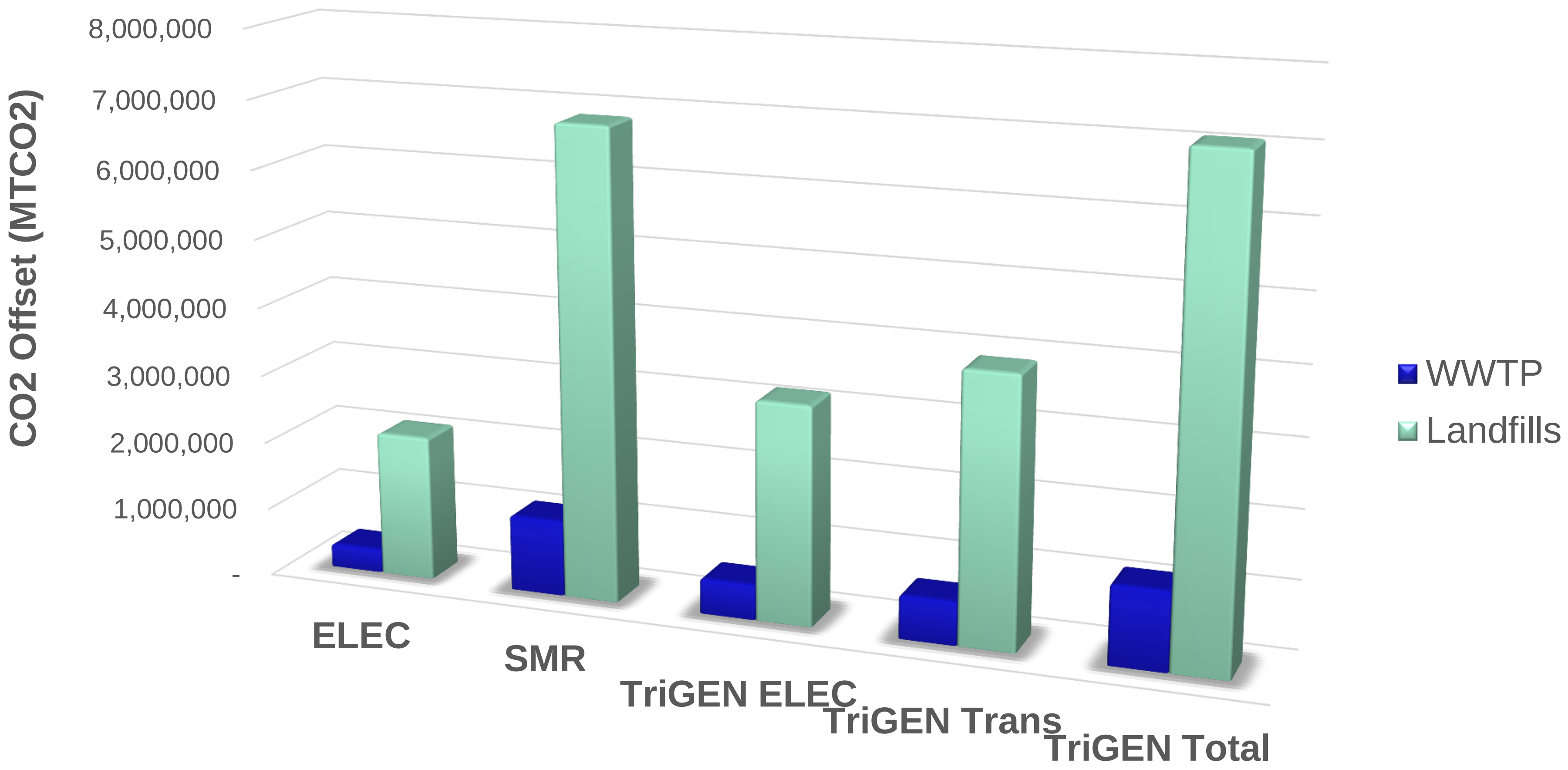


California: CO_2 Emissions by Sector



- Most CO_2 emissions are from the transportation sector
- Thus, target offsetting CO_2 emissions in this sector.

CO_2 Emissions Offset Comparison



- **Offsetting conventional transportation fuels alone has large benefit in offsetting CO_2 emissions**
- **Tri-generation (*i.e.*, power + heat + hydrogen) combines transportation and electricity sector CO_2 reductions.**

Conclusions

- **Lowest power generation LCOE results from:**
  - **1 MW reciprocating engines + CHP for smaller facilities**
  - **3 MW combined cycle plants for larger facilities**
- **LCOE increases as available biogas decreases due to low capacity factor of marginal unit**
  - **Most significant impact when a single unit is installed**
- **Onsite transportation fuel production and use is more economical than centralized fuel production**
  - **CNG most economical for both WWTPs and LFG facilities but H2 provides greater CO_2 emissions reductions**
- **Onsite transportation fuel production and use has more air quality benefits than using biogas for power generation.**

Author Contact Details

Lori Smith Schell, Ph.D., ERP
Empowered Energy
+1 (970) 247-8181
LSchell@EmpoweredEnergy.com

Brendan Shaffer, M.S.
University of California-Irvine
+1 (949) 444-3761
bps@apep.uci.edu

Professor Scott Samuelsen
University of California-Irvine
+1 (949) 824-5468
gss@apep.uci.edu