CHP Technology Roadmapping and Modeling

DRAFT findings and recommendations from Michigan Energy Office CHP Roadmap Project



Modeling to inform Roadmap

- In second year of Michigan Energy Office CHP Roadmap project
- 5 Lakes Energy's project partners include:
 - Sustainable Partners LLC
 - NextEnergy
 - Energy Resources Center of University of Illinois at Chicago
- Using modeling to inform development of roadmap for optimized CHP deployment in Michigan
- Technology taxonomy and modeling results may have implications for IRP guidance by MPSC to utilities

CHP Technology Roadmap

 A technology roadmap is a plan that matches short-term and longterm market goals, such as the widespread deployment of costeffective CHP systems in Michigan, with specific technology solutions to help meet those goals.

State Tool for Electricity Emissions Reduction (STEER) Model

- In order to give state lawmakers, regulators, and stakeholders the ability to evaluate competing energy resources (such as in an IRP process), 5 Lakes Energy, working with researchers at the University of Michigan, previously developed the STEER model with funding from the Energy Foundation and Advanced Energy Economy Institute.
- The principal purpose of the STEER model is to facilitate stakeholder access to data and integrated resource planning analysis.

State Tool for Electricity Emissions Reduction (STEER) Model

- The STEER model automatically calculates the least-cost compliance and implementation strategies, along with cost to users, given certain policy options and forecasts of electricity demand, fuel prices, and technology costs and performance.
- All data, inputs, and formulae are visible to and changeable by the user.
- The Michigan version of the STEER model is available for download online.

State Tool for Electricity Emissions Reduction (STEER) Model

- STEER can dynamically model Michigan's electricity system on an hourly basis by dispatching resource options based on lowest marginal cost, and has the advantage of representing a range of supply-side and demand-side resource options at the level of individual units.
- This provides a rigorous capability to screen and quantify CHP potential in Michigan.

EIA Data

- STEER is populated with U.S. Energy Information Administration (EIA) data of Michigan's existing portfolio of power plants and various modules of fossil-fueled and renewable generating units that can be deployed as needed to meet hourly energy and capacity requirements out to the year 2030.
- Modifications were made to include an expanded, more detailed suite of CHP prime mover technologies, system sizes, and operating characteristics.

U.S. EPA's "Catalog of CHP Technologies"

- STEER modifications required the establishment of criteria to evaluate prime mover technologies for the suite of CHP options.
- According to the U.S. EPA's "Catalog of CHP Technologies" published in March 2015, 97% of CHP projects installed in the U.S. and 99% of total installed CHP capacity are comprised of <u>reciprocating engines</u>, <u>combustion turbines</u>, microturbines, steam turbines and fuel cells.

http://www.epa.gov/sites/production/files/2015-07/documents/catalog_of_chp_technologies.pdf

Prime Mover Technologies

The project team limited its focus to these five technologies:

- Reciprocating engines
- Combustion turbines
- Microturbines
- Steam turbines
- Fuel cells

Goals

Project partners identified and evaluated CHP technologies and applications as a prelude to modifying the STEER model in order to achieve the following goals:

- Quantify Michigan CHP technical potential by prime mover type;
- Quantify industry average cost and performance data for each prime mover type;
- Extrapolate these data to Michigan prime mover technical potential.

Technical Potential

 The U.S. DOE's report "Combined Heat and Power (CHP) Technical Potential in the United States" published in March 2016, defines technical potential as "an estimation of market size constrained only by technological limits – the ability of CHP technologies to fit customer energy needs without regard to economic or market factors."

http://energy.gov/sites/prod/files/2016/04/f30/CHP%20Technical%20P otential%20Study%203-31-2016%20Final.pdf

Upper Boundary

 Technical potential provides a valid upper boundary of CHP deployment in Michigan, with actual deployment levels being lower due to a number of factors that can be represented as inputs to the STEER model that act to constrain deployment below technical potential.

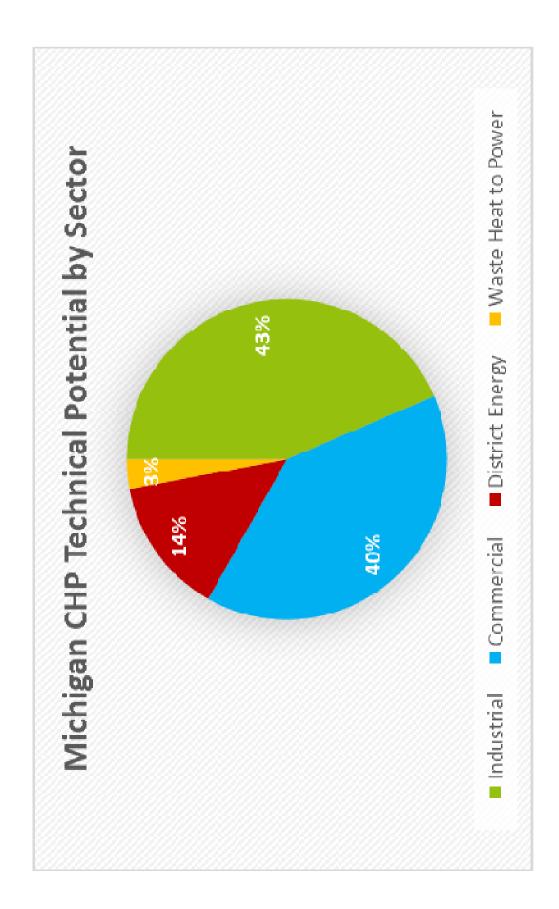
http://energy.gov/sites/prod/files/2016/04/f30/CHP%20Technical%20P otential%20Study%203-31-2016%20Final.pdf

Michigan's Technical Potential

- According to the DOE report, Michigan has nearly 5 GW of CHP technical potential across more than 10,000 sites, as depicted in Figure 3.
- There are 2.2 GW of industrial on-site CHP potential primarily in the transportation equipment, chemicals, primary metals, paper, and food sectors.
- Another 2.0 GW of commercial CHP technical potential exists primarily at commercial office buildings, colleges and universities, hospitals, retail locations, and multifamily housing sectors.

Michigan's Technical Potential

 Michigan also has 700 MW of CHP potential deployment at 2 district energy sites and 150 MW of waste heat to power (WHP) potential identified at 36 sites primarily in the oil and gas extraction, refining, stone/clay/glass, and primary metals sectors.



Technical Potential - capacity

 Beyond commercial and industrial business types, the DOE database also quantifies the technical CHP potential in Michigan, by number of sites and capacity potential, according to annual operating hours (7,500 hours/full-time versus 4,500 hours/part-time) and project size classification (50 to 500 kW, 500 kW to 1 MW, 1 MW to 5 MW, 5 MW to 20 MW, and 20+ MW).

Differentiating Prime Mover Types

- For STEER customization, the DOE's CHP technical potential data for Michigan needed to be broken down one level further, from the total number of CHP sites and capacity (per project size range), to differentiate among the five prime mover types. To complete this task, the project team relied on:
 - CHP cost and performance data from the EPA catalog for the prime movers across the spectrum of available capacities;
 - Project members' collective experience with public and private-sector CHP projects;
 - Various assumptions about the future of the market and pricing trends.

Prime Mover Technologies by System Capacity

Capacity	Fuel Cell	Microturbine	Reciprocating Engine	Combustion Turbine	Steam Turbine
50 kW – 500 KW	Х	Х	Х		
500 kW – 1 MW		Х	Х		
1 MW – 5 MW		Х	Х	Х	
5 MW – 20 MW			х	x	х
> 20 MW				х	Х

EPA Technology and System Size Combinations

In their "Catalog of CHP Technologies", the EPA compiled cost and performance data for twenty-four CHP technology and size combinations as indicated here:

Prime Mover Technology	System Sizes (kW)	EPA Catalog Reference
Fuel Cell	0.7, 1.5, 300, 400, 1400	Table 6-3
Microturbine	30, 65, 200, 250, 333, 1000	Table 5-2
Reciprocating Engine	100, 633, 1121, 3326, 9341	Table 2-2
Combustion Turbine	3510, 7520, 10680, 21730, 45607	Table 3-5
Steam Turbine	500, 3000, 15000	Table 4-2

Cost and Performance Data

- Project partners extrapolated, via simple regression modeling, the cost and performance data for the EPA's 24 technology/size combinations to include 33 additional technology/size combinations, which reflect average system sizes determined by allocating prime movers to Michigan technical potential.
- The following table lists all 57 resource options that are now available in the STEER model's CHP suite. The extrapolated data in combination with the EPA provided data provide the basis for technical analysis of CHP in the STEER model.

STEER Model CHP Suite

Prime Mover Technology	System Sizes (kW)
Fuel Cell	0.7, 1.5, 78, 124, 179, 300, 400, 1400
Microturbine	30, 65, 78, 124, 179, 200, 250, 333, 427, 597, 710, 1000, 1083
Reciprocating Engine	78, 100, 124, 179, 427, 597, 633, 710, 1083, 1121, 1800, 2093, 3326, 8000, 8758, 9341
Combustion Turbine	2093, 3510, 5000, 7520, 8000, 8758, 10680, 21730, 31000, 35867, 45607
Steam Turbine	500, 3000, 8000, 8758, 9091, 15000, 25000, 31000, 35867

Modeling CHP Costs

- Since STEER is a model of the electrical system and CHP provides heat-related benefits to the site host, we assumed that CHP systems will be sized to meet host thermal requirements.
- We used the incremental capital and fuel costs associated with adding electricity production as the costs of CHP generation of electricity.
- The required capital and fuel costs for production of heat presumably would occur anyway, so they are appropriately excluded from the analysis of optimum CHP deployment.

Modeling CHP with STEER

 This modified version of STEER containing these 57 CHP options can now identify which CHP configurations are economically viable across a wide variety of scenarios, narrowing the scope of Michigan's technical potential to only include those projects that should be implemented based on financial expectations and Michigan's overall electricity generation portfolio.

Results

Using the EIA Reference Case for fuel prices and allowing STEER to choose renewables to meet generation requirements, STEER Michigan CHP produced the results for the various CHP technologies that are shown in <u>Attachment B</u>. In this scenario, steam turbines of any size, combustion turbines larger than 20 MW capacity, and reciprocating engines larger than 3 MW capacity are profitable. Michigan technical potential for these CHP technologies totals 1.014 GW.

Variable Technical Teatriate (MMBtU) Capacity (MBtU) Capacity (MBtU) Recovery (MBtU) Const Lateriff Recovery (MBtU) L					Electric			Capital	Marginal	Value of	Unmet					
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0 0.000 12.00 5.48 5.90 44.36 43.7% 43.21 54.000 18.00 5.48 5.48 5.68 43.44 58.2% 34.98 0.000 12.30 5.48 5.68 43.44 50.1% 38.74 228.467 12.20 5.48 5.79 43.93 39.80 59.840 12.30 5.48 5.79 43.93 38.74 59.840 12.30 5.48 5.79 43.93 38.76 144.200 19.00 5.48 5.79 43.40 57.1% 40.57 485.450 19.00 5.48 4.45 4.40 51.7% 40.57 485.450 19.00 5.48 4.40 47.11 45.9% 57.01 144.200 20.00 5.48 4.40 45.12 47.29 57.01 0.000 21.00 5.48 4.40 45.12 47.29 57.01 0.000 21.00 5.48 4.40		650	17.50	5.48		41.81	62.5%	32.00	53.15	20.42	0.24	0.61	1111311	1	-	0
54.000 18.00 5.48 4.44 42.34 58.2% 34.98 0.0000 12.30 5.48 5.68 43.44 50.1% 38.74 228.467 12.20 5.48 5.79 43.93 38.74 59.840 12.30 5.48 5.79 43.93 38.74 59.840 12.30 5.48 5.79 43.93 38.70 90.000 19.00 5.48 5.79 43.93 38.10 144.200 5.48 4.45 43.40 55.6% 38.10 144.200 20.000 5.48 4.40 44.11 45.9% 57.01 0.000 20.00 5.48 4.40 45.12 47.29 57.6% 47.29 144.200 20.000 5.48 4.40 45.11 45.9% 57.01 0.0000 21.00 5.48 4.40 45.12 47.29 57.6% 34.400 5.414 45.12 43.7% 57.6% 57.01		000	12.00	5.48	20	44.36	43.7%	43.21	57.88	29.20	0.49	1.55	12058	г	•	0
0.000 12.30 5.48 5.68 43.44 50.1% 38.74 228.467 12.20 5.48 5.79 43.93 39.80 59.840 12.30 5.48 5.79 43.93 48.3% 39.80 59.840 12.30 5.48 5.79 44.03 46.7% 41.54 90.000 19.00 5.48 4.45 43.40 55.6% 38.10 485.450 19.00 5.48 4.45 43.40 55.6% 38.10 144.200 20.00 5.48 4.40 44.11 45.9% 57.01 0.000 21.00 5.48 4.40 45.12 47.29 57.6% 57.01 34.400 21.00 5.48 4.40 45.12 47.29 56.03 0.0000 21.00 5.48 4.40 45.12 47.29 57.6% 34.400 5.41 45.26 37.6% 57.01 57.6% 57.01 0.0000 21.00 5.48<		000	18.00	5.48	4.44	42.34	58.2%	34.98	54.67		0.68	1.72	108446	2	0	0
228.467 12.20 5.48 5.79 43.93 48.3% 39.80 59.840 12.30 5.48 5.79 43.03 46.7% 41.54 59.840 12.30 5.48 5.79 44.03 46.7% 41.54 485.450 19.00 5.48 4.45 43.40 55.6% 38.10 485.450 19.00 5.48 4.45 43.40 55.6% 38.10 144.200 20.00 5.48 4.40 44.11 45.9% 57.01 0.0000 9.00 5.48 4.40 45.11 45.9% 57.01 0.0000 21.00 5.48 4.40 45.11 45.9% 57.01 0.0000 21.00 5.48 4.40 45.10 44.0% 60.93 345.150 21.00 5.48 4.40 45.10 44.0% 60.93 345.150 22.00 5.48 4.41 47.17 40.7% 61.19 137.550 23.00 5		000	12.30	5,48		43.44	50.1%	38.74	56.08	25.47	0.64	1.96	10064	2	1	0
59.840 12.30 5.48 5.79 44.03 46.7% 41.54 0.000 19.00 5.48 5.79 43.40 52.1% 40.57 485.450 19.00 5.48 4.45 43.40 55.6% 38.10 485.450 19.00 5.48 4.45 43.40 55.6% 38.10 144.200 20.00 5.48 4.40 44.11 45.9% 57.01 0.000 9.00 5.48 6.17 42.82 57.6% 47.29 0.000 21.00 5.48 6.17 42.82 57.6% 47.29 34.400 21.00 5.48 4.40 45.10 44.0% 60.93 345.150 21.00 5.48 4.40 45.10 40.7% 61.19 345.150 22.00 5.48 4.40 45.10 40.7% 61.19 345.150 23.00 5.48 4.41 47.17 40.7% 67.14 110.800 23.50 5.48	580	467	12.20	5.48	40	43.93	48.3%	39.80	56.13	26.42	1.18	3.70	309089	2	2	0
$\begin{array}{llllllllllllllllllllllllllllllllllll$		840	12.30	5.48	5.79	44.03	46.7%	41.54	56.89	27.34	1.34	4.17	2	2	~	0
485.450 19.00 5.48 4.45 43.40 55.6% 38.10 144.200 20.00 5.48 4.45 43.40 55.6% 38.10 0.000 9.00 5.48 4.40 44.11 45.9% 57.01 0.000 9.00 5.48 6.17 42.82 57.6% 47.29 0.000 21.00 5.48 6.17 42.82 57.6% 57.01 34.400 21.00 5.48 6.17 42.82 57.6% 57.01 34.400 21.00 5.48 6.14 47.0% 60.93 345.150 22.00 5.48 4.40 45.10 44.0% 67.14 137.550 23.00 5.48 4.41 47.17 40.7% 67.14 110.800 23.50 5.48 4.34 47.30 39.0% 70.37 0.0000 24.00 5.48 4.73 47.30 39.0% 70.37 0.0000 24.00 5.48 4.34 <td></td> <td>000</td> <td>19.00</td> <td>5.48</td> <td>4.45</td> <td>43.40</td> <td>52.1%</td> <td>40.57</td> <td>56.08</td> <td></td> <td>3.40</td> <td>8.56</td> <td>2036</td> <td>2</td> <td>24</td> <td>0</td>		000	19.00	5.48	4.45	43.40	52.1%	40.57	56.08		3.40	8.56	2036	2	24	0
144.200 20.00 5.48 4.40 44.11 45.9% 57.01 0.000 9.00 5.48 6.17 42.82 57.6% 47.29 0.000 9.00 5.48 6.17 42.82 57.6% 47.29 0.000 21.00 5.48 6.17 42.82 57.6% 47.29 34.400 21.00 5.48 4.40 45.10 44.0% 60.93 345.150 21.00 5.48 6.36 47.25 39.3% 58.72 345.150 22.00 5.48 4.40 46.10 42.3% 64.26 137.550 23.00 5.48 4.41 47.17 40.7% 67.14 110.800 23.50 5.48 4.34 47.30 39.0% 70.37 0.0000 24.00 5.48 4.37 47.38 39.1% 79.52 0.0000 24.00 5.48 4.27 47.38 39.1% 79.52 0.0000 11.00 5.48 <td>~</td> <td>450</td> <td>19.00</td> <td>5,48</td> <td>4.45</td> <td>43.40</td> <td>55.6%</td> <td>38.10</td> <td>54.85</td> <td>22.96</td> <td>3.69</td> <td>9.35</td> <td>932244</td> <td>2</td> <td>5</td> <td>0</td>	~	450	19.00	5,48	4.45	43.40	55.6%	38.10	54.85	22.96	3.69	9.35	932244	2	5	0
0.000 9.00 5.48 6.17 42.82 57.6% 47.29 0.000 21.00 5.48 4.40 45.12 43.7% 61.19 34.400 21.00 5.48 4.40 45.12 43.7% 61.19 34.5150 21.00 5.48 4.40 45.10 44.0% 60.93 345.150 22.00 5.48 6.36 47.25 39.3% 58.72 345.150 22.00 5.48 4.40 46.10 42.3% 64.26 137.550 233.00 5.48 4.34 47.17 40.7% 67.14 110.800 235.0 5.48 4.34 47.30 39.0% 70.37 0.000 24.00 5.48 4.27 47.38 39.1% 79.52 0.000 24.00 5.48 4.27 47.38 39.1% 79.52 0.000 11.00 5.48 4.27 47.38 39.1% 79.52		200	20.00	5.48	2	44.11	45.9%	57.01	57.08	27.82	16.22	40.20	233914	51	-	0
0.000 21.00 5.48 4.40 45.12 43.7% 61.19 34.400 21.00 5.48 4.40 45.10 44.0% 60.93 34.500 12.40 5.48 4.40 45.10 44.0% 60.93 345.150 22.00 5.48 6.36 47.25 39.3% 58.72 345.150 22.00 5.48 4.40 46.10 42.3% 64.26 137.550 23.00 5.48 4.41 47.17 40.7% 67.14 110.800 23.50 5.48 4.34 47.30 39.0% 70.37 0.000 24.00 5.48 4.27 47.38 39.1% 79.52 0.000 24.00 5.48 4.27 47.38 39.1% 79.52 0.000 11.00 5.48 6.42 46.16 42.2% 67.19		000	00.6			42.82	57.6%	47.29	54.85	22.17	13.09	44.59	474	52	2	0
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0.000 12.40 5.48 6.36 47.25 39.3% 58.72 345.150 22.00 5.48 4.40 46.10 42.3% 64.26 137.550 23.00 5.48 4.41 47.17 40.7% 67.14 110.800 23.50 5.48 4.34 47.30 39.0% 70.37 0.000 23.400 5.48 4.27 47.30 39.0% 70.37 0.000 24.00 5.48 4.27 47.38 39.1% 79.52 0.000 11.00 5.48 6.42 46.16 42.2% 67.19		400	21.00		2	45.10	44.0%	60.93	57.91	29.01	19.11	47.25	53646	54	4	0
345.150 22.00 5.48 4.40 46.10 42.3% 64.26 137.550 23.00 5.48 4.41 47.17 40.7% 67.14 110.800 23.50 5.48 4.34 47.30 39.0% 70.37 0.000 24.00 5.48 4.27 47.30 39.0% 70.37 0.000 24.00 5.48 4.27 47.38 39.1% 79.52 0.000 11.00 5.48 6.42 46.16 42.2% 67.19		000	12.40		2	47.25	39.3%	58.72	59.16	32.48	14.33	49.58	4655	55	10	0
137.550 23.00 5.48 4.41 47.17 40.7% 67.14 110.800 23.50 5.48 4.34 47.30 39.0% 70.37 0.000 24.00 5.48 4.27 47.38 39.1% 79.52 0.000 24.00 5.48 4.27 47.38 39.1% 79.52 0.000 11.00 5.48 6.42 46.16 42.2% 67.19		150	22.00		2	46.10	42.3%	64.26	58.06	30.23	22.07	54.60	516484	56	5	0
110.800 23.50 5.48 4.34 47.30 39.0% 70.37 0.000 24.00 5.48 4.27 47.38 39.1% 79.52 0.000 11.00 5.48 6.42 46.16 42.2% 67.19		550	23.00		2	47.17	40.7%	67.14	58.76	31.39	24.16	59,94	197587	57	2	0
0.000 24.00 5.48 4.27 47.38 39.1% 79.52 0.000 11.00 5.48 6.42 46.16 42.2% 67.19		800	23.50		2	47.30	39.0%	70.37	59.18	32.78	25.70	63.15	153875	58	~	0
0.000 11.00 5.48 6.42 46.16 42.2% 67.19		000	24.00	5.48	20	47.38	39.1%	79.52	29,67		34.54	84.02	141	59		0
		000	11.00	5.48		46.16	42.2%	67.19	58.76	30.30	24.29	84.95	253	9	60	0
5.48 6.68 47.61 37.3% 77.88		558	11.00	5.48	6.68	47.61	37.3%	77.88	59.67	34.75	26.58	98.47	155700	G	-	C

0 0	0 0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63 64	65 66	67	89	69	70	71	72	73	74	75	76	11	78	79	80	81	82
74 47373	2355 602	15172	108733	160400	42659	86952	74965	66	17	106	378	3807	2165	0	0	0	0
103.81 107.49	118.70 133.60	135.10	138.11	154.38	206.54	215.95	247.02	287.47	367.73	2152.57	6395.20	7022.20	7440.21	340941.96	581730.08	081471.51	181683.55
32.28 27.92																	
28.61 36.02	40.91 44.84	45.17	44.71	37.36	53.78	47.80	50.86	54.08	54.08	125.29	313.22	313.22	313.22	1277.19	1277.19	1277.19	1277.19
58.06 60.84	62.05 63.55	63.66	63.14	60.92	65.51	63.90	65.23	66.23	66.23	72.51	74.88	74.88	74.88	0.00	0.00	0.00	0.00
73.09 76.28	83.95 92.10	92.56	112.14	95.46	116.57	122.13	129.95	138.18	175.34	981.52	2775.48	3016.74	3177.58	4602.61	7003.98	22012.50	23013.07
44.6% 35.5%	31.2% 28.5%	28.3%	28.6%	34.2%	23.7%	26.7%	25.1%	23.6%	23.6%	10.2%	4.1%	4.1%	4.1%	0.0%	0.0%	0.0%	0.0%
45.85 48.49	49.94 50.23	50.38	50.14	48.88	52.32	50.54	51.87	54.32	54.05	67.38	73.38	73.38	73.38	83.99	90.51	79.41	80.96
5.99 6.84	6.81 6.98	7.00	4.59	6.18	7.17	6.48	6.73	6:99	6.21	4.08	4.27	4.27	4.27	8.03	9.95	3.54	4.74
5.48 5.48	5.48 5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48	5.48
13.00 11.00	12.60 12.00	12.00	25.00	15.00	13.00	15.00	15.00	16.00	20.00	45.00	50.00	50.00	50.00	40.00	36.00	60.00	55.00
0.000 58.710	0.000	24.273	110.250	179.550	85.412	131.575	128.059	0.000	0.000	0.000	2.751	27.700	15.750	0.000	0.000	0.000	0.000
Cogen_MT_65 Cogen_MT_710	Cogen_CT_3510 Cogen_MT_1000	Cogen_MT_1083	Cogen_RE_78	Cogen_MT_78	Cogen_CT_2093	Cogen_MT_124	Cogen_MT_179	Cogen_MT_200	Cogen_MT_30	Cogen_FC_300	Cogen_FC_179	Cogen_FC_124	Cogen_FC_78	Cogen_FC_1400	Cogen_FC_400	Cogen_FC_0.7	Cogen_FC_1.5

 Using the EIA Reference Case for fuel prices without allowing STEER to choose renewables to meet generation requirements, STEER Michigan CHP produced the results for the various CHP technologies that are shown in <u>Attachment C</u>. In this scenario, the same CHP technologies as in the scenario with renewables are profitable, but in order to meet Clean Power Plan carbon emissions limits, STEER is also choosing combustion turbines down to 3 MW capacity and reciprocating engines down to 1 MW capacity. Michigan technical potential for these additional CHP technologies totals 1.345 GW, for a total selected capacity of 2.36 GW.

				Capacity	Capital Recovery	Marginal	Value of Capacity		Cost to	Carbon	
Electric Heat Rate Dispatch (MMBtu/MWh) Cost	Fuel Electric Heat Rat (S/MMBtu) (MMBtu/MWh)	(ate l	Dispatch Cost	Factor If Built	Rev Req (\$/MWh)	(\$/MWh) If Built	(5/MWn) If Built	(\$/MWh) If Built	Mitigate (\$/t)	Mitugated (t/yr)	Rank Built?
4.45	5.48 4.45	10	32.38	69.8%	8.72	51.35	18.31	-28.56	-70.01	135382	1
4.45		10	32.38	70.1%	8.67	51.24	18.22	-28.41	-68.85	141858	2
4.54		-	33.90	69.3%	8.82	51.46	18.42	-27.16	-68,34	t 7242	
4.45		1:23	32.38				- Adami			t 258420	ব
4.44		4	30.34	72.7%	8.27	50.54		-29,49	-67.07	42016	
4.44	5.48 4.4	4	30.31	73.0%	8.22	50.34		-29.29	-65.94	1 88121	
4.44	5.48 4.4	4	30.31	73.5%		50.34	17.38	-29.23	-65.79	9 71513	
	5.48 4.4	4	30.31	74.3%	8.08	49.92				396757	00
4.54	5.48 4.5	4	34.87	69.3%	14.83	51.46	18.42	-20.18	-50.75	1208	6
5.59	5.48 5.59	en.	39.86	63.3%		53.13	20.17	-14.23	-43.91	79969	10
	5,48 4,63	527	33.85	75.3%					-39.51	24339	
5.55	5.48 5.55	32	39.69	66.6%	20.10	52.19	19.17	-11.57	-35.59	715771	12
	5.48 5.55		39.69					-11.49			
			39.36							39879	
4.57	5.48 4.57		37.07	73.8%	19.82	51.46	17.31	-11.88	-30.04	t 624721	15
	5.48 4.57		37.57	71.9%	20.81	52.02	17.77	-11.42	-29.93	115268	
			40.36						7		
			41.81							Π	
			44.36								
			42.34								
			43.44								
		1	43.93							m	
			44.03								
4,45	74.4 24.5 74.4 24.5		43.40	52.1%	10.95	20.05	24,49 27 QK	3.60	00.0	9502 0	75
		0	44.11						4		
		~	42.82	57.6%	47.29		22.17	13.09	44.59		52
4.40	5.48 4.4	0	45.12	43.7%	61.19	58.06	29.20	19.05	47.16	980	53
4.40	5.48 4.40	~	45.10	44.0%	60.93	57.91	29.01	19.11	47.25	53646	
6.36	5.48 6.36	10	47.25	39.3%	58.72	59.16	32.48	14.33	49.58	3 4655	
4.40	5.48 4.40	1	46.10	42.3%	64.26	58.06	30.23	22.07	54.60	516484	
4.41	5.48 4.41		47.17	40.7%	67.14	58.76	31.39	24.16	59,94	197587	57
4.34	5.48 4.34		47.30	39.0%	70.37	59.18	32.78	25.70	63.15	153875	58
4.27	5.48 4.27		47.38	39.1%	79.52	29.62	32.70	34.54	84.02	141	59
6,42	5.48 6.42		46.16	42.2%	67.19	58.76	30.30	24.29	84.95	253	60
		-	47.61	37.3%			34.25	26.58	98.47	155700	
6.76	5.48 6.7	10	48.05			60.67	35.39	27.13	102.52	6834	
5.99	5.48 5.9	66	45.85	44.6%	73.09	58.06	28.61	32.28	103.81	74	63
1 10 1		ŀ									

 Using the EIA High Resource Case for fuel prices and allowing STEER to choose renewables to meet generation requirements, STEER Michigan CHP produced the results for the various CHP technologies that are shown in <u>Attachment D</u>. Although natural gas prices are lower in this scenario, CHP is generally competing with combined cycle natural gas in the dispatch order, so that the same technologies are profitable as in the Reference Case: steam turbines of any size, combustion turbines larger than 20 MW capacity, and reciprocating engines larger than 3 MW capacity. As in the Reference case, these have Michigan technical potential totaling 1.014 GW.

				Electric Heat	eat			Capital	Marginal	Value of	Unmet					
		Variable		Rate		-		Recovery	LMP	Capacity	Rev Req	Cost to	Carbon			
	Technical	0&M	Fuel	(MMBtu/MW Dispatch	MW Di		Factor If	Rev Req	(S/MWh)	(A/WWh)	(4/MM/s)	Mitigate	Mitigated	P		
Name	Potential	(\$/MWh)	(\$/MMBtu)	<u>ل</u>	3	Cost E	Built	(\$/MWh)	If Built	If Built	If Built	(\$/t)	(t/yr)	Rank	Built?	~
Cogen_ST_31000	31.000	6.00	3.89		4.44	23.26	90.6%	6.63	37.18	14.10	-21.39	-41.12	127983	983	1	-
Cogen_ST_35867	134.500	6.00	3.89		4.44	23.26	90.6%	6.63	37.18	14.10	-21.39	41.12		555279	2	-
Cogen_ST_25000	25.000	6.00	3.89		4.44	23.26	89.06	6.63	37.18	14.10	-21.39	-41,11		103223	m	-
Cogen_ST_15000	15.000	6.00	3.89		4.44	23.28	89.06	6.64	37.18	14.10	-21.36	-41.08		61896	4	-
Cogen_ST_3000	3.000	00'6	3.89		4.54	26.67	83.0%	7.37	38.20	15.39	-19.54	-39.83		10701	5	-
Cogen_57_8758	54.300	8.00	3.89		4.45	25.31	89.8%	6.77	37.29	14,23	-19.44	-37.58		220865	9	-
Cogen ST 8000	56.000	8.00	3.89		4.45	25.31	89.8%	6.77	37.27	14.22	-19.41	-37.50	50 228125	125	2	-
Cogen_ST_9091	100.000	8.00	3.89		4.45	25.31	90.1%	6.75	37.23	14.18	-19.35	-37.30		409307	00	Ч
Cogen_ST_500	0.500	10.00	3.89		4.54	27.65	71.0%	14.48	40.14	17.99	-15.99	-37.25		1335	6	н
Cogen_CT_45607	44.488	9.20	3.89		5.59	30,96	64.0%	19.00	41.51	19.96	-11.50	-30.45		94172	10	H
Cogen_CT_35867	377.273	9.30	3.89		5.55	30.87	66.9%	20.01	40.91	19.08	-9.11	-24.25		831539	11	H
Cogen_CT_31000	28.985	9.30	3.89		5.55	30.87	68.2%	19.75	40.90	18.74	-9.02	-24.01		65025	12	-
Cogen_CT_21730	20.336	9.30	3.89		5.49	30.64	70.0%	19.90	40.61	18.23	-8.30	-22.01		47058	13	-
Cogen_RE_9341	9.341	8.50	3.89		4.63	26.49	90.1%	15.80	38.18	14.17	-10.06	-20.70		35848	14	H
Cogen_RE_8758	244.350	12.00	3.89		4.57	29.80	75.6%	19.34	40.23	16,89	-7.99	-18.68		692206	15	-
Cogen_RE_8000	48.000	12.50	3.89		4.57	30.30	73.9%	20.24	40,54	17.29	-7.29	-16.96		133499	16	-
Cogen_RE_3326	3.326	16.00	3.89		4.45	33.29	66.6%	23.82	41.65	19.17	-3.71	-8.31		8656	17	0
Cogen_CT_7520	7.038	12.30	3.89		5.68	34.41	64.3%	30.23	41.65	19.88	3.11	8.33		14801	18	0
Cogen_CT_8758	228.467	12.20	3.89		5.79	34.72	63.6%	30.27	41.65	20.09	3.25	8.84		467386	19	0
Cogen_CT_10680	9,950	12.00	3.89		5.90	34.97	54.6%	34.62	42.86	23.39	3.34	10.26		15471	20	0
Cogen_RE_2093	517.650	17.50	3.89		4.44	34.76	60.2%	33.22	41.89	21.20	4.88	11.15	1196212	212	21	0
Cogen_CT_8000	59.840	12.30	3.89		5.79	34.82	54.9%	35.38	42.81	23.28	4.10	12.36		95393	22	0
Cogen_RE_1800	54.000	18.00	3.89		4.44	35.28	56.0%	36.33	42.89	22,81	5.90	14.36		108745	23	0
Cogen_RE_1083	485.450	19.00	3.89		4,45	36.32	52.6%	40.26	43.03	24.26	9.29	22.65	55 917817	817	49	0
Cogen_RE_1121	1.121	19.00	3.89		4,45	36.32	49.1%	43.10	43.88	26.02	9.52	23.20		1978	50	0
Cogen_MT_333	0.320	00.6	3.89		6.17	33.00	66.5%	40.99	41.65	19.21	13.13	38.04		643	51	0
Cogen_CT_5000	4.675	12.40	3.89		6.36	37.14	43.7%	52.79	44.47	29.20	16.26	54.25		5368	52	0
Cogen_RE_710	144.200	20.00	3.89		4.40	37.12	44.9%	58.26	44.32	28.43	22.62	54.69		234659	53	0
Cogen_RE_633	0.633	21.00	3.89		4.40	38.12	43.0%	62.19	44.67	29.68	25.96	62.47		592	54	0
Cogen_RE_597	34.400	21.00	3.89		4.40	38.11	43.2%	62.08	44,60	29.56	26.03	62.68		54071	55	0
Cogen_MT_250	0.240	11.00	3.89		6.42	35,96	55.4%	51.16	43.03	23.07	21.02	71.21		344	56	0
Cogen_RE_427	345.150	22.00	3.89		4.40	39.11	39.9%	68.10	44.87	32.03	30.30	72.55		503513	57	0
Cogen_RE_179	137.550	23.00	3.89		4.41	40.16	35.8%	76.36	45.62	35.70	35.20	83.09		182593	58	0
Cogen_MT_427	176.558	11.00	3.89		6.68	36.99	47.4%	57.35	43.93	26.95	23.46	83.76		205310	59	0
Cogen_RE_124	110,800	23,50	3.89		4.34	40.39	33.4%	82.10	46.04	38.25	38.21	88.68		139635	60	0
Cogen_MT_597	8.170	11.00	3.89		6.76	37.30	45.3%	59.92	44.47	28.22	24.53	88.83		8943	61	0
Cogen_MT_710	58.710	11.00	3.89		6.84	37.62	44.9%	60.20	44.47	28.42	24.92	91.81		62726	62	0
Casa 17 3510	NUC C	13 61	00 C		10 2	1110	A4 DOV	NO 63	LO VV	21 10	IU LL			VOLE	G	

 Using the EIA High Resource Case for fuel prices without allowing STEER to choose renewables to meet generation requirements, STEER Michigan CHP produced the results for the various CHP technologies that are shown in <u>Attachment E</u>. In this scenario, the same CHP technologies are profitable as in the preceding scenario, but in order to meet Clean Power Plan carbon emissions limits, STEER is also choosing combustion turbines down to 8 MW, for an additional technical potential of 228 MW and a total technical potential of 1.242 GW.

	Tachnicsl	Variable	Lind	Heat Rate	Heat Rate		Capacity Cactor If	Recovery	LMP	Capacity rc/wwwh	Rev Req	Cost to	Carbon			
Name	Potential	(AWWh)	(S/MMBtu)	2.50			Built	(\$/MWh)	If Built	If Built	if Built	(\$/t)	(t/yr)	Rank	Built?	1000
Cogen_ST_31000	0.000	6.00	3.8	6	4.44	23.26	69.06	6.63	37.18	14.10	0 -21.39	-41,12	12 127983		1	
Cogen_ST_35867	134.500	6.00	3.89	c.	4.44	23.26	90.6%	6.63	37.18	14.10	-21.39	-41.12	12 555279	<u>, 1</u> 25	2	
Cogen_ST_25000	0.000	6.00	3.89	6	4.44	23.26	90.6%	6.63	37.18	14.10	-21.39	-41.11	11 103223		m	
Cogen_ST_15000	0.000	6.00	3.89	6	4.44	23.28	90.6%	6.64	37.18	14.10	-21.36	-41.08	08 61896	15	4	
Cogen_ST_3000	0.000	9.00	3.89	6	4.54	26.67	83.0%	7.37	38.20	15.39	-19.54	1 -39.83	83 10701	100	5	
Cogen_ST_8758	54.300	8.00	3.89	5	4.45	25.31	89.8%	6.77	37.29	14.23	19.44	1 -37.58	58 220865		9	
Cogen_ST_8000	56.000	8.00	3.89	6	4.45	25.31	89.8%	6.77	37.27	14.22	-19.41	-37.50	50 228125		7	
Cogen_ST_9091	100.000	8.00	3.89	6	4.45	25.31	90.1%	6.75	37.23	14.18	19.35	-37.30	30 409307		00	
Cogen_ST_500	0.000	10.00	3.89	6	4.54	27.65	71.0%	14.48	40.14	17.99	-15.99	-37.25	25 1335		6	
Cogen_CT_45607	0.000	9.20	3.89	0	5.59	30.96	64.0%	19.00	41.51	19.96	-11.50	-30.45	45 94172		10	
Cogen_CT_35867	377.273	9.30	3.89	CP.	5.55	30.87	66.9%	20.01	40.91	19.08	11.9-11	-24.25	25 831539	-	11	
Cogen_CT_31000	0.000	9.30	3.89	6	5.55	30.87	68.2%	19.75	40.90	18.74	1 -9.02	-24.01	01 65025		12	
Cogen_CT_21730	0.000	9.30	3.89	6	5.49	30.64	70.0%	19.90	40.61	18.23	8-30	-22.01	01 47058	-	13	
Cogen_RE_9341	0.000	8.50	3.89	6	4.63	26.49	90.1%	15.80	38.18	14.17	-10.06	-20.70	70 35848	1	14	
Cogen_RE_8758	244.350	12.00	3.89	6	4.57	29.80	75.6%	19.34	40.23	16.89	66'1- (-18.68	68 692206	17	15	
Cogen_RE_8000	48.000	12.50	3.89	6	4.57	30.30	73.9%	20.24	40.54	17.29	-7.29	-16.96	96 133499		16	
Cogen_RE_3326	0.000	16.00	3.89	6	4.45	33.29	66.6%	23.82	41.65	19.17	-3.71	-8.31	31 8656	1.00	17	
Cogen_CT_7520	0.000	12.30	3.89	6	5.68	34.41	64.3%	30.23	41.65	19,88	3.11		8.33 14801	523	18	
Cogen_CT_8758	228.467	12.20	3.89	6	5.79	34.72	63.6%	30.27	41.65	20.09	3.25		8.84 467386	12	19	
Cogen_CT_10680	0.000			6	5.90	34.97	54.6%							10.0	20	
Cogen_RE_2093	517.650	17.50	3.89	6	4.44	34.76	60.2%	33.22	41.89	21.20	4.88	3 11.15	15 1196212	<u>.</u>	21	
Cogen_CT_8000	59.840	12.30	3.89	5	5.79	34.82	54.9%	35.38	42.81	23.28	4.10	12.36	36 95393		22	
Cogen_RE_1800	54.000	18.00		0	4.44	35.28	56.0%	36.33	42.89		5.90	14.36	36 108745		23	
Cogen_RE_1083	485.450	19.00	3.89	5	4.45	36.32	52.6%	40.26	43.03	24.26	9.29	9 22.65	65 917817		49	
Cogen_RE_1121	0.000	19.00	3.89	6	4.45	36.32	49.1%				9.52	23.20	20 1978		20	
Cogen_MT_333	0.000	00'6	3.89	б	6.17	33.00	66.5%	40.99	41.65	19.21	13.13	38.04	04 643	1	51	
Cogen_CT_5000	0.000	12.40	3.89	đ	6.36	37.14	43.7%	52.79	44.47	29.20	16.26	54.25	25 5368	-	52	
Cogen_RE_710	144.200	20.00	3.89	6	4.40	37.12	44.9%	58.26	44.32	28.43	22.62	54.69	69 234659		23	
Cogen_RE_633	0.000	21.00	3.89	6	4.40	38.12	43.0%	62.19	44.67	29.68	325.96	5 62.47	47 992		54	
Cogen_RE_597	34.400	21.00		6	4.40	38.11	43.2%	62.08	44.60		5 26.03	62.68	68 54071	100	55	
Cogen_MT_250	0.000	11.00	3.89	0	6.42	35.96	55.4%	51.16	43.03	23.07	21.02	11.21	21 344	200	56	
Cogen_RE_427	345.150	22.00	3.89	0	4.40	39.11	39.9%	68.10	44.87	32.03	30.30	1 72.55	55 503513		57	
Cogen_RE_179	137.550	23.00	3.89	6	4.41	40.16	35.8%	76.36	45.62	35.70	35.20	83,09	09 182593	0	58	
Cogen_MT_427	176.558	11.00	3.89	6	6.68	36.99	47.4%	57.35	43.93	26.95	23.46	83.76	76 205310		59	
Cogen_RE_124	110.800	23.50	3.89	5	4.34	40.39	33.4%	82.10	46.04	38.25	38.21	88.68	68 139635	12	60	
Cogen_MT_597	8.170	11.00	3.89	5	6.76	37.30	45.3%	59.92	44.47	28.22	24.53	88.83	83 8943		61	
Cogen_MT_710	58.710	11.00	3.89	CP.	6.84	37.62	44.9%	60.20	44.47	28.42	24.92	18.19	81 62726	1.0	62	

Using the EIA Low Resource Case for fuel prices and allowing STEER to choose renewables to meet generation requirements, STEER Michigan CHP produced the results for the various CHP technologies that are shown in <u>Attachment F</u>. With the higher natural gas prices used in this scenario, the relative fuel efficiency of CHP generation as compared to combined cycle and electricity-only combustion turbines causes a wider range of CHP technologies to be profitable, including steam turbines of any size, combustion turbines 8 MW capacity and larger, and reciprocating engines 1 MW capacity and larger. Michigan technical potential for these technologies totals 2.36 GW.

				Electric Heat	ti	100 S	Capital	Marginal	Value of	Unmet		: :		
Name	Technical Potential	Variable O&M (\$/MWh)	Variable O&M Fuel (\$/MWh) (\$/MMBtu)	Rate (MMBtu/M Wh)	Dispatch Cost	Capacity Factor If Built	Recovery Rev Req (\$/MWh)	LMP (S/MWh) If Built	Capacity (\$/MWh) If Built	Rev Req (S/MWh) If Built	Cost to Mitigate (\$/t)	Carbon Mitigated (t/yr) Ra	Rank	Built?
Cogen_ST_8758	54.300	8.00	.8.	5 4.45	5 45,82	2 67.7%	8.98	72.45	18.87	-36.52	-94.56	124309	1	
Cogen_ST_8000	56.000	8.00	.8.	5 4.45	5 45.82	2 68.0%	\$ 8.94	72.29	18.77	-36.31	-94.07	128834	2	
Cogen_ST_3000	0.000	00.6	8.5	5 4.54	4 47.62	2 67.3%	\$ 9.10	72.65	18.99	-34.92	-91.70	6732	m	
Cogen_ST_15000	0.000	6.00	8.5	5 4.44	4 43.75	5 70.2%	6 8.57	71.53	18.20	-37.40	-90.66	38048	4	
Cogen_ST_31000	0.000	6.00	8.5	5 4.44	4 43.71	1 70.3%	6 8.54	71.41	18.17	-37.32	-89.71	79414	5	
Cogen ST 25000	0.000	6.00	8.5	5 4.44	4 43.71	1 70.5%	8.52	71.41	18.11	-37.28	-89.62	64238	9	
Cogen_ST_9091	100.000	8.00		5 4.45	5 45.82	2 68.8%	6 8.84	71.85	18.57	-35.76	-88.86	242411	7	
Cogen_ST_35867	134.500	6.00	8.5	5 4.44	4 43.71	1 71.3%	6 8.42	70.84	17.91	-36.62	-85.85	358348	00	
Cogen_ST_500	0.000	10.00	8.5	5 4.54	4 48.58	8 67.3%	\$ 15.29	72.65	18.99	-27.78	-72.88	1123	6	
Cogen_CT_45607	0.000	9.20	8,5	5.59	9 56.76	5 52.4%	6 23.22	78.58	24.39	-22.99	-70.24	66803	10	
Cogen_RE_9341	0.000	8.50	80	5 4.63	3 47.81	1 72.9%	6 19.52	72.65	17.51	-22.83	-60.70	22443	11	
Cogen_CT_35867	377.273	9.30	00	5.55	5 56.44	4 54.0%	6 24.79	77.30	23.64	-19.71	-60.02	586311	12	
Cogen_CT_31000	0.000	9.30	8.5	5.55	5 56.44	4 55.8%	6 24.11	71.17	22.88	-19.50	-59.42	46504	13	
Cogen_CT_21730	0.000	9.30	00	5 5.49	9 55.93	3 56.2%	6 24.83	77.13	22.74	-19.12	-57.65	33183	14	
Cogen_RE_8000	48.000	12.50		5 4.57	7 51.38	8 67.8%	\$ 22.05	74.14	18.84	-19.54	-51.33	108500	15	
Cogen_RE_8758	244.350	12.00		5 4.57	7 50.88	3 71.5%	\$ 20.46	72.83	17.87	-19.35	-51.04	579973	16	
Cogen_RE_3326	0.000	16.00		5 4.45	5 53.79	67.6%	23.49	74.35	18.91	-15.97	-41.12	7644	17	
Cogen_CT_10680	0.000	12.00	8.5	5 5.90	0 62.19	34,4%		89.37		-9.37		9345	18	
Cogen_CT_7520	0.000	12.30	00	5.68	8 60.61	1 38.8%	50.02	86.20	32.89	-8.45	-25.95	7799	19	
Cogen_CT_8000	59.840	12.30	8.5		9 61.51	1 34.8%	\$ 55.76	88.75	36.70	-8.17	-25.66	58099	20	
Cogen_CT_8758	228.467	12.20										234739	21	
Cogen_RE_1800	54.000	18.00	8.5	5 4.44	4 55.75	5 59.3%	\$ 34.31	76.74	21.55	-8.22	-20.96	109946	22	
Cogen_RE_2093	517.650	17.50	8.5	5 4.44	4 55.21	I 64.1%	\$ 31.21		19.92	-8.01	-20.59	1131297	23	
Cogen_RE_1121	0.000	19.00		5 4.45	5 56.84			82.40			-19.30		24	
Cogen_RE_1083	485.450	19.00		5 4.45	5 56.84	4 50.8%	6 41.68	78.71	25.12	-5.31	-13.47		25	
Cogen_RE_710	144.200	20.00		5 4.40	0 57.40	0 45.3%			28.19		11.41	229533	26	
Cogen_RE_633	0.000	21.00		5 4.40	0 58.42	2 44.8%	\$ 59.69	82.97	28.49	6.65	16.55	666	27	
Cogen_RE_597	34.400	21.00		5 4.40				82.92			16.88	54353	28	
Cogen_RE_427	345.150	22.00		5 4.40	0 59.38	3 42.8%	63.50	83.11	29.87	6.90	24.62	519882	29	
Cogen_CT_5000	0.000	12.40		5 6.36	6 66.45	5 33.7%	68.52	89.92	37.90	7.16	25.14		30	
Cogen_RE_124	110.800	23.50		5 4.34	4 60.41	1 41.4%	66.16	84.78	30.82	10.97	27.10	162768	31	
Cogen_RE_179	137.550	23.00		5 4.41	1 60.49	9 40.1%	68.05	85.14	31.81	11.58	28.92	193748	32	
Cogen_MT_333	0.000	00.6	8.5	5 6.17	7 61.45	5 36.4%	6 74.80	88.75	35.06	12.44	42.01	302	33	
Cogen_RE_100	0.000	24.00	œ	5 4.27	7 60.26	5 42.5%	6 73.12	84.78	30.06	18.54	45.31	152	34	
Cogen_MT_250	0.000	11.00	8.5	5 6.42	2 65.53	34.9%	6 81.25	89.92	36.64	20.23	71.90	206	60	
Cogen_RE_78	110.250	25.00	8.5	5 4.59	9 64.00	34.6%	6 92.57	89.37	36.91	30.29	77.98	129822	61	
Cogen_MT_427	176.558	11.00	8.5	5 6.68	8 67.79	9 29.6%	6 91.84	92.94	43.15	23.54	89,06	120967	62	
Cogen MIT 597	8.170	11.00	00	5 6.76	6 68.47	7 28.7%	6 94.38	94.67	44.46	23.73	91.54	5330	63	

 Using the EIA Low Resource Case for fuel prices without allowing STEER to choose renewables to meet generation requirements, STEER Michigan CHP produced the results for the various CHP technologies that are shown in <u>Attachment G</u>. As is generally true, the same set of CHP technologies is profitable in this scenario as in the previous scenario that uses the same fuel prices but also allows renewables. Without renewables available in this scenario and the carbon emissions constraint of the Clean Power Plan, STEER also chooses reciprocating engines down to 700 kW capacity, which adds 144 MW technical potential for a total of 2.5 GW.

	Capacity	VOM (\$/MWh)	Fuel (\$/MMBtu)	(MMBtu/ MWh)	Dispatch Cost	Capacity Factor	Rev Req (\$/MWh)	LMP (S/MWh)	Capacity (\$/MWh)	Rev Reg (\$/MWh)	Mitigate (S/t)	Mitigated (t)	Rank Corrected	Built?	
Cogen ST 8758	54.300	8.00	8.5	5 4.45	45.82	67.7%	8.98	72.45	18.87	-36.52	-94.56	5 124309	6	1	
Cogen_ST_8000	56,000	8.00	8.5	5 4.45	45.82	68.0%	8.94	72.29	18.77	-36.31	-94.07	7 128834	4	2	
Cogen_ST_3000	3,000	9.00	8.5	5 4.54	47.62	67.3%	9.10	72.65	18.99	-34.92	-91.70	0 6732	~	m	
Cogen_ST_15000	15.000	6.00	00	5 4.44	43.75	70.2%	8.57	71.53	18.20	-37.40	-90.66	5 38048		4	
Cogen_ST_31000	31.000	6.00	8.5	4.44	43.71	70.3%	8.54	71.41	18.17	-37.32	-89.71	1 79414	st	2	
Cogen_ST_25000	25.000	6.00	8.5	4.44	43.71	70.5%	8.52	71.41	18.11	-37.28	-89.62	2 64238		9	
Cogen_ST_9091	100.000	8.00	8.5	6 4.45	45.82	68.8%	8.84	71.85	18.57	-35.76	-88.86	5 242411	-	7	
Cogen_ST_35867	134.500	6.00	8.5	5 4.44	43.71	71.3%	8.42	70.84	17.91	-36.62	-85.85	358348		00	
ST_500	0.500	10.00	8.5	5 4.54	48.58	67.3%	15.29	72.65	18.99	-27.78	-72.88	3 1123		6	
Cogen_CT_45607	44.488	9.20	8.5	5.59	56.76	52.4%	23.22	78.58	24.39	-22.99	-70.24	t 66803		10	
Cogen_RE_9341	9.341	8.50	8.5	4.63	47.81	72.9%	19.52	72.65	17.51	-22.83	-60.70	22443	3	1	
Cogen CT 35867	377.273	9.30	8.5	5.55		54.0%	24.79	77.30	23.64	17.01-	-60.02	2 586311	-	2	
Cogen_CT_31000	28.985	9.30	8.5	5.55	56.44	55.8%	24.11	77.17	22.88	-19.50	-59.42	2 46504		13	
Cogen_CT_21730	20.336	9.30	8.5	5 5.49	55.93	56.2%	24.83	77.13	22.74	-19.12	-57.65	5 33183		14	
Cogen RE 8000	48.000	12.50	8.5	5 4.57	51.38	67.8%	22.05	74.14	18.84	-19.54	-51.33	108500		15	
Cogen_RE_8758	244.350	12.00	8.5	5 4.57	50.88	71.5%	20.46	72.83	17.87	-19.35	-51.04	t 579973		16	
Cogen_RE_3326	3.326	16.00	8.5	5 4.45	53.79	67.6%	23.49	74.35	18.91	-15.97	-41.12	2 7644	+	7	
Cogen_CT_10680	9.950	12.00	8.5	5.90	62.19	34.4%	54.92	75.68	37.11	-9.37	-30.07	7 9345		18	
Cogen_CT_7520	7.038	12.30	8.5	5.68	60.61	38.8%	50.02	86.20	32.89	-8.45	-25.95	5 7799		61	
Cogen_CT_8000	59.840	12.30	8.5	5.79	61.51	34.8%	55.76	88.75	36.70	-8.17		58099		20	
Cogen_CT_8758	228.467	12.20	00	5.79	61.41	36.7%	52.42	86.20	34.79	-7.16	-22.40	0 234739		21	
Cogen_RE_1800	54.000	18.00	8.5	5 4.44	55.75	59.3%	34.31	76.74	21.55	-8.22		109946	2	2	
Cogen_RE_2093	517.650	17.50	8.5	5 4.44	55.21	64.1%	31.21	74.52	19.92	-8.01	-20.59	9 1131297		23	
Cogen_RE_1121	1.121	19.00	8.5	5 4.45	56.84	46.9%	45.09	82.40	27.22	-7.68	-19.30	0 1834		24	
Cogen_RE_1083	485.450	19.00	8.5	5 4.45	56.84	50.8%	41.68	78.71	25.12	-5.31	-13,47	7 852748		25	
Cogen_RE_710	144.200	20.00	00	5 4.40	57.40	45.3%	57.77	82.40	28.19	4.58	11.41	1 229533	2	9	
Cogen_RE_633	0.633	21,00	8.5	5 4.40	58.42		59.69	82.97	28.49	6.65	16.55	666 9	6	7	
Cogen_RE_597	34.400	21,00	8.5	5 4.40	58.38	44.9%	59.80	82.92	28.47	6.79	16.88	8 54353		28	
Cogen_RE_427	345.150	22.00	8.5	5 4.40	59.38	42.8%	63.50	83.11	29.87	6.90	24.62	2 519882		29	
Cogen_CT_5000	4.675	12.40	8.5	6.36	66.45	33.7%	68.52	89.92	37.90	7.16	25.14	t 3929		30	
Cogen_RE_124	110.800	23.50	8.5	5 4.34	60.41	41.4%	66.16	84.78	30.82	10.97	27.10	162768		31	
Cogen_RE_179	137.550	23.00	8.5	5 4.41	60.49	40.1%	68.05	85.14	31.81		28.92	2 193748		32	
Cogen_MT_333	0.320	9.00	8.5	6.17	61.45	36.4%	74.80	88.75	35.06	12.44	42.01	1 302	2	E	
Cogen_RE_100	0.100	24.00	8,5	5 4.27	60.26	42.5%	73.12	84.78	30.06	18.54	45.31	1 152		34	
Cogen_MT_250	0.240	11.00	8.5	5 6.42	65.53	34.9%	81.25	89.92	36.64	20.23	71.90	206		60	
Cogen_RE_78	110.250	25.00	8.5	6 4.59	64.00	34.6%	92.57	89.37	36.91	30.29	77.98	129822		61	
Cogen_MT_427	176.558	11.00	80		67.79	29.6%	91.84	92.94	43.15	23.54		120967	-	62	
Cogen_MT_597	8.170	11.00	8.5	6.76	68.47	28.7%	94.38	94.67	44.46	23.73	91.54	t 5330		63	

Results

- Across a fairly broad range of scenarios, neither microturbines nor fuel cells appear economically viable for broad application in Michigan.
- Steam turbines, combustion turbines, and reciprocating engines above some threshold size appear profitable in each scenario with the minimum size threshold being lower under higher natural gas pricing and when renewables aren't available.

Results

- The CHP technologies that appear viable based on STEER modeling results based solely on their value to the power system have potential in specific economic sectors.
- The following table summarizes the number of sites in each sector for which there appear to be viable technologies, where a range reflects the results in the various scenarios described above.

Sector	Steam Turbine	Combustion Turbine	Reciprocating Engine
Food/Beverages	1	3	3-36
Lumber/Wood	-	1	1-16
Paper/Pulp	1	2-3	1-21
Chemicals	3	2-13	11-66
Petroleum Refining	-	-	0-8
Rubber/Plastics	-	-	0-9
Stone/Clay/Glass	-	1	1-3
Primary Metals	1	2-3	1-26
Machinery/Comp Equip	-	-	0-2
Transportation Equip	3	4-14	10-87
Gas Processing	-	-	0-2
Refrigerated Warehouses	-	-	1
Wastewater Treatment	-	-	1
Commercial Office Buildings	-	-	0-284
Multifamily Housing	-	-	0-16
Hotels	-	-	0-15
Data Centers	-	-	0-8
Hospitals	-	0-3	1-57
Colleges/Universities	8	1-6	5-37
Prisons	-	-	0-34
Military Facilities	-	-	0-3
Airports	-	-	0-2
Museums	-	-	0-1

Recommendations Regarding IRP Assumptions and Scenarios

- Cogeneration resources must be included in the Integrated Resource Plan, both as a forecast offset to load and demand and as a potential resource.
- Resource screening should at least include steam turbines, combustion turbines, and reciprocating engines in CHP applications.
- DOE Technical Potential and EPA Catalog of CHP Technologies are valid references and should be the default information for IRP.
- CHP economic potential is concentrated in a few sectors. IRP analysis should include specific outreach to customers in these sectors, likely as a formal solicitation of interest offering both PURPA contracts and utility-ownership models.

An Important Additional Observation

- The analysis above ignored a critical potential value of CHP as an element of a microgrid for a critical facility. Consideration of this value would broaden the applicability of CHP for hospitals, extended care facilities, water and sewer systems, public safety facilities, and government buildings as refuges.
- Utilities should consider supporting applications of CHP at critical facilities as a resilience strategy for the communities they serve.
- The Commission could establish means to identify and authorize cost recovery for such a strategy.

Questions?

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