MAE 119: Homework 4

Due: Friday, Feb. 21, 2020

You must show all work for full credit. Joint submissions can be made in groups of two. All submissions and code must be uploaded to Canvas for full credit.

Problem 1 (100 points)

The Konocti substation in the Bay Area is considering to build a microgrid in order to be more resilient to PG&E outages. Let's consider their economic options for the month of October, when wildfires usually occur. The following is the electric demand for a typical day in October.

Hour	Demand (MW)	Hour	Demand (MW)
0	5.1	12	6.2
1	4.9	13	5.9
2	5.1	14	5.9
3	5.3	15	5.9
4	5.6	16	6.5
5	6.7	17	7.2
6	8.0	18	7.9
7	8.6	19	8.1
8	8.3	20	8.1
9	7.6	21	7.4
10	7.2	22	6.4
11	6.7	23	5.6

1. **(20 points)** We will consider 3 options for the microgrid. Determine the nominal capacity for each:

   - Diesel generation: Size to be equal to the peak load.
   - Solar: Size to produce as much as the monthly demand. To do this, size the actual generation that we could get during October at this site using TMY3 data for Ukiah, CA, and considering arrays of 5000 Canadian Solar panels (220 W nominal power each) connected to a Green Power Technologies: PV900WD inverter (1 MW nominal capacity). How many 1 MW arrays are needed to produce the monthly demand?
   - Battery: Size to equal the nighttime energy use ($t \geq 7$ PM or $t \leq 7$ AM).

   Solution: The peak load in October is 8.6 MW, so $P_{diesel} \geq 8.6$ MW. Generator sizes are discrete, so we will probably pick a 10 MW generator set.

   The daily total energy that we need to generate is 160.2 MWh. We can size the PV system using pvlib and TMY3 data for a site close to the Konocti substation. We will take TMY3 data for Ukiah, and will consider the month of October. A valid choice would be to have the panels tilted 38° (latitude) and facing south. We will use a number of 1 MW inverters, which will receive the DC power of 5000 x 200 W panels. Picking a setup of 250 strings, we obtain that a $P_{solar} = 33$ MW system produces 162.7 MWh daily, which satisfies the required condition.

   The nightly total energy is 84.9 MWh, so $E_{battery} \geq 84.9$ MWh. The size of battery storage energy systems can usually be customized, so we could have a 85 MWh system.

2. **(80 points)** Let us consider only the operation during the power outages which are assumed occur during 20 days in October, for the three following solutions:

   - A diesel microgrid, where the investment costs are \$550/kW, O&M yearly costs are \$0.012/kW, fuel costs are \$3.96/gal, and the fuel consumption is 0.10 gal/kWh.
   - A solar+battery microgrid, where the solar investment costs are \$1800/kW, and the O&M costs are \$9/kW, and there is a 30% tax incentive, and the battery investment costs are \$600/kWh, and the O&M costs are \$0 for the first 10 years (10 year warranty). The battery system is replaced at year 10 (and a new 10 year warranty applies).
   - A hybrid solar and diesel microgrid, where the solar system is sized for the daytime peak instead. To do this, model the solar generation for October 15, and assume that the rest of the demand is satisfied with diesel.

   For each solution, evaluate two scenarios: the first with a loan with 10% down payment and a 5%/year interest rate, and the second paying for the investment cash (without a loan). Consider a market discount rate of 6%, inflation of 5%, and compute the present worth and cumulative costs for years 0-20. Report the net present value (LLC for diesel and LCS for the solar+battery and solar+diesel) and LCOE for the two financing scenarios.

   Why does the analysis not capture the full value of solar? Assume that during the non-outage periods (the remaining days of the year), solar energy can be sold at 15 cents per hour. Recalculate the life cycle savings of adding solar (without battery) to a diesel powered microgrid.

   Solution: For the diesel microgrid, the equipment's capacity is 10,000 kW, with a consumption of 20 outage days that equals a total yearly energy of $E = 20 \times 160.2$ MWh $= 3,204$ MWh.

   We can compute the initial investment as $C_{inv} = 550$ \$/kW $\times$ 10000 kW $=$ \$5,500,000, O&M costs as $C_{O\&M} = 0.012$ \$/kW $\times$ 10000 kW $=$ \$120 per year, and the fuel consumption needed to satisfy the demand is $F = 0.1$ gal/kWh $\times\ 3,204,000$ kWh $= 320,400$ gal, which translate to initial costs of $C_{fuel} = 3.64$ \$/gal $\times$ $320,400$ gal $=$ \$1,268,784 per year. We expect both O&M and fuel costs to increase with inflation.

   For the loan with a 10% down payment, 20 years and 5% interest rate, we get a yearly payment of \$397,201.

   The LCC is \$27,018,468 with a loan and \$27,412,606 paying in cash, which gives LCOE of \$0.42/kWh and \$0.43/kWh, respectively.

With loan

Year	Investment	Loan	O&M	Fuel	Total costs	Discounted	Cumulative costs
0	$550,000	$0	$0	$0	$550,000	$550,000	$550,000
1	$0	$397,201	$120	$1,268,784	$1,666,105	$1,571,797	$2,121,797
2	$0	$397,201	$126	$1,332,223	$1,729,550	$1,539,293	$3,661,090
3	$0	$397,201	$132	$1,398,834	$1,796,167	$1,508,097	$5,169,187
4	$0	$397,201	$139	$1,468,776	$1,866,116	$1,478,138	$6,647,326
5	$0	$397,201	$146	$1,542,215	$1,939,562	$1,449,353	$8,096,679
6	$0	$397,201	$153	$1,619,326	$2,016,680	$1,421,680	$9,518,358
7	$0	$397,201	$161	$1,700,292	$2,097,654	$1,395,059	$10,913,418
8	$0	$397,201	$169	$1,785,307	$2,182,676	$1,369,438	$12,282,856
9	$0	$397,201	$177	$1,874,572	$2,271,950	$1,344,764	$13,627,620
10	$0	$397,201	$186	$1,968,300	$2,365,687	$1,320,987	$14,948,607
11	$0	$397,201	$195	$2,066,715	$2,464,112	$1,298,063	$16,246,670
12	$0	$397,201	$205	$2,170,051	$2,567,457	$1,275,948	$17,522,618
13	$0	$397,201	$216	$2,278,554	$2,675,970	$1,254,599	$18,777,217
14	$0	$397,201	$226	$2,392,481	$2,789,909	$1,233,979	$20,011,196
15	$0	$397,201	$238	$2,512,106	$2,909,544	$1,214,051	$21,225,247
16	$0	$397,201	$249	$2,637,711	$3,035,161	$1,194,780	$22,420,027
17	$0	$397,201	$262	$2,769,596	$3,167,059	$1,176,133	$23,596,160
18	$0	$397,201	$275	$2,908,076	$3,305,552	$1,158,080	$24,754,240
19	$0	$397,201	$289	$3,053,480	$3,450,970	$1,140,590	$25,894,830
20	$0	$397,201	$303	$3,206,154	$3,603,658	$1,123,638	$27,018,468
					LCC	$27,018,468	
					LCOE ($/kWh)	$0.42	

Without loan

Year	Investment	Loan	O&M	Fuel	Total	Discounted	Cumulative costs
0	$5,500,000	$0	$0	$0	$5,500,000	$5,500,000	$5,500,000
1	$0	$0	$120	$1,268,784	$1,268,904	$1,197,079	$6,697,079
2	$0	$0	$126	$1,332,223	$1,332,349	$1,185,786	$7,882,865
3	$0	$0	$132	$1,398,834	$1,398,967	$1,174,599	$9,057,465
4	$0	$0	$139	$1,468,776	$1,468,915	$1,163,518	$10,220,983
5	$0	$0	$146	$1,542,215	$1,542,361	$1,152,542	$11,373,525
6	$0	$0	$153	$1,619,326	$1,619,479	$1,141,669	$12,515,193
7	$0	$0	$161	$1,700,292	$1,700,453	$1,130,898	$13,646,091
8	$0	$0	$169	$1,785,307	$1,785,475	$1,120,229	$14,766,321
9	$0	$0	$177	$1,874,572	$1,874,749	$1,109,661	$15,875,982
10	$0	$0	$186	$1,968,300	$1,968,487	$1,099,193	$16,975,174
11	$0	$0	$195	$2,066,715	$2,066,911	$1,088,823	$18,063,997
12	$0	$0	$205	$2,170,051	$2,170,256	$1,078,551	$19,142,548
13	$0	$0	$216	$2,278,554	$2,278,769	$1,068,376	$20,210,924
14	$0	$0	$226	$2,392,481	$2,392,708	$1,058,297	$21,269,221
15	$0	$0	$238	$2,512,106	$2,512,343	$1,048,313	$22,317,534
16	$0	$0	$249	$2,637,711	$2,637,960	$1,038,423	$23,355,958
17	$0	$0	$262	$2,769,596	$2,769,858	$1,028,627	$24,384,584
18	$0	$0	$275	$2,908,076	$2,908,351	$1,018,923	$25,403,507
19	$0	$0	$289	$3,053,480	$3,053,769	$1,009,310	$26,412,817
20	$0	$0	$303	$3,206,154	$3,206,457	$999,789	$27,412,606
					LCC	$27,412,606	
					LCOE ($/kWh)	$0.43	

For the solar+battery microgrid, the solar plant size is 33,000 kW. The initial costs associated then are $C_{inv,solar} = 1,800\ \$/kW \times 33,000\ kW = \$59,400,000$, $C_{O\&M,solar} = 9\ \$/kW \times 33,000\ kW = \$297,000$ per year, and tax incentives are $C_{tax} = -30\% C_{inv,solar} = -\$17,820,000$, applicable in the first period.

For the battery costs, we have a capacity of 85,000 kWh. We will invest twice, first at year 0 and then at year 10. For year 0, the investment will be $C^0_{inv,batt} = 600\ \$/kWh \times 9,000\ kWh = \$51,000,000$. At year 10, we expect this cost to increase with inflation, totaling $C^1_{inv,batt}0 = C^0_{inv,batt}(1+i)^9 = \$79,117,739$.

In this case, we will get separate loans: 1 for the solar system (for 20 years), 1 for the battery system at year 0 (for 10 years) and 1 for the battery system at year 10 (for 10 years). This results in annual payments of $4,289,796 for solar, $5,944,260 for the battery system between years 1 and 10, and $9,221,498 for the battery system between years 11 and 20.

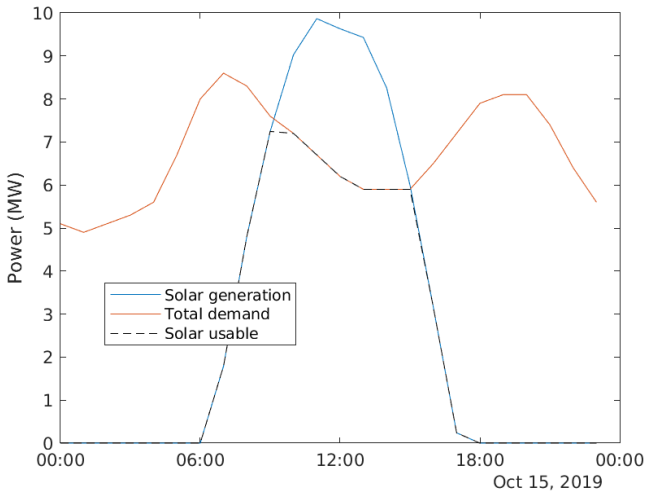
The LCC is $135,449,165 with a loan and $141,887,802 paying in cash, which gives LCOE of $2.11/kWh and $2.21/kWh, respectively. For the savings, the total LCS is $LCC_{baseline} - LCC$, which translates into -$108,430,697 with a loan (negative savings means that the baseline option is cheaper in terms of costs), while LCS is -$114,475,197 without a loan.

	With loan					For LCC		
Year	Investment	Loans	O&M	Tax inc.	Fuel costs	Total	Discounted	Cumulative costs
0	$11,040,000	$0	$0	-$17,820,000	$0	-$6,780,000	-$6,780,000	-$6,780,000
1	$0	$10,234,029	$297,000	$0	$0	$10,531,029	$9,934,933	$3,154,933
2	$0	$10,234,029	$311,850	$0	$0	$10,545,879	$9,385,795	$12,540,727
3	$0	$10,234,029	$327,443	$0	$0	$10,561,471	$8,867,615	$21,408,342
4	$0	$10,234,029	$343,815	$0	$0	$10,577,843	$8,378,643	$29,786,985
5	$0	$10,234,029	$361,005	$0	$0	$10,595,034	$7,917,226	$37,704,211
6	$0	$10,234,029	$379,056	$0	$0	$10,613,084	$7,481,806	$45,186,016
7	$0	$10,234,029	$398,008	$0	$0	$10,632,037	$7,070,912	$52,256,928
8	$0	$10,234,029	$417,909	$0	$0	$10,651,938	$6,683,157	$58,940,086
9	$0	$10,234,029	$438,804	$0	$0	$10,672,833	$6,317,233	$65,257,319
10	$7,911,774	$13,511,267	$460,744	$0	$0	$21,883,785	$12,219,791	$77,477,110
11	$0	$13,511,267	$483,782	$0	$0	$13,995,049	$7,372,417	$84,849,527
12	$0	$13,511,267	$507,971	$0	$0	$14,019,238	$6,967,132	$91,816,659
13	$0	$13,511,267	$533,369	$0	$0	$14,044,636	$6,584,674	$98,401,333
14	$0	$13,511,267	$560,038	$0	$0	$14,071,305	$6,223,752	$104,625,084
15	$0	$13,511,267	$588,040	$0	$0	$14,099,307	$5,883,148	$110,508,232
16	$0	$13,511,267	$617,442	$0	$0	$14,128,709	$5,561,714	$116,069,946
17	$0	$13,511,267	$648,314	$0	$0	$14,159,581	$5,258,364	$121,328,310
18	$0	$13,511,267	$680,729	$0	$0	$14,191,996	$4,972,078	$126,300,388
19	$0	$13,511,267	$714,766	$0	$0	$14,226,033	$4,701,889	$131,002,277
20	$0	$13,511,267	$750,504	$0	$0	$14,261,771	$4,446,888	$135,449,165
						LCC	$135,449,165	
						LCOE	$2.11	
						LCS	-$108,430,697	

	Without loan					For LCC		
Year	Investment	Loan	O&M	Tax inc.	Fuel savings	Total	Discounted	Cumulative costs
0	$110,400,000	$0	$0	-$17,820,000	$0	$92,580,000	$92,580,000	$92,580,000
1	$0	$0	$297,000	$0	$0	$297,000	$280,189	$92,860,189
2	$0	$0	$311,850	$0	$0	$311,850	$277,545	$93,137,734
3	$0	$0	$327,443	$0	$0	$327,443	$274,927	$93,412,661
4	$0	$0	$343,815	$0	$0	$343,815	$272,333	$93,684,994
5	$0	$0	$361,005	$0	$0	$361,005	$269,764	$93,954,759
6	$0	$0	$379,056	$0	$0	$379,056	$267,219	$94,221,978
7	$0	$0	$398,008	$0	$0	$398,008	$264,698	$94,486,676
8	$0	$0	$417,909	$0	$0	$417,909	$262,201	$94,748,877
9	$0	$0	$438,804	$0	$0	$438,804	$259,728	$95,008,605
10	$79,117,739	$0	$460,744	$0	$0	$79,578,483	$44,436,210	$139,444,815
11	$0	$0	$483,782	$0	$0	$483,782	$254,850	$139,699,665
12	$0	$0	$507,971	$0	$0	$507,971	$252,446	$139,952,111
13	$0	$0	$533,369	$0	$0	$533,369	$250,064	$140,202,175
14	$0	$0	$560,038	$0	$0	$560,038	$247,705	$140,449,880
15	$0	$0	$588,040	$0	$0	$588,040	$245,368	$140,695,249
16	$0	$0	$617,442	$0	$0	$617,442	$243,054	$140,938,302
17	$0	$0	$648,314	$0	$0	$648,314	$240,761	$141,179,063
18	$0	$0	$680,729	$0	$0	$680,729	$238,489	$141,417,552
19	$0	$0	$714,766	$0	$0	$714,766	$236,239	$141,653,792
20	$0	$0	$750,504	$0	$0	$750,504	$234,011	$141,887,802
						LCC	$141,887,802	
						LCOE	$2.21	
						LCS	-$114,475,197	

For the solar+diesel microgrid, the solar plant size is now the same as the diesel capacity: 10,000 kW. So we have to scale the costs for the solar plant, while the costs for the diesel will stay the same as before. The initial costs associated with solar are $C_{inv,solar} = 1800\ \$/kW \times 10,000\ kW = \$18,000,000$, $C_{O\&M,solar} = 9\ \$/kW \times 10,000\ kW = \$90,000$ per year, and tax incentives are $C_{tax} = -30\% C_{inv,solar} = \$5,400,000$, applicable in the first period.

In order to compute the fuel costs (or fuel savings), we need to first obtain the solar generation for a typical day (October 15). We do that in pvlib for a 10 MW solar system, obtaining a daily profile like the following, and daily we can generate 69,449 kWh with solar. But we don't have a storage system, so the usable solar energy is less: 55,043 kWh. This means that the rest of the daily energy demand must be generated with diesel, that is 160.2 MWh-55.043 MWh=105.16 MWh per day. With this, the new fuel consumption will be 210,314 gal, which means an initial cost of $C_{fuel} = \$832,843$.



The LCC is $32,354,541 with a loan and $34,038,585 paying in cash, which gives an LCOE of $0.50/kWh and $0.53/kWh, respectively. For the saving analysis, the total LCS is -$5,336,073 with a loan, while LCS is -$6,625,979 without a loan.

		With loan				For LCC		
Year	Investment	Loans	O&M	Tax inc.	Fuel cost	Total costs	Discounted	Cumulative costs
0	$2,350,000	$0	$0	-$5,400,000	$0	-$3,050,000	-$3,050,000	-$3,050,000
1	$0	$1,697,131	$90,120	$0	$832,843	$2,620,094	$2,471,787	-$578,213
2	$0	$1,697,131	$94,626	$0	$874,486	$2,666,242	$2,372,946	$1,794,733
3	$0	$1,697,131	$99,357	$0	$918,210	$2,714,698	$2,279,313	$4,074,046
4	$0	$1,697,131	$104,325	$0	$964,120	$2,765,576	$2,190,595	$6,264,641
5	$0	$1,697,131	$109,541	$0	$1,012,326	$2,818,999	$2,106,520	$8,371,161
6	$0	$1,697,131	$115,018	$0	$1,062,943	$2,875,092	$2,026,826	$10,397,987
7	$0	$1,697,131	$120,769	$0	$1,116,090	$2,933,990	$1,951,271	$12,349,258
8	$0	$1,697,131	$126,808	$0	$1,171,894	$2,995,833	$1,879,623	$14,228,881
9	$0	$1,697,131	$133,148	$0	$1,230,489	$3,060,768	$1,811,664	$16,040,545
10	$0	$1,697,131	$139,806	$0	$1,292,014	$3,128,950	$1,747,189	$17,787,734
11	$0	$1,697,131	$146,796	$0	$1,356,614	$3,200,541	$1,686,005	$19,473,739
12	$0	$1,697,131	$154,136	$0	$1,424,445	$3,275,711	$1,627,928	$21,101,667
13	$0	$1,697,131	$161,843	$0	$1,495,667	$3,354,640	$1,572,786	$22,674,454
14	$0	$1,697,131	$169,935	$0	$1,570,451	$3,437,516	$1,520,417	$24,194,870
15	$0	$1,697,131	$178,431	$0	$1,648,973	$3,524,535	$1,470,665	$25,665,536
16	$0	$1,697,131	$187,353	$0	$1,731,422	$3,615,905	$1,423,388	$27,088,924
17	$0	$1,697,131	$196,721	$0	$1,817,993	$3,711,844	$1,378,447	$28,467,370
18	$0	$1,697,131	$206,557	$0	$1,908,892	$3,812,580	$1,335,714	$29,803,084
19	$0	$1,697,131	$216,885	$0	$2,004,337	$3,918,352	$1,295,066	$31,098,150
20	$0	$1,697,131	$227,729	$0	$2,104,554	$4,029,413	$1,256,390	$32,354,541
						LCC	$32,354,541	
						LCOE	$0.50	
						LCS	-$5,336,073	

	Without loan					For LCC		
Year	Investment	Loan	O&M	Tax inc.	Fuel cost	Total	Discounted	Cumulative costs
0	$23,500,000	$0	$0	-$5,400,000	$0	$18,100,000	$18,100,000	$18,100,000
1	$0	$0	$90,120	$0	$832,843	$922,963	$870,720	$18,970,720
2	$0	$0	$94,626	$0	$874,486	$969,112	$862,506	$19,833,226
3	$0	$0	$99,357	$0	$918,210	$1,017,567	$854,369	$20,687,595
4	$0	$0	$104,325	$0	$964,120	$1,068,446	$846,309	$21,533,904
5	$0	$0	$109,541	$0	$1,012,326	$1,121,868	$838,325	$22,372,229
6	$0	$0	$115,018	$0	$1,062,943	$1,177,961	$830,416	$23,202,645
7	$0	$0	$120,769	$0	$1,116,090	$1,236,859	$822,582	$24,025,227
8	$0	$0	$126,808	$0	$1,171,894	$1,298,702	$814,822	$24,840,049
9	$0	$0	$133,148	$0	$1,230,489	$1,363,637	$807,135	$25,647,184
10	$0	$0	$139,806	$0	$1,292,014	$1,431,819	$799,520	$26,446,704
11	$0	$0	$146,796	$0	$1,356,614	$1,503,410	$791,978	$27,238,682
12	$0	$0	$154,136	$0	$1,424,445	$1,578,581	$784,506	$28,023,188
13	$0	$0	$161,843	$0	$1,495,667	$1,657,510	$777,105	$28,800,294
14	$0	$0	$169,935	$0	$1,570,451	$1,740,385	$769,774	$29,570,068
15	$0	$0	$178,431	$0	$1,648,973	$1,827,404	$762,512	$30,332,580
16	$0	$0	$187,353	$0	$1,731,422	$1,918,775	$755,319	$31,087,898
17	$0	$0	$196,721	$0	$1,817,993	$2,014,713	$748,193	$31,836,091
18	$0	$0	$206,557	$0	$1,908,892	$2,115,449	$741,134	$32,577,226
19	$0	$0	$216,885	$0	$2,004,337	$2,221,222	$734,143	$33,311,368
20	$0	$0	$227,729	$0	$2,104,554	$2,332,283	$727,217	$34,038,585
						NPV	$34,038,585	
						LCOE	$0.53	
						LCS	-$6,625,979	

From these three analyses, in the scenario with a loan, the diesel only microgrid is the cheapest option, followed by solar+diesel. Loans reduce the total cost, which is an effect of the higher value of present money and a favorable interest rate. We cannot capture the total value of solar because the energy that could be generated the rest of the year is not being used, while in the case of diesel, we only consume fuel when we need it.

For the solar+diesel microgrid, selling solar energy the rest of the year, we first need to estimate the annual generation of the 10 MW solar plant. We can do that in pvlib, which gives us a total annual generation of 18,920 MWh. The energy that we can sell is then $(18,920 - 20 \times 55.043)$ MWh=17,819 MWh (can also be estimated as all days but any 20 days in October). The initial profit of selling this energy is then $P_{sell} = \$0.15/\text{kW} \times 17,819,140 \text{ kWh} = \$2,672,871$.

Adding this profit to our life cycle analysis, the costs structure will not change, and so LCC and LCS are the same as before. But because the energy generated is now greater(is the sum of solar and diesel generation per year), LCOE is now \$0.077/kWh with a loan and \$0.081 without a loan. We can also compute the net present value now (we didn't ask for it), which gives \$13,803,064 for the case with a loan and \$26,501,329 for the case without a loan. In this case, the loan decreases the net value of the profits, making the NPV lower.

	With loan						For LCC and NPV				
Year	Investment	Loans	O&M	Tax inc.	Fuel cost	Energy sale	Total costs	Total profit	Cash flow	Discounted	Cumulative profits
0	$2,350,000	$0	$0	-$5,400,000	$0	$0	-$3,050,000	$0	$3,050,000	$3,050,000	$3,050,000
1	$0	$1,697,131	$90,120	$0	$832,843	-$2,672,871	$2,620,094	$2,672,871	$52,777	$49,789	$3,099,789
2	$0	$1,697,131	$94,626	$0	$874,486	-$2,806,515	$2,666,242	$2,806,515	$140,272	$124,842	$3,224,631
3	$0	$1,697,131	$99,357	$0	$918,210	-$2,946,840	$2,714,698	$2,946,840	$232,142	$194,911	$3,419,542
4	$0	$1,697,131	$104,325	$0	$964,120	-$3,094,182	$2,765,576	$3,094,182	$328,606	$260,287	$3,679,829
5	$0	$1,697,131	$109,541	$0	$1,012,326	-$3,248,891	$2,818,999	$3,248,891	$429,893	$321,241	$4,001,070
6	$0	$1,697,131	$115,018	$0	$1,062,943	-$3,411,336	$2,875,092	$3,411,336	$536,244	$378,031	$4,379,101
7	$0	$1,697,131	$120,769	$0	$1,116,090	-$3,581,903	$2,933,990	$3,581,903	$647,913	$430,899	$4,810,000
8	$0	$1,697,131	$126,808	$0	$1,171,894	-$3,760,998	$2,995,833	$3,760,998	$765,165	$480,074	$5,290,074
9	$0	$1,697,131	$133,148	$0	$1,230,489	-$3,949,048	$3,060,768	$3,949,048	$888,280	$525,771	$5,815,845
10	$0	$1,697,131	$139,806	$0	$1,292,014	-$4,146,500	$3,128,950	$4,146,500	$1,017,550	$568,195	$6,384,040
11	$0	$1,697,131	$146,796	$0	$1,356,614	-$4,353,825	$3,200,541	$4,353,825	$1,153,284	$607,536	$6,991,576
12	$0	$1,697,131	$154,136	$0	$1,424,445	-$4,571,516	$3,275,711	$4,571,516	$1,295,805	$643,975	$7,635,551
13	$0	$1,697,131	$161,843	$0	$1,495,667	-$4,800,092	$3,354,640	$4,800,092	$1,445,452	$677,684	$8,313,236
14	$0	$1,697,131	$169,935	$0	$1,570,451	-$5,040,097	$3,437,516	$5,040,097	$1,602,581	$708,823	$9,022,059
15	$0	$1,697,131	$178,431	$0	$1,648,973	-$5,292,102	$3,524,535	$5,292,102	$1,767,567	$737,544	$9,759,602
16	$0	$1,697,131	$187,353	$0	$1,731,422	-$5,556,707	$3,615,905	$5,556,707	$1,940,801	$763,989	$10,523,592
17	$0	$1,697,131	$196,721	$0	$1,817,993	-$5,834,542	$3,711,844	$5,834,542	$2,122,698	$788,295	$11,311,886
18	$0	$1,697,131	$206,557	$0	$1,908,892	-$6,126,269	$3,812,580	$6,126,269	$2,313,689	$810,587	$12,122,473
19	$0	$1,697,131	$216,885	$0	$2,004,337	-$6,432,583	$3,918,352	$6,432,583	$2,514,230	$830,986	$12,953,459
20	$0	$1,697,131	$227,729	$0	$2,104,554	-$6,754,212	$4,029,413	$6,754,212	$2,724,799	$849,605	$13,803,064
									NPV	$13,803,064	
									LCC	$32,354,541	(same as before)
									LCOE	$0.077	(more energy gen.)

	Without loan						For NPV				
Year	Investment	Loan	O&M	Tax inc.	Fuel cost	Energy sale	Net costs	Net profits	Cash flow	Discounted	Cumulative profits
0	$23,500,000	$0	$0	-$5,400,000	$0	$0	$18,100,000	$0	-$18,100,000	-$18,100,000	-$18,100,000
1	$0	$0	$90,120	$0	$832,843	-$2,672,871	$90,120	$2,672,871	$2,582,751	$2,436,558	-$15,663,442
2	$0	$0	$94,626	$0	$874,486	-$2,806,515	$94,626	$2,806,515	$2,711,889	$2,413,571	-$13,249,871
3	$0	$0	$99,357	$0	$918,210	-$2,946,840	$99,357	$2,946,840	$2,847,483	$2,390,802	-$10,859,070
4	$0	$0	$104,325	$0	$964,120	-$3,094,182	$104,325	$3,094,182	$2,989,857	$2,368,247	-$8,490,823
5	$0	$0	$109,541	$0	$1,012,326	-$3,248,891	$109,541	$3,248,891	$3,139,350	$2,345,905	-$6,144,918
6	$0	$0	$115,018	$0	$1,062,943	-$3,411,336	$115,018	$3,411,336	$3,296,317	$2,323,774	-$3,821,144
7	$0	$0	$120,769	$0	$1,116,090	-$3,581,903	$120,769	$3,581,903	$3,461,133	$2,301,851	-$1,519,293
8	$0	$0	$126,808	$0	$1,171,894	-$3,760,998	$126,808	$3,760,998	$3,634,190	$2,280,136	$760,843
9	$0	$0	$133,148	$0	$1,230,489	-$3,949,048	$133,148	$3,949,048	$3,815,900	$2,258,625	$3,019,468
10	$0	$0	$139,806	$0	$1,292,014	-$4,146,500	$139,806	$4,146,500	$4,006,695	$2,237,317	$5,256,785
11	$0	$0	$146,796	$0	$1,356,614	-$4,353,825	$146,796	$4,353,825	$4,207,029	$2,216,211	$7,472,996
12	$0	$0	$154,136	$0	$1,424,445	-$4,571,516	$154,136	$4,571,516	$4,417,381	$2,195,303	$9,668,299
13	$0	$0	$161,843	$0	$1,495,667	-$4,800,092	$161,843	$4,800,092	$4,638,250	$2,174,592	$11,842,891
14	$0	$0	$169,935	$0	$1,570,451	-$5,040,097	$169,935	$5,040,097	$4,870,162	$2,154,077	$13,996,969
15	$0	$0	$178,431	$0	$1,648,973	-$5,292,102	$178,431	$5,292,102	$5,113,670	$2,133,756	$16,130,725
16	$0	$0	$187,353	$0	$1,731,422	-$5,556,707	$187,353	$5,556,707	$5,369,354	$2,113,626	$18,244,351
17	$0	$0	$196,721	$0	$1,817,993	-$5,834,542	$196,721	$5,834,542	$5,637,822	$2,093,686	$20,338,037
18	$0	$0	$206,557	$0	$1,908,892	-$6,126,269	$206,557	$6,126,269	$5,919,713	$2,073,935	$22,411,972
19	$0	$0	$216,885	$0	$2,004,337	-$6,432,583	$216,885	$6,432,583	$6,215,698	$2,054,369	$24,466,341
20	$0	$0	$227,729	$0	$2,104,554	-$6,754,212	$227,729	$6,754,212	$6,526,483	$2,034,988	$26,501,329
									NPV	$26,501,329	
									LCC	$34,038,585	(same as before)
									LCOE	$0.081	(more energy gen.)

Costs summary:

With loan	LCC	LCS	NPV	LCOE
Diesel only	$27,018,468	-	-$27,018,468	$0.422
Solar+Battery	$135,449,165	-$108,430,697	-$135,449,165	$2.114
Solar+Diesel	$22,354,541	-$5,336,073	-$32,354,541	$0.505
Solar+Diesel+Sales	$32,354,541	-$5,336,073	$13,803,064	$0.077
Without loan	**LCC**	**LCS**	**NPV**	**LCOE**
Diesel only	$27,412,606	-	-$27,412,606	$0.428
Solar+Battery	$141,887,802	-$114,475,197	-$141,887,802	$2.214
Solar+Diesel	$34,038,585	-$6,625,979	-$34,038,585	$0.531
Solar+Diesel+Sales	$34,038,585	-$6,625,979	$26,501,329	$0.081