Applying Cogeneration to Facilities with Industrial Refrigeration

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The learning objectives are:

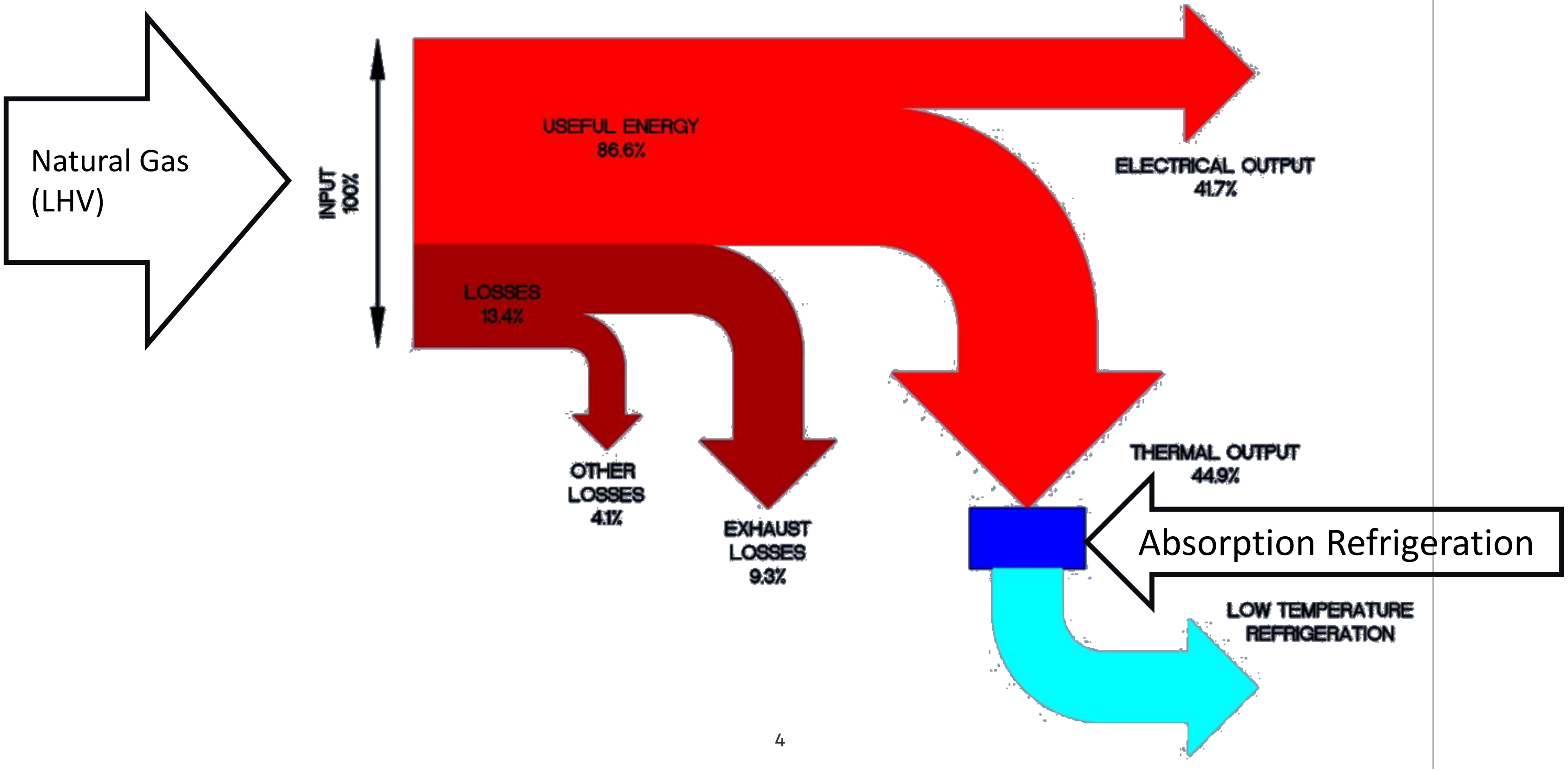
1. Develop basic understanding of cogeneration and its application to industrial refrigeration
2. What are the key elements of a good technical application.
3. What are the key elements of a financially feasible application.
4. What added value opportunities exist for a total energy solution

What is Cogeneration and why explore it for facilities with Refrigeration?

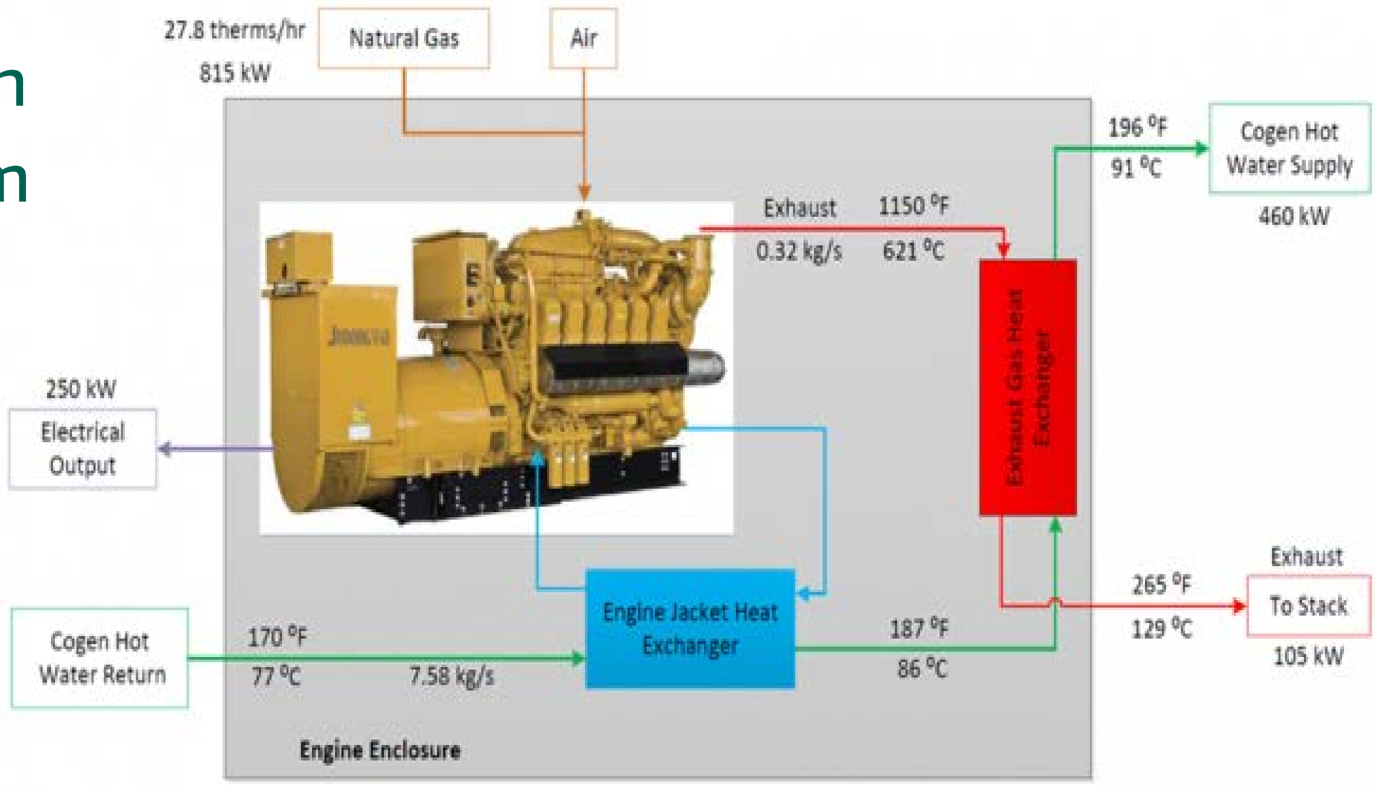
Answer: Operating Cost Savings

- Cogeneration is using fuel to simultaneously produce electrical power and useful heat
- Properly applied Cogeneration results in lower cost of operation for a facility.
- The by product heat of Natural Gas power generation provides economical industrial and commercial refrigeration

The Cogen + Refrigeration Concept



Basic Natural Gas Engine Cogeneration Unit Diagram



Basic Ammonia Water Absorption Refrigeration System Diagram

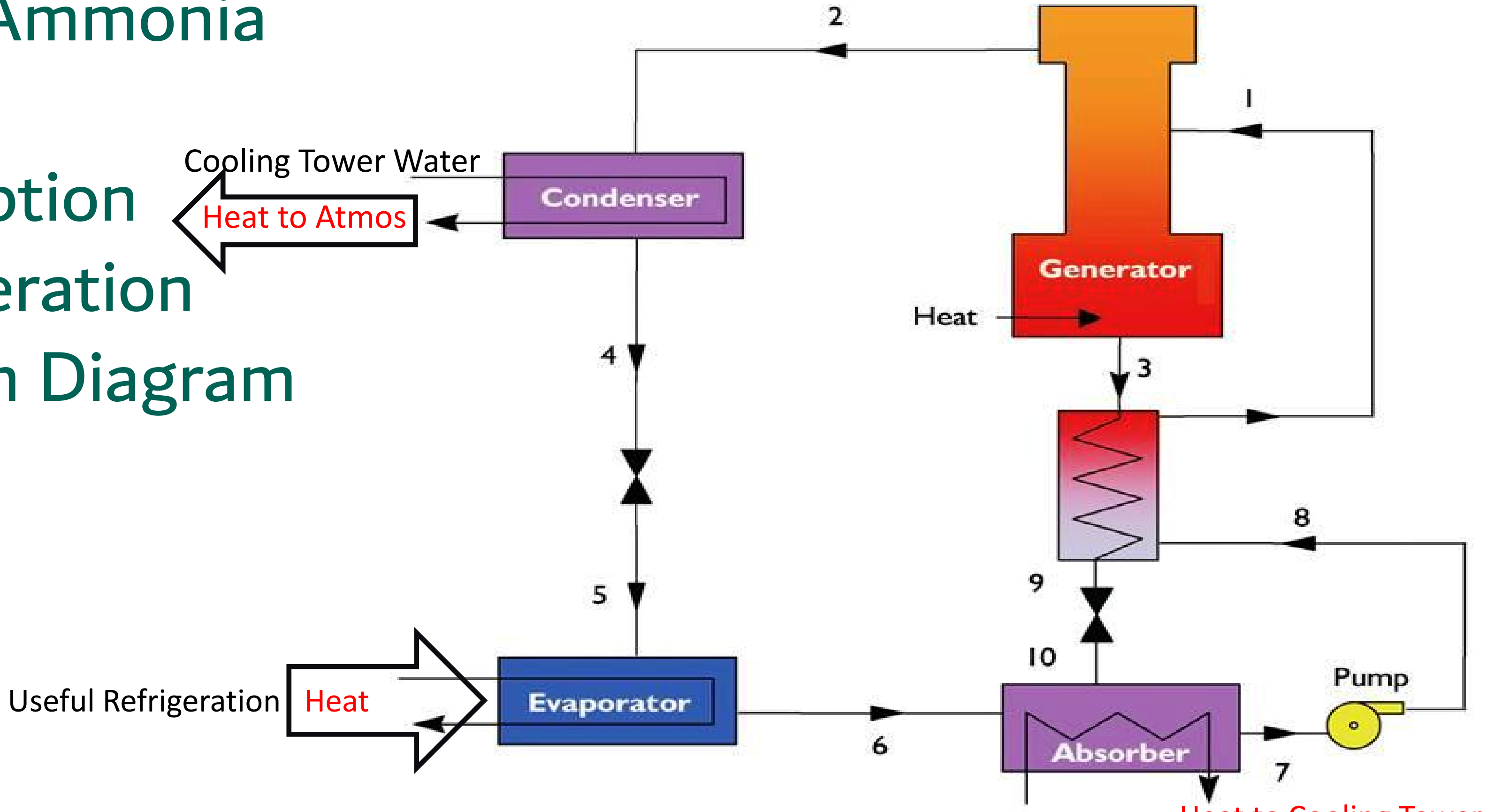
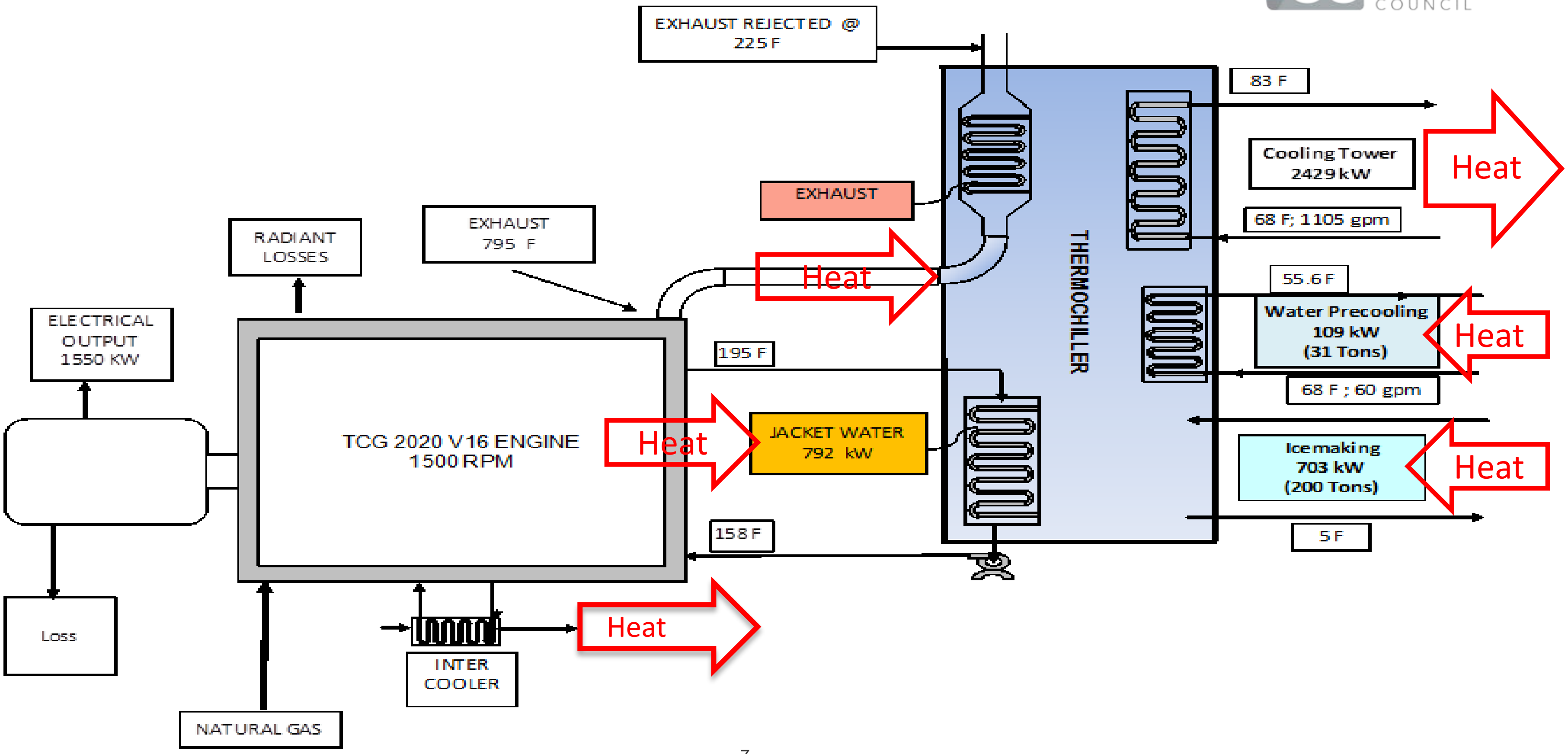


Figure 6: Ammonia-water absorption refrigeration system.

The "Axiom Cycle" Cogen System



The Economics of Cogeneration coupled to Ammonia Absorption Refrigeration Depend On:

- Efficiency of Engine Generator
- Cost of The Plant
- Cost of Capital
- Cost of Maintenance
- Cost of Fuel i.e. Nat Gas
- The Cost of Utility Electrical Energy
- Annual operating Hours
- Percent of byproduct heat used beneficially
- COP of Absorption Unit

The Economics of Cogeneration are greatly affected by Public Policy

EMERGING TECHNOLOGIES COORDINATING COUNCIL

- Air Quality Regulations
  - Can significantly increase Cost of Plant
- Utility interconnection requirements
  - Can increase cost and extend schedule
- Incentives and Tax Policy
- Utility Rate Structures
- Carbon Footprint Concerns

Developments Reducing First Cost

- Factory Packaged Modular Cogeneration Units
- Factory Packaged Modular Ammonia Absorption Refrigeration
- Standardization of Designs
- Automation with Remote Monitoring and Control

Developments Reducing Operating Cost

- Shale Gas development
- Higher efficiency natural gas engines
  - Above 40% fuel to electric efficiency is common
- Longer Maintenance Intervals
  - Up to 60 K hours before Major Overhaul
- Smart On Board Control and Remote Monitoring
  - Ability to maintain efficiency and minimize unplanned service outages
- Factory Standard Designs for optimum efficiency

So, when does Cogeneration with Absorption Refrigeration Make Sense?

Build a Spreadsheet Model and Test for Variations in:

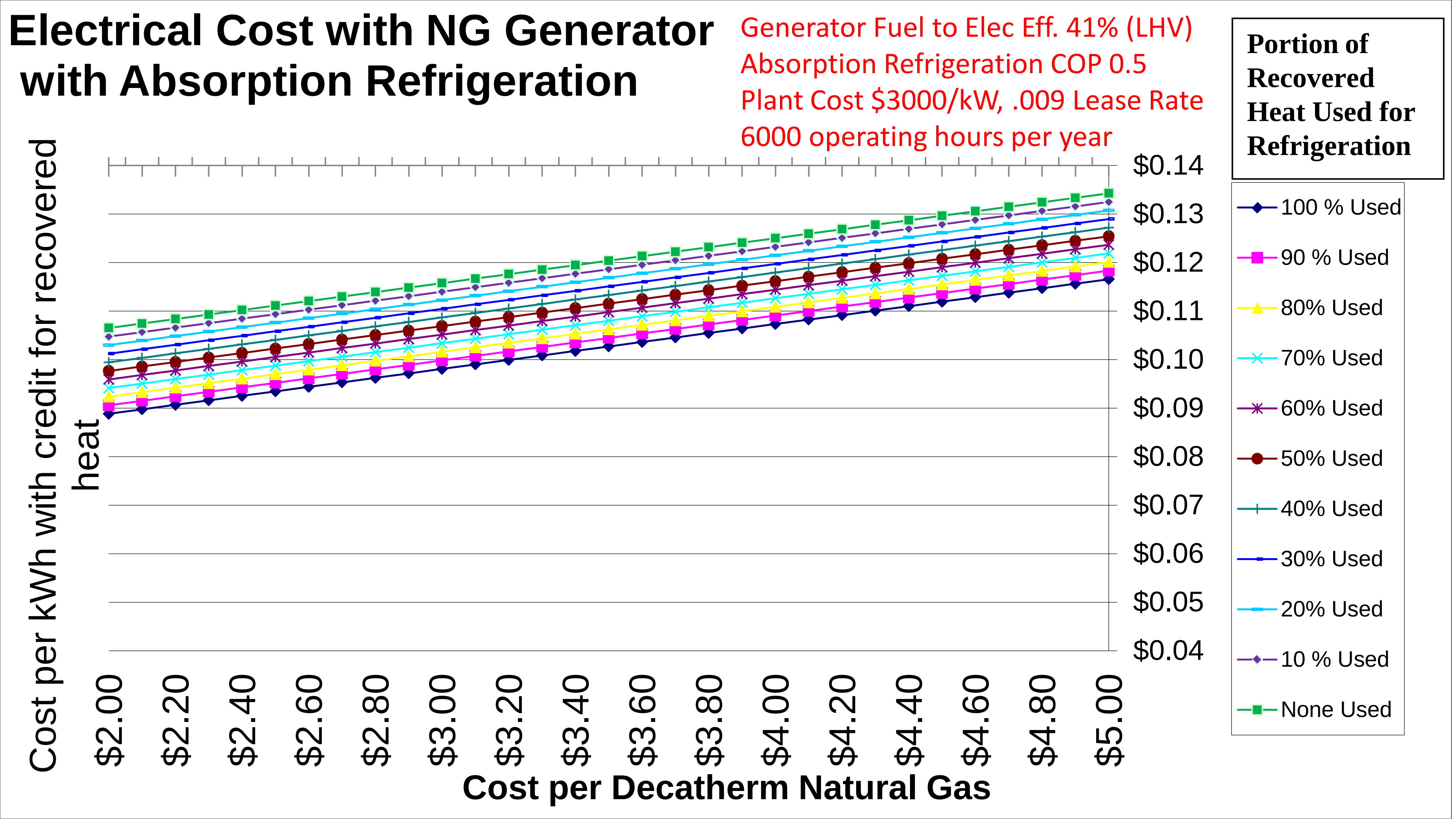
- First Cost
- Fuel Cost
- Capital Recovery Cost
- Operating Hours
- Maintenance Cost
- Absorption Unit COP
- Generator Efficiency
- % Heat Recovery

Example Spreadsheet Model for 8200 annual operating hours

HHV BTU Per Deca-therm	Therms per Deca-therm	Plant Cost per kW net Power Out	LHV BTU per Deca-therm	Electrical Eff.(LHV)	BTU/kWh	kWh per DecaTherm	Heat Recovery Potential (LHV)	Potential Recovered Heat (LHV) BTU per DecaTherm	Potential Rec. Heat BTU per kWh (LHV)	COP of Absorption Refrig	BTU of Refrig per kWh	Refrig tons (RT)/kWh
1,000,000	10	3500	900,000	41.00%	3413	108.12	40%	360000	3330	0.5	1665	0.1387

Existing Refrig Sys kWh/RT	kWh savings per kWh generated	Utility Cost per kWh	Refrig $ savings per kWh made	Utility Cost per kWh	Refrig $ savings per kWh made	Utility Cost per kWh	Refrig $ savings per kWh made	Utility Cost per kWh	Refrig $ savings per kWh made
0.85	0.1179	0.1000	0.0118	0.1250	0.0147	0.1500	0.0177	0.1750	0.020638

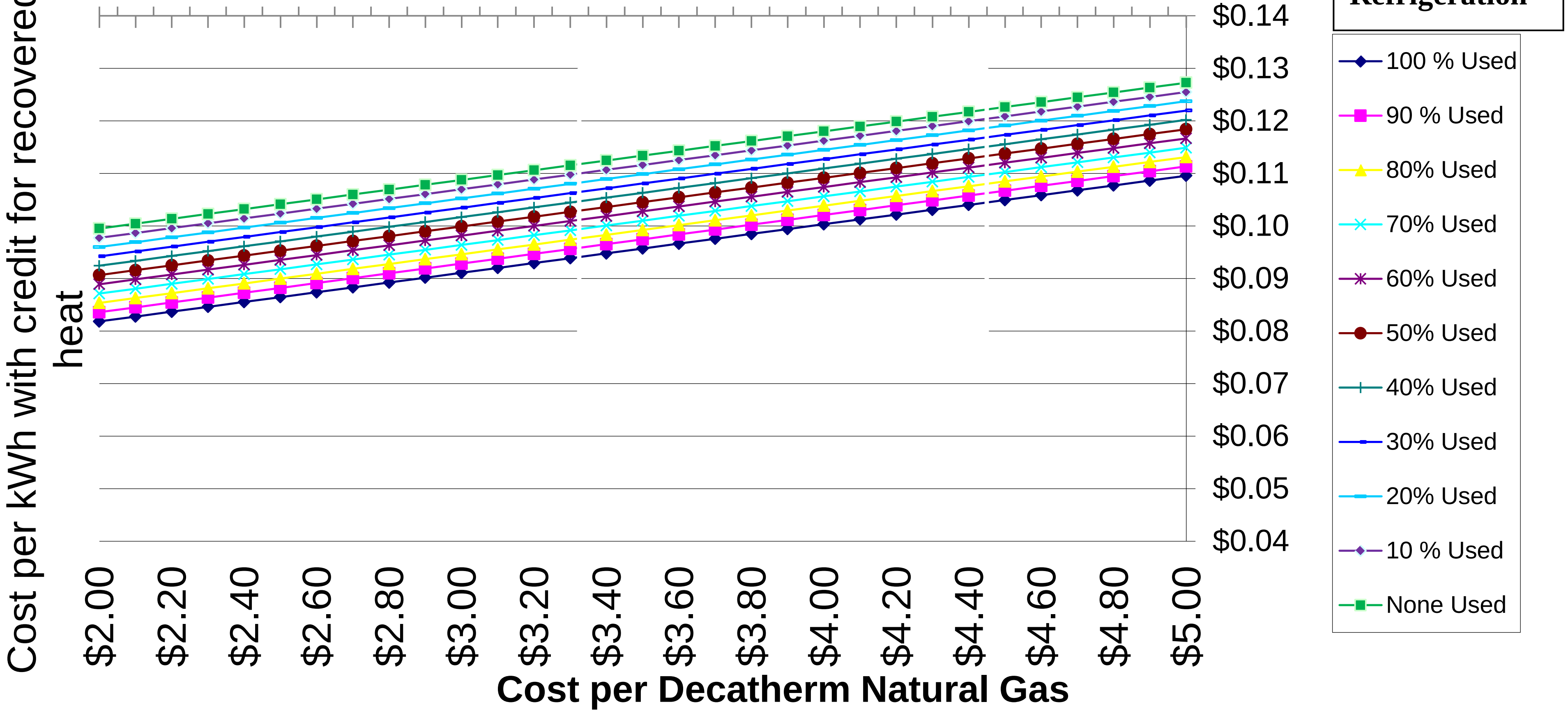
Natural Gas Cost per Deca-Therm	Fuel Cost per kWh	Maint. cost per kWh	Capital Recovery Cost (lease rate .009)	Total Operating Cost	% of Potential Rec Heat Used	Value per kWh at COP of 0.5	Net Cost per kWh after heat recovery	% of Potential Rec Heat Used	Value per kWh at COP of 0.5	Net Cost per kWh after heat recovery	% of Potential Rec Heat Used	Value per kWh at COP of 0.5	Net Cost per kWh after heat recovery
$4.00	$0.0370	$0.025	$0.046	$0.108	100%	$0.018	$0.090	90%	$0.018	$0.092	80%	$0.018	$0.094
$3.90	$0.0361	$0.025	$0.046	$0.107	100%	$0.018	$0.089	90%	$0.018	$0.091	80%	$0.018	$0.093
$3.80	$0.0351	$0.025	$0.046	$0.106	100%	$0.018	$0.088	90%	$0.018	$0.090	80%	$0.018	$0.092
$3.70	$0.0342	$0.025	$0.046	$0.105	100%	$0.018	$0.088	90%	$0.018	$0.089	80%	$0.018	$0.091
$3.60	$0.0333	$0.025	$0.046	$0.104	100%	$0.018	$0.087	90%	$0.018	$0.088	80%	$0.018	$0.090
$3.50	$0.0324	$0.025	$0.046	$0.103	100%	$0.018	$0.086	90%	$0.018	$0.087	80%	$0.018	$0.089
$3.40	$0.0314	$0.025	$0.046	$0.102	100%	$0.018	$0.085	90%	$0.018	$0.087	80%	$0.018	$0.088
$3.30	$0.0305	$0.025	$0.046	$0.102	100%	$0.018	$0.084	90%	$0.018	$0.086	80%	$0.018	$0.087
$3.20	$0.0296	$0.025	$0.046	$0.101	100%	$0.018	$0.083	90%	$0.018	$0.085	80%	$0.018	$0.086
$3.10	$0.0287	$0.025	$0.046	$0.100	100%	$0.018	$0.082	90%	$0.018	$0.084	80%	$0.018	$0.086
$3.00	$0.0277	$0.025	$0.046	$0.099	100%	$0.018	$0.081	90%	$0.018	$0.083	80%	$0.018	$0.085

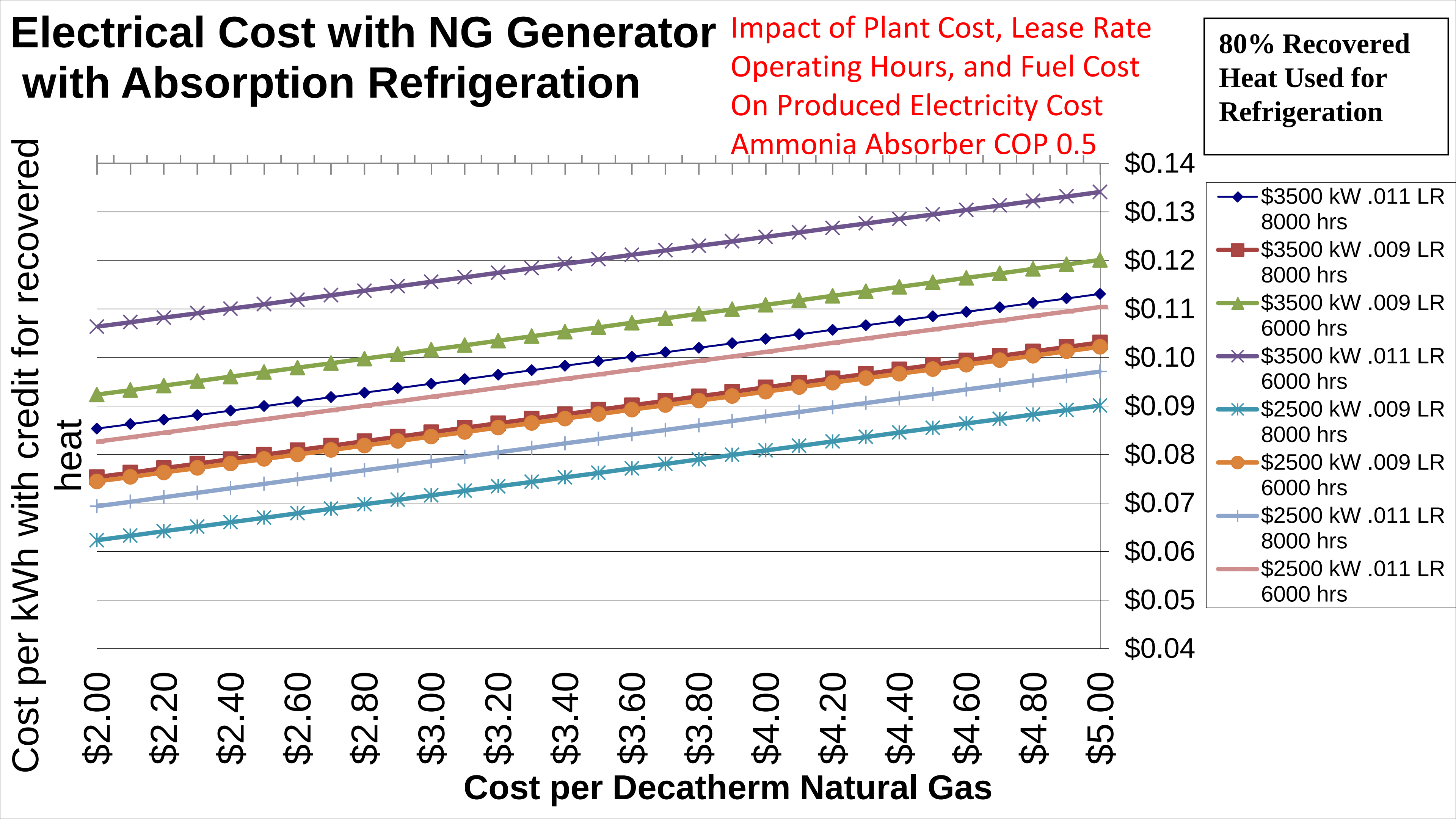


Electrical Cost with NG Generator with Absorption Refrigeration
Generator Fuel to Elec Eff. 41% (LHV)
Absorption Refrigeration COP 0.5
Plant Cost $3000/kW, .009 Lease Rate
6000 operating hours per year
Portion of Recovered Heat Used for Refrigeration
100 % Used
90 % Used
80% Used
70% Used
60% Used
50% Used
40% Used
30% Used
20% Used
10 % Used
None Used
Cost per kWh with credit for recovered heat
$0.14
$0.13
$0.12
$0.11
$0.10
$0.09
$0.08
$0.07
$0.06
$0.05
$0.04
$2.00
$2.20
$2.40
$2.60
$2.80
$3.00
$3.20
$3.40
$3.60
$3.80
$4.00
$4.20
$4.40
$4.60
$4.80
$5.00
Cost per Decatherm Natural Gas

Electrical Cost with NG Generator with Absorption Refrigeration

Generator Fuel to Elec Eff 41% LHV
Ammonia Refrigeration COP 0.5
Plant Cost $3500/kW, .011 Lease Rate
8200 operating hours per year





Electrical Cost with NG Generator with Absorption Refrigeration
Impact of Plant Cost, Lease Rate Operating Hours, and Fuel Cost On Produced Electricity Cost
Ammonia Absorber COP 0.5
80% Recovered Heat Used for Refrigeration
Cost per kWh with credit for recovered heat
Cost per Decatherm Natural Gas
$0.14
$0.13
$0.12
$0.11
$0.10
$0.09
$0.08
$0.07
$0.06
$0.05
$0.04
$2.00
$2.20
$2.40
$2.60
$2.80
$3.00
$3.20
$3.40
$3.60
$3.80
$4.00
$4.20
$4.40
$4.60
$4.80
$5.00
$3500 kW .011 LR 8000 hrs
$3500 kW .009 LR 8000 hrs
$3500 kW .009 LR 6000 hrs
$3500 kW .011 LR 6000 hrs
$2500 kW .009 LR 8000 hrs
$2500 kW .009 LR 6000 hrs
$2500 kW .011 LR 8000 hrs
$2500 kW .011 LR 6000 hrs

So, where is this solution competitive?

Obviously depends on the factors discussed:

- High utilization, cost of Capital, First Cost
- Economical Natural Gas
- States with High Industrial User Power Rates
- California, New England (exc Maine), New Jersey
- Commercial Users with Significant Refrigeration in above states plus New York

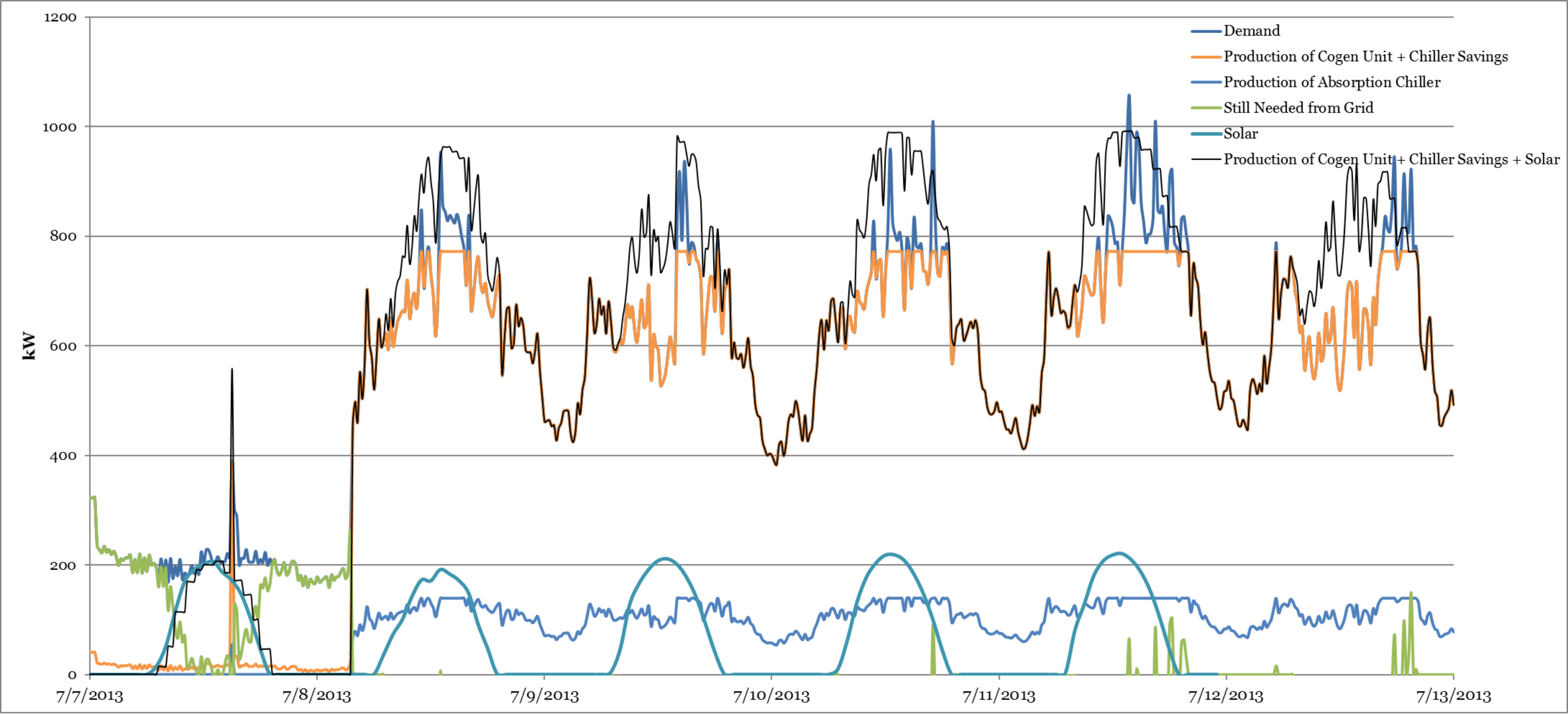
Case Study: Precut Packaged Salad Plant

- Challenge: No requirement for hot water, daily variable power demand profile
- Motivation: Their electrical cost of operation for new facility was three times the pro-forma business case
- Constrained Site, no room for solar, building not built for structural load of solar panels
- Solution: A 633 kW natural gas fueled cogeneration plant also producing 125 TR

633 kW 125 RT Cogeneration
Ammonia Absorption
Refrigeration
Fresh Venture Foods
Santa Maria, California

Future Steps and Opportunities

- Net Zero Challenges
  - High energy intensity utility customers such as food processors cannot achieve net zero onsite energy use
- Combine with Battery and Solar
  - Greater Reliability
  - Increased Utility bill savings
    - Reduced Demand Charges
  - Lower Carbon Footprint



One week Electrical use profile for precut bagged salad plant

Salad Plant Case Study

EMERGING TECHNOLOGIES COORDINATING COUNCIL

- 633 kW Cogen Unit with 125 RT absorption unit
  - With refrigeration effect from absorption refrigeration system reduces demand peak 780 kW
  - Peak Daily Demand in previous Slide 1055 kW
  - Prior to Cogen system coming on line demand charges were >40% of electrical billing
  - After Cogen online demand charges >70% of remaining electrical bill

Salad Plant Case Study

Rate Schedule	Customer Charge/ Meter Charge	Season	Time-of-Use Period	Demand Charges ($/kW)	Energy Charges ($/kWh)		PDP[1/] Charges	PDP[2/] Credits DEMAND (per kW)	PDP[2/] Credits ENERGY (per kWh)	Power Factor Adjustment ($/kWh/%)		"Average" Total Rate[3/] ($/kWh)
E20 Secondary Firm	$39.42505 per day	Summer	Max Peak	$19.02	$0.15018		$1.20	($5.69)	$0.00000	$0.00005		$0.17553
			Part-Peak	$5.23	$0.10981			($1.40)	$0.00000			
			Off-Peak	-	$0.08210			-	-			
			Maximum	$17.87								
		Winter	Part-Peak	$0.05	$0.10395			-	-	$0.00005		
			Off-Peak	-	$0.08893							
			Maximum	$17.87	-							

- Maximum demand charge $17.87/kW plus peak summer demand charge of $19.02/kW
  - Potential to avoid 275 kW X $36.89 = $10,145 each summer month and 275 X $17.87 = $4914 each winter month for a total annual savings of $90,000.

Salad Plant Case Study

- 3 Li Ion battery units at 220 kWh each with 100 kW inverters will meet requirement
- Cogen can charge during lower load night hours
- Only delta operating cost is cost of fuel
- What battery cost makes economic sense?
  – 5 year simple payback for an installed battery system cost of $682/kWh. (Current Pricing without incentives)
  – 3 year simple payback requires $409/kWh (2020 Price)
  – 1.5 year simple payback @ $200/kWh (Predicted 2024)

Salad Plant Case Study

- Does a combined Cogen plus battery solution make sense? Simple Answer: yes
  - Rapidly declining battery costs, Accelerated Depreciation, 30% ITC if solar charged, California $400/$290 kWh incentive
  - Battery storage also protects against unplanned "trips" of the Cogen Unit causing a monthly demand charge spike. Improves reliability
- Can couple with solar to reduce carbon footprint of facility

Questions?

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