Decarbonization of the Detroit Diesel Corporation with ISO 50001, SEP 50001 and Electrification Technologies

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ABSTRACT

The Detroit Diesel Corporation (DDC) engine manufacturing facility has been certified to the ISO 50001 energy management system (EnMS) since 2014 and US Department of Energy SEP 50001 program since 2015 (U.S. DOE). The facility improved energy performance improvement by 22% from 2014 to 2022, which built upon a 33% improvement from 2005 to 2014. Moving forward, the structured ISO 50001 EnMS will contribute to the facility's 42% onsite absolute carbon emission reduction goal by 2030 (2021 baseline) and meeting the Daimler corporate carbon neutrality goal by 2039.

A recent study by Lawrence Berkeley National Laboratory of 83 manufacturing facilities (including DDC) that have implemented and become certified to ISO 50001 EnMS under the SEP 50001 program "achieve annual energy performance rates of around 4.1% in the initial year of implementation and maintain rates of around 3.4% twelve years after implementation (Fitzgerald, 2023)." This paper will show that the DDC facility has demonstrated these levels of energy performance improvement, and ISO 50001 and SEP 50001 can be expected to continue to produce well-above typical industry energy saving rates (0.5% per year). However, even more aggressive energy efficiency and electrification approaches are required and being considered to meet DDC's ambitious carbon emission reduction goal. One key electrification approach being evaluated is an industrial heat pump (IHP) system. The IHP will benefit from process cooling water discharge (waste heat) during the winter. Other technological approaches evaluated were test engine and production engine electricity regeneration, test engine waste-heat recovery, a combined heat and power system and an electric boiler for comfort heating. The various decarbonization technologies analyzed in this paper target the facility's comfort heating system which accounts for 48% of the facility's natural gas consumption and 27% of the site's Scope 1 carbon emissions.

Introduction

DDC produces a complete line of state-of-the-art engines, axles, and transmissions while also pursuing a robust energy management system. The plant is an industry leader within engine equipment manufacturing. Through the plant's 9-year history of certification through ISO 50001 and U.S. Department of Energy's Superior Energy Performance (SEP) 50001, the Detroit plant recognizes the successful competitive advantage that energy efficiency delivers as well as its place as an important leader for greener manufacturing. The robust structure of the ISO 50001 energy management system requirements combined with the SEP 5001 program (U.S. DOE 2023-1) that adds third party verification of energy performance improvement played a key role in this success.

Facility Energy and Carbon Emission Profile

At around 3.2 million square feet and 3,200 employees, the DDC manufactures diesel engines and external components for both the heavy-duty and mid-range markets. The plant contains research and development labs, production, and assembly lines, as well as extensive engine testing areas. Annually, the facility spends approximately $11 million in total for electric, gas, and water bills, highlighting the interest in further energy usage improvements.

Figure 1 shows Detroit Diesels 2022 annual energy consumption which consisted mostly of purchased electricity followed by natural gas and diesel fuel providing just about a quarter of total energy consumption combined. DDC currently purchases 15% of its electricity with renewable electricity and plans to purchase 35% by end of 2024 and 100% by end of Q1, 2025.

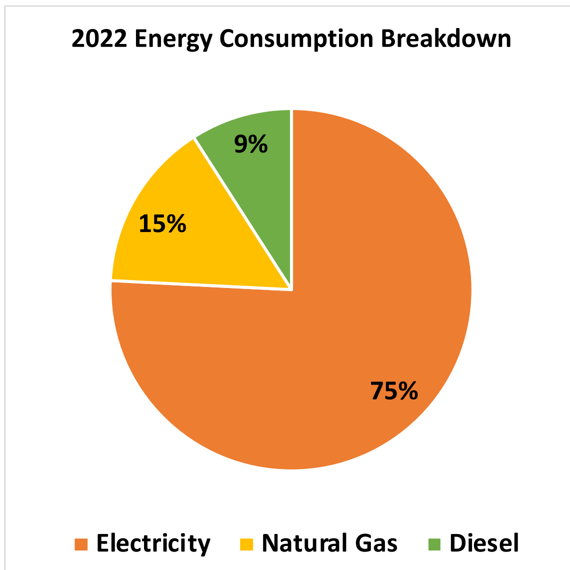


Figure 1. 2022 DDC energy consumption breakdown (BTU, site).

Figure 2 shows the breakout of the facilities Scope 1 and Scope 2 carbon footprint of 83,458 metric tons (MT) CO_2e (2022). Scope 1 emissions are onsite emissions from fuel combustion. Scope 2 emissions result from offsite electrical generation.

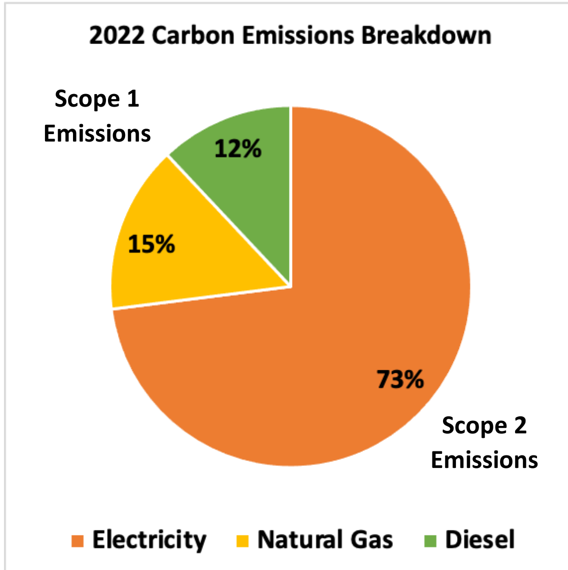


Figure 2. 2022 DDC Scope 1 and 2 carbon emission by fuel type breakdown

DDC is undergoing a radical transformation in its product line by creating new electric propulsion powertrain as an alternative to the traditional diesel fuel engines. Increased electric powertrains will impact the facility's energy fuel mix. The diesel engine research facility and production engine testing will gradually be reduced, and electric vehicle testing will increase in the next 10 to 15 years. This presents DDC with an opportunity to decarbonize the site's emissions by producing more electric powertrains and implementing more efficient facility energy support systems that can be electrified or eliminated.

Background of Energy Program

The plant's culture of energy improvement stems from their long-term commitment to environmental management and goals to reduce greenhouse gas emissions. Participation in ISO 50001 and SEP 50001 brought in a new wave of sustainability activities and achievements including the addition of a high visibility "Green Corner" which highlights current and completed projects. DDC has been a shining example for Daimler since becoming the first subsidiary in the United States to achieve ISO 50001 and SEP 50001 certification. The plant has received the global "Environmental Leadership Award" from Daimler, the "Michigan Green Leader Award" from the Detroit Free Press and from DTE Detroit the Education and Energy Efficiency Award. In May 2021, DDC joined the DOE Better Plants Program (BPP) which aims to reduce carbon emissions associated with manufacturing by improving industrial efficiency. DDC's BPP's goal is to improve energy intensity by 20% over 10 years (baseline 2019).

Business Case for ISO 50001 and SEP 50001

DDC's parent company is Daimler. Daimler and DDC's management understand the value of energy efficiency improvements, yet the company has limited internal resources to devote to such projects. This means that the EnMS implementation, ISO 50001 and SEP certification, and energy efficiency projects must compete with funding for other important business priorities, e.g., quality, environmental performance, et al.

Once ISO 50001 certified in 2014, DDC then pursued SEP certification in 2015 and applied the rigorous SEP Measurement and Verification (M&V) protocol (U.S. DOE 2019). The DDC plant was able to verify its energy performance improvement and energy savings of 33% and $37 million, respectively, over 10 years (2005 to 2014) (U.S. DOE 2016 and 2017). The plant's energy savings also happened as production scaled up by 93%. In addition, in 2015, just 12 months after their initial ISO 50001 certification, Detroit Diesel saved $815,000 in annual energy costs with improvements from operational procedures, requiring low capital investment, and several capital improvements. The SEP third-party verification confirmed financial savings and motivated management to invest additional funding for future energy projects that would yield attractive return on investment at low risk. Management's viewed energy reduction projects as less risky opening doors to capital expenditures with more relaxed payback period requirements. In addition to large-scale monetary savings, the business case for improved energy management derives from increased confidence in decision making.

Finally, DDC is using their ISO 50001 certification and SEP 50001 program to contribute to meeting the company's energy goal of 1% absolute and 2.5% normalized per year through 2030 and absolute carbon emission reduction goal of 42% by 2030 using a 2021 baseline.

Energy Use Breakdown

When the facility initially started working towards SEP 50001 in 2015, additional meters were installed throughout the plant to better visualize energy flow, identify significant energy uses (SEU), and prioritize energy efficiency efforts. This additional meter data is evaluated regularly to determine the percentage of energy used by specific processes and equipment. Each energy use category is then given a scorecard rating to determine which energy systems are SEUs. Figure 3 shows the top energy uses. In 2021, the boilers and the HVAC system were designated as SEUs. These two SEUs were based on their high energy consumption along with large, anticipated energy saving opportunities and the short time required for implementation. Classifying an energy use as an SEU is important within ISO 50001 because SEUs are given more attention by determining the SEU's relevant variables, energy performance and identifying the person(s) doing work that affect the SEU. Staff responsible for SEUs require training. SEU energy consumption needs to be tracked and regularly monitored. Other relatively energy-intensive processes at the facility include the E-4 test cells and engine block machining.

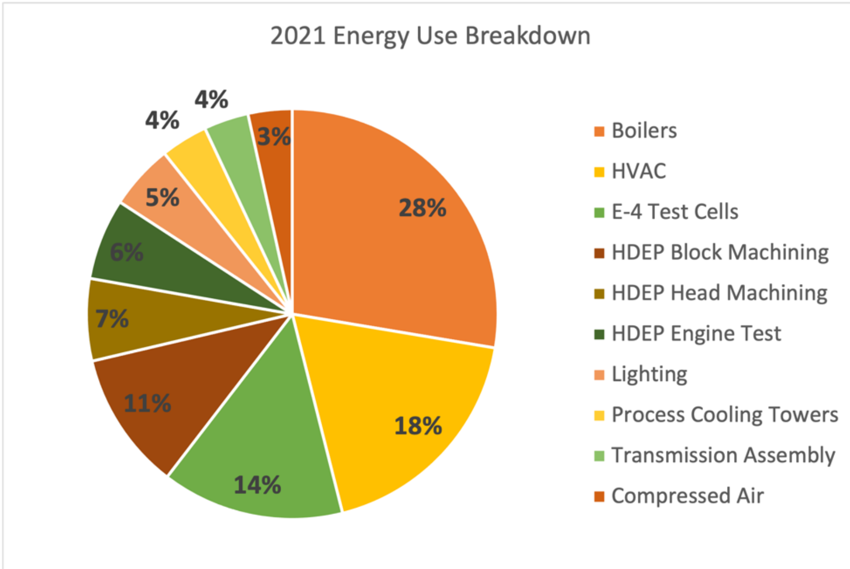


Figure 3. 2021 DDC energy use breakdown.

Energy Performance Over Time

For ISO 50001 and SEP 50001, it is crucial to analyze overall energy performance of the facility over time to track progress and detect where changes may have had an impact on consumption. Figure 4 shows the continual energy performance improvement over the past 17 years. Note the steady improvement from 2014 to 2022 of 22% after the ISO 50001 energy management system was implemented. In both 2018 and 2021, DDC achieved the highest recognition from DOE for SEP 50001, with Platinum level recognition. Achieving Platinum level requires implementation of many energy management best practices beyond those required of ISO 50001.

Detroit Diesel's projected energy efficiency improvement of 20% over 10 years (2.0% per year, Better Plants goal) will contribute to the facility's carbon reduction goal. DDC's goal is to maximize onsite energy efficiency and electrification technologies as much as cost effectively possible to avoid the purchase of higher cost renewable energy and carbon offsets.

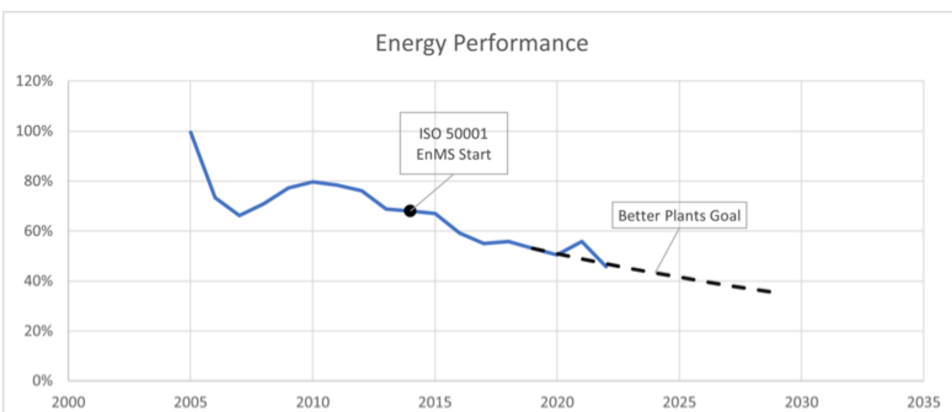


Figure 4. DDC energy performance** over time.

**** Note: Calculation of DDC's energy performance improvement for both SEP 50001 and Better Plants applies the SEP M&V protocol which normalizes energy consumption to key relevant variables, including production rate, weather (heating and cooling degree days) and other variables that meet statistical criteria set by the protocol for each energy source (i.e., natural gas, electricity, diesel fuel).**

Implemented Energy Saving Projects

Historically, DDC has implemented many energy saving projects starting in 2005 with a major roof replacement (changing from R3 to R28 insulation). In 2020 Detroit Diesel qualified for the Strategic Energy Management (SEM) program sponsored by the facility's energy supplier, DTE Energy. The SEM program inspired projects such as improving compressed air operations by operating at optimal efficiency levels and fixing compressed air leaks. Identification and repair of air leaks alone resulted in annual energy savings of $76,674. In addition, adjusting and introducing new set points for steam and HVAC operations led to annual savings of $4,000 and $85,110, respectfully.

For the 2021 SEP Certification Achievement Period (2018-2021), projects for the previous three years totaled annual energy savings of $1.4 million. By energy commodity, 31 projects were targeted towards electricity, 13 were associated with natural gas, and 1 was diesel related. Energy savings by end-use, shown in Table 1 below, involving projects ~~in~~ for boilers, compressed air and the E-4 test cells had the most impact on annual energy savings, followed by chillers, HVAC, and lighting. Projects involving the boilers during this time period, in order of their energy saving potential, included reducing the heating setpoint to reduce boiler load, converting steam-heated water heaters to electric water heaters, increased roofing insulation, and retubing a boiler to increase reliability and efficiency.

Table 1. Energy savings by end use type.

Total Energy Savings by Source (achievement period)	Annual Energy Savings (MMBtu/yr.)
Boilers	45,468
Compressed Air	31,232
E-4 Test Cells	29,355
Chillers & CT	24,171
HVAC	22,529
Lighting	14,275
Total	167,031

As of 2022, DDC's boilers and HVAC are still the top two significant energy uses for the facility. Recent projects to reduce HVAC energy usage have included updating temperature setpoint schedules, adding roof insulation, replacing, and upgrading older units, increasing cooling temperature setpoints to reduce chiller load, and replacing one large rooftop unit with five smaller units to provide the option for staged loading. DDC still has considerable opportunities to improve the boilers and HVAC systems.

Challenge to Close Gap

One could expect that DDC will continue to improve its energy performance by 2-4% per year by using the ISO 50001 energy management system and the SEP 50001 program's energy practices. However, reaching the carbon reduction goal in the most cost-effective manner demands consideration of more capital-intensive and advanced energy efficiency and electrification technologies. In what follows we will focus on various decarbonization technologies that target the facility's comfort heating system which accounts for 48% of the facility's natural gas consumption and 27% of the site's Scope 1 carbon emissions.

Waste Heat Recovery and Electricity Regeneration

DDC consumes about 1 million gallons of diesel fuel each year for diesel engine product research and durability testing as well as production engine testing. Each engine produced is tested prior to being shipped. In 2021 and 2022, DDC partnered with U.S. Department of Energy Midwest Combined Heat and Power Technical Assistance Partnerships (TAPs) center, based at the University of Illinois at Chicago (UIC), to analyze three different approaches to capture waste heat or engine horsepower from diesel fuel-powered equipment:

- Project 1 - adding electric generation capability to diesel engine production test bays (CHP TAP-1 2022)
- Project 2 - adding electric generation capability to all research and durability diesel engine testing (CHP TAP-2 2021)
- Project 3 - capturing wasted energy from research and durability diesel engine test bays to offset steam/hot water from the boiler system supplying comfort heat (CHP TAP 2021)

Table 2 summarizes the cost-benefits of the three projects.

Table 2. Summary of three CHP opportunities

	Project 1	**Project 2**	**Project 3**
Type of energy savings	Increased electricity generated to offset grid electricity	Increased electricity generated to offset grid electricity	Waste heat recovered to save boiler fuel
Amount energy generated or saved	6,380,968 kw-hr generated	14,398,870 kw-hr generated	50,028 MMBtu natural gas saved kw-hr
Cost savings	$345K/yr.	$780K/yr.	$203K/yr.
Capital Expense	$4.0 million	$4.3 million	$2.0 million
Simple payback	11.4 yrs.	5.0 yrs.	9.0 yrs.

While these three projects offered reasonable energy savings, the payback periods were too long, and the engine test research facility has already been scaled back since the studies were performed in 2021 due to the transition from diesel engine to electric drivetrain product development mentioned previously.

Moving Forward: Decarbonization of DDC's Energy Footprint

By necessity, decarbonization of the site will focus on natural gas (15% of energy footprint and 55% of Scope 1 emissions) and diesel fuel (9% of energy footprint and 45% of Scope 1 emissions). As mentioned above, the reduction of diesel fuel will naturally occur due to changes in DDC's product portfolio mix from diesel engines to electric drive propulsion. Biodiesel or Renewable diesel fuel is one option to address decarbonization as an alternative to petroleum-based diesel fuel. The cost of biodiesel or renewable diesel fuel can be cost competitive to diesel fuel (U.S. DOE 2023-2).

Currently all production engines are run hot under load to test the engine before release to the customer. One alternative to save diesel fuel is "cold testing" where an electric motor is used to rotate the crankshaft with the engine "cold" (i.e., not running). During this process sensors monitor operation, including torque, crankshaft angle and pressures, to ensure proper functioning in conditions that mimic actual function in the field (Sciemetric 2021).

In this paper, we will discuss technologies to decarbonize natural gas, in particular, address opportunities to save energy and decarbonize DDC's comfort heating system which is the largest natural gas end use. Figure 5 below shows a breakdown of DDC's natural gas uses.

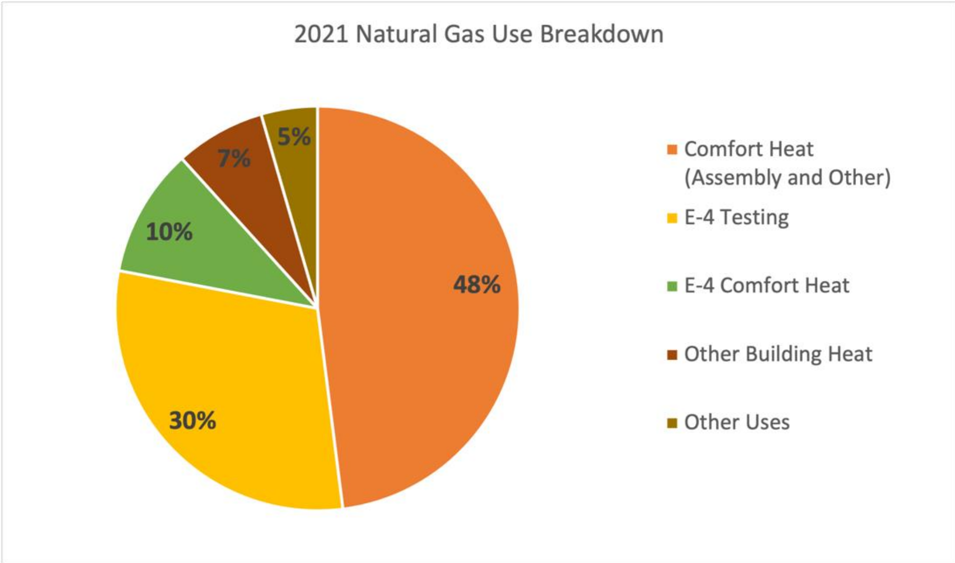


Figure 5. Detroit Diesel's natural gas consumption by general end use.

Currently the DDC facility is undergoing a complete re-design of the comfort heating system to replace three older steam boilers with a combination of new natural gas low pressure, steam and hot water boilers. This requires, for example, resizing and upgrading of comfort heating air handlers to accommodate hot water supply versus steam. After the change to hot water boilers the facility will consume an estimated 25,000 MW-hr per year to accommodate the winter heating season.

Recent efforts to decarbonize and consider electrification options include the cost/benefits of an alternative electric heat pump system compared to the hot water boilers. For completeness in the evaluation process combined heat and power and electric boilers have also been evaluated in this paper. Therefore, the following compares four options available to DDC for comfort heating:

1. Natural gas hot water boilers
2. Natural gas combined heat and power system
3. Electric boilers
4. Electric heat pumps

Each system is conceptually illustrated below in Figure 6 with corresponding energy consumption percentages.

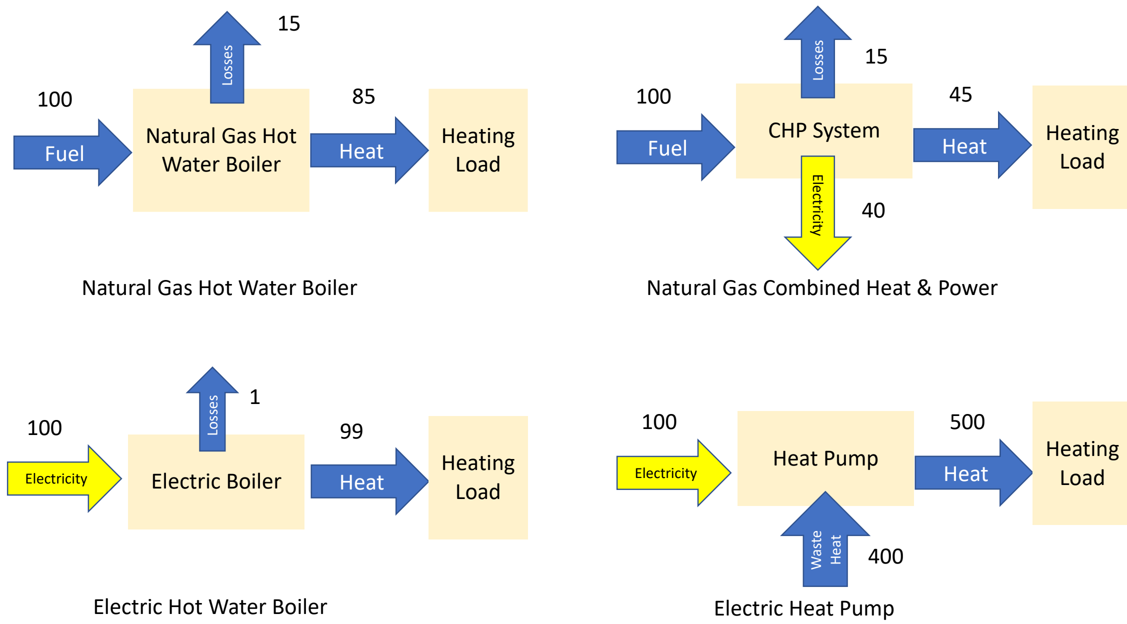


Figure 6. Conceptual diagrams of four energy systems (numbers represent % energy consumption).

While the two boiler configurations and CHP system are conventional systems, the heat pump system needs greater explanation.

Figure 7 below illustrates how the heat pump would work to capture the process cooling water waste heat to avoid this heat from being directed to the cooling towers. The heat pump boosts the waste heat extracted from the 75 F process cooling water to heat the circulating comfort heat hot water loop to 120 F. It is anticipated that hot water boilers (electric or natural gas) would be installed as redundant and backup heating supply to the heat pump.

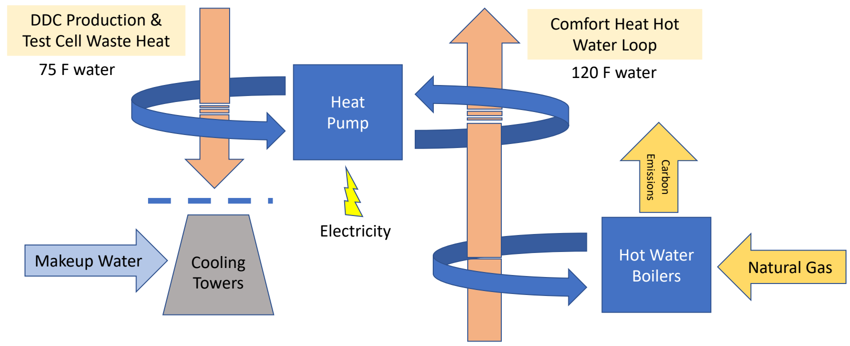


Figure 7. Heat pump to capture DDC production and test cell waste heat.

The heat pump performance is defined by the coefficient of performance (COP). COP for an electric heat pump is defined as the heat delivered by the heat pump divided by the electricity input to the heat pump. Figure 8 illustrates the thermodynamics of the heat pump with heat being pumped from T_{source} (Q_{source}) to T_{sink} (Q_{sink}). T_{sink} and T_{source} are in absolute temperatures (Rankine or Kelvin). The Carnot efficiency is η, and,

$$COP = \eta * [\ T_{sink} / (T_{sink} - T_{source})\ ] = Q_{sink} / Electricity_{in}$$

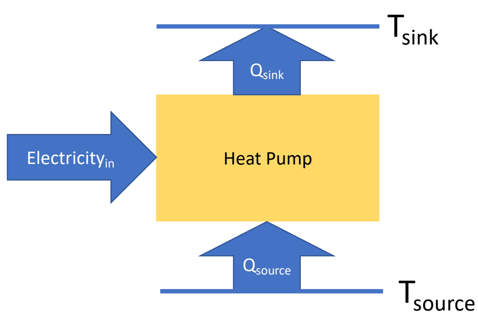


Figure 8. Thermodynamic representation of electric heat pump.

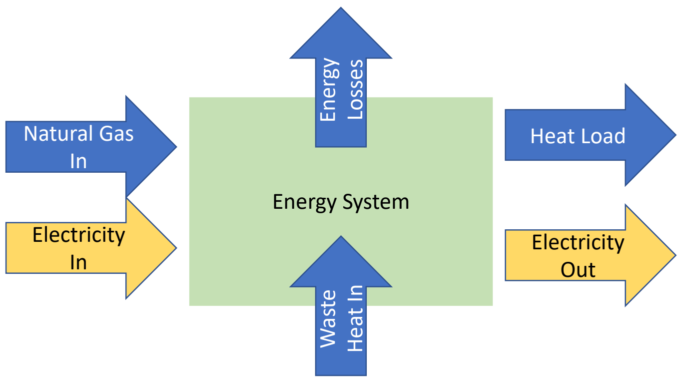
We assumed the heat pump's condenser and evaporator temperatures were 125 and 58 degrees F, respectively because we assumed the 75 F process cooling water is reduced by 12 F by the heat pump/chiller evaporator (typical chiller design load), the heat exchanger delta T across both condenser and evaporator were at a minimum 5 F and the overall Carnot efficiency of the heat pump, η, was 55% (average performing closed cycle heat pump/chiller technology). Therefore,

$$COP = \eta * ((120+5)+460)/((120+5)-(75-12-5)) = 4.8$$

Therefore, for every 1 unit of electricity into the heat pump, 4.8 units of heat are delivered to the hot water loop.

An added benefit of the heat pump is an estimated annual 6 million gallons of water savings and reduced water treatment chemicals from reduced cooling tower operation in the winter.

Figure 9 shows the energy balance with natural gas or electricity requirements for each system to meet the 25,000 MW-hr heat load as well as the energy losses and electricity out (CHP). Note that the heat pump requires waste heat.



Energy System	Natural Gas In MW-Hr	Electricity In MW-Hr	Waste Heat In MW-Hr	Energy Losses MW-Hr	Heat Load MW-Hr	Electricity Out MW-Hr
NG Boiler	29412	294	0	4412	25000	0
CHP system	55556	0	0	8333	25000	22222
Electric Boiler	0	25253	0	253	25000	0
Electric Heat Pump	0	5000	20000	0	25000	0

Figure 9. Energy balance of four comfort heating systems.

Life Cycle Cost of Comfort Heating System

An economic model was created to estimate the life cycle cost of the four energy systems over a 25-year lifetime. It should be noted that the cost of carbon (CO_2 emissions) was not explicitly applied in the life cycle cost analysis described below. However, below we set three levels of energy prices in the life cycle analysis. Level 3 is the estimated cost of renewable natural gas which serves as a de-facto cost of CO_2 mitigation being that it is considerably higher cost than market natural gas. Utility energy efficiency program rebates were not included since it was unclear, at present, if DTE, DDC's utility, offered rebates for large energy consuming electrification technologies – heat pump and electric boiler.

Accordingly, the life cycle cost was composed of the following:
Capital cost – depreciated over 7 years using the modified accelerated cost recovery system (Doty 2009).

Capital cost was reduced for three systems (CHP, electric boiler and heat pump) assuming these systems qualify for a 30% Federal tax credit using IRS 48C ruling (IRS 2023). Table 3 shows the capital costs for the four systems.

Table 3. Capital cost of four energy systems before tax credit applied.

	NG Boiler	**NG CHP**	**Electric Boiler**	**Electric Heat Pump**
Capital Cost ($K)	3,950 (PBA-1 2023)	20,000 (EPA 2015)	2,950 (Jadun 2017)	11,250 (PBA-2 2023)
Federal tax credit (%)	0	30	30	30

Cost of capital – applying a 4% interest rate each year for remaining capital cost not fully depreciated.

Energy cost – Natural gas costs were assumed at three levels and electricity at two levels

a. natural gas prices:
   1. low market: $4/MMBtu (below current DDC cost)
   2. high market: $8/MMBtu (above current DDC cost)
   3. renewable natural gas: $25/MMBtu (DDC-1 2023)
b. electricity prices:
   1. market: 6.0 cts/kW-hr (current DDC cost)
   2. renewable electricity: 7.4 cts/kW-hr (current DDC cost)

Table 4 are the assumed maintenance costs of the four energy systems.

Table 4. Maintenance cost as % of capital cost (DDC-2 2023).

	NG Boiler	**NG CHP**	**Electric Boiler**	**Electric Heat Pump**
Maintenance cost (% of capital)	5	5	3	4

Life Cycle Results

Table 5 below shows the 25-year life cycle costs for the four energy systems at three energy price levels:

Level 1 – low market natural gas cost and market electricity ($4/MMBtu, 6.0 cts/kW-hr)
Level 2 – high market natural gas cost and market electricity ($8/MMBtu, 6.0 cts/kW-hr)
Level 3 – renewable natural gas and renewable electricity cost ($25/MMBtu, 7.4 cts/kW-hr)

Table 5. Life Cycle Cost for four energy systems at Level 1 to 3 energy prices ($K).

	Level 1 Energy Cost	Level 2 Energy Cost	Level 3 Energy Cost
NG Boiler	$19,996	$30,031	$86,317
CHP System	$26,862	$45,818	$118,601
Electric Boiler	$42,487	$42,487	$51,325
Electric Heat Pump	$27,885	$27,885	$29,635

The natural gas hot water boiler provides the lowest life cycle cost for low natural gas price. CHP is competitive to the natural gas boiler and electric heat pump only at low natural gas price but not the lowest life cycle cost in any case. The electric boiler is not competitive at any of the three energy price levels. The heat pump life cycle cost is relatively flat for the three price levels and is the clear choice assuming natural gas cost is at or above the high market natural gas price.

Carbon Emission Reduction Impact

Table 6 shows the Scope 1 and 2 carbon emissions from the four energy systems. The CHP system offers the highest overall Scope 1 and 2 emission reduction at 12.3% relative to the natural gas boiler, while the electric boiler and electric heat pump offer the highest Scope 1 emission reduction, both at 23.3%. Carbon emission factors for natural gas and electricity were 0.181 and 0.540 metric tons/MW-hr CO_2e, respectively (U.S. EPA 1996, 2015, 2019).

Table 6. Carbon emissions of four energy systems using present grid emission factors

	Scope 1 carbon emissions	Scope 2 carbon emissions	Scope 1 + 2 carbon emissions	Scope 1 reduction relative to NG Boiler & Total DDC emissions	Scope 1 + 2 reduction relative to NG Boiler & Total DDC emissions
	metric tons/yr	metric tons/yr	metric tons/yr	%	%
NG Boiler	5324	159	5482	-	-
CHP System	10056	-12000	-1944	-20.7	12.3
Electric Boiler	0	13636	13636	23.3	-13.5
Electric Heat Pump	0	2700	2700	23.3	4.6

Total DDC Scope 1 and 2 emissions are 22,854 and 60,603 metric tons/yr.

However, Table 7 gives a view toward the future when we can imagine DDC having access to electricity that is 100% renewable and carbon free (2025, Q1 plan is to purchase 100% renewable). Here the electric boiler and heat pump are the only choices that reflect a positive carbon reduction for both Scope 1 and Scope 1 plus 2 carbon emissions and yield an 8.8% reduction of Scope 1 + 2 emissions.

Table 7. Carbon emissions of four energy systems with carbon free electricity

	Scope 1 carbon emissions	Scope 2 carbon emissions with carbon free electricity	Scope 1 + 2 carbon emissions with carbon free elctricity	Scope 1 reduction relative to NG Boiler & Total DDC emissions	Scope 1 + 2 reduction relative to NG Boiler & Total DDC emissions
	metric tons/yr	metric tons/yr	metric tons/yr	%	%
NG Boiler	5324	0	5324	-	-
CHP System	10056	0	10056	-20.7	-7.8
Electric Boiler	0	0	0	23.3	8.8
Electric Heat Pump	0	0	0	23.3	8.8

Summary

The Detroit Diesel Corporation (DDC) has improved its energy performance by 58% from 2005 to 2022. ISO 50001 certification and the SEP 50001 program's robust energy management system have yielded 22% energy performance improvement since 2014 (through 2022) and can be expected to continue to improve of 2 to 4%, annually, thus helping DDC to meet its Better Plants goal by 2029. DDC has committed to participation in the MIGreenPower with 100% renewable power by Q1, 2025. Therefore, the complete facility decarbonization of the site will necessarily focus on diesel fuel and natural gas. Market changes in DDC product portfolio from diesel to electric drive engines will gradually reduce its onsite diesel fuel consumption. Electrification of the site’s comfort heating system with electric heat pumps offers the lowest 25-year equipment life cycle cost if boilers or CHP systems were fueled with natural gas at a price of $8/MMBtu or greater. Electric heat pumps and electric boilers for the site’s comfort heating system provide the largest Scope 1 + 2 reductions of 8.8%, if purchasing renewable electricity. The site’s remaining natural gas consumption could be further reduced by energy efficiency investments and similar technological approaches of electrification with electric heat pumps and electric boilers.

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