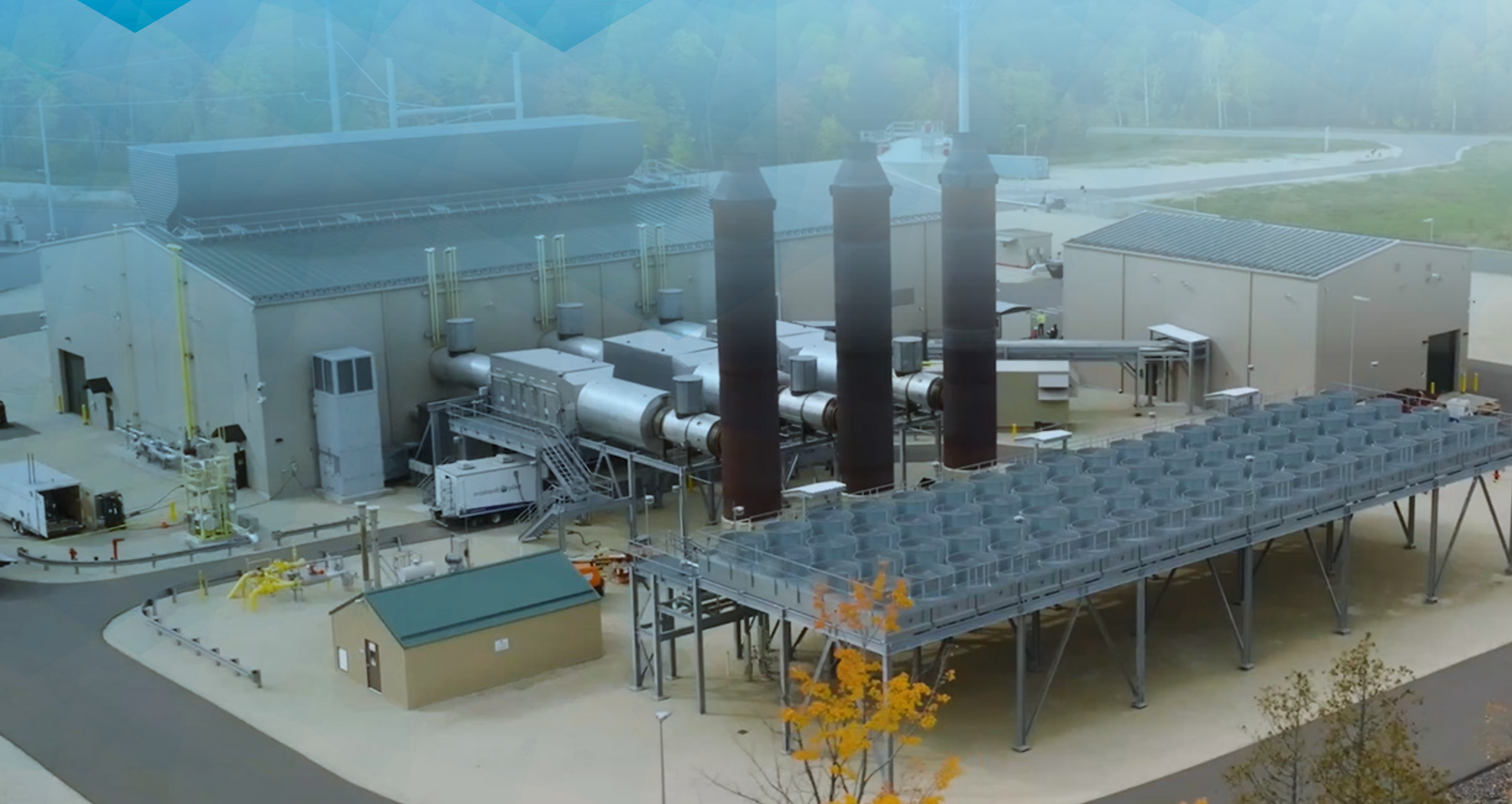
HYDROGEN BLENDING DEMONSTRATION AT UMERC'S A.J. MIHM GENERATING STATION: WÄRTSILÄ 18V50SG RECIPROCATING INTERNAL COMBUSTION ENGINE

EXECUTIVE SUMMARY



ADVANCING CLEAN ENERGY: HYDROGEN BLENDING DEMONSTRATION PROJECT

WEC Energy Group (WEC) is working to reduce emissions across its energy subsidiaries, which serve electric and natural gas (NG) customers in the Midwest. The company has set targets for cutting carbon dioxide (CO_2) emissions from electric generation: 60% reduction by the end of 2025 and 80% reduction by the end of 2030, both from the perspective of a 2005 baseline and net carbon neutral electric generation by 2050. It also aims to achieve net-zero methane emissions from the NG distribution system by the end of 2030.

In support of its commitment to advance clean energy technologies, WEC hosted a hydrogen-NG blending demonstration project at Upper Michigan Energy Resource Corporation's (UMERC) A.J. Mihm Generating Station (Mihm) on one of the three 18.8-MWe Wärtsilä reciprocating internal combustion engine (RICE) units that constitute the site. The goal of the project was to demonstrate that hydrogen-NG blends up to 25% by volume (vol%) hydrogen could be successfully used by a grid-connected, commercial-scale RICE unit. A hydrogen blending system was temporarily installed at the site for the tests.

WEC and UMERC collaborated with EPRI on the project. EPRI facilitated project meetings and supported safety, design engineering, and test planning activities. EPRI also participated in the testing and led the assessment of the engine performance. Other project team members included Blue Engineering, Burns & McDonnell, Certarus, Lectrodryer, Mostardi Platt, and Wärtsilä.

A full test plan was developed and enacted, and measurements taken were used to assess the engine's performance over a range of operating conditions when using a hydrogen-NG blend. Key parameters measured included electrical output, efficiency, and emissions.

ABOUT THE A.J. MIHM GENERATING STATION

Mihm, which was placed into service in 2019, is located in Baraga Township in the Upper Peninsula of Michigan. Figure 1 is an aerial photograph of Mihm with the hydrogen blending system in view on the left side of the photo.

PLANT SAFETY

Coordination

UMERC had overall responsibility for coordinating safety at Mihm. All contractors visiting the plant were required to complete the online environment, health, and safety orientation/training for the plant to confirm all personnel on site during testing were familiar with Mihm's existing safety policies and procedures. A restricted access zone was placed around the perimeter of the hydrogen blending system equipment.

Figure 1. *Aerial photograph of the A.J. Mihm generating station during the testing*

Communication

Both written and verbal forms of communication were employed to ensure safety was maintained. Appropriate signage was placed throughout the plant to indicate the location of hazardous areas or where additional personal protection equipment was required, e.g., double hearing protection inside the engine hall when an engine was running. Safe operating conditions of the RICE unit operating on the blended fuel were also identified in the test plan as well as corrective actions that needed to be implemented if key performance indicators exceeded established thresholds.

Hydrogen Blending System

The location of the hydrogen blending system was determined based on several factors including access within the facility, roads, proximity to fuel gas tie-ins, and preferred engine isolation in addition to meeting requirements of the National Fire Protection Association 2 – Hydrogen Technologies Code (NFPA 2). The hydrogen blending system was certified to meet requirements of American Society of Mechanical Engineers (ASME) B31.12 – Hydrogen Piping and Pipeline Code, which incorporated items such as weld hardness and vent height.

Leak Detection and Monitoring

A combination of stationary and portable detectors was employed. The stationary detectors included lower explosive limit sensors. Team members working directly with the hydrogen supply, pressure reduction, and fuel blending equipment were required to wear personal hydrogen gas monitors as part of their normal operating procedures.

Hydrogen leak detection tape was also used to provide a visual indication of a leak. It was applied on all flanged connections for piping that contained either pure hydrogen or the hydrogen/NG blend, and all flanged connections were inspected before each engine startup and after each engine shutdown or trip.

Hazard and Operability (HAZOP) Study

A HAZOP study was performed to identify potential hazards associated with the demonstration test. Determining the causes and impacts of these items allowed for effective safeguards to be prioritized in the final recommendations to remove or mitigate hazards.

SITE PREPARATION

Hydrogen Blending System

Two trucks supplying the hydrogen were located on the plant road 70 ft (21.3 m) from the engine hall, which met the NFPA 2 setback requirements. The pressure of the hydrogen from the trucks was reduced prior to mixing with the right amount of NG to meet the blend target for the test. Figure 2 shows the placement of the hydrogen blending system.

Figure 2. *Placement of hydrogen blending system at Mihm*

Table 1. *High-level test plan*

TEST DAY	TEST POINT	ENGINE LOAD	HYDROGEN BLEND LEVEL (VOL%)	DURATION (HOURS)
1	1	50%	0%	1
	2	50%	10%	1
	3	50%	15%	1
	4	50%	20%	1
	5	50%	25%	1
2	6	75%	0%	1
	7	75%	10%	1
	8	75%	15%	1
	9	75%	20%	1
	10	75%	25%	1
3	11	100%	0%	1
	12	95%	25%	1
	13	100%	12%	1

Engine Modifications

The main objective of the project was to demonstrate the capability of an unmodified utility-scale RICE in the field to operate on hydrogen blends. No mechanical modifications that would impact the engine performance were made to the engine.

TEST RESULTS

The test plan consisted of evaluating engine performance at three loads along with several fuel blends ranging from 10–25 vol% hydrogen. For each engine load, a 100% NG run served as the baseline to benchmark the engine's performance and emissions with the blended fuel runs. The test runs conducted during three days of testing are shown in Table 1.

For the 50% engine load runs, engine tuning was not performed as the engine was able to operate reliably on hydrogen blends up to 25 vol%. For the 75% and 100% engine load runs, engine tuning of the charge-air pressure and ignition timing using existing controls was performed to maintain stable operation of the engine for the blended fuel.

Capacity/Engine Output

For each of the 50%, 75%, and 100% engine load test runs, the RICE unit was able to achieve the full engine load setpoint at all hydrogen blends, with the exception that at a blend of 25 vol% hydrogen, the engine was only able to make 95% capacity.

Efficiencies

The gross plant efficiency, on a lower heating value (LHV) basis, was calculated for each test run using the input/output method, i.e., dividing the fuel heat input (in Btu/hr) by the gross electrical generation (in kW), which in this analysis was measured at the generator terminals. Fuel heat content and flow rate were measured at the inlet to the engine.

In general, efficiency only changed incrementally when hydrogen-NG blends were used compared against the 100% NG baseline, even at 25 vol% hydrogen blends. Comparisons to the baseline for efficiency data are shown in Table 2 and are summarized below.

- **50% Engine Load:** An increase in gross plant efficiency of about one percentage point relative to the baseline was observed as the hydrogen blend percentage was increased. The primary reason for the improvement in efficiency is from faster, more complete combustion with higher hydrogen blends..
- **75% Engine Load:** For the 75% engine load points, the engine was retuned after performing the baseline (100% NG). All test points with hydrogen blends then had the same engine settings. Tuning resulted in keeping the efficiency at nominally the same level as the baseline for all hydrogen blends.
- **95% Engine Load:** Only one hydrogen blend test run was conducted at this load setting. Based on the test setup, a maximum hydrogen blend of 25 vol% was achieved with the same efficiency as the baseline.

Table 2. *Efficiency and emissions data as a percentage of the baseline for each load and fuel blend*

LOAD, %	FUEL H_2, %VOL	EFFICIENCY, % OF BASE	CO_2, % OF BASE	CO, % OF BASE		NOX, % OF BASE	
				UNCONTROLLED	CONTROLLED	UNCONTROLLED	CONTROLLED
50	0	Base	Base	Base	Base	Base	Base
50	10	101.1	95.9%	78.7	96.0	121.4	87.0
50	15	101.3	94.0%	72.6	85.7	135.9	84.0
50	20	101.6	91.9%	69.0	96.3	153.5	84.7
50	25	101.6	89.8%	65.8	103.9	174.2	83.0
75	0	Base	Base	Base	Base	Base	Base
75	10	99.8	97.2%	90.4	88.6	87.1	110.4
75	15	100.0	95.1%	83.1	84.9	97.5	111.4
75	20	100.2	92.9%	78.3	80.6	107.4	114.6
75	25	100.4	90.7%	74.6	82.6	119.6	119.4
100	0	Base	Base	Base	Base	Base	Base
95	25	100.0%	90.9%	79.0	118.2	53.7	97.5
100	12	97.6%	98.5%	121.1	154.3	41.9	100.1

Note that CO_2, CO, and NOx emissions data are based on mass emission rates (CO_2 emissions in mass per produced electrical energy and CO and NOx in mass per unit of thermal energy input).

- **100% Engine Load:** Only one hydrogen blend test run was conducted. Based on the test setup, a maximum hydrogen blend of 12 vol% was achieved, which resulted in a 2.4% drop in efficiency compared to the baseline. However, the test configurations of the hydrogen blending system, fuel supply piping, and fuel gas system tie-ins were not optimal, limiting the hydrogen content for blending and adversely affecting the efficiency.

Engine Emissions Data

Carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NOx), and total hydrocarbons (THC) were measured at both the engine outlet and the outlet of the selective catalytic reduction (SCR) system going to the stack. Engine outlet emissions going into the SCR are labeled as "uncontrolled" emissions, while those at the SCR outlet going to the stack are termed as "controlled" emissions. Emissions testing was conducted following the methods specified in the Code of Federal Regulations, Title 40, Part 60, Appendix A 40CFR60, 40CFR61, and 40CFR63. Comparisons to the baseline for both uncontrolled and controlled emissions data are also shown in Table 2 and summarized below.

Uncontrolled Emissions

- **50% Engine Loads:** CO emissions decreased by 21–35% as a result of faster, more complete combustion with increased hydrogen blend ratios. In general, CO also drops as more hydrogen is in the blend, and carbon in the fuel is in turn reduced. By contrast, NOx increased by 21–74% at higher hydrogen content due to increased cylinder temperatures. It should be noted that no engine tuning was done in these test runs.
- **75% Engine Loads:** The engine was retuned after performing the baseline with the goal of lowering NOx, resulting in NOx emissions actually being lower at 10% and 15% vol hydrogen blends and then increasing to 20% above the baseline at 25% vol hydrogen. It should be noted that further engine tuning could have been done to maintain even lower NOx emissions levels. CO emissions decreased by 10–25% over the tests, with the reductions increasing with hydrogen content.
- **95% Engine Load:** CO and NOx emissions were substantially lower than the baseline as the engine was tuned to reduce NOx and the CO was reduced in part due to the lower carbon content in the fuel.
- **100% Engine Load:** CO emissions increased by 20% during the 12 vol% hydrogen full-load testing because the air-fuel ratio and ignition timing were changed to keep NOx low. NOx emissions were substantially lower than the baseline by 58%.

Controlled Emissions

- Stack emissions of CO and NOx after the environmental controls, including the SCR, were kept well below the regulatory permit limits of the plant in all cases and test runs.
- **50% Engine Loads:** CO emissions decreased by up to 15%, and NOx decreased by 13–17%.
- **75% Engine Loads:** CO emissions decreased by 12–18%, and NOx increased by 10–20%.
- **95% Engine Load:** CO emissions increased by 18%, while NOx decreased by 2.5%.
- **100% Engine Load:** CO emissions increased by 54% during the 12 vol% hydrogen full-load testing, while NOx was comparable to the baseline.

Other Emissions

- Emissions of CO_2 as well as THC, methane, and formaldehyde were also measured. As expected, CO_2 decreased with increasing hydrogen content as the amount of carbon in the fuel blend was reduced. The reductions in the calculated CO_2 mass emission rates (lb/kWh) with increasing hydrogen fuel percentages followed the expected trends. CO_2 mass emission rate was reduced by approximately 10% at 25% by volume hydrogen cofiring. Similar trends were observed for THC, methane, and formaldehyde. A graph showing the reduction in CO_2 with increasing hydrogen is shown in Figure 3.

POTENTIAL IMPROVEMENTS IN ENGINE OPERABILITY WITH HYDROGEN

The results from this study are only representative for this particular engine during these specific conditions, and variations are to be expected for other sites and engines. According to Wärtsilä, the capability of the 18V50SG engine to burn higher ratios of hydrogen can be increased through several modifications including:

- **Increased air flow to the cylinders.** Increased capability to lean out the air-fuel mix enables a controlled combustion of higher hydrogen blending ratios. This would entail rematching of the turbocharger or an upgrade to a more efficient turbocharger. Typically, this would be done in conjunction with a major overhaul, where the turbocharger would already be scheduled for maintenance.
- **Lower compression ratio.** Lowering the engine's compression ratio would create more margin in terms of knocking and cylinder pressures and increase the capability of using higher hydrogen blending ratios. In most cases, this kind of operation can be done quickly to minimize downtime.
- **Enhanced pre-chamber control.** To optimize conditions in the pre-chamber regardless of the NG quality and hydrogen content, electrically controlled pre-chambers should be used. This upgrade would optimize starting reliability, load ramping, and overall operation. For engines with a ready design available, this replacement is a straightforward activity.
- **Heat release control.** With the latest Wärtsilä engine control system, heat release control comes as a standard feature where the combustion is phased automatically, which maintains the engine performance regardless of what gas composition is fed to the engine.

HIGHLIGHTS

Safety

- **Hydrogen can be safely handled and utilized in a properly designed and monitored fuel system.** Commissioning procedures were effective, and there was no evidence of any hydrogen leaks during the test including from the engine itself. A hydrogen detection meter and hydrogen leak tape were both used and showed no indication of leaks.

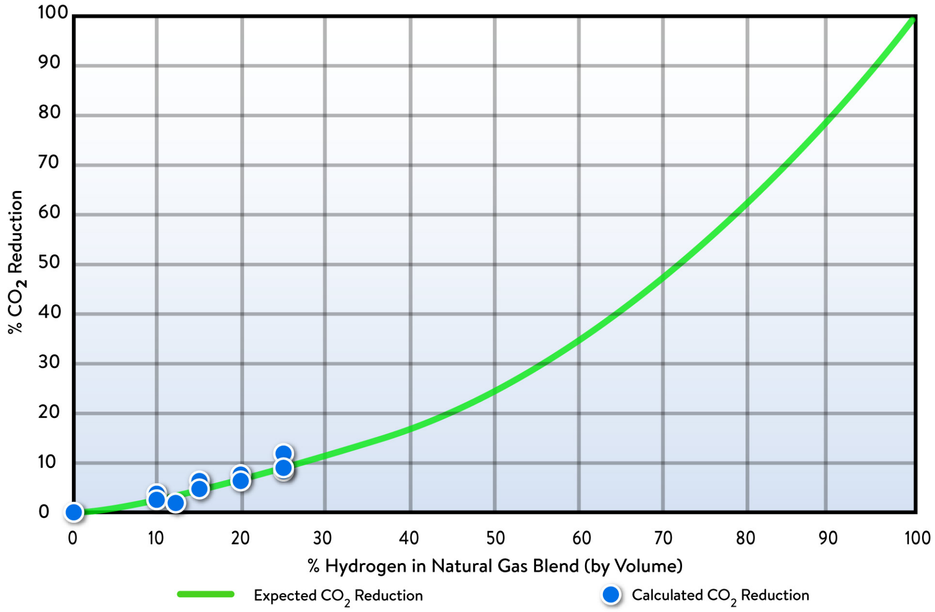


Figure 3. *Expected and calculated CO_2 emissions reductions for natural gas/hydrogen blends*

Performance

- **Engine efficiency was not significantly impacted by hydrogen fuel blending.** This class of engine can therefore maintain its higher efficiency compared to simple-cycle gas turbines. Because engines in general have higher efficiency, their relative CO_2 output compared to turbines will also be lower, as was the case in this study
- **Advanced engine control systems are highly effective at controlling engine operations across varying fuel composition.** Minimal intervention was needed other than adjusting charge-air pressure and ignition timing manually for changes in fuel composition, and then the automated controls operated effectively under those parameters.

Emissions

- **Hydrogen blends in NG ranging up to 25 vol% of hydrogen resulted in greenhouse gas emissions reduction, with an important reduction in hydrocarbon emissions along with the expected reduction in CO_2 emissions,** all while maintaining engine efficiency across a broad range of engine loads.
- **All measured, uncontrolled emissions, including unburnt hydrocarbons and formaldehyde, were generally lower with hydrogen cofiring compared to the 100% NG baseline,** with the exception of NOx. As expected, uncontrolled NOx emissions increased, although this could be mitigated by further engine tuning. However, the existing SCR system on the engine was still able to reduce the controlled NOx to below permit levels.
- **The capabilities of the existing CO and SCR catalyst systems were validated,** as stack emissions of NOx, CO, THC, methane, and formaldehyde were well below the regulatory permit limits of the plant

LESSONS LEARNED

This demonstration project helped the project team gain a better understanding of the requirements for blending hydrogen. Key learnings from the project include the following:

- **Communication protocols with operations should be established and agreed upon early in the planning process.** These were essential in coordinating a successful test.
- **Applicable/required codes and hazardous area classifications need to be identified early** in the project to facilitate proper designs and to ensure that equipment and piping systems comply.
- **Accuracy of existing plant drawings should be verified in coordination with the development of new drawings for the test configuration,** particularly in regard to compliant equipment tags. This can prevent design errors and facilitate more efficient and accurate design reviews by the team.
- **A coordinated effort on the piping design for the injection and mixing of hydrogen is needed** to produce an optimum approach to minimize flow resistance with the existing NG system.
- **The pressure drop of the fuel blending system was underestimated, which resulted in limiting the fuel supply pressure** and hence the charge-air pressure that could be supplied to the engine at full load. Having prior knowledge of the friction factors for the hoses could have resulted in a higher fuel supply pressure to be delivered to the engine.
- **The addition of pretest and contingency days in the project schedule allowed for adjustments to be made** with the equipment configuration and test plan prior to testing and enabled the team to successfully conduct the demonstration. The pretest step also helped ensure instrumentation and recording of data were operating correctly.

NEXT STEPS

Lessons learned during the design and execution of the project are documented in this report. Researchers can take this information into account in building a foundational knowledge base and exploring future hydrogen blending pilot projects as part of the clean energy transition. The full report (3002026259) can be accessed at www.epri.com.

About EPRI

Founded in 1972, EPRI is the world's preeminent independent, non-profit energy research and development organization, with offices around the world. EPRI's trusted experts collaborate with more than 450 companies in 45 countries, driving innovation to ensure the public has clean, safe, reliable, affordable, and equitable access to electricity across the globe. Together, we are shaping the future of energy.

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