SCR Economics for Diesel Engines

Cost of Generation Scenarios for a 2 MW Diesel Engine using SCR Technology [1] Exhibit 1

Operating Hours	Generation Cost Without SCR ($/kWh)	Generation Cost With SCR ($/kWh)	Differential ($/kWh)	Total Capital & Operating Cost (with SCR)	Energy Savings ($/kWh)	Energy Delivered (kWh)	Energy Savings ($)	Discounted Profit Estimate (with SCR)
1000	0.294	0.393	0.099	785 663	0.207	2 000 000	414 337	N/A
2000	0.200	0.249	0.049	995 163	0.351	4 000 000	1 404 837	254 804
3000	0.168	0.201	0.033	1 204 663	0.399	6 000 000	2 395 337	714 404
4000	0.152	0.177	0.025	1 414 163	0.423	8 000 000	3 385 837	1 183 004
5000	0.143	0.162	0.020	1 623 663	0.438	10 000 000	4 376 337	1 651 604
6000	0.136	0.153	0.016	1 833 163	0.447	12 000 000	5 366 837	2 120 204
7000	0.132	0.146	0.014	2 042 663	0.454	14 000 000	6 357 337	2 588 804

by Ravi Krishnan

Traditionally, diesel generation has not been viewed as a long-term baseload solution to avoid potential energy shortfalls. However, many power producers in the Pacific Northwest of the United States are resorting to diesel-fired generation as low water conditions have reduced the generating capacity of the region's hydropower systems. In the state of Washington, newly permitted diesel and natural gas engines will produce about 396 MW and 75 MW of electricity respectively for their owners this summer. Each diesel and natural gas generator has an average size of about 1.5 MW and 1.05 MW, respectively. The engines have been installed in 18 counties in Washington to satisfy the increased need for additional short-term generation.

Across the U.S., the demand for diesel-fired baseload generation has increased giving the shortage of supply infrastructure. Fueling this rapid growth is the realization among regulators and air boards nationwide that diesel-fired generation with selective catalytic reduction (SCR) technology can have lower emissions than an untreated natural gas engine. Diesel engines are only one-third the cost of their natural gas counterpart and when installed with an SCR technology, become a cost-effective, clean and reliable source of generation.

SCR technologies are often mistaken for high costs that can be potentially crippling on the cost of generation. While this may be true for fossil-fired boilers, SCR costs have a minimal effect on the cost of generation for diesel-fired units. The investment in an SCR on a 2.0 MW diesel-fired unit can range between US$140 000 to US$160 000 in capital and installed costs, with costs varying by the extent of

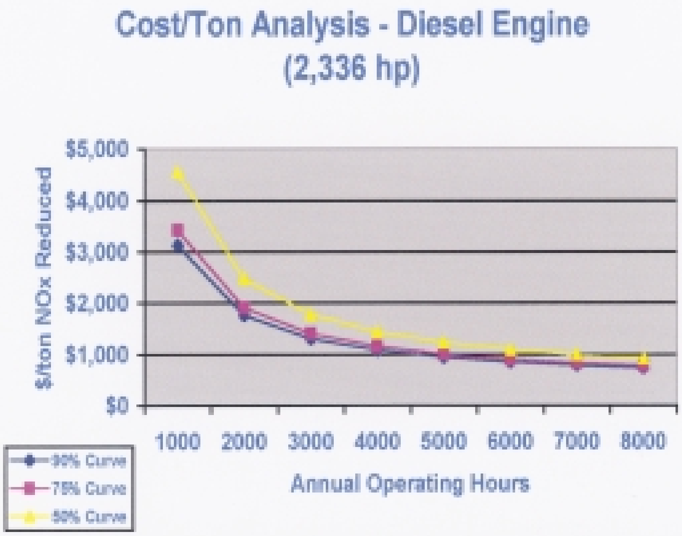
Ravi Krishnan is director of strategic planning at RJM Corporation, Norwalk, Connecticut, U.S.A.

Assumptions & Operating Variables Exhibit 2

Operating Variables	90% NO_x Reduction	75% NO_x Reduction	50% NO_x Reduction
Diesel Engine (Average hp)	2336	2336	2336
Annual Operation (hours)	8000	8000	8000
Two or Four Stroke Cycle (cycle)	4	4	4
Fuel Consumption (lb/bhp-hr)	0.34	0.34	0.34
Engine (rpm)	1800	1800	1800
Engine Load (%)	100	100	100
NO_x (ppmv)	687	687	687
Normalized Stoichiometric Ratio	0.9	0.75	5
Exhaust Density @ 60¡F	0.076	0.076	0.076
Urea wt% with balance water	0.32	0.32	0.32
Fuel Density	7.0	7.0	7.0
NO_x Emissions (tons/year)	101	101	101
NO_x Reduction	90%	75%	50%
Tons of NO_x Reduced	91	76	50
Capital Cost of the RJM ARIS System	$157 590	$149 940	$142 290

Annualized Capital & Operating Cost Analysis Exhibit 3

Cost Category	90% NO_x Reduction	75% NO_x Reduction	50% NO_x Reduction
1. Capital Cost Recovery - Hardware	$20 714	$19 708	$18 703
2. Capital Cost Recovery - Catalyst	$6595	$5276	$3957
3. Variable Operating Cost	$37 997	$32 011	$22 034
4. Fixed Operating Cost	$1576	$1499	$1423
Total Annualized Operating Costs	$66 882	$58 494	$46 116
Cost/Ton of NO_x Reduced	$738	$775	$916



Cost/Ton Analysis Under Varying Operating Conditions – Exhibit 4

Diesel Engine (hp)	Hours of Operation	90% NOx Reduction ($/ton of NOx reduced)	75% NOx Reduction ($/ton of NOx reduced)	50% NOx Reduction ($/ton of NOx reduced)
2,336	1,000	$ 3,130	$ 3,422	$ 4,554
2,336	2,000	$ 1,763	$ 1,909	$ 2,475
2,336	3,000	$ 1,307	$ 1,406	$ 1,782
2,336	4,000	$ 1,080	$ 1,153	$ 1,436
2,336	5,000	$ 943	$ 1,002	$ 1,228
2,336	6,000	$ 852	$ 901	$ 1,089
2,336	7,000	$ 787	$ 829	$ 990
2,336	8,000	$ 738	$ 775	$ 916

NO_x reduction required. Typically, the leading SCR systems in the market such as the RJM ARIS technology, can reduce NO_x by over 90% at less than US$750/ton of NO_x reduced. In other words, the impact on the cost of generation is minimal. For example, a 2.0 MW baseload unit operating at 4000 hours annually can install an SCR system for less than US$0.025/kWh. At today's California energy prices, such systems are very attractive for merchant plant projects.

The ARIS system works to reduce NO_x emissions in diesel or lean-burn natural gas engines by metering precise amounts of reagent into the engine's exhaust stream. When injected into the exhaust stream of a diesel engine, urea will decompose to ammonia and react with oxides of nitrogen (NO_x) across a catalyst located downstream of the injection point to reduce NO_x. ARIS technology utilizes a urea-based reducing reagent, which contains 32.5% urea in aqueous solution, to deliver ammonia to the catalyst.

The economics of an SCR system on diesel engines can be analyzed in a variety of ways. While there are many ways to analyze the cost of an SCR system over the lifetime of the power generating equipment, the unanimous consensus despite the type of analysis is the minimal effect of the SCR technology on the cost of generation under current market conditions. Two different scenarios are presented to understand the economics of the SCR technology on diesel engines.

One scenario examines the operating cost of a diesel engine and the effect of installing the SCR technology on generation costs. The cost of generation with an SCR is minimal at higher levels of operation. For example, a 2.0 MW unit at 4000 hours of operation, the cost of generation without an SCR equipment averages at US$0.152/kWh compared to US$0.177/kWh using an SCR equipment. The differential is a mere US$0.025/kWh, compared to energy savings of US$3.3 million at current California prices and a conservative profit estimate of US$1.1 million for an independent power producer. Energy savings is defined as the cost difference between post-SCR diesel-fired generation and current grid prices in the region. For example: In the Pacific Northwest, load-intensive users on interruptible rates pay as high as US$0.60/kWh on interruptible rates. Exhibit compares the cost of generation scenario over varying operating hours for a 2.0 MW diesel engine.

A second scenario analyzes the capital and operating cost of the ARIS technology over a 15-year lifetime for a 1752 kW, four-stroke diesel engine operating at baseload capacity. Exhibits 2 and 3 provide a detailed operating and capital cost estimate, Exhibit 4 compares the investment cost recovery over varying operating conditions for the RJM ARIS technology, which range from US$738/ton of NO_x reduced for an 8000 hour operation to US$4554/ton of NO_x reduced for an 1000 hour operation.

It is evident from the analysis that the cost of the SCR equipment has a minimal effect on the cost competitiveness of diesel-fired generation. SCR costs are insignificant, but the operating benefits are tremendous including eliminating approximately 100 tons of NO_x annually from each baseload unit. SCR technologies such as the RJM ARIS use urea as a reagent, which is easy to store and handle.

The analysis also challenges the popular misconception that SCR costs on diesel engines are potentially inflationary. On a baseload unit (defined as 2000 hours of operation or greater), the incremental cost of installing an SCR unit can range from US$0.014/kWh to US$0.099/kWh. This is exceptionally attractive given that current prices in California and the Pacific Northwest for energy-users on interruptible rates are as high as US$0.60/kWh. As demonstrated, a large energy-user that plans to displace 8 million kWh of electricity can generate its own clean power (with SCR technology) at US$0.17/kWh, as opposed to buying it from the grid at US$0.60/kWh. Similarly, a marketer can install SCR technology and yet generate a profit in excess of US$1.1 million or US$0.147/kWh. a

CIRCLE 119 ON READER SERVICE CARD