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TRU Diesel PM Control Technology Option Matrix[1] 9-4-02

Technology	PM/Nox Control Efficiency	Demonstrated in TRUs?	Cost[2]	Verified with ARB for TRU?	Pros	Cons
Electric standby	100% when in use at facility.	Yes	Truck: $350-$600 Trailer: $2000-$2600, plus facility infrastructure.[3]	NA	Dramatic reductions in health risk near facilities. Option now available for truck models and some trailer models.	No health risk reductions along roadways, current retrofit costs high.
Ultra-low aromatic synthetic diesel fuel: Fischer-Tropsch (GTL) Diesel	30% PM; 4-11% NOx[4]	No	$0.15 to $0.25 per gal more than CARB diesel.[5]	No	Available now. 0- 5 ppm sulfur, no aromatics in fuel – very low PAH emissions, 70+ cetane # - lower NOx.	2-3% fuel penalty, 2-4% torque loss, Viton hoses and seals required, dual fuel infrastructure may be necessary, limited availability (but over 12 new plants under construction or design review for 2008 production.[6]
Cryogenic Refrigeration (open cycle)[7]	100% PM 100% NOx	New trailer & truck models in production, hybrid systems in production for retrofit on straight truck units and under development for trailer units.	Cost models available. Unit list price is within 10% of diesel unit.	NA	Elimination of PM and NOx emissions, noise levels of 60 dB or less, available now for new truck and trailer, hybrid cryogenic systems currently available for retrofit on straight trucks.	Infrastructure for cryogenic fuel needs to be expanded for use in TRUs.
Active Particle Traps – electric regeneration (Rypos Trap)[8]	70-90% PM	No	Unknown	No	Independent of exhaust temp, sulfur level tolerant, low back pressure, no NO2 issue unless catalyzed.	Durability & cost unknown, may require generator upgrade, ash handling as hazardous waste, no CO or HC emission reduction.

[1] Trade names mentioned herein do not imply ARB endorsement.
[2] Costs shown are based on best information now available. Annualized cost and cost-effectiveness will be analyzed as technologies are demonstrated.
[3] Range of retail costs provided by ThermoKing and Carrier Transicold.
[4] California Energy Commission, "Gas-toLiquids (GTL) Fuel Fact Sheet", July 13, 2000.
[5] Gary Yowell, California Energy Commission, June 12, 2001 email to Rod Hill.
[6] See footnote 7.
[7] Robert Geisen, Manager, Product Engineering, ThermoKing Corporation, March 13, 2002 email to Rod Hill. Also, reference Aurthur D Little Report for South Coast Air Quality Management District, February 28, 2001, SCAQMD Contract #97141.
[8] Frank DePetrillo, Rypos Inc, Innovative Clean Air Technologies proposal, "A Plan to Retrifit 3 Diesel Generatiors with Rypos/Bekaert System", February 20, 2001.

Technology	PM/Nox Control Efficiency	Demonstrated in TRUs?	Cost	Verified with ARB for TRU?	Pros	Cons
Biodiesel (100%)	25-50% PM; 12% NOx increase (can be reduced with additives and fuel system adjustments).[9]	No, but 200 hour tests on Yanmar 3-cylinder DI engine passed EMA tests with no problems.[10]	$1.25 to $1.50/gal plus taxes[11]; additional fueling infrastructure costs, if dual fuel needs.	No	No engine modifications necessary for post-1993; compared to diesel: higher Cetane, better lubricity, better energy balance, no sulfur, reduces greenhouse gas emissions, substantial reductions in PAH emissions.	Cost, 7% lower torque, higher BSFC, replace hoses and seals with Viton required for pre-1993, shorter shelf life due to microbe growth (controlled with additives), higher pour point affects cold weather performance, operating practices necessary for contaminated rags.
CNG		Yes		NA	Available now. Reduces NOx and PM simultaneously.	Significant compliance costs for >25 hp LSI[12] Regulation, gaseous fuel supply, storage system, compression station, periodic tank inspections.
LPG		Under development		NA	Reduces NOx and PM simultaneously.	Same as CNG. Fuel cost is about twice that of conventional diesel.
Gasoline				NA	Reduces NOx & PM simultaneously, available at the pump.	Same LSI issue as for CNG and LNG, shorter engine life.
Water emulsions (Lubrizol/PuriNox)[13]	63% PM (74% with DOC); 14% NOx	No	15% higher cost than conventional diesel.	Yes	Available now, no engine modifications necessary, reduces NOx and PM simultaneously, emission reduction credits allowed.	Requires periodic agitation to extend shelf life, 20% power loss, higher BSFC, up to 15% increased operating costs, cold weather operating issues.

[9] Dr. Shane Tyson, National Renewable Energy Lab; Technical Assistance Fact Sheet, U.S. Department of Energy, May 2001; R. L. McCormick, et. Al. Colorado School of Mines, "NOx Solutions for Biodiesel" Final Report to National Renewable Energy Labs, Contract No. XCO-0-30088-01.

[10] Peterson, C., Hammond, B., Reese, D., Thompson, J., Beck, S., "Performance and Durability Testing of Diesel Engines Using Ethyl and Methyl Ester Fuels", December, 1995. (Download at www.biodiesel.org.)

[11] Margi Marrero, National Biodiesel Board, 5-8-02 comments at TRU Workgroup meeting.

[12] LSI stands for Large Spark-Ignited Engine.

[13] Lubrizol Corporation press release announcing CARB verification of PuriNox, February 1, 2002. And, Kimberly Jones, Lubrizol Corp., 5/30/01 phone conversation with Rod Hill.

Technology	PM/NOx Control Efficiency	Demonstrated in TRUs?	Cost	Verified with ARB for TRU?	Pros	Cons
Bi-fuel CNG Fumigation[14]	40-85% PM; 20-80% NOx	Yes	Unit conversion <$400, but fuel system cost is $6K to $8K.	No	Lower fuel costs (depends on current cost of fuels), reduced engine oil change frequency.	Gaseous fuel supply & storage system, compression station, periodic tank inspections, added fuel tank weight cuts into payload, marginal emission benefit at low speed/torque.
Fuel-borne Catalysts (FBC)[15]	10-25% PM (with no increase in the number of nanoparticles), minor reductions or no change in NOx[16]	Yes	On-board dosing system: $500-$1,000 (factory), $1500 to $3000 for field retrofit, + $0.05 to $0.10/gal.	Rhodia and Lubrizol in process.	Improves fuel economy 10-20%, can be used in conjunction with a particle trap to enhance emission reduction, PM emission benefit if trap is required.	Difficult to assure FBC use, 5 year shelf life, if properly packaged to eliminate light exposure, trap may be required to capture catalyst.
Offroad Engine Standards (special category)	Depends on standard.	NA	Unknown	NA	Reductions in health risk near facilities & along roadways.	Delayed effects.
Passive Particle Traps (catalyzed diesel particulate filters - CDPFs)[17]	85-95% PM	Yes, but some issues with first prototype.	MECA[18] est. $3,300 to $5,000 initial cost[19], $167 installation, $156 annual maintenance.	No	Automatic regeneration if exhaust achieves regeneration temperature for necessary duration, CO & HC reductions.	Difficult match due to low exhaust temperatures; back pressure affects fuel economy, engine performance & life; annual maint., ash handling as hazardous waste, low sulfur fuel required to avoid sulfate formation, Increased NO2 emissions with some catalysts.

[14] Tom Sem, ThermoKing Corp., 1-29-02 Email to Rod Hill. ARB has not reviewed detailed data.

[15] Clean Diesel Technologies provided most of the information for this entry, excerpted from the Diesel Risk Reduction Plan, Appendix IX.

[16],Valentine, J. M., Peter-Hoblyn, J. D., Acres, Dr. G. K., "Emission Reduction and Improved Fuel Economy Performance from a Bimetallic Platinum/Cerium Diesel Fuel Additive at Ultra-Low Dose Rates", SAE Paper #2000-01-1934.

[17] Nett Technologies, Engelhard Corp, and Clean Air Systems provided the information for this entry, excerpted from the Diesel Risk Reduction Plan, Appendix IX

[18] MECA stands for Manufacturers of Emission Controls Association.

[19] ThermoKing's experience is lower initial costs than MECA's estimate.

Technology	PM/Nox Control Efficiency	Demonstrated in TRUs?	Cost	Verified with ARB for TRU?	Pros	Cons
Diesel Oxidation Catalysts[20]	16-30% PM	R&D only	$400 - $600, $167 install'n, $64 - $712 annual maint.	No	Commercially available, installed on thousands of larger engines.	Sulfur content >500 ppm affects performance and durability.
Fuel Cells[21]	100% PM; 100% NOx (near zero emissions)	No	Unknown	NA	Zero/near-zero emissions, reduced water pollution (oil leaks), lower greenhouse gas emissions, higher fuel economy, quieter, smoother operation, energy diversity.	Technical issues remain to integrate components to meet consumers' performance and cost demands.

[20] Nett Technologies, Catalytic Exhaust Products, Ltd, and Engelhard Corp provided the information for this entry, excerpted from the Diesel Risk Reduction Plan, Appendix IX

[21] ARB Fact Sheet, *Fuel Cell Electric Vehicles*, 1-09-02.