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TRU Diesel PM Control Technology Option Matrix[1] 11-19-02

Technology	PM/Nox Control Efficiency	Demonstrated in TRUs?	Cost[2]	Verified with ARB for TRU?	Pros	Cons
Biodiesel (100%)	25-50% PM; 12% NOx increase (can be reduced with additives and fuel system adjustments).[3]	No, but 200 hour tests on Yanmar 3-cylinder DI engine passed EMA tests with no problems.[4]	$1.25 to $1.50/gal plus taxes[5]; 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, higher BSFC, Viton hoses and seals required, shorter shelf life due to microbe growth (controlled with additives), higher pour point affects cold weather performance, operating practices necessary for contaminated rags, special monitoring & reporting required to assure use.
Electric standby	100% when in use at facility.	Yes	Truck: $350-$600 Trailer: $2000-$2600, plus facility infrastructure.[6]	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[7]	No	$0.15 to $0.25 per gal more than CARB diesel.[8]	No	Available now. 0- 5 ppm sulfur, no aromatics in fuel – very low PAH emissions, 70+ cetane # - lower NOx.	Special monitoring & reporting required to assure use, 2-3% fuel penalty, 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.[9]

[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] 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.
[4] 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.)
[5] Margi Marrero, National Biodiesel Board, 5-8-02 comments at TRU Workgroup meeting.
[6] Range of retail costs provided by ThermoKing and Carrier Transicold.
[7] California Energy Commission, "Gas-toLiquids (GTL) Fuel Fact Sheet", July 13, 2000.
[8] Gary Yowell, California Energy Commission, June 12, 2001 email to Rod Hill.
[9] See footnote 7.

Technology	PM/Nox Control Efficiency	Demonstrated in TRUs?	Cost	Verified with ARB for TRU?	Pros	Cons
Cryogenic Refrigeration (open cycle)[10]	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)[11]	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.
Diesel Oxidation Catalysts (DOC))[12]	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.
CNG		Yes		NA	Available now. Reduces NOx and PM simultaneously.	Significant compliance costs for >25 hp LSI[13] 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.
Offroad Engine Standards (special category)	Depends on standard.	NA	Unknown	NA	Reductions in health risk near facilities & along roadways.	Delayed effects.

[10] 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.

[11] Frank DePetrillo, Rypos Inc, Innovative Clean Air Technologies proposal, "A Plan to Retrifit 3 Diesel Generatiors with Rypos/Bekaert System", February 20, 2001.

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

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

Technology	PM/NOx Control Efficiency	Demonstrated in TRUs?	Cost	Verified with ARB for TRU?	Pros	Cons
Water emulsions (Lubrizol/PuriNox)[14]	63% PM (74% with DOC); 14% NOx	No	15% higher cost than conventional diesel.	No	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.
Bi-fuel CNG Fumigation[15]	40-85% PM; 20-80% NOx	Yes	Conversion ~$800. Fuel tank cost is $4K to $4.5K for CNG $5K.for LNG. LNG $1.41/equiv diesel gal. CNG - $0.98/equiv diesel gal[16]	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) @ 4-8 ppm [17]	10-25% PM (with no increase in the number of nanoparticles), minor reductions or no change in NOx[18]	Yes	On-board dosing system: $500-$1,000 (factory), $1500 to $3000 for field retrofit, + $0.05 to $0.10/gal. Slow release fuel filter could be $200-$300.	Clean Diesel Technologies in process. Rhodia and Lubrizol also in process for different dosing rates.	Improves fuel economy 10-20%, can be used in conjunction with a particle trap to enhance emission reduction.	Special monitoring and reporting required to assure FBC use, 5 year shelf life, if properly packaged to eliminate light exposure, higher FBC dosing rates may required trap to prevent ultrafines.
FBC + ULSD + B20 (Fuelborne catalyst plus ultra-low sulfur diesel plus 20% biodiesel)[19]	30-40% PM, No NOx increase.	No	$0.30 – 0.40/gal combined premium for biodiesel and FBC components.	No	No increase in NOx or BSFC.	Special monitoring and reporting required to assure biodiesel and FBC use. Higher FBC dosing rates may require trap to prevent ultra-fines.

[14] 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.
[15] Tom Sem, ThermoKing Corp., 1-29-02 email to Rod Hill and 7-29-02 follow-up questions. ARB has not reviewed detailed data.
[16] LNG cost/equivalent gallon from HEB in Texas. CNG cost/equivalent gallon from PG&E web site, 10/28/02.
[17] Jim Valentine, Clean Diesel Technologies, 9-10-02 email to Rod Hill.
[18],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.
[19] Information provided by Jim Valentine, Clean Diesel Technologies, 9-10-02.

Technology	PM/NOx Control Efficiency	Demonstrated in TRUs?	Cost	Verified with ARB for TRU?	Pros	Cons
Passive Particle Traps (catalyzed diesel particulate filters – CDPFs)[20]	85-95% PM	Yes, but some issues with first prototype.	MECA[21] est. $3,300 to $5,000 initial cost[22], $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.
FBC + ULSD + DOC[23]	30-40% PM, 10% NOx	Testing underway @ Clean Air Systems (CAS)	$300 to $500 + $0.05 to $0.10/gal.	CDT in process.	Lightly catalyzed lower cost DOC; 3-7% fuel economy improvement; No NO_2 increase.	Special monitoring and reporting required to assure FBC use. Higher FBC dosing rates may require filter to prevent ultra-fines.
FBC + ULSD + DOC + FTF (flow-through filter).[24]	50-60% PM, 10% NOx	Testing underway @ CAS	$600 to $1000 + $0.05 to $0.10/gal	CDT in process.	Lightly catalyzed lower cost DOC; 3-7% fuel economy improvement; No NO_2 increase.	Special monitoring and reporting required to assure FBC use. Higher FBC dosing rates may require filter to prevent ultra-fines.
FBC + ULSD + Lightly Catalyzed DFP[25]	85% PM, 10% NOx	Testing underway @ CAS & TRU Mfr.	$1500 to $3500 + $0.05 to $0.10/gal	No	Lightly catalyzed lower cost DPF; passive regeneration @ 280 °C – 320 °C, No BSFC penalty; No NO_2 increase.	Must match exhaust temperatures, ash handling as hazardous waste.
Fuel Cells[26]	100% PM; 100% NOx (near zero emissions)	No	Unknown	NA	Near-zero emissions, lower greenhouse gas emissions, fuel economy, quieter operation, energy diversity.	Technical issues remain to integrate components to meet consumers' performance and cost demands.

[20] Nett Technologies, Engelhard Corp, and Clean Air Systems provided the information for this entry, excerpted from the Diesel Risk Reduction Plan, Appendix IX
[21] MECA stands for Manufacturers of Emission Controls Association.
[22] ThermoKing's experience is lower initial costs than MECA's estimate.
[23] Information provided by Jim Valentine, Clean Diesel Technologies, email to Rod Hill, 9-10-02.
[24] Information provided by Jim Valentine, Clean Diesel Technologies, email to Rod Hill, 9-10-02.
[25] Information provided by Jim Valentine, Clean Diesel Technologies, email to Rod Hill, 9-10-02.
[26] ARB Fact Sheet, *Fuel Cell Electric Vehicles*, 1-09-02.