EARLY ENTRANCE COPRODUCTION PLANT

PHASE II

Topical Report

Task 2.6: FISCHER-TROPSCH DIESEL FUEL/ENGINE PERFORMANCE AND EMISSIONS

Reporting Period: January 2001 to June 2003

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Abstract

The overall objective of this project is the three phase development of an Early Entrance Coproduction Plant (EECP) which uses petroleum coke to produce at least one product from at least two of the following three categories: (1) electric power (or heat), (2) fuels, and (3) chemicals using ChevronTexaco's proprietary gasification technology. The objective of Phase I is to determine the feasibility and define the concept for the EECP located at a specific site; develop a Research, Development, and Testing (RD&T) Plan to mitigate technical risks and barriers; and prepare a Preliminary Project Financing Plan. The objective of Phase II is to implement the work as outlined in the Phase I RD&T Plan to enhance the development and commercial acceptance of coproduction technology. The objective of Phase III is to develop an engineering design package and a financing and testing plan for an EECP located at a specific site.

The project's intended result is to provide the necessary technical, economic, and environmental information needed by industry to move the EECP forward to detailed design, construction, and operation. The partners in this project are Texaco Energy Systems LLC or TES (a subsidiary of ChevronTexaco), General Electric (GE), Praxair, and Kellogg Brown & Root (KBR) in addition to the U.S. Department of Energy (DOE). TES is providing gasification technology and Fischer-Tropsch (F-T) technology developed by Rentech, GE is providing combustion turbine technology, Praxair is providing air separation technology, and KBR is providing engineering.

Each of the EECP subsystems was assessed for technical risks and barriers. A plan was developed to mitigate the identified risks (Phase II RD&T Plan, October 2000). Phase II RD&T Task 2.6 identified as potential technical risks to the EECP the fuel/engine performance and emissions of the F-T diesel fuel products. Hydrotreating the neat F-T diesel product reduces potentially reactive olefins, oxygenates, and acids levels and alleviates corrosion and fuel stability concerns. Future coproduction plants can maximize valuable transportation diesel by hydrocracking the F-T Synthesis wax product to diesel and naphtha. The upgraded neat F-T diesel, hydrotreater F-T diesel, and hydrocracker F-T diesel products would be final blending components in transportation diesel fuel.

Phase II RD&T Task 2.6 successfully carried out fuel lubricity property testing, fuel response to lubricity additives, and hot-start transient emission tests on a neat F-T diesel product, a hydrocracker F-T diesel product, a blend of hydrotreater and hydrocracker F-T diesel products, and a Tier II California Air Resources Board (CARB)-like diesel reference fuel. Only the neat F-T diesel passed lubricity inspection without additive while the remaining three fuel candidates passed with conventional additive treatment. Hot-start transient emission tests were conducted on the four fuels in accordance with the U.S. Environmental Protection Agency (EPA) Federal Test Procedure (FTP) specified in Code of Federal Regulations, Title 40, Part 86, and Subpart N on a rebuilt 1991 Detroit Diesel Corporation Series 60 heavy-duty diesel engine. Neat F-T diesel fuel reduced oxides of nitrogen (NO_x), total particulate (PM), hydrocarbons (HC), carbon monoxide (CO), and the Soluble Organic Fraction (SOF) by 4.5%, 31%, 50%, 29%, and 35%, respectively, compared to the Tier II CARB-like diesel. The hydrocracker F-T diesel product and a blend of hydrocracker and hydrotreater F-T diesel products also reduced NO_x, PM, HC, CO and SOF by 13%, 16% to 17%, 38% to 63%, 17% to 21% and 21% to 39% compared to the

Tier II CARB-like diesel. The fuel/engine performance and emissions of the three F-T diesel fuels exceed the performance of a Tier II CARB-like diesel.

Phase II RD&T Task 2.6 successfully met the lubricity property testing and F-T diesel fuel hot-start transient emissions test objectives. The results of the testing help mitigate potential economic risks on obtaining a premium price for the F-T diesel fuel in the marketplace. The F-T diesel fuel superior properties of low sulfur, low aromatics, and high cetane resulted in lower emissions yields if compared to conventional diesel fuels.

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Executive Summary

The overall objective of this project is the three phase development of an Early Entrance Coproduction Plant (EECP) which uses petroleum coke to produce at least one product from at least two of the following three categories: (1) electric power (or heat), (2) fuels, and (3) chemicals using ChevronTexaco's proprietary gasification technology. The objective of Phase I is to determine the feasibility and define the concept for the EECP located at a specific site; develop a Research, Development, and Testing (RD&T) Plan to mitigate technical risks and barriers; and prepare a Preliminary Project Financing Plan. The objective of Phase II is to implement the work as outlined in the Phase I RD&T Plan to enhance the development and commercial acceptance of coproduction technology. The objective of Phase III is to develop an engineering design package and a financing and testing plan for an EECP located at a specific site.

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Each of the EECP subsystems was assessed for technical risks and barriers. A plan was developed to mitigate the identified risks (Phase II RD&T Plan, October 2000). Phase II RD&T Task 2.6 identified as potential technical risks to the EECP the fuel/engine performance and emissions of the F-T diesel fuel products. Hydrotreating the neat F-T diesel product reduces potentially reactive olefins, oxygenates, and acids levels and alleviates corrosion and fuel stability concerns. Future coproduction plants can maximize valuable transportation diesel by hydrocracking the F-T Synthesis wax product to diesel and naphtha. The upgraded neat F-T diesel, hydrotreater F-T diesel, and hydrocracker F-T diesel products would be final blending components in transportation diesel.

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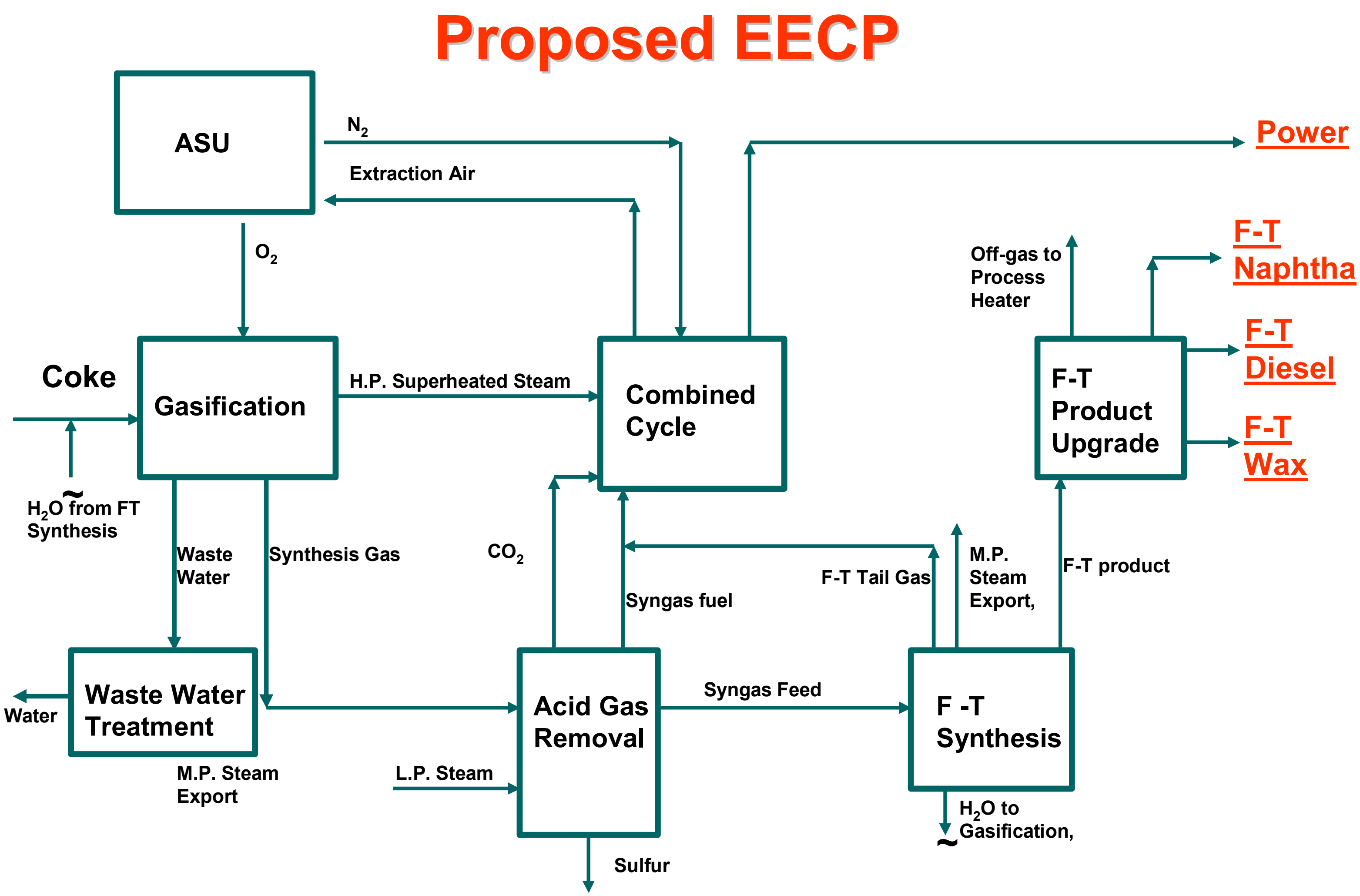
Background

The overall objective of this project is the three phase development of an Early Entrance Coproduction Plant (EECP) which uses petroleum coke to produce at least one product from at least two of the following three categories: (1) electric power (or heat), (2) fuels, and (3) chemicals. The objective of Phase I was to determine the feasibility and define the concept for the EECP located at a specific site; develop a Research, Development, and Testing (RD&T) Plan for implementation in Phase II; and prepare a Preliminary Project Financing Plan. The objective of Phase II was to implement the work as outlined in the Phase I RD&T Plan to enhance the development and commercial acceptance of coproduction technology. The objective of Phase III is to develop an engineering design package and a financing and testing plan for an EECP located at a specific site. The project's intended result is to provide the necessary technical, economic, and environmental information needed by industry to move the EECP forward to detailed design, construction, and operation.

The proposed EECP facility will coproduce electric power and steam for export and internal consumption, finished high-melt wax, finished low-melt wax, F-T diesel, F-T naphtha, elemental sulfur, and will consume approximately 1,235 short tons per day of petroleum coke. The EECP Concept is illustrated in **Schematic 1**, which follows. **Schematic 1** identifies the various Subsystems (Applications of Technology) to be integrated into the EECP.

EECP Concept

Petroleum coke is ground, mixed with water and pumped as thick slurry to the Gasification Unit. This coke slurry is mixed with high-pressure oxygen from the Air Separation Unit (ASU) and a small quantity of high-pressure steam in a specially designed feed injector mounted on the gasifier. The resulting reactions take place very rapidly to produce synthesis gas, also known as syngas, which is composed primarily of hydrogen, carbon monoxide, water vapor, and carbon dioxide with small amounts of hydrogen sulfide, methane, argon, nitrogen, and carbonyl sulfide. The raw syngas is scrubbed with water to remove solids, cooled, and then forwarded to the Acid Gas Removal Unit (AGR), where the stream is split. One portion of the stream is treated in the AGR to remove carbon dioxide (CO_2) and hydrogen sulfide (H_2S) and then forwarded to the F-T Synthesis Unit. The other portion is treated in the AGR to remove the bulk of H_2S with minimal CO_2 removal and then forwarded as fuel to the General Electric frame 6FA gas turbine. In the AGR solvent regeneration step, high pressure nitrogen from the ASU is used as a stripping agent to release CO_2. The resulting CO_2 and nitrogen mixture along with the bulk nitrogen is also sent



Schematic 1 - EECP Concept

to the gas turbine, which results in increased power production and reduced nitrogen oxides (NO_x) emissions.

Overall, approximately 75% of the sweetened syngas is sent to the gas turbine as fuel. The remaining 25% is first passed through a zinc oxide bed arrangement to remove the remainingtraces of sulfur and then forwarded to the F-T Synthesis Unit. In the F-T reactor, CO and H_2 react, aided by an iron-based catalyst, to form mainly heavy straight-chain hydrocarbons. Since the reactions are highly exothermic, cooling coils are placed inside the reactor to remove the heat released by the reactions. Three hydrocarbon product streams, heavy F-T liquid, medium F-T liquid, and light F-T liquid are sent to the F-T Product Upgrading Unit (F-TPU), while F-T water, a reaction byproduct, is returned to the Gasification Unit and injected into the gasifier or used in the petroleum coke slurry. The F-T tail gas and AGR off gas are sent to the gas turbine as fuel to increase electrical power production by 11%.

In the F-TPU the three F-T liquids are combined and processed as a single feed. In the presence of a hydrotreating catalyst, H_2 reacts slightly exothermally with the feed to produce saturated hydrocarbons, water, and some hydrocracker light ends. The resulting four liquid product streams are naphtha, diesel, low-melt wax, and high-melt wax and leave the EECP facility via tank truck. Hydrotreating of the neat F-T naphtha and F-T diesel products reduces reactive acids, olefins, and oxygenates levels and alleviates corrosion and product instability concerns.

Future coproduction plants can maximize valuable diesel transportation fuel by conversion of the F-T Synthesis wax product by hydrocracking. The upgraded neat F-T diesel or hydrotreater neat F-T diesel product along with hydrocracker F-T diesel product could be final blending components in transportation diesel fuel. Both the hydrotreater neat F-T naphtha and the hydrocracker naphtha by-product could be suitable feedstock components to either a chemical plant steam cracker or to a fuel cell reformer.

The power block consists of a GE PG6101 (FA) 60 Hz heavy-duty gas turbine generator and is integrated with a two-pressure level heat recovery steam generator (HRSG) and a non-condensing steam turbine generator. The system is designed to supply a portion of the compressed air feed to the ASU, process steam to the refinery, and electrical power for export and use within the EECP facility. The gas turbine has a dual fuel supply system with natural gas as the start-up and backup fuel, and a mixture of syngas from the gasifier, off gas from the AGR Unit, and tail gas from the F-T Synthesis Unit as the primary fuel. Nitrogen gas for injection is supplied by the ASU for NO_x abatement, power augmentation, and the fuel purge system.

The Praxair ASU is designed as a single train elevated pressure unit. Its primary duty is to provide oxygen to the gasifier and Sulfur Recovery Unit (SRU), and all of the EECP's requirements for nitrogen and instrument and compressed air. ASU nitrogen product applications within the EECP include its use as a stripping agent in the AGR Unit, as diluents in the gas turbine where its mass flow helps increase power production and reduce NO_x emissions, and as an inert gas for purging and blanketing. The gas turbine, in return for diluent nitrogen, supplies approximately 25% of the air feed to the ASU, which helps reduce the size of the ASU's air compressor, hence oxygen supply cost.

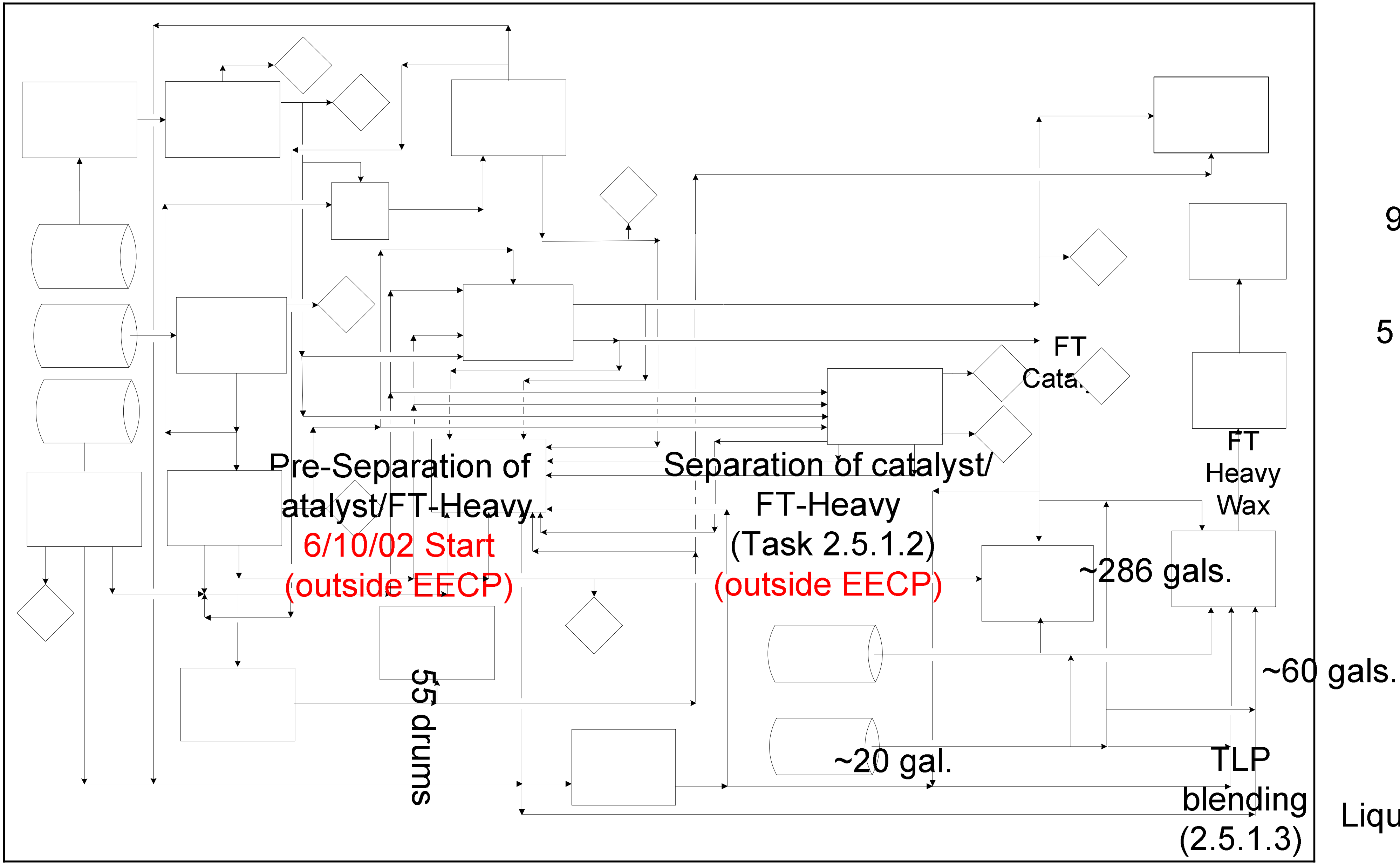
Acid gases from the AGR, as well as sour water stripper (SWS) off gas from the Gasification Unit, are first routed to knockout drums as they enter the Claus SRU. After entrained liquid is removed in these drums, the acid gas is preheated and fed along with the SWS off gas, oxygen, and air to a burner. In the thermal reactor, the H_2S, a portion of which has been combusted to sulfur dioxide (SO_2), starts to recombine with the SO_2 to form elemental sulfur. The reaction mixture then passes through a boiler to remove heat while generating steam. The sulfur-laden gas is sent to the first pass of the primary sulfur condenser where all sulfur is condensed. The gas is next preheated before entering the first catalytic bed in which more H_2S and SO_2 are converted to sulfur. The sulfur is removed in the second pass of the primary sulfur condenser, and the gas goes through a reheat, catalytic reaction, and condensing stage two more times before leaving the SRU as a tail gas. The molten sulfur from all four condensing stages is sent to the sulfur pit, from which sulfur product is transported off site by tank truck.

The tail gas from the SRU is preheated and reacted with hydrogen in a catalytic reactor to convert unreacted SO_2 back to H_2S. The reactor effluent is cooled while generating steam before entering a quench tower for further cooling. A slip stream of the quench tower bottoms is filtered and sent along with the condensate from the SRU knockout drums to the SWS. H2S is removed from the quenched tail gas in an absorber by using lean methyldiethanolamine (MDEA) solvent from the AGR Unit. The tail gas from the absorber is thermally oxidized and vented to the atmosphere. The rich MDEA solvent returns to the AGR Unit to be regenerated in the stripper.

Technical & Economic Risk Mitigation for F-T Product Upgrading

Each of the EECP subsystems (Applications of Technology to be integrated in the EECP) was assessed for technical risks and barriers. A plan was identified to mitigate the identified risks (Phase II RD&T Plan, October 2000). The intent of the Phase II RD&T work carried out under Task 2.6 entitled "Fuel/Engine Performance and Emissions" was to mitigate those technical and economic risks identified with this task. The risks to the EECP from Task 2.6 can be mitigated by demonstrating that the products derived from the upgrading of the F-T Synthesis total liquid product meet or exceed current specifications associated with finished diesel transportation fuels. Appended to the Task 2.6 Topical report prepared for the DOE for the EECP is the Subtask 2.6.1 topical report entitled "Lubricity Additive Testing", and a combined topical report for Subtask 2.6.2 entitled "Fuel/Engine Performance and Emissions & Subtask 2.6.3 entitled "Solvent Extraction of Particulate Matter."

Testing during Phase II RD&T Task 2.5 entitled "F-T Product Upgrading" and Task 2.6 entitled "Fuel/Engine Performance and Emissions" determined actual conversions and product qualities from the licensor processes. The chronological flow of work from left to right is illustrated in **Schematic 2** showing the individual Subtasks performed for both Task 2.5 and Task 2.6. Not all of the work conducted under Task 2.5, as illustrated in Schematic 2, prepared end-use products for Task 2.6 product evaluations. Only the results for Task 2.6 entitled "Fischer-Tropsch Diesel Fuel/Engine Performance and Emissions" prepared for the DOE are reported herein. Those activities conducted under Task 2.5, which generated end-products for the Task 2.6 product evaluations, will be identified and discussed in detail later in this report.



Schematic 2-Chronological Flow of Work for Phase II RD&T Task 2.5 and Task 2.6

Risk Mitigation for Phase II RD&T F-T Product Upgrading

Schematic 2 illustrates the chronological flow of work for the Phase II RD&T individual Subtasks performed under Task 2.5 entitled "F-T Product Upgrading" and under Task 2.6 entitled "Fuel/Engine Performance and Emissions" to mitigate technical and economical risks identified for upgrading the F-T total liquid product from the EECP. Not all of the 2.5 Subtasks prepared end-use products for Task 2.6 product evaluations. Only the results for the Task 2.6 Topical report entitled "Fuel/Engine Performance and Emissions" prepared for the DOE are reported herein. Those 2.5 Subtasks which generated end products for Task 2.6 product evaluations are illustrated in **Schematic 3** as the shaded blocks and their contributions to Task 2.6 will be discussed in detail in this report. Separate Task 2.5 and Task 2.6 Topical reports were prepared for the DOE. Results for each Subtask funded by the DOE as part of the Phase II RD&T were also prepared and are appended to the respective Task 2.5 and Task 2.6 Topical reports. Only the results for the Task 2.6 Topical report entitled "Fuel/Engine Performance and Emissions" are reported herein. Appended to this Task 2.6 Topical Report prepared for the DOE for the EECP is Appendix A consisting of the Subtask 2.6.1 results report entitled "Lubricity Additive Testing", and Appendix B consisting of the combined results report for Subtask 2.6.2 entitled "Fuel/Engine Performance and Emissions & Subtask 2.6.3 entitled "Solvent Extraction of Particulate Matter."

The risks to the EECP can be mitigated by demonstrating that the products derived from the upgrading of the F-T Synthesis total liquid product meets or exceeds current specifications associated with producing an acceptable naphtha feedstock component for a chemical plant steam cracker to produce ethylene and propylene or as a naphtha feedstock component for hydrogen fuel generation from a fuel cell reformer, finished diesel transportation fuels, and specialty food grade wax products.

F-T Product Distilled to Fuel and Specialty Wax Specifications

The F-T Synthesis liquid products from the LaPorte Alternative Fuels Development Unit (AFDU) must be distilled to the required fuel or specialty wax product boiling range specifications. There are technical and economic risks to the EECP if the F-T Synthesis products undergo degradation or liquid yield losses to light ends during the distillation process. There are technical risks with Subtasks regarding the degree of laboratory fractionation efficiency, recovery of products and possible contamination of distilled products for end-use product evaluations. These technical and economic risks to the EECP are mitigated if the distilled products achieve desired yield recoveries and qualities meeting fuel or specialty product boiling range specifications in order to satisfy the end-use evaluation needs of the Subtasks illustrated in **Schematic 2** for Task 2.5 and Task 2.6.

<u>Subtask 2.5. 2 Lab Batch Fractionation</u>

The water free F-T Light Product from Subtask 2.5.1.1 entitled **"**Water Separation of LaPorte Commingled Water and F-T Light Product Streams" was blended in a ratio-of-production blend with the F-T Heavy product from Subtask 2.5.1.2 entitled "Catalyst/Wax Separation to 10 ppmw" and fractionated in Subtask 2.5.2 entitled "Lab Batch Fractionation" to maximize the recovery of a neat F-T diesel overhead distillation product meeting Task 2.6 diesel fuel flash point, viscosity, and boiling range specifications. Neat F-T naphtha was recovered from Subtask 2.5.2 as an end product for use in Task 2.5 product evaluations to be presented in a separate Task 2.5 Topical Report prepared for the DOE. Foaming from the presence of free water in the

Subtask 2.5.2 distillation column could have caused poor separation and failure to meet required Task 2.6 fuel specifications. The Subtask 2.5.2 neat F-T diesel product for Task 2.6 was tested and approved for blending with the neat F-T diesel product from Subtask 2.5.7.1.b&c entitled "Naphtha Fractionation."

Subtask 2.5.7.1 Naphtha Fractionation

The Phase II RD&T Subtask 2.5.7.1 Topical Report entitled "Naphtha Fractionation" is appended to the separate EECP DOE Topical Report Task 2.5 entitled "F-T Product Upgrading." The risks to be mitigated by Subtask 2.5.7.1 fractionations were the maximum recoveries of neat F-T diesel, neat F-T naphtha, and neat F-T soft wax products meeting both fuel and specialty wax product boiling range specifications with the minimal introduction of background contaminants from equipment and handling. Subtask 2.5.7.1 fractionated the F-T Light Product after the risk of free water was successfully removed by Subtask 2.5.1.1. Subtask 2.5.7.1 performed the fractionation of three different size retains of F-T Light Product recovered from the LaPorte AFDU. Subtask 2.5.7.1.a fractionated approximately 322 gallons of F-T Light Product collected in a commercial ISOtainer vessel receiver to maximize the recovery of neat F-T naphtha, a neat F-T heavy diesel, and a neat F-T soft wax product. Task 2.5.7.1.b and Task 2.5.7.1.c each fractionated the contents of a partial filled 55-gallon drum receiver from the LaPorte AFDU demonstration to recover the neat F-T naphtha, neat F-T diesel, and neat F-T soft wax products.

Inspection testing was done on each of the fractionation products obtained from Subtask 2.5.7.1.a, 2.5.7.1.b, and 2.5.7.1.c before composite blending was done to maximize end-use product recovery of neat F-T diesel product meeting Task 2.6 diesel fuel flash point, viscosity, and boiling range specifications, neat F-T naphtha (Task 2.5 product evaluations), and neat F-T soft wax products (Task 2.5 product evaluations). Inspection testing found the neat F-T diesel product from Subtask 2.5.7.1.a to have some loss of front end boiling range components due to operating a continuous distillation column overhead product diesel receiver too hot resulting in the loss of diesel vapors from flashing. The neat F-T heavy diesel was not used directly in Task 2.6 product evaluations. The neat F-T heavy diesel was considered satisfactory end-use product for Task 2.5 product evaluations. The neat F-T diesel product from Subtask 2.5.7.1.b&c is the designated end-use product for the Task 2.6 product evaluations. The Subtask 2.5.7.1.b&c neat F-T diesel products for Task 2.6 product evaluations was tested and approved for blending with the neat F-T diesel product from Subtask 2.5.2 entitled "Lab Batch Fractionation."

In order to maximize the recovery of neat F-T diesel for Task 2.6 product evaluations the Subtask 2.5.7.1.b&c neat F-T diesel products were tested and approved for blending with the above Subtask 2.5.2 neat F-T diesel product. The combined blend of Subtask 2.5.2 and Subtask 2.5.7.1.b&c neat F-T diesel overhead distillation products took two routes for Task 2.6 product evaluations. A designated quantity of the combined blend of Subtask 2.5.2 and Subtask 2.5.7.1.b&c neat F-T diesel overhead distillation products went directly to product evaluation in Subtask 2.6.1 entitled "Lubricity Additive Testing" to measure the lubricity property of the neat F-T diesel and determine the need for treatment with a commercial additive to pass lubricity. A Subtask 2.6.1 neat F-T diesel product passing lubricity qualified for product evaluation in Subtask 2.6.2 entitled "Hot-Start Cycle Transient Engine Test" and in Subtask 2.6.3 entitled "Solvent Extraction of Particulate Matter." A second designated quantity of the combined blend of Subtask 2.5.2 and Subtask 2.5.7.1.b&c neat F-T diesel overhead distillation products did under go product evaluation in Subtask 2.5.7.6 entitled "Neat Diesel Hydrotreating."

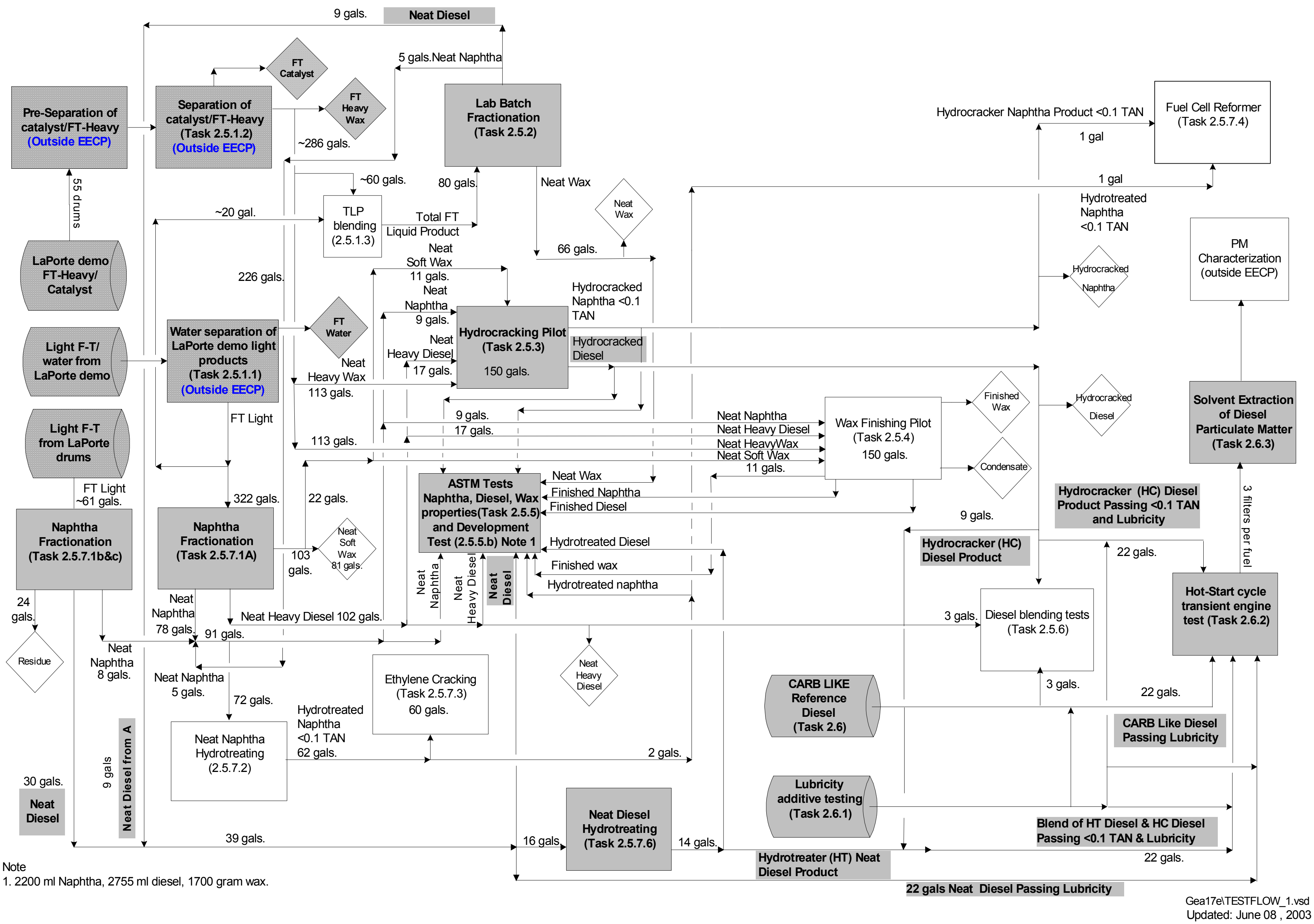
Subtask 2.5.7.1.a entitled "Naphtha Fractionation" generated the neat F-T naphtha product, the neat F-T heavy diesel product, and the neat F-T soft wax product used as feedstock blend components for Subtask 2.5.3 entitled "Hydrocracking Pilot." The remaining feedstock blend component for Subtask 2.5.3 entitled "Hydrocracking Pilot" is the neat F-T hard wax product (F-T Heavy Product) from Subtask 2.5.1.2 entitled "Catalyst/Wax Separation to 10 ppmw." The feedstock to Subtask 2.5.3 is a ratio-of-production blend of the F-T Light and F-T Heavy Products. However special feed handling considerations require individual boiling range neat F-T products to mitigate risks associated with the operation of the available feed delivery systems of the product upgrading pilot units. Subtask 2.5.3 entitled "Hydrocracking Pilot" generated the hydrocracker F-T diesel product for Task 2.6 product evaluations.

Subtask 2.5.3 Hydrocracker F-T Diesel for Task 2.6

One objective of the DOE EECP was to produce transportation fuel such as diesel. There are a number of barriers to producing transportation fuel from F-T Synthesis liquid products. One economic barrier is the desired result that the EECP have a favorable economic return on investment. In order to achieve favorable economics, the finished product lines from the EECP need to receive premium values. The neat F-T naphtha and neat F-T diesel products have premium qualities such as low sulfur contents, low aromatic contents, and high hydrogen contents. The neat F-T diesel product has a high cetane number that may justify higher prices in the market place. The quantity of distillate transportation fuels from the EECP will be small when compared to typical fuel amounts produced by even small refineries. Therefore, it may be difficult to achieve a premium value or a large market share for the fuels produced from the EECP.

Future coproduction plants will likely need to maximize the conversion of the highly paraffinic F-T Synthesis wax product into transportation diesel while minimizing the production of naphtha by-product. Phase II RD&T Subtask 2.5.3 entitled "Wax Hydrocracking Pilot" discussed in the EECP DOE Topical Report Task 2.5 entitled "F-T Product Upgrading" addresses this technical concern. The finished diesel product from hydrocracking of the F-T wax is expected to be a stable and desired high cetane blending component in transportation diesel.

The hydrocracker pilot plant hard wax feed blend component (F-T Heavy Product) contains mostly normal paraffins with minor amounts of olefins, oxygenates, and acids. The F-T Heavy product wax from the EECP could be hydrocracker to maximize the yield and quality of the hydrocracker F-T diesel product for transportation diesel along with the production of a hydrocracker F-T naphtha by-product by using the correct combination of upgrading process and



Schematic 3 – Flow of Work for Task 2.5 Subtasks to Task 2.6 Subtasks

catalyst technologies. The value from the conversion of the F-T Heavy Product wax to transportation diesel fuel is expected to benefit the future economics of the EECP. The hydrocracker F-T diesel product from wax conversion is expected to be a desired high cetane blending component in transportation diesel. The hydrocracker F-T naphtha by-product from wax hydrocracking is expected to be a desired feedstock for chemical plant steam crackers for the production of ethylene and propylene and as a feedstock for hydrogen fuel generation from a fuel cell reformer.

The technical and economic risks to the EECP to be mitigated for hydrocracking the F-T Heavy Product wax is adapting existing processing technology to achieve high yields of high quality diesel transportation fuel. Processing technology to maximize hydrocracking of paraffinic heavy gas oil to diesel product is known and practiced for gas oil feeds from conventional crude sources but is not commercially practiced for synthetic waxes such as the F-T Heavy Product wax. Although hydrocracking technology has not been commercially applied to F-T Heavy Product wax, the concept of processing paraffinic gas oil feeds considered similar in composition is commercially proven. Future design solutions can be formulated from the data base developed during the research phase. Performance estimates on product yield structures, appropriate selection of hydrocracking catalyst, reactor bed configuration and operating conditions could be prepared for future economic case evaluations.

The Phase II RD&T Subtask 2.5.3 entitled “Hydrocracking Pilot” is structured in a way to mitigate these risks. Producing a high yield of diesel product by the hydrocracking processing route is a technical challenge based on the extended heavy carbon number distribution for the F-T Heavy Product wax from the LaPorte AFDU. Mitigating future risks to the EECP would require Subtask 2.5.3 to confirm a product yield distribution along with product sampling, testing of the hydrocracker diesel product against transportation fuel quality specifications, and testing the hydrocracker naphtha by-product for determination of its final product market disposition.

Potential risks were identified with using F-T hydrocracker diesel product as a direct blending component in transportation diesel for the Task 6 product evaluations. To mitigate these risks to the Task 2.6 product evaluations, a hydrocracker F-T diesel product was generated from the Subtask 2.5.3 entitled “Hydrocracking Pilot” to conduct Task 2.6 product evaluations. The Subtask 2.5.3 feed to the hydrocracker represented a ratio-of-production blend of the LaPorte AFDU Demonstration F-T Light Product from Subtask 2.5.1.1 and the F-T Heavy Product from Subtask 2.5.1.2. The Subtask 2.5.3 hydrocracker pilot plant was equipped with a dual feed delivery system. It was necessary to split the hydrocracker feed into two feed blend components to carry out the Subtask 2.5.3 hydrocracker pilot plant evaluation. The first hydrocracker feed blend component was the combined neat F-T naphtha and neat F-T diesel charged to the pilot plant from an enclosed cold feed receiver externally cooled to avoid the lost of feed vapors. The second hydrocracker feed blend component was the combined neat F-T soft and neat F-T hard waxes charged to the hydrocracker pilot plant from an enclosed hot feed receiver externally heated. The neat F-T hard wax feed component to the hydrocracker requires elevated heating temperatures to melt and flow.

Potential risks were identified with using hydrocracker F-T diesel product as a direct blending component in transportation diesel for the Task 2.6 product evaluations. The hydrocracker F-T diesel product is the sum of the upgraded neat F-T diesel feed component to the hydrocracker and the synthesis diesel produced from conversion of the F-T Heavy Product wax to diesel and lighter products. A Total Acid Number (TAN) number content of less than 0.1 (milligrams of Potassium Hydroxide (KOH) titrated per gram of hydrocracker F-T naphtha product) was obtained on the hydrocracker F-T diesel product. The TAN number test was used as a rapid turnaround diesel product quality control test for to address stability concerns. The TAN number is an indicator of the remaining presence of reactive compounds from the neat F-T diesel feed blend component to the hydrocracker. The Subtask 2.5.3 hydrocracker F-T diesel product was produced for three end-use product evaluations.

To mitigate the risk of using F-T diesel products as direct blending components in transportation diesel for Task 2.6 product evaluations the hydrocracker F-T diesel product will under go product evaluation in Subtask 2.6.1 entitled "Lubricity Additive Testing" to measure the lubricity property of the hydrocracker F-T diesel product and determine the need for treatment with an additive to pass lubricity. A hydrocracker F-T diesel product passing lubricity will qualify as a fuel candidate for product evaluation in Subtask 2.6.2 entitled "Hot-Start Cycle Transient Engine Test" and in Subtask 2.6.3 entitled "Solvent Extraction of Particulate Matter."

The hydrocracker F-T diesel product from Subtask 2.5.3 was used as a component to prepare a blend with a "topped" hydrotreater F-T diesel product from Subtask 2.5.7.6. The blend of hydrocracker and "topped" hydrotreater F-T diesel products under went product evaluation in Subtask 2.6.1 entitled "Lubricity Additive Testing" to measure the lubricity property of the blend of hydrocracker and "topped" hydrotreater F-T diesel products and determine the need for treating the blend with an additive to pass lubricity. A blend of hydrocracker F-T and "topped" hydrotreater diesel products passing lubricity qualified as a fuel candidate for product evaluation in Subtask 2.6.2 entitled "Hot-Start Cycle Transient Engine Test" and in Subtask 2.6.3 entitled "Solvent Extraction of Particulate Matter."

To mitigate the risk of using F-T diesel products as direct blending components in transportation diesel for Task 2.6 product evaluations the hydrocracker diesel product from Subtask 2.5.3 entitled "Hydrocracking Pilot" underwent product evaluation in Subtask 2.5.6 entitled "Diesel Blending Tests". Three blends were prepared with different ratios of hydrocracker F-T diesel product with a Tier II CARB-like diesel. The cetane, pour point, cloud point, kinematic viscosity @ 40 degrees Centigrade (^{o}C), stability, and lubricity properties of the hydrocracker F-T diesel, the Tier II CARB-like diesel, and the three blends were evaluated.

Quality Inspection Testing on End-Use Products for Task 2.6

There is a technical risk to the EECP if the F-T Synthesis Product Liquid can not be distilled into diesel, naphtha, and wax products while maintaining their inherent qualities and meeting boiling range specifications for fuels and specialty wax products.

Subtask 2.5.5 ASTM Tests for Naphtha, Diesel, and Wax Properties

As continuing quality assurance checks that fuel and specialty wax product specifications were being produced for Task 2.6 and Task 2.5 product evaluations, Phase II RD&T Subtask 2.5.5 entitled "ASTM Naphtha, Diesel, Wax properties and Development Tests" consisting of three individual inspection test schedules presented as Table 1 for naphtha, Table 2 for diesel, and

Table 3 for wax were routinely performed on products generated from the Subtask 2.5.2 entitled "Lab Batch Fractionation", Subtask 2.5.3 entitled "Hydrocracking Pilot", Subtask 2.5.7.2 entitled "Neat Naphtha Hydrotreating", and Subtask 2.5.7.6 entitled "Neat Diesel Hydrotreating" that are appended to the separate EECP DOE Topical Report Task 2.5 entitled "F-T Product Upgrading" prepared for the DOE. The Subtask 2.5.5 test results obtained on each set of Subtask products are reported in their respective Subtask Reports appended to the separate Task 2.5 Topical Report entitled "F-T Product Upgrading" prepared for the DOE.

Table 1
Naphtha Characterization Testing Schedule for Subtask 2.5.5.1

Test Standard	**Test Name**
ASTM D287	**API Gravity, Specific Gravity, Density**
ASTM D86 or ASTN D2887	**Distillation or Simulated Distillation of Fuel Oils**
ASTM D3120	**Sulfur Content by Coulometric Titration**
ASTM D4629	**Nitrogen by Chemiluminescence**
ASTM D2699	**Research Octane Number**
ASTM D2700	**Motor Octane Number**
ASTM D3242	**Total Acid Number (TAN)**
Developmental Task 2.5.5.b	**Oxygenates and/or Total Oxygen Content see Note 1**
Developmental	**Paraffins, Iso-Paraffins, Aromatics, Naphthenes, and Olefins (PIANO) see Note 1**
	Note 1 – Additional RD&T Test method development required to achieve detection levels desired or due to test interference from compounds present.

Table 2 Diesel Characterization Testing Schedule for Subtask 2.5.5.2	
Test Standard	**Test Name**
ASTM D287	API Gravity, Specific Gravity, Density
ASTM D86 or ASTM D2887	Distillation or Simulated Distillation of Fuel Oils
ASTM D1500	Color, ASTM
ASTM D130	Copper Corrosion
ASTM D3120	Sulfur Content by Coulometric Titration
ASTM D4629	Nitrogen by Chemiluminescence
ASTM D613	Cetane Number
ASTM D4737	Calculated Cetane Index
ASTM D6078	Scuffing Load (Ball on Cylinder
ASTM D6079	Lubricity of Diesel Fuel by HFRR
ASTM D93	Pensky-Marten (PM) Flash Point
ASTM D445	Kinematic Viscosity at 40°C
ASTM D97	Pour Point
ASTM D2500	Cloud Point
ASTM D482	Ash Content
ASTM D524	Ramsbottom Carbon, 10% Bottoms
ASTM D3242	Total Acid Number (TAN)
Developmental	ASTM D2425 Hydrocarbon Types in Middle Distillates by MS, Aromatics see Note 1
Developmental	Hydrocarbon Type analysis by Clay-Gel Absorption Chromatography see Note 1
ASTM D 5542	Carbon Number Distribution
Developmental Task 2.5.5.b	Oxygenates and/or Total Oxygen see Note 1
	Note 1 – Additional RD&T Test method development required to achieve lower detection levels desired or due to test interference from compounds present.

Table 3
Wax Characterization Testing Schedule for Subtask 2.5.5.3

Test Standard	Test Name
Developmental	ASTM D287 API Gravity, Specific Gravity, Density see Note 1
ASTM D2887	Simulated Distillation
ASTM D156	Color, Saybolt
ASTM D1500	Color, ASTM
ASTM D3120	Sulfur Content by Coulometric Titration
ASTM D4629	Nitrogen by Chemiluminescence
21CFR 172.886	FDA approval for Wax, Part 1 and 2
Developmental	ASTM D721 Oil in Wax see Note 1
ASTM D87	Melting Point of Wax
ASTM D127	Drop Melting Point
ASTM D937	Cone Penetration of Petrolatum
ASTM D1321	Needle Penetration
ASTM D445	Kinematic Viscosity at 100°C
ASTM D938	Congealing Point of Wax
ASTM D1832	Peroxide Number of Petroleum Wax
ASTM D5185	ICP Elemental Analysis
Developmental	Paraffins, Iso-Paraffins, Aromatics, Naphthenes, and Olefins (PIANO) see Note 1
Developmental Task 2.5.5.b	Oxygenates or Total Oxygen Content see Note 1
Developmental	Extended ASTM D 5542 Carbon Number Distribution see Note 1
	Note 1 – Additional RD&T test method development required to achieve lower detection levels desired or due to lack of solubility of wax in solvents specified in ASTM Methods.

The lack of solubility of F-T wax products in the specified ASTM Test Method solvents limited testing from the Table 3 test schedule for wax products. Additional RD&T developmental work will be required resolve these wax solubility issues.

To mitigate the risk of reactive oxygenates and acids remaining as coke precursors in the hydrotreater F-T naphtha product intended as feed for Subtask 2.5.7.3 entitled "Ethylene cracking' and for Subtask 2.5.7.4 entitled "Fuel Cell Reformer" a need was identified to measure total oxygen or oxygenates in the ppmw range on the hydrotreater neat F-T naphtha product to mitigate this technical risk. Total oxygen test method development work was initiated at the Southwest Research Institute (SwRI) in San Antonio, Texas. A Subtask 2.5.5.b Report was prepared entitled "Oxygen Concentration Determination for F-T Naphtha and F-T Diesel Boiling Range Fractions" and is appended to the separate Task 2.5 Topical Report entitled "F-T Product Upgrading" prepared for the DOE. Conclusion drawn from the EECP Team from the Subtask 2.5.5.b Topical report is that additional RD&T test method development is required to extend the lower detection level of the current exploratory analysis method.

Subtask 2.5.6 Direct Blending to Transportation Diesel

Potential risks were identified with using F-T diesel products as direct blending components in transportation diesel for the Task 2.6 product evaluations. There is the potential for unexpected adverse effects on cetane, pour point, cloud point, kinematic viscosity @ 40 degrees Centigrade, stability, and lubricity properties when F-T diesel products are used as direct blending components in transportation diesel. The blending responses of two F-T diesel products with a Tier II CARB-like diesel were evaluated. The neat F-T heavy diesel distillation product from Subtask 2.5.7.1.a entitled "Naphtha Fractionation" and the hydrocracker F-T diesel product from Subtask 2.5.3 entitled "Hydrocracker Pilot" were evaluated. The open literature claims that the presence of oxygenate compounds similar to those compounds that may exist in the neat F-T diesel product may enhance the cetane property of a fuel. Hydrotreater diesel product from Subtask 2.5.7.6 entitled "Neat Diesel Hydrotreating" was in short supply for Task 2.6 product evaluations and was not available for the Subtask 2.5.6 product evaluations. Results on Subtask 2.5.6 entitled "Diesel Blending Tests" are documented in the Subtask 2.5.6 Report entitled "Diesel Blending Tests" included in the Task 2.5 Topical Report entitled "F-T Product Upgrading" prepared for the DOE.

<u>Neat F-T Diesel Direct Blending</u>

To mitigate the risk of using F-T diesel products as direct blending components in transportation diesel for Task 6 product evaluations the neat F-T heavy diesel product from Subtask 2.5.7.1.a entitled "Naphtha Fractionation" underwent product evaluation in Subtask 2.5.6 entitled "Diesel Blending Tests". The neat F-T diesel product may contain reactive olefins, oxygenates, and acids which can lead to the risks of corrosion and instability in transportation diesel. Three blends were prepared with different ratios of neat F-T heavy diesel with a Tier II CARB-like diesel. The cetane, pour point, cloud point, kinematic viscosity @ 40 degrees Centigrade, stability, and lubricity properties of the neat F-T heavy diesel, the Tier II CARB-like diesel, and the three blends were evaluated.

Hydrocracker F-T Diesel Direct Blending

To mitigate the risk of using F-T diesel products as direct blending components in transportation diesel for Task 2.6 product evaluations the hydrocracker diesel product from Subtask 2.5.3 entitled "Hydrocracking Pilot" underwent product evaluation in Subtask 2.5.6 entitled "Diesel Blending Tests". Three blends were prepared with different ratios of hydrocracker F-T diesel product with a Tier II CARB-like diesel. The cetane, pour point, cloud point, kinematic viscosity @ 40 degrees Centigrade, stability, and lubricity properties of the hydrocracker F-T diesel, the Tier II CARB-like diesel, and the three blends were evaluated.

Subtask 2.5.7. 6 "Topped" Hydrotreater F-T Diesel for Task 2.6

Potential risks were identified with using F-T diesel products as direct blending components in transportation diesel for the Task 2.6 product evaluations. The neat F-T diesel product may contain reactive olefins, oxygenates, and acids which can lead to corrosion and fuel instability. To mitigate these risks to Task 2.6 product evaluations, a designated quantity of the combined blend of Subtask 2.5.2 and Subtask 2.5.7.1.b&c neat F-T diesel overhead distillation products under went product evaluation in Subtask 2.5.7.6 entitled "Neat Diesel Hydrotreating". Subtask 2.5.7.6 entitled "Neat Diesel Hydrotreating" will mitigate the risks to Task 2.6 of potentially reactive olefins, oxygenates, and acids by targeting their removal. A Subtask 2.5.7.6 performance standard of reducing the TAN content of the hydrotreater F-T diesel product to a number of less than 0.1 (milligrams of Potassium Hydroxide (KOH) titrated per gram of hydrotreater F-T naphtha product) was achieved. The TAN number test was used as a rapid turnaround product quality control test to set the severity of the hydrotreating process variables during the production of end-use diesel product for Task 2.6. The TAN number is an indicator of the remaining presence of reactive feed compounds.

The Subtask 2.5.7.6 hydrotreater F-T diesel total liquid product off the pilot unit failed the 52 Degree Centigrade minimum ASTM D 93 flash point requirement for No. 2-D grade low-sulfur diesel fuel oils as specified in ASTM D 975 entitled "Standard Specifications for Diesel Fuel Oils". A comparison was made of the ASTM D 2887 distillation results for the Task 2.5.7.6 hydrotreater F-T diesel total liquid product with the ASTM D 2887 distillation results for the combined blend of Subtask 2.5.2 and Subtask 2.5.7.1.b&c neat F-T diesel overhead distillation products which make up the feed to the Subtask 2.5.7.6 hydrotreater pilot unit. A downward shift (initial boiling point "droop') was observed in the front end of the boiling range of the Subtask 2.5.7.6 hydrotreater F-T diesel total liquid product. There was no reduction in the back end of the ASTM D 2887 feed distillation to support cracking in the hydrotreater pilot plant operations. The hydrogenation of olefins oxygenates, and acids in the feed may have contributed to the initial boiling point "droop" observed in the hydrotreater F-T diesel product. Laboratory batch fractionations were carried out on the Subtask 2.5.7.6 hydrotreater F-T diesel product to obtain a "topped" (lab batch fractionation bottoms product) hydrotreater F-T diesel product with a greater than 52 Degree Centigrade ASTM D 975 flash point. The "topped" hydrotreater (HT) F-T diesel product from batch fractionation of the Subtask 2.5.7.6 product under went product evaluation in Subtask 2.6.1 entitled "Lubricity Additive Testing" to measure the lubricity property of the "topped" hydrotreater F-T diesel product and to determine the need for treatment with an additive to pass lubricity. A Subtask 2.5.7.6 "topped" hydrotreater F-T diesel product passing lubricity will qualify as a fuel candidate for product evaluation in Subtask 2.6.2 entitled

"Hot-Start Cycle Transient Engine Test" and in Subtask 2.6.3 entitled "Solvent Extraction of Particulate Matter."

F-T Diesel Fuel/Engine Performance and Emissions - Task 2.6

Each of the EECP subsystems was assessed for technical risks and barriers. A plan was developed to mitigate the identified risks (Phase II RD&T Plan, October 2000). Phase II RD&T Task 2.6 identified as potential technical risks to the EECP the fuel/engine performance and emissions of the F-T diesels. F-T diesel fuels must meet current fuel specifications. Failure to achieve specifications will reduce the product value and acceptance in the market. Based on past work, it is expected that all F-T diesel fuels will meet specifications. There is a medium-level technical risk involved with the fuel/engine performance and emissions and with the impact on product stability from direct blending of F-T diesels into transportation diesel. The technical risk is due to the unknown stability of F-T diesel fuels. Phase II RD&T Subtask 2.5.6 entitled "Diesel Blending Tests" is discussed in the EECP DOE Topical Report Task 2.5 entitled "F-T Product Upgrading" addresses the technical risks on product stability of direct blending of F-T diesel fuels into transportation diesel. Overall, the risk to the EECP from the outcome of the Task 2.6 product upgrading is low.

Task 2.6 entitled "Fuel/Engine Performance and Emissions" was executed in Phase II RD&T and results are reported herein. Phase II RD&T Task 2.6 successfully carried out fuel lubricity property testing, fuel response to lubricity additives, and hot-start transient emission tests on a neat F-T diesel product, a hydrocracker F-T diesel product, a blend of hydrotreater and hydrocracker F-T diesel products, and a Tier II CARB-like diesel reference fuel. Testing was be done to specifically demonstrate that the F-T diesel fuels available from the upgrader section have better emission characteristics than conventional fuels.

Experimental

Each of the EECP subsystems was assessed for technical risks and barriers. A plan was developed to mitigate the identified risks (Phase II RD&T Plan, October 2000). Phase II RD&T Task 2.6 identified as potential technical risks to the EECP the fuel/engine performance and emissions of the F-T diesels. Hydrotreating the neat F-T diesel product reduces potentially reactive olefins, oxygenates, and acids levels and alleviates corrosion and fuel stability concerns. Future coproduction plants can maximize valuable transportation diesel by hydrocracking the F-T Synthesis wax product. The upgrader neat F-T diesel, hydrotreater F-T diesel, and hydrocracker F-T diesel products could be final blending components in transportation diesel fuel.

Phase II RD&T Task 2.6 successfully carried out fuel lubricity property testing, fuel response to lubricity additives, and hot-start transient emission tests on a neat F-T diesel product, a hydrocracker F-T diesel product, a blend of hydrotreater and hydrocracker F-T diesel products, and a Tier II CARB-like reference diesel.

Subtask 2.6.1 Lubricity Additive Testing

The lubricity of interacting surfaces is a standardized parameter related to the inherent coefficient of friction between the materials making up the surfaces and including the media between the surfaces.[1] While many factors contribute to measured lubricity[2],it is known that the heteroatom-containing compounds in fuels are major contributors to the lubricating quality (lubricity) of a fuel[3]. Processed F-T products being devoid of heteroatom compounds could have posed a danger to the expensive engine equipment used for the emissions testing in another part of the current work; hence, the lubricity of the test fuels was measured with and without lubricity enhancing additives. The lubricity testing was performed in response to a concern that beyond the F-T test fuels even the highly processed petroleum reference fuel[4] could harm the test engine during the emissions test.

Subtask 2.6.1 entitled "Lubricity Additive Testing" mitigates the potential risk of engine failure from the use of F-T diesels. The chronological flow of work performed in completing Subtask 2.6.1 is illustrated in **Schematic 4**. The ASTM D6079 lubricity test (Lubricity of Diesel Fuel by High Frequency Reciprocating Rig [HFRR]) was conducted on the fuels. This ASTM test relies upon measurement of the width of a wear scar produced by a pin moving back and forth across a test block immersed in the fuel of interest. A HFRR wear scar width of less than 450 microns is considered acceptable by United States and European standards.

The EECP team conducted trials with two commercial lubricity additives on each of the four test diesel fuel candidates at target additive concentrations of 15 ppm, 100 ppm, and 200 ppm. The two commercial lubricity additives designated as Additive 1 and Additive 2 were provided by the Southwest Research Institute (SwRI) at their San Antonio, Texas testing facilities. The four test diesel fuel candidates were the neat F-T diesel product, a hydrocracker F-T diesel product, a blend of hydrocracker and hydrotreater F-T diesel products, and a Tier II CARB-like diesel fuel. Fuel candidate lubricity property testing must first confirm the need for additive use. For those fuel candidates failing lubricity, the additive treatment necessary to pass were determined for each fuel candidate. Each of the four fuel candidates must pass lubricity requirements before being run on the SwRI rebuilt 1991 Detroit Diesel Corporation (DDC) Series 60 heavy-duty diesel engine used in Subtask 2.6.2 entitled "Hot-Start Cycle Transient Engine Test".

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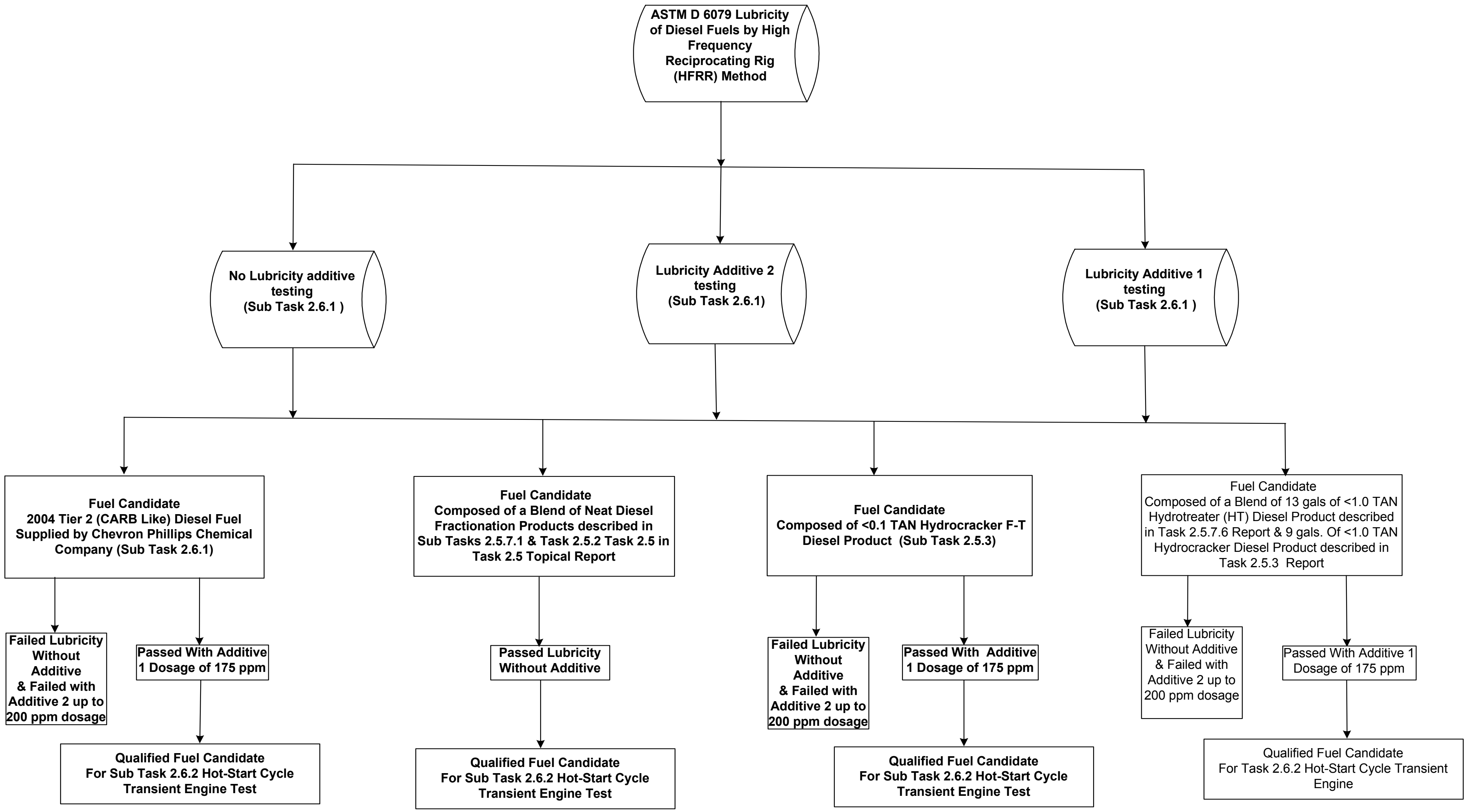
[*] Numbers in the text refer to bibliographic entries at the end of the document

EECP RD&T Task 2.6 Fuel/Engine Performance and Emissions

Schematic 4 – Flow of Work for Subtask 2.6.1 Lubricity Additive Testing of F-T Diesel Fuels



Task 2.6.1 Lubricity Additive
TESTFLOW_1.vsd
Updated: June 08 , 2003

Subtask 2.6.2 Hot-Start Cycle Transient Engine Test

Diesel engines play a respected role of providing reliable power in mobile applications in trucks, buses, and other equipment. The engine mechanically processes fuel and air to achieve controlled combustion to deliver rotating mechanical power with reasonable exhaust emissions. Although the levels of exhaust emissions depend largely on the combustion processing of the fuel and air by the engine, fuel properties alone can have significant effects on emissions.

Numerous studies have related changes in fuel properties to changes in engine emissions. Of the many fuel properties that can be used to characterize a diesel fuel, aromatic content and cetane number are respected as two important properties that relate to the hydrogen-carbon components of the fuel and the ignition quality of the fuel, respectively. Many other fuel properties are also important in combustion, such as oxygen and sulfur content. Physical properties, such as density, viscosity, and boiling point distribution, are also important in that they affect how the fuel is delivered, dispersed and ultimately combusted, which also affects engine performance and emissions.

Reducing aromatic content of the fuel, particularly multi-ringed aromatics in favor of more paraffinic fuel has been shown to reduce NO_x. Many diesel engines are sensitive to cetane number, a fuel property closely associated with aromatic content. For the DDC Series 60, increased cetane number, associated with low aromatic or cetane improver additives, has resulted in reductions of NO_x and total particulate matter (PM), as well as hydrocarbons (HC) and CO.[5] In addition, it has been recognized that reducing fuel sulfur content not only reduces particulate emissions, it often allows catalyst technology to be implemented to reduce various engine emissions.

Fischer-Tropsch (F-T) fuels generally are defined as having low aromatics (<1%), high cetane number (>70), and essentially sulfur free. Previous work with Sasol Oil's, "Sasol Slurry Phase Distillate" indicated that heavy-duty diesel engine emissions of NO_x, PM, HC, and CO could be reduced by 14-15 percent, 21-23 percent, 15-28 percent, and 23-25 percent, respectively; from levels obtained with a CARB-like fuel, similar to the reference fuel used in this work.[6] In work with an F-T fuel from Syntroleum Corp., diesel engine emissions of NO_x, PM, HC, and CO were reduced 14, 27, 0, and 27 percent, respectively; again, from levels obtained with a CARB-like fuel.[7,8] Finally, CARB summarized changes to diesel emissions with the use of F-T fuels, relative to CARB-like fuel, as reducing NO_x by 5 percent, PM by 30 percent, HC by 23 percent, and CO by 39 percent.[9]

Subtask 2.6.2 entitled "Hot-Start Cycle Transient Engine Test" will mitigate the potential economic risks identified in the Phase II RD&T Task 2.6 plan dealing with obtaining a premium price in the market place for the anticipated superior performance of these F-T diesel fuels. Subtask 2.6.2 determined whether the superior properties of low sulfur, low aromatics, and high transient engine test performances that yield lower fuel emissions than conventional diesel fuels. The screening protocol used in this study was based on the transient emission measurement procedure developed by the EPA for emissions regulatory purposes. In general, this screening protocol required less time and fuel than the complete CARB test protocol, Section 2282, Aromatic Content of Diesel Fuel of Title 13, California Code of Regulations (CCR), December 26, 1991; but will yield sufficient emissions information to identify fuel formulations with potential to significantly reduce emissions. This fuel-screening program generated hot-start transient emission results for HC, CO_2, CO, NO_x, and PM for each test fuel candidate.

The chronological flow of work performed in completing Subtask 2.6.2 is illustrated in **Schematic 5**. Hot-start transient emission tests were conducted by the Southwest Research Institute (SwRI) at their San Antonio, Texas testing facilities on a rebuilt 1991 Detroit Diesel Corporation series 60 heavy-duty diesel engine. The hot-start transient emission tests were conducted in accordance with the EPA Federal Test Procedure (FTP) specified in Code of Federal Regulations, Title 40, Part 86, Sub part N. The four fuel candidates passed lubricity inspection based upon applying the knowledge gained from Subtask 2.6.1 prior to the test fuel candidates being run on the SwRI rebuilt 1991 Detroit Diesel Corporation series 60 heavy-duty diesel engine.

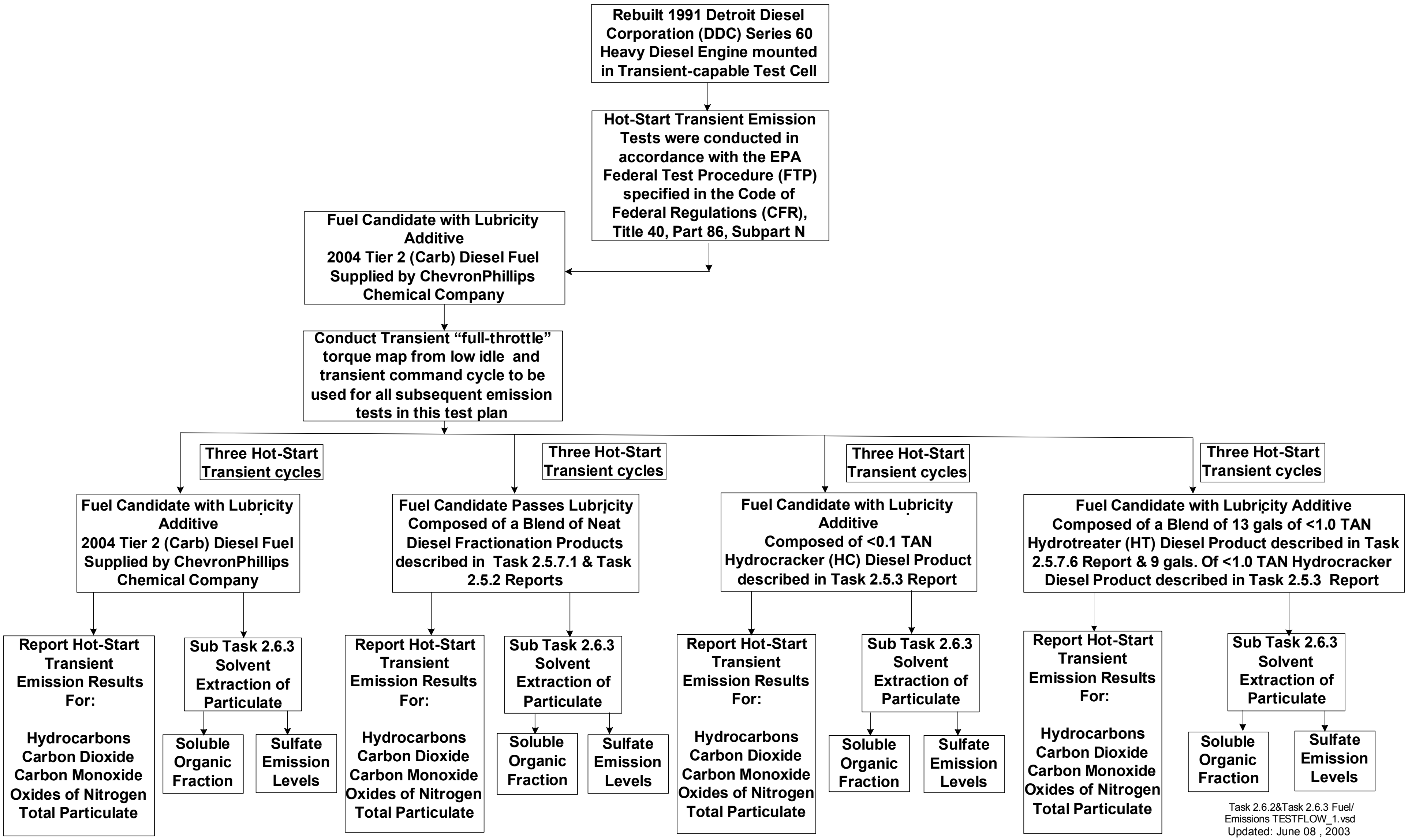
A Tier II CARB-like diesel purchased from the Chevron Phillips Chemical Company was designated as the reference fuel for Subtask 2.6.2 in order to benchmark the fuel emissions from the F-T diesels. The hot-start transient command cycle, used for all four diesel fuel test candidates, was created based on a torque-map generated from the Tier II CARB-like diesel reference fuel. The four test diesel fuel candidates were the neat F-T diesel product, a hydrocracker F-T diesel product, a blend of hydrocracker and hydrotreater F-T diesel products, and the Tier II CARB-like diesel fuel reference. Three hot-start transient cycles were conducted per day on each diesel test fuel candidate. The Subtask 2.6.2 fuel-screening program generated hot-start transient emission results for HC, CO_2, CO, NO_x, and PM for each fuel.

Subtask 2.6.3 Solvent Extraction of Soluble Organic Fraction from PM

Subtask 2.6.3 entitled "Solvent Extraction of Particulate Matter" extracted the soluble organic fraction (SOF) from the PM collected during the three hot-start transient cycles conducted each day on a diesel test fuel candidate. SwRI used solvent extraction laboratory procedures to quantify the amount of soluble organic fraction present in the diesel PM for each of the four diesel fuel candidates. This solvent extraction procedure took four-weeks for three hot-start transient cycle filters per one-day testing of each diesel test fuel candidate.

Schematic 5

Flow of Work for Subtask 2.6.2 Hot-Start Cycle Transient Engine Test and Subtask 2.6.3 Solvent Extraction of Particulate Matter (PM)



Results and Discussion

A summary is presented below of the important findings which mitigated potential risks to the EECP as result of the work conducted in Phase II RD&T Subtask 2.6.1 entitled “Lubricity Additive Testing”, Subtask 2.6.2 entitled “Hot-Start Cycle Transient Engine Test”, and Subtask 2.6.3 entitled “Solvent Extraction of Particulate Matter”. Documentation of the work and detailed discussions of the results are to be found in the Subtask 2.6.1 Report and the combined Subtask 2.6.2& Subtask 2.6.3 Report attached as Appendix A and Appendix B, respectively.

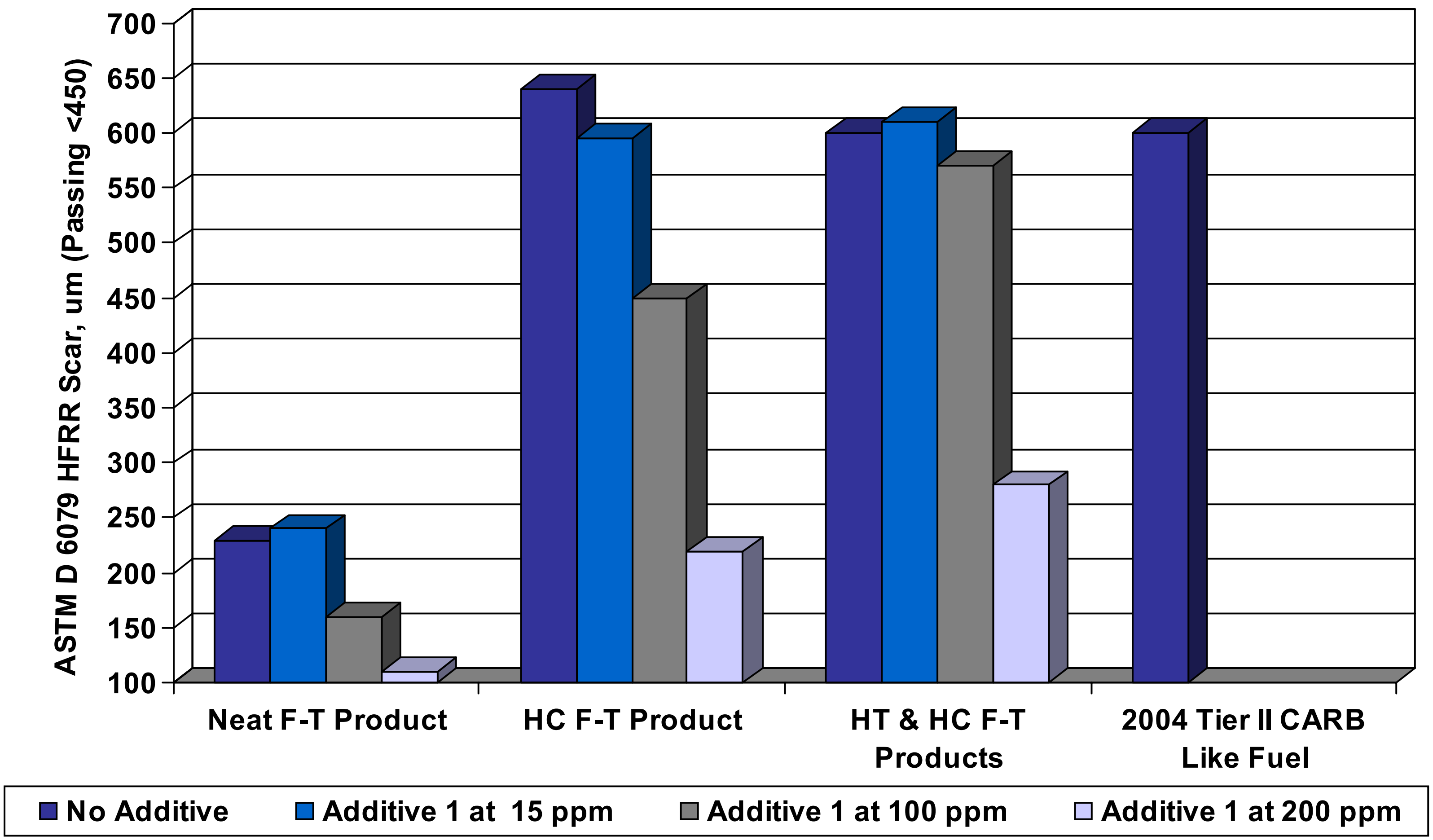
Subtask 2.6.1 Lubricity Additive Testing

Subtask 2.6.1 entitled “Lubricity Additive Testing” mitigated the potential risk of engine failure from the use of F-T diesels. The chronological flow of work performed in completing Subtask 2.6.1 is illustrated in **Schematic 5**. The ASTM D6079 lubricity test (Lubricity of Diesel Fuel by High Frequency Reciprocating Rig [HFRR]) was conducted on the four fuels. Fuel candidate lubricity property testing was performed first to confirm the need for additive use. The EECP team then conducted trials with two commercial lubricity additives on each of the four diesels at target additive concentrations of 15 ppm, 100 ppm, and 200 ppm. Two commercial lubricity additives designated as Additive 1 and Additive 2 for the Subtask 2.6.1 test program were utilized in these Task 2.6 product evaluations. The four diesels are the neat F-T diesel product, a hydrocracker (HC) F-T diesel product, a blend of hydrocracker (HC) and hydrotreater (HT) F-T diesel products, and a Tier II CARB-like diesel.

The HFRR wear scar width data presented in **Figure 1** show the results of the initial lubricity inspection done on the neat F-T diesel product, the HC F-T diesel product, the blend of HC and HT F-T diesel products, and the Tier II CARB-like diesel. The data in Figure 1 confirm that the neat F-T diesel passes lubricity inspection without additive treatment with an HFRR 230 micron wear scar width that is well below the HFRR wear scar width of less than 450 microns considered acceptable by United States and European standards. The hydrocracker F-T diesel product, the blend of hydrocracker and hydrotreater F-T diesel products, and the Tier II CARB-like diesel all exhibited failing HFRR wear scar widths in the 600 micron to 640 micron range.

The HFRR wear scar width data presented in Figure 1 show the response of the neat F-T diesel product, the hydrocracker F-T diesel product, and the blend of hydrocracker and hydrotreater F-T diesel products to treatments with the commercial lubricity Additive 1 at target concentrations of 15 ppm, 100 ppm, and 200 ppm. The HFRR wear scar width was reduced for each of the three F-T diesels as the Additive 1 concentration was increased. The 640 HFRR wear scar width without additive for the HC F-T diesel product decreased to 450 micron to 220 micron as the Additive 1 concentration was increased from a target concentration of 100 ppm to 200 ppm. The 600 HFRR wear scar width without additive for the blend of HC and HT F-T diesel products decreased to 570 micron to 280 micron as the Additive 1 concentration was increased from a target concentration of 100 ppm to 200 ppm. Base on the HFRR wear scar width data presented in Figure 1 from the Additive 1 trials with the HC F-T diesel product and the blend of HC and HT F-T diesel products, an Additive 1 treatment at 175 ppm concentration was selected for qualifying these two F-T diesels as test fuel candidates for the Subtask 2.6.2 product evaluations.

Figure 1 – Subtask 2.6.1 F-T Diesel Response to Additive



The data presented in **Figure 2** shows the Subtask 2.6.2 Fuel candidates passing lubricity. The neat F-T diesel product passed with an HFRR wear scar width of 230 microns without additive. A passing HFRR wear scar width of 415 microns was obtained on the hydrocracker F-T diesel product at an Additive 1 concentration of 175 ppm. A passing HFRR wear scar width of 400 microns was obtained on the blend of hydrocracker and hydrotreater F-T diesel products at an Additive 1 concentration of 175 ppm. A passing HFRR wear scar width of 385 microns was obtained on the Tier II CARB-like diesel at an Additive 1 concentration of 175 ppm. All four of the test fuel candidates qualify for the Subtask 2.6.2 product evaluations.

HFRR wear scar widths obtained with each of the three F-T diesels during the commercial lubricity Additive 2 trials at target concentrations of 15 ppm, 100 ppm, and 200 ppm are not discussed here but the work is documented in the Subtask 2.6.1 Report attached as Appendix A. The hydrocracker F-T diesel product and the blend of hydrocracker and hydrotreater F-T diesel products which failed lubricity without additive treatment did not have a significant response to treatment with the commercial lubricity Additive 2. A passing HFRR wear scar of less than 450 microns could not be obtained on Additive 2 to the F-T diesels treatments in the 15 ppm to 200 ppm concentration range.

Subtask 2.6.2 Hot-Start Cycle Transient Engine Test

Subtask 2.6.2 entitled "Hot-Start Cycle Transient Engine Test" mitigated the potential economic risks identified in the Phase II RD&T Task 2.6 plan dealing with obtaining a premium price in the market place for the anticipated superior performance of these F-T diesel fuels. Subtask 2.6.2 determined whether the superior properties of low sulfur, low aromatics, and high cetane exhibited by the F-T diesels from initial inspection testing produce hot-start cycle transient engine test performances yield lower fuel emissions than conventional diesel fuels. Subtask 2.6.2 yielded sufficient emissions information to identify the F-T diesels has fuels providing significant reductions in emissions. The Subtask 2.6.2 fuel-screening program generated hot-start transient emission results for NO_x, PM, HC, CO, and the SOF from the PM for each of the three F-T diesels.

The hot-start transient emission data presented in Figure 3 shows the neat F-T diesel reduced NO_x, PM, HC, CO, and the SOF from the PM by 4.5 %, 31 %, 50 %, 29 %, and 35%, repectively, compared to a Tier II CARB-like diesel. The hydrocracker F-T diesel product also reduced NO_x, PM, HC, CO and SOF by 13%, 16%, 38%, 17%, and 21%, respectively, compared to the Tier II CARB-like diesel. The blend of hydrocracker and hydrotreater F-T diesel products also reduced NO_x, PM, HC, CO and SOF by 13%, 17%, 63%, 21%, and 39%, respectively, compared to a Tier II CARB-like diesel. The fuel/engine performance and emissions of the three F-T diesels exceeded the performance of a Tier II CARB-like diesel fuel.

Figure 2 – Subtask 2.6.2 Test Fuel Candidates Passing Lubricity

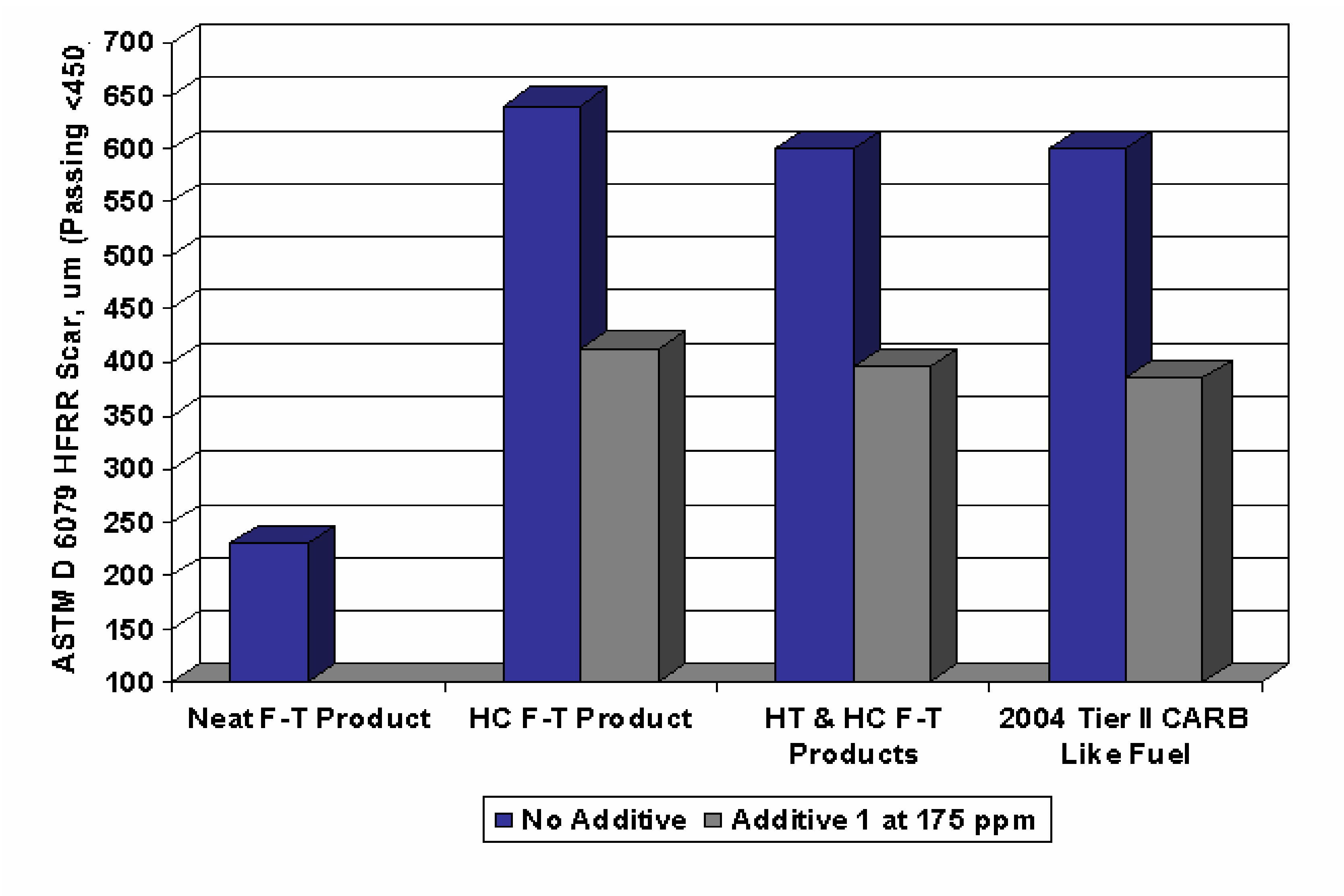
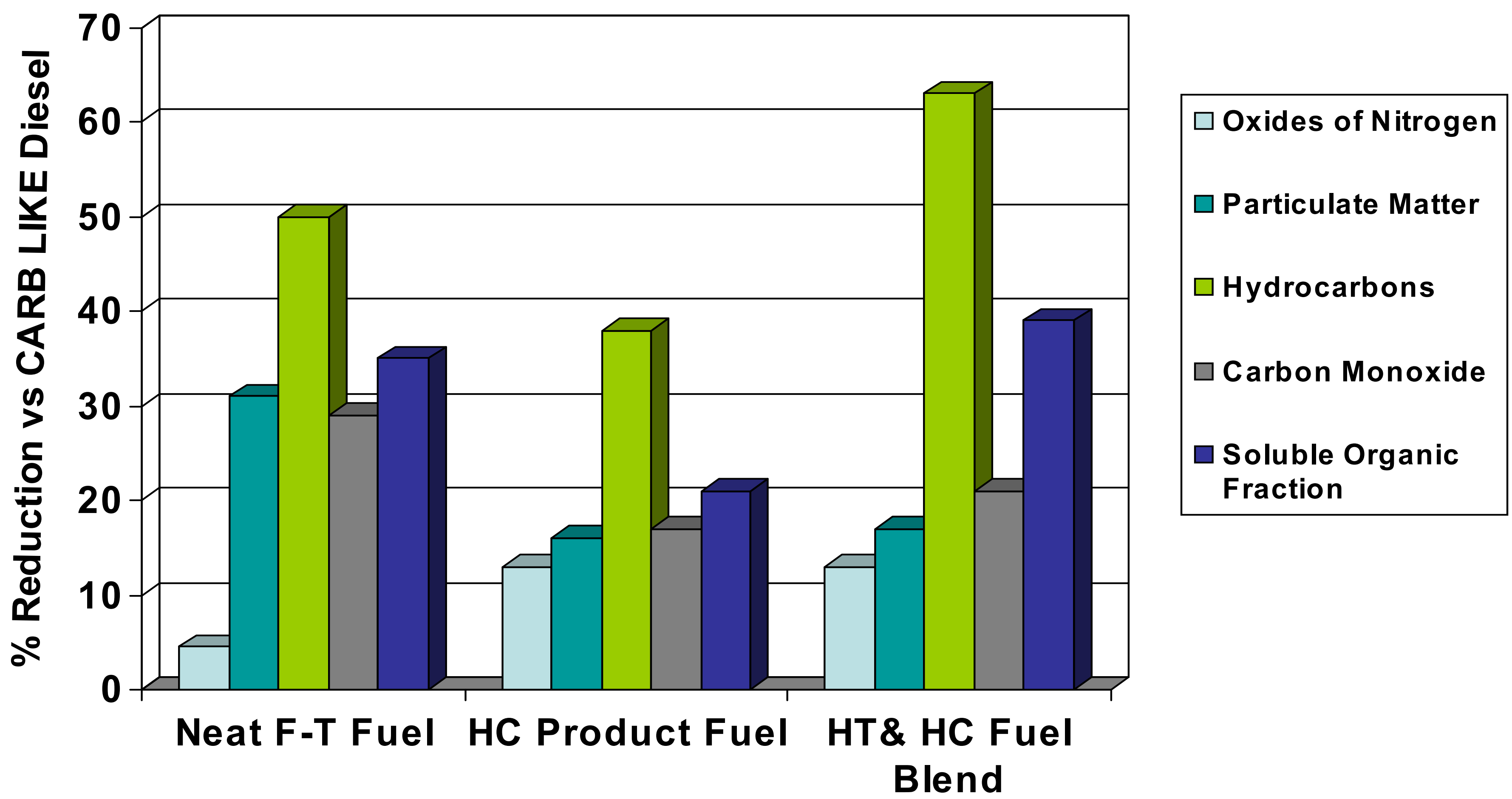


Figure 3 – Subtask 2.6.2 Hot-Start Transient Emissions Results



Subtask 2.6.3 Solvent Extraction of Soluble Organic Fraction from PM

Subtask 2.6.3 entitled "Solvent Extraction of Particulate Matter" extracted the SOF from the PM collected during the three hot-start transient cycles conducted each day on a diesel test fuel candidate. SwRI used solvent extraction laboratory procedures to quantify the amount of soluble organic fraction present in the diesel PM for each of the four diesel fuel candidates. The solvent extraction procedure was performed on three hot-start transient cycle filters per one-day testing of each diesel test fuel candidate. The SOF from the PM was determined for the three F-T diesel fuels and the Tier II CARB-like diesel reference fuel. The data presented in Figure 3 shows the percent reduction in the SOF from total particulate for each of the three F-T diesels compared to the Tier II CARB-like diesel.

The hot-start transient emission data presented in Figure 3 shows that the neat F-T diesel reduced Soluble Organic Fraction (SOF) from total particulate (PM) by 35% compared to a Tier II CARB-like diesel. The hydrocracker F-T diesel product reduced SOF by 21% compared to the Tier II CARB-like diesel. The blend of hydrocracker and hydrotreater F-T diesel products reduced SOF by 39% compared to a Tier II CARB-like diesel. The fuel/engine performance and emissions of the three F-T diesels exceed the performance of a Tier II CARB-like diesel fuel.

Conclusions

Phase II RD&T Task 2.6 successfully carried out fuel lubricity property testing, fuel response to lubricity additives, and hot-start transient emission tests in accordance with the EPA Federal Test Procedure (FTP) specified in Code of Federal Regulations, Title 40, Part 86, Subpart N on a rebuilt 1991 Detroit Diesel Corporation Series 60 heavy-duty diesel engine on a neat F-T diesel product, a hydrocracker F-T diesel product, a blend of hydrocracker and hydrotreater F-T diesel products, and on a Tier II CARB-like reference diesel.

Phase II RD&T Subtask 2.6.1 lubricity additive testing concluded the neat F-T diesel passed lubricity inspection without treatment while the remaining two F-T diesels and the 2004 Tier II diesel passed lubricity with additive treatment at a conventional 175 ppm dosage. The three F-T diesels did not respond to one of the two commercial lubricity additives (Additive 2) evaluated. Tests were conducted on the three F-T diesels with 15 ppm, 100 ppm, and 200 ppm concentrations of Additive 2. HFRR wear scar widths obtained during the Additive 2 trails did not meet the United States or European standards.

Phase II RD&T Subtask 2.6.2 hot-start transient emission tests concluded the neat F-T diesel reduced NO_x, PM, HC, CO, and the SOF from the PM by 4.5%, 31%, 50%, 29%, and 35%, respectively, compared a Tier II CARB-like diesel. The hydrocracker F-T diesel product reduced NO_x, PM, HC, CO and SOF by 13%, 16%, 38%, 17%, and 21%, respectively, compared to the Tier II CARB-like diesel. The blend of hydrocracker and hydrotreater F-T diesel products reduced NO_x, PM, HC, CO and SOF by 13%, 17%, 63%, 21%, and 39%, respectively, compared to the Tier II CARB-like diesel.

The fuel/engine performance and emissions of the three F-T diesels were found to exceed the performance of a Tier II CARB-like diesel fuel.

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List of Acronyms and Abbreviations

AGR	acid gas removal unit
ASTM	American Society for Testing and Materials
C_1	Compounds with Carbon Number of One
C_2	Compounds with Carbon Number of Two
C_3	Compounds with Carbon Number of Three
CARB	California Air Resources Board
CCR	California Code of Regulations
CFR	Code of Federal Regulations
cm	centimeters
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COV	Coefficients of Variation
DCRP	Delaware City Repowering Project
DDC	Detroit Diesel Corporation
DER	Department of Emissions
DOE	U.S. Department of Energy
EECP	Early Entry Coproduction Plant
EPA	U.S. Environmental Protection Agency
F-T	Fischer-Tropsch
ft	feet
FTP	Federal Test Procedure
g	gram
GC	gas chromatograph
HC	Hydrocarbons or Hydrocracking
HT	Hydrotreater
HFRR	High Frequency Reciprocating Rig
IGCC	Integrated Gasification Combined Cycle
in	inch
kPa	kilo Pascals
mm	millimeter
NO_x	nitrogen oxides
O_2	oxygen
PM	Total Particulate
ppm	parts per million
Psia	ounds force per square inch absolute
SOF	Soluble Organic Fraction
SRU	Sulfur recovery unit
SO_4	Sulfate
SwRI	Southwest Research Institute
TGTU	tail gas recovery unit
WTC	Westhollow Technology Center
wt%	weight percent

EARLY ENTRANCE COPRODUCTION PLANT
PHASE II

Appendix A – Test Report

Subtask 2.6.1: LUBRICITY ADDITIVE TESTING

Reporting Period: January 2001 to June 2003

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Date Issued: July 2003

Executive Summary

The overall objective of this project is the three phase development of an Early Entrance Coproduction Plant (EECP) which uses petroleum produces at least one product from at least two of the following three categories: (1) electric power (or heat), (2) fuels, and (3) chemicals using ChevronTexaco's proprietary gasification technology. The objective of Phase I is to determine the feasibility and define the concept for the EECP located at a specific site; develop a Research, Development, and Testing (RD&T) Plan to mitigate technical risks and barriers; and prepare a Preliminary Project Financing Plan. The objective of Phase II is to implement the work as outlined in the Phase I RD&T Plan to enhance the development and commercial acceptance of coproduction technology. The objective of Phase III is to develop an engineering design package and a financing and testing plan for an EECP located at a specific site.

The project's intended result is to provide the necessary technical, economic, and environmental information needed by industry to move the EECP forward to detailed design, construction, and operation. The partners in this project are Texaco Energy Systems LLC or TES (a subsidiary of ChevronTexaco), General Electric (GE), Praxair, and Kellogg Brown & Root (KBR) in addition to the U.S. Department of Energy (DOE). TES is providing gasification technology and Fischer-Tropsch (F-T) technology developed by Rentech, GE is providing combustion turbine technology, Praxair is providing air separation technology, and KBR is providing engineering.

Each of the EECP subsystems was assessed for technical risks and barriers. A plan was developed to mitigate the identified risks (Phase II RD&T Plan, October 2000). Phase II RD&T Task 2.6 identified as potential technical risks to the EECP the fuel/engine performance and emissions of the F-T diesels. Hydrotreating the neat F-T diesel product reduces potentially reactive olefins, oxygenates, and acids levels and alleviates corrosion and fuel stability concerns. Future coproduction plants can maximize valuable transportation diesel by hydrocracking the F-T Synthesis wax product to diesel and naphtha. The upgrader neat F-T diesel, hydrotreater F-T diesel, and hydrocracker F-T diesel products would be final blending components in transportation diesel.

Phase II RD&T Task 2.6 successfully carried out fuel lubricity property testing, fuel response to lubricity additives, and hot-start transient emission tests on a neat F-T diesel product, a hydrocracker F-T diesel product, a blend of hydrotreater and hydrocracker F-T diesel products, and a Tier II CARB-like diesel reference fuel. Only the neat F-T diesel passed lubricity inspection by ASTM D 6079 Lubricity of Diesel Fuel by High Frequency Reciprocating Rig (HFRR) without additive while the remaining three fuel candidates passed the US and European acceptable wear scar threshold value of less than 450 microns after additive treatment at a concentration of 175 ppm. This concentration falls within the additive manufacturers' recommended range of 15 to 200 ppm. For the hydrocracker F-T diesel and the blend of hydrocracker and hydrotreater F-T diesels, only one of the lubricity additives tried was successful at lowering the wear scar dimension to levels below the US and European limits. The four test fuel candidates passed lubricity prior conducting the Subtask 2.6.2 hot-start transient emission testing.

Lubricity Additive Testing

The lubricity of interacting surfaces is a standardized parameter related to the inherent coefficient of friction between the materials making up the surfaces and including the media between the surfaces.[1] While many factors contribute to measured lubricity[2],it is known that the heteroatom-containing compounds in fuels are major contributors to the lubricating quality (lubricity) of a fuel[3]. Processed F-T diesel products being devoid of heteroatom compounds could have posed a danger to the expensive engine equipment used for the emissions testing in another part of the current work; hence, the lubricity of the test fuels was measured with and without lubricity enhancing additives. The lubricity testing was performed in response to a concern that beyond the F-T test fuels even the highly processed petroleum Tier II CARB-like diesel used as a reference fuel[4] could harm the test engine during the emissions test.

The EECP Team supplied three F-T diesel fuels and a petroleum-derived Tier II CARB-like diesel reference fuel. These diesels were tested for their lubricating behavior and their response to two commercial lubricity additives. The test fuels were: a composite blend of Subtask 2.5.2 and Subtask 2.5.7.1.b&c neat F-T diesel product, Subtask 2.5.3 hydrocracker F-T diesel product, a blend composed of Subtask 2.5.3 hydrocracker and Subtask 2.5.7.6.a hydrotreater F-T diesel products, and a Tier 2 CARB-like diesel used as a reference fuel. The lubricity additives used were designated Lubricity Additive 1 and Lubricity Additive 2 for the sake of impartiality. The 22 gallon-size test blend retains designated for product evaluations in Subtask 2.6.2 Hot-Start Transient Emission testing were tested for passing lubricity as a final quality check on the preliminary work in order to mitigate the risk of damage to the test engine. The following sections describe the lubricity testing and results.

Experimental

The lubricity measurements were made in two sets: 1) test samples of the F-T neat and blended mixtures for evaluation testing and 2) the actual 22 gallon retains of each of the four test fuel candidates designated for product evaluation in Subtask 2.6.2 Hot-Start Transient emission testing. Sample solutions of 24 compositions were prepared in the laboratory and used for the lubricity inspection tests. These 24 compositions constituted a matrix of four levels of lubricity additive dosage for each of the three F-T diesel test fuel candidates and two commercial lubricity additives to be examined. The Tier II CARB-like diesel was not part of the additive trials. The Tier II CARB-like diesel failed lubricity inspection and passed lubricity with an Additive 1 treatment of 175 ppm equivalent to the additive treatment used on the two failing F-T diesels. The samples are described in **Table 1**.

[*] Numbers in the text refer to bibliographic entries at the end of the document

Evaluation Measurements

Each diesel fuel composition was tested for lubricity by ASTM D 6079 Lubricity of Diesel Fuel by High Frequency Reciprocating Rig (HFRR). This test relies upon measurement of the width of a wear scar in microns produced by a pin moving back and forth across a test block immersed in the liquid of interest. The results were collected and examined for attainment of an acceptably less than 450 micron HFRR wear scar width at the additive treatment levels tested. If these HFRR test results had not provided a clear indication of the lubricating behavior of the samples, further evaluation by ASTM D6078 Ball on Cylinder Lubricity Evaluation at Scuffing Load would have been made. The mass balance calculations for the 18 concentrations of lubricity additives used in the three test fuels are given in **Table 2**.

Emissions Test Fuels

The EECP Team provided the individual 22 gallon test retains required for Subtask 2.6.2 product evaluations with a composite blend (Subtask 2.5.2 and Subtask 2.5.7.1b&c) of neat F-T diesel product, the Subtask 2.5.3 hydrocracker F-T diesel product, and a blend composed of Subtask 2.5.3 hydrocracker F-T diesel product and Subtask 2.5.7.6.a hydrotreater F-T diesel products. The EECP Team purchased sufficient quantity of the Tier II CARB-like diesel used as reference fuel. These four test fuel candidates were qualified for the Subtask 2.6.2 Hot-Start Transient emission testing program after passing lubricity inspection.

The passing low wear scar width of 230 microns for the composite blend (Subtask 2.5.2 and Subtask 2.5.7.1b&c) neat F-T diesel product (SwRI Internal Code FL-2783 for test fuel) made it possible to omit lubricity additive from this test fuel for the emissions work performed in Subtasks 2.6.2. The Subtask 2.5.3 hydrocracker F-T diesel product (SwRI Internal Code FL2784 for test fuel), the blend) composed of Subtask 2.5.3 hydrocracker F-T diesel product and Subtask 2.5.7.6.a hydrotreater F-T diesel product (SwRI Internal Code 2785 for test fuel), and the Tier II CARB-like diesel (SwRI Internal Code FL-2782 for test fuel) used as a reference fuel were all treated and passed with a commercial lubricity Additive 1 treatment at 175 ppm.

Table 1. Solutions of test fuels with varying concentrations of lubricity additives

Test No.	FUEL	ADDITIVE	CONC ppm
	Neat FT Diesel		
	FL-2783	**None**	**0**
1	FL-2783	Lubricity Additive 1	12.7
2	FL-2783	Lubricity Additive 1	103.9
3	FL-2783	Lubricity Additive 1	207.1
	FL-2783	**None**	**0**
4	FL-2783	Lubricity Additive 2	12.1
5	FL-2783	Lubricity Additive 2	100.6
6	FL-2783	Lubricity Additive 2	205.6
	Hydrocracker F-T Diesel		
	FL2784	**None**	**0**
7	FL-2784	Lubricity Additive 1	12.8
8	FL-2784	Lubricity Additive 1	100.5
9	FL-2784	Lubricity Additive 1	201.4
	FL2784	None	**0**
10	FL-2784	Lubricity Additive 2	12.2
11	FL-2784	Lubricity Additive 2	103.2
12	FL-2784	Lubricity Additive 2	201.9
	Blend of HC + HT F-T Diesel		
	LN-1300	**None**	**0**
13	LN-1300	Lubricity Additive 1	12.1
14	LN-1300	Lubricity Additive 1	99.3
15	LN-1300	Lubricity Additive 1	200.3
	LN-1300	**None**	**0**
16	LN-1300	Lubricity Additive 2	12.3
17	LN-1300	Lubricity Additive 2	100.7
18	LN-1300	Lubricity Additive 2	200.1

Table 2. Mass balance calculations for test solutions

Stock Solution Prepared Neat F-T Diesel			**ppm**	**FL-2783, G**	**Lubricity Additive 1, G**	**TOTAL, Grams**	
			1039	29.5462	0.0307	29.5769	
			ppm	**FL-2783, G**	**Lubricity Additive 2, G**	**TOTAL, Grams**	
			1176	33.84119	0.0398	33.88099	
Blend	**fuel**	**Additive**	**ppm**	**PPM CONC**	**Additve, G**	**FL-2783, Grams**	**TOTAL, G**
1	fl-2783	Additive 1	12.7	1039.05071	0.6081	49.258	49.8661
2	fl-2783	Additive 1	103.9	1039.05071	4.9114	44.2043	49.1157
3	fl-2783	Additive 1	207.1	1039.05071	9.7791	39.2724	49.0515
1	fl-2783	Additive 2	12.1	1176.08157	0.5043	48.4884	48.9927
2	fl-2783	Additive 2	100.6	1176.08157	4.1506	44.3781	48.5287
3	fl-2783	Additive 2	205.6	1176.08157	8.4623	39.9389	48.4012
Stock Solution Prepared Hydrocracker Diesel			**ppm**	**FL-2784, G**	**Lubricity Additive 1, G**	**TOTAL, Grams**	
			1125	29.0574	0.0327	29.0901	
			ppm	**FL-2784, G**	**Lubricity Additive 2, G**	**TOTAL, Grams**	
			1444	28.5393	0.0412	28.5805	
Blend	**fuel**	**Additive**	**ppm**	**PPM CONC**	**Additve, G**	**FL-2783, Grams**	**TOTAL, G**
1	fl-2784	Additive 1	12.8	1125.35877	0.5484	47.8468	48.3952
2	fl-2784	Additive 1	100.5	1125.35877	4.0107	40.8848	44.8955
3	fl-2784	Additive 1	201.4	1125.35877	8.026	36.8312	44.8572
1	fl-2784	Additive 2	12.2	1443.62335	0.3805	44.674	45.0545
2	fl-2784	Additive 2	103.2	1443.62335	3.2177	41.7923	45.01
3	fl-2784	Additive 2	201.9	1443.62335	6.2838	38.6452	44.929
Stock Solution Prepared Blend of Hydrotreater and Hydrocracker Diesel			**ppm**	**LN-1300,G**	**Lubricity Additive 1, G**	**TOTAL, Grams**	
			1014	29.2828	0.0297	29.3125	
			ppm	**LN-1300, G**	**Lubricity Additive 2, G**	**TOTAL, Grams**	
			1041	32.2616	0.0336	32.2952	
Blend	**fuel**	**Additive**	**ppm**	**PPM CONC**	**Additve, G**	**FL-2783, Grams**	**TOTAL, G**
1	LN-1300	Additive 1	12.1	1014.24727	0.591	48.8508	49.4418
2	LN-1300	Additive 1	99.3	1014.24727	4.4049	44.1	44.9735
3	LN-1300	Additive 1	200.3	1014.24727	8.9117	39.2	45.1328
1	LN-1300	Additive 2	12.3	1041.48585	0.532	39.2	45.1464
2	LN-1300	Additive 2	100.7	1041.48585	4.4253	39.2	45.7875
3	LN-1300	Additive 2	200.1	1041.48585	8.7861	39.2	45.72029

Results and Discussion

Subtask 2.6.1 entitled "Lubricity Additive Testing" mitigates the potential risk of engine failure from the use of F-T diesels. The ASTM D6079 lubricity test (Lubricity of Diesel Fuel by High Frequency Reciprocating Rig [HFRR]) was conducted on the fuels. A HFRR wear scar width of less than 450 microns is considered acceptable by United States and European standards. The lubricity measurements were made in two sets: 1) test samples of the F-T neat and blended mixtures for evaluation testing and 2) the actual 22 gallon retains of each of the four test fuel candidates designated for product evaluation in Subtask 2.6.2 Hot-Start Transient emission testing. Sample solutions of 24 compositions were prepared in the laboratory and used for the lubricity inspection tests. These 24 compositions constituted a matrix of four levels of lubricity additive dosage for each of the three F-T diesel test fuel candidates and two commercial lubricity additives to be examined.

Fuel candidate lubricity property testing was performed first to confirm the need for additive use The EECP team then conducted trials with two commercial lubricity additives on each of the three F-T test diesel fuel candidates at target additive concentrations of 15 ppm, 100 ppm and 200 ppm. Two commercial lubricity additives designated as Additive 1 and Additive 2 provided by the EECP team were evaluated at the above treatment levels on the three F-T diesels. The three F-T diesel fuel candidates are the composite blend of the Subtask 2.5.2 and Subtask 2.5.7.1.b&c neat F-T diesel product, the Subtask 2.5.3 hydrocracker F-T diesel product, and a blend of the Subtask 2.5.3 hydrocracker F-T diesel product and the Subtask 2.5.7.6.a hydrotreater F-T diesel product.

The results on the tests samples are presented in the last column of Table 3. The HFRR wear scar width data presented in **Table 3** show the results of the initial lubricity inspection done on the neat F-T diesel product, the hydrocracker (HC) F-T diesel product, and the blend of hydrocracker (HC) and hydrotreater (HT) F-T diesel products. An evaluation of the data in Table 3 confirms that the neat F-T diesel passes lubricity inspection without additive treatment with an HFRR 230 micron wear scar width that is well below the HFRR wear scar width of less than 450 microns considered acceptable by United States and European standards. The hydrocracker F-T diesel product, the blend of hydrocracker and hydrotreater F-T diesel products, and the Tier II CARB-like diesel all exhibited failing HFRR wear scar widths in the 600 micron to 640 micron range.

An evaluation of the data presented in **Table 3** show the response of the neat F-T diesel product, the hydrocracker F-T diesel product, and the blend of hydrocracker and hydrotreater F-T diesel products to treatments with the commercial lubricity Additive 1 at target concentrations of 15 ppm, 100 ppm, and 200 ppm. The HFRR wear scar width was reduced for each of the three F-T diesels as the Additive 1 concentration was increased. The 640 HFRR wear scar width without additive for the hydrocracker (HC) F-T diesel product decreased to 450 micron to 220 micron as the Additive 1 concentration was increased from a target concentration of 100 ppm to 200 ppm. The 600 HFRR wear scar width without additive for the blend of hydrocracker (HC) and hydrotreater (HT) F-T diesel products decreased to 570 micron to 280 micron as the Additive 1 concentration was increased from a target concentration of 100 ppm to 200 ppm.

The Tier II CARB-like diesel was not part of the additive trials. The Tier II CARB-like diesel failed lubricity inspection with an HFRR wear scar width of 605 microns and passed lubricity with a HFRR wear scar width of 385 microns with an Additive 1 treatment of 175 ppm As discussed later the Additive 1 treatment at 175 ppm is equivalent to the additive treatment used on the failing Subtask 2.5.3 hydrocracker diesel F-T diesel product and the blend composed of Subtask 2.5.3 hydrocracker F-T diesel product and Subtask 2.5.7.6.a hydrotreater F-T diesel products.

To observe the effect of concentration upon the response of the lubricity of the F-T test fuels to additive concentration, the wear scar dimension for the neat (unadditized) and additized samples were plotted along with the US and European wear scar threshold values in **Figure 1**. The results from Table 3 are plotted in Figure 1 where the broken lines correspond to Lubricity Additive 1 and the solid lines correspond to Lubricity Additive 2. The actual emissions test fuels were tested for their lubricity. The correlations presented in Figure 1 were the basis for determining the 175 ppm additive treatment level required on the 22 gallon retains of each of the two F-T diesel test fuel candidates requiring treatment to quality for product evaluations in Subtask 2.6.2 Hot-Start Transient emission testing.

HFRR wear scar widths obtained with the Additive 2 trials conducted on each of the three F-T diesels at target concentrations of 15 ppm, 100 ppm, and 200 ppm are presented in **Table 3**.The hydrocracker F-T diesel product and the blend of hydrocracker and hydrotreater F-T diesel products which failed lubricity without additive treatment did not have a significant response to treatment with the commercial lubricity **Additive 2**. A passing HFRR wear scar of less than 450 microns could not be obtained on the F-T diesels with Additive 2 treatments in the 15 ppm to 200 ppm concentration range.

The correlations presented in Figure 1 indicate an Additive 1 treatment at a 175 ppm concentration should qualify the Subtask 2.5.3 hydrocracker diesel F-T diesel product and the blend composed of Subtask 2.5.3 hydrocracker F-T diesel product and Subtask 2.5.7.6.a hydrotreater F-T diesel products as test fuel candidates for the Subtask 2.6.2 product evaluations. The data presented in **Table 4** shows these two F-T test fuel candidates passing lubricity and qualifying for Subtask 2.6.2 product evaluations. A passing HFRR wear scar width of 415 microns was obtained on the hydrocracker F-T diesel product at an Additive 1 concentration of 175 ppm. A passing HFRR wear scar width of 4oo microns was obtained on the blend of hydrocracker and hydrotreater F-T diesel products at an Additive 1 concentration of 175 ppm. A passing HFRR wear scar width of 385 microns was obtained on the Tier II CARB-like diesel at an Additive 1 concentration of 175 ppm. The neat F-T diesel product produced a 230 micron HFRR wear scar width with out additive treatment which passed the less than 450 micron specification for the US and Europe. All four of the test fuel candidates qualify for the Subtask 2.6.2 product evaluations.

Table 3

Wear scar dimensions for test fuel solutions with varying lubricity additive concentrations

Test No.	FUEL	ADDITIVE	CONC ppm	HFRR Φm
	Neat FT Diesel			
	FL-2783	**None**	**0**	**230**
1	FL-2783	Lubricity Additive 1	12.7	240
2	FL-2783	Lubricity Additive 1	103.9	160
3	FL-2783	Lubricity Additive 1	207.1	110
	FL-2783	**None**	**0**	**230**
4	FL-2783	Lubricity Additive 2	12.1	235
5	FL-2783	Lubricity Additive 2	100.6	225
6	FL-2783	Lubricity Additive 2	205.6	205
	Hydrocracker F-T Diesel			
	FL2784	**None**	**0**	**640**
7	FL-2784	Lubricity Additive 1	12.8	595
8	FL-2784	Lubricity Additive 1	100.5	450
9	FL-2784	Lubricity Additive 1	201.4	220
	FL2784	None	**0**	**640**
10	FL-2784	Lubricity Additive 2	12.2	580
11	FL-2784	Lubricity Additive 2	103.2	595
12	FL-2784	Lubricity Additive 2	201.9	580
	Blend of HC + HT F-T Diesels			
	LN-1300	**None**	**0**	**600**
13	LN-1300	Lubricity Additive 1	12.1	610
14	LN-1300	Lubricity Additive 1	99.3	570
15	LN-1300	Lubricity Additive 1	200.3	280
	LN-1300	**None**	**0**	**600**
16	LN-1300	Lubricity Additive 2	12.3	610
17	LN-1300	Lubricity Additive 2	100.7	585
18	LN-1300	Lubricity Additive 2	200.1	530

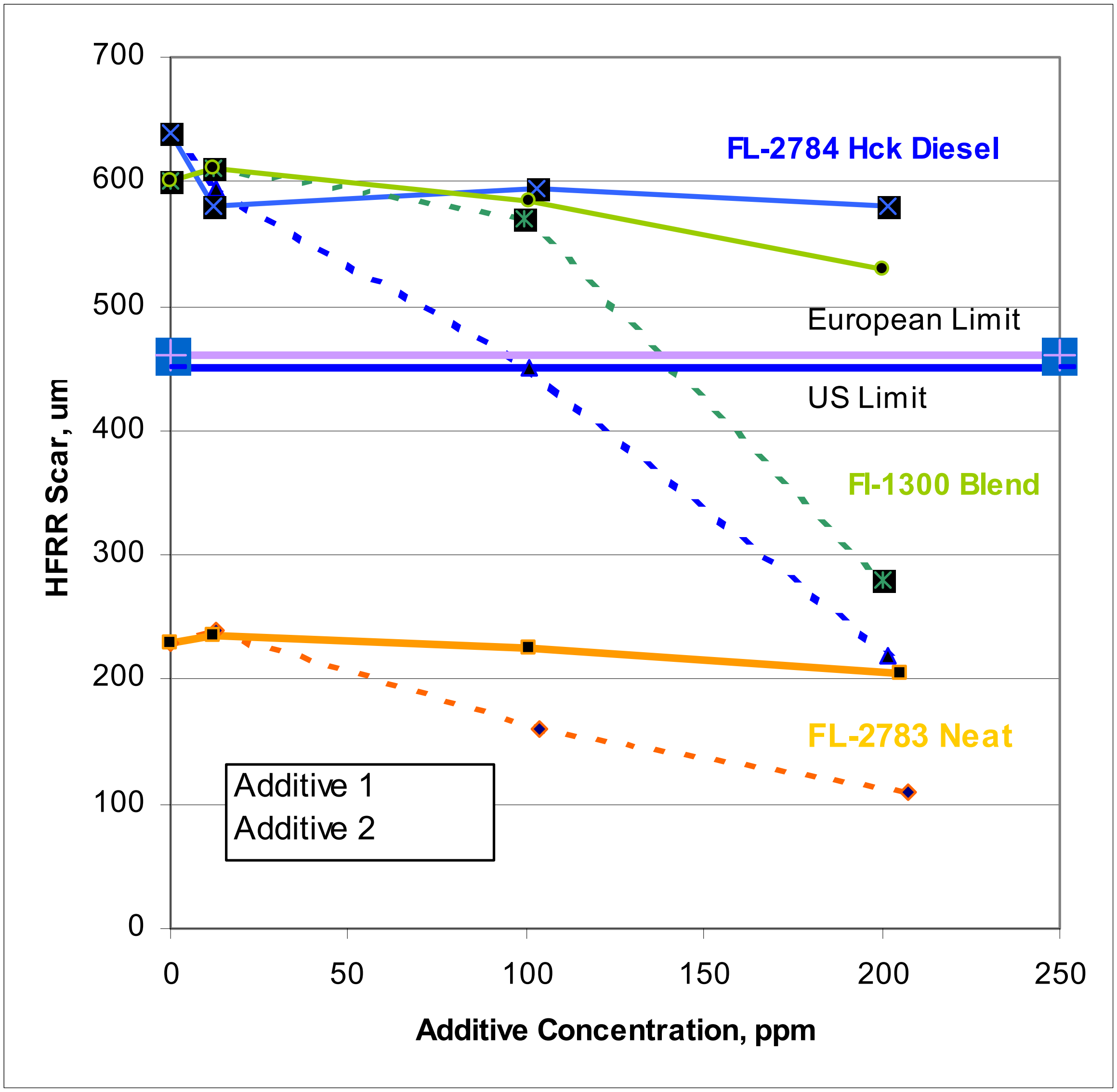

Figure 1. Wear scar dimension versus additive concentration

Table 4. Wear scar dimensions for emissions fuel blends with lubricity additive

Emissions Fuels Testing Results				
Test #	**Sample ID**	**Run #1**	**Run#2**	**Average**
1	FL-2782 neat DIESEL 2004 TIER 1	610	600	605
2	FL-2782 HC FT DIESEL + 175 PPM Additive 1	415	410	412.5
3	FL-2783 HC +HT +175 PPM Additive 1	400	390	395

Conclusions

1. The Neat F-T Diesel did not require additive to produce a wear scar less than either the working US or European thresholds.

2. For the hydrocracker F-T diesel product and the blend of hydrocracker and hydrotreater F-T diesel products, Lubricity Additive 1 provided a greater effect at lowering the wear scar dimension per unit of concentration compared to Lubricity Additive 2. In addition, for the concentrations tested, only Lubricity Additive 1 was successful at lowering the wear scar dimension to levels below the US and European limits for all test fuels.

3. The 2004 Tier 2 CARB-like diesel produced a 605 micron wear scar width, clearly above the threshold of 450 microns. The Tier II CARB-like diesel was therefore treated at the 175 ppm lubricity Additive 1 concentration. The HFRR wear scar width was reduced from 605 microns to a passing 385 micron wear scar width.

4. A concentration of 175 ppm of Lubricity Additive 1 in the three test fuel candidate requiring additive treatment provided adequate wear protection based upon the US and European threshold wear scar dimensions. This concentration falls within the additive manufacturers' recommended range of 15 to 200 ppm.

5. All four test fuel candidates passed lubricity inspection and are qualified for Subtask 2.6.2 Hot-Start Transient Emission Testing.

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List of Acronyms and Abbreviations

AGR	acid gas removal unit
ASTM	American Society for Testing and Materials
C_1	Compounds with Carbon Number of One
C_2	Compounds with Carbon Number of Two
C_3	Compounds with Carbon Number of Three
CARB	California Air Resources Board
CCR	California Code of Regulations
CFR	Code of Federal Regulations
cm	centimeters
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COV	Coefficients of Variation
DCRP	Delaware City Repowering Project
DDC	Detroit Diesel Corporation
DER	Department of Emissions
DOE	U.S. Department of Energy
EECP	Early Entry Coproduction Plant
EPA	U.S. Environmental Protection Agency
F-T	Fischer-Tropsch
ft	feet
FTP	Federal Test Procedure
g	gram
GC	gas chromatograph
HC	Hydrocarbons or Hydrocracking
HT	Hydrotreater
HFRR	High Frequency Reciprocating Rig
IGCC	Integrated Gasification Combined Cycle
in	inch
kPa	kilo Pascals
mm	millimeter
NO_x	nitrogen oxides
O_2	oxygen
PM	Total Particulate
ppm	parts per million
Psia	ounds force per square inch absolute
SOF	Soluble Organic Fraction
SRU	Sulfur recovery unit
SO4	Sulfate
SwRI	Southwest Research Institute
TGTU	tail gas recovery unit
WTC	Westhollow Technology Center
wt%	weight percent

EARLY ENTRANCE COPRODUCTION PLANT
PHASE II

Appendix B -Test Report

Subtask 2.6.2: HOT-START TRANSIENT ENGINE TEST

Reporting Period: January 2001 to June 2003

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Date Issued: July 2003

Executive Summary

The overall objective of this project is the three phase development of an Early Entrance Coproduction Plant (EECP) which uses petroleum coke produces at least one product from at least two of the following three categories: (1) electric power (or heat), (2) fuels, and (3) chemicals using ChevronTexaco's proprietary gasification technology. The objective of Phase I is to determine the feasibility and define the concept for the EECP located at a specific site; develop a Research, Development, and Testing (RD&T) Plan to mitigate technical risks and barriers; and prepare a Preliminary Project Financing Plan. The objective of Phase II is to implement the work as outlined in the Phase I RD&T Plan to enhance the development and commercial acceptance of coproduction technology. The objective of Phase III is to develop an engineering design package and a financing and testing plan for an EECP located at a specific site.

The project's intended result is to provide the necessary technical, economic, and environmental information needed by industry to move the EECP forward to detailed design, construction, and operation. The partners in this project are Texaco Energy Systems LLC or TES (a subsidiary of ChevronTexaco), General Electric (GE), Praxair, and Kellogg Brown & Root (KBR) in addition to the U.S. Department of Energy (DOE). TES is providing gasification technology and Fischer-Tropsch (F-T) technology developed by Rentech, GE is providing combustion turbine technology, Praxair is providing air separation technology, and KBR is providing engineering.

Each of the EECP subsystems was assessed for technical risks and barriers. A plan was developed to mitigate the identified risks (Phase II RD&T Plan, October 2000). Phase II RD&T Task 2.6 identified as potential technical risks to the EECP the fuel/engine performance and emissions of the F-T diesels. Hydrotreating the neat F-T diesel product reduces potentially reactive olefins, oxygenates, and acids levels and alleviates corrosion and fuel stability concerns. Future coproduction plants can maximize valuable transportation diesel by hydrocracking the F-T Synthesis wax product to diesel and naphtha. The upgrader neat F-T diesel, hydrotreater F-T diesel, and hydrocracker F-T diesel products would be final blending components in transportation diesel.

Phase II RD&T Task 2.6 successfully carried out fuel lubricity property testing, fuel response to lubricity additives, and hot-start transient emission tests on a neat F-T diesel product, a hydrocracker F-T diesel product, a blend of hydrotreater and hydrocracker F-T diesel products, and a Tier II CARB-like diesel reference fuel. Only the neat F-T diesel passed lubricity inspection without additive while the remaining three fuel candidates passed with conventional additive treatment. Hot-start transient emission tests were conducted on the four fuels in accordance with the EPA Federal Test Procedure (FTP) specified in Code of Federal Regulations, Title 40, Part 86, and Subpart N on a rebuilt 1991 Detroit Diesel Corporation series 60 heavy-duty diesel engine. Neat F-T diesel fuel reduced oxides of nitrogen ($N0_x$), total particulate (PM), hydrocarbons (HC), carbon monoxide (CO), and the Soluble Organic Fraction (SOF) by 4.5%, 31%, 50%, 29% and 35% compared to the Tier II CARB-like diesel. The hydrocracker F-T diesel product and a blend of hydrocracker and hydrotreater F-T diesel products also reduced NO_x, PM, HC, CO and SOF by 13%, 16% to 17%, 38% to 63%, 17% to 21% and 21% to 39% compared to the Tier II CARB-like diesel. The fuel/engine performance and emissions of the three F-T diesels exceed the performance of a Tier II CARB-like diesel.

Hot-Start Transient Engine Test

Test results presented in this report were generated by the Department of Emissions Research (DER), Automotive Products and Emissions Research of Southwest Research Institute (SwRI), for Texaco Energy Systems. This report documents emission results collected from a 1991 Detroit Diesel Corporation (DDC) Series 60 heavy-duty diesel engine using three candidate F-T fuels and a reference fuel. The results were generated using a protocol similar to that specified by the California Air Resources Board (CARB). The testing procedure was based on transient emission measurement procedures developed by the EPA for emission regulatory purposes. This protocol utilized several hot-start transient emission tests run in a specific sequence using four diesel fuels: a low-sulfur 2D as a reference fuel, Fuel R; and three F-T fuels identified as Fuels C_1, C_2, and C_3.

Experimental
For testing, a rebuilt 1991 Detroit Diesel Corporation (DDC) Series 60 heavy-duty diesel engine was mounted in transient-capable Test Cell 16. **Figure 1** shows the engine as connected to the dynamometer. A portable fuel metering system was positioned near the engine to reduce the length of the fuel transport lines. **Figure 2** shows the position of this fuel system relative to the engine, and **Table 1** lists the four fuels that were tested along with their respective SwRI fuel codes and a brief description of the fuels.

Hot-start transient emission tests were conducted in accordance with the EPA Federal Test Procedure (FTP) specified in the Code of Federal Regulations (CFR), Title 40, Part 86, Sub part N. For purposes of this study, hot-start transient tests were run with the four fuels in the specific test sequence requested by Texaco Energy Systems (a subsidiary of ChevronTexaco) given in **Table 2**. This sequence was established in an effort to minimize the effects of any potential residual from the previous fuel tested on the results obtained for the neat F-T diesel fuel. Established test procedures were followed for instrumentation and sample system calibrations, fuel changes, engine performance checks, gaseous and particulate sampling and measurement, and transient test performance.

The hot-start transient command cycle, used for all fuels, was created based on a torque-map generated from the reference fuel (ID Number FL-2782). The reference fuel was obtained from Chevron Phillips Chemical Company as their Diesel 2004 Tier II fuel. The torque-map on reference fuel along with torque-maps generated with fuels C_1, C_2, and C_3 are listed in **Table 3**, given in the order run. The torque-map results for the candidate fuels are given for record purposes only.

The screening protocol used in this study was based on the transient emission measurement procedure developed by the EPA for emissions regulatory purposes. In general, this screening protocol required less time and fuel than the complete CARB test protocol, Section 2282, Aromatic Content of Diesel Fuel of Title 13, California Code of Regulations (CCR), December 26, 1991; but should yield sufficient emissions information to allow Texaco Energy Systems (a subsidiary of ChevronTexaco) to identify fuel formulations with potential to significantly reduce emissions. This fuel-screening program generated hot-start transient emission results for hydrocarbons (HC), carbon dioxide (CO_2), carbon monoxide (CO), oxides of nitrogen (NO_x), and total particulate (PM) for each fuel. Soluble organic fraction (SOF) of PM and sulfate emission levels were also determined from the analysis of total particulate samples collected for each test fuel. The analytical methods used to detect these pollutants are listed in **Table 4**.

FIGURE 1. 1991 DDC SERIES 60 ENGINE INSTALLED IN TRANSIENT TEST CELL 16

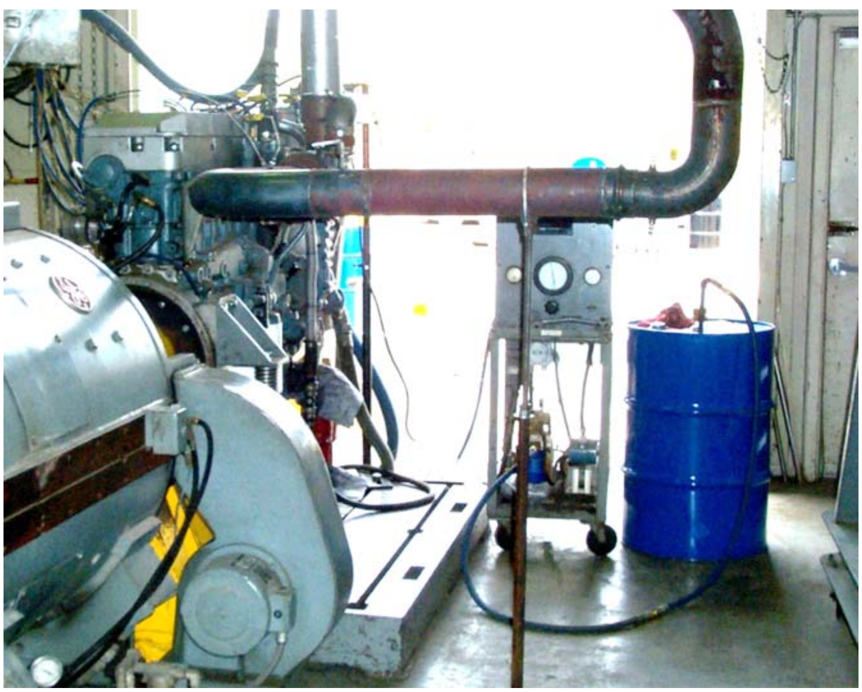

FIGURE 2. FUEL METERING SYSTEM FOR 1991 DDC SERIES 60 ENGINE

TABLE 1. LIST OF TEXACO ENERGY SYSTEMS SUPPLIED DIESEL FUELS FOR TASKS 2.6.2 AND 2.63

Fuel Label	SwRI Fuel Code	Description	Task Nomenclature
Reference	FL-2782	Philips 2004 Diesel Tier 2	Reference Fuel
Candidate 1	FL-2783	Neat F-T Diesel	Neat F-T Diesel
Candidate 2	FL-2784	Hydrocracked Diesel	WOW 9298
Candidate 3	FL-2785	HCK+HDT Blend Diesel	Blend PGQ 1142 & WOW 9306

TABLE 2. PROCEDURE FOR ACCUMULATING EMISSIONS DATA ON SEVERAL FUELS USING HOT-START TRANSIENT TESTING

Step	Description (SwRI Project 01-04786)
1	Perform emission instrument calibrations as required. Calibrate torquemeter and check signal conditioning systems. Validate CVS gaseous and particulate sampling systems using propane recovery techniques.
2	With the engine installed in a transient-capable test cell, check engine condition using in-house, low sulfur emissions type fuel, and note fault codes if any. Bring engine oil level to "full" using Mobil Delvac Super 1300 15w-40 oil.
3	On Day 1 of testing, perform fuel change procedure to Fuel R (FL-2782 Phillips 2004 Diesel Tier 2). Change fuel filters, purge fuel supply, etc.
4	Operate engine at rated speed and load for approximately 10 minutes, then power validate engine.
5	Conduct transient "full-throttle" torque map from low to high-idle and create a transient command cycle. This initial transient command cycle, generated with Fuel R, will be used for all subsequent emission tests in this test plan. Torque-map data generated with other fuels will be saved for review.
6	Run two 20-minute practice EPA transient cycles without engine-off soak between cycles, and adjust dynamometer controls to meet statistical limits for transient cycle operation.
7	After a 20-minute engine-off soak, run a hot-start transient cycle for HC, CO, CO_2, and total particulate emissions. Process samples of total particulate for sulfate and SOF levels. Repeat until emission data for three hot-start transient cycles are accumulated.
8	Repeat Steps 3-7 with Fuel C2 FL-2784.
9	Repeat Steps 3-7 with Fuel C1 FL-2783 on Day 2 of testing.
10	Repeat Steps 3-7 with Fuel R on Day 2 of testing.
11	Repeat Steps 4-7 with Fuel R on Day 3 of testing.
12	Repeat Steps 3-7 with Fuel C3 FL-2785 on Day 3 of testing.
13	Summarize data and prepare final report.

TABLE 3. TRANSIENT TORQUE MAPS FOR THE 1991 DDC SERIES 60 TEST ENGINE OVER THREE TEST DAYS AND WITH FOUR FUELS

Engine Speed, rpm	TRANSIENT TORQUE MAPS USING FOUR TEST FUELS, N-m					
	Day 1		Day 2		Day 3	
	FL-2782[(a)]	FL-2784	FL-2782	FL-2783	FL-2782	FL-2785
400	703	659	705	673	701	681
500	728	709	732	697	727	717
600	839	821	839	804	833	826
700	930	890	922	882	921	887
800	1088	1035	1071	1009	1078	1023
900	1249	1203	1240	1162	1249	1187
1,000	1425	1398	1420	1363	1429	1393
1,100	1591	1576	1588	1556	1602	1579
1,200	1838	1756	1820	1748	1821	1764
1,300	1785	1717	1789	1691	1786	1716
1,400	1722	1657	1732	1633	1722	1652
1,500	1644	1581	1641	1557	1646	1580
1,600	1550	1495	1549	1470	1550	1504
1,700	1448	1391	1454	1370	1444	1390
1,800	1359	1303	1359	1279	1359	1299

(a) The initial Fuel FL-2782 torque-map was the basis for generating the transient command cycle used in emission tests for all fuels.

TABLE 4. LIST OF MEASURED EMISSIONS AND ANALYTICAL METHODS

Compound	Abbreviation	Analytical Method
Hydrocarbon	HC	Heated Flame Ionization Detector
Carbon Monoxide	CO	Non-Dispersive Infrared Analyzer
Carbon Dioxide	CO2	Non-Dispersive Infrared Analyzer
Oxides of Nitrogen	NOx	Chemiluminescent Analyzer
Particulate Matter	PM	Microbalance
Soluble Organic Fraction of PM	SOF	Micro-Soxhlet with Toluene-Ethanol
Sulfate	SO4	Ion Chromatography

Results and Discussion

Subtask 2.6.2 entitled "Hot-Start Cycle Transient Engine Test" mitigates the potential economic risks identified in the Phase II RD&T Task 2.6 plan dealing with obtaining a premium price in the market place for the anticipated superior performance of these F-T diesel fuels. Subtask 2.6.2 determined whether the superior properties of low sulfur, low aromatics, and high cetane exhibited by the F-T diesels from initial inspection testing produce hot-start cycle transient engine test performances that yield lower fuel emissions than conventional diesel fuels. Subtask 2.6. 2 yielded sufficient emissions information to identify the F-T diesels has fuels providing significant reductions in emissions. The Subtask 2.6.2 fuel-screening program generated hot-start transient emission results for oxides of nitrogen (NO_x), total particulate (PM) hydrocarbons (HC), carbon monoxide (CO), and the Soluble Organic Fraction from the total particulates (PM) for each of the three F-T diesels.

The matrix of emission tests in this program consisted of eighteen hot-start transient tests performed over a three-day period. Hot-start tests using a reference and three candidate fuels were conducted in an order specified by Texaco Energy Systems (Subsidiary of ChevronTexaco). The transient command cycle was generated from torque-map information obtained on Test Day 1, using reference fuel FL-2782.

The hot-start transient emission results generated in this study are presented in chronological order in **Table 5**. Corresponding computer printouts of emission results for hot-start tests on the four diesel fuels are provided in the Appendix. A total of eighteen hot-start transient tests were conducted in this project using four diesel fuels. During the three test days, hot-start transient HC, CO, CO_2, NO_x, and PM, emissions were measured for three tests on each of the three candidate fuels and with the reference fuel. SOF and sulfate emission levels were also determined from total particulate samples generated during the testing. Hot-start test results were averaged for each fuel with three tests being averaged for the each candidate fuel and nine tests being averaged for the reference fuel. These averages are presented in Table 6, along with the coefficients of variation (COV) for emissions and performance. Figure 3 summarizes the results and indicates the variance for HC, CO, NO_x and PM emissions.

The hot-start transient emission data presented in Figure 3 shows the neat F-T diesel reduced oxides of nitrogen ($N0_x$), particulate matter (PM), hydrocarbons (HC), carbon monoxide (CO), and the Soluble Organic Fraction (SOF) from total particulates (PM) by 4.5 %, 31 %, 50 %, 29 % and 35% compared to a Tier II CARB-like diesel. The hydrocracker F-T diesel product also reduced NO_x, PM, HC, CO and SOF by 13%, 16%, 38%, 17% and 21% compared to the Tier II CARB-like diesel. The blend of hydrocracker and hydrotreater F-T diesel products also reduced NO_x, PM, HC, CO and SOF by 13%, 17%, 63%, 21% and 39% compared to a Tier II CARB-like diesel. The fuel/engine performance and emissions of the three F-T diesels exceed the performance of a Tier II CARB-like diesel fuel

Each of the candidate fuels produced lower emission levels than the reference fuel. The neat F-T diesel fuel (SwRl Internal Code No. FL-2783) produced the greatest PM improvement; however, this fuel produced the highest amount of NO_x compared to the other candidate fuels. The hydrocracked (FL-2784) and blended (FL-2785) diesel fuels produced similar amounts of NO_x and PM.

TABLE 5. HOT-START EMISSION RESULTS FROM A 1991 DDC SERIES 60 USING FOUR DISTINCT FUELS

Test Day	Fuel Code	Fuel Description	Test Number	Ref. Work (kW-hr)	Actual Work (kW-hr)	Brake-Specific Emission Results: BSFC (kg/kW-hr)	BSHC (g/kW-hr)	BSCO (g/kW-hr)	$BSCO_2$ (g/kW-hr)	$BSNO_x$ (g/kW-hr)	BSPM (g/kW-hr)	SOF (mg/kW-hr)	$SO_4^{=}$ (mg/kW-hr)
DAY 1	FL-2782	Philips 2004 Diesel Tier 2	TEX R-2782-H1	17.55	17.65	0.229	0.11	3.08	715	5.94	0.237	69.1	0.14
			TEX R-2782-H2	17.55	17.64	0.230	0.12	3.12	720	5.92	0.237	68.4	ND
			TEX R-2782-H3	17.55	17.60	0.230	0.09	3.10	718	5.84	0.238	102.2	ND
	R-2782 Three Test Average			17.55	17.63	0.229	0.11	3.10	718	5.90	0.238	79.9	0.14
	FL-2784	Hydrocracked Diesel	TEX C2-2784-H1	17.55	17.47	0.227	0.07	2.65	702	5.15	0.198	55.8	ND
			TEX C2-2784-H2	17.55	17.47	0.227	0.05	2.56	703	5.14	0.198	59.7	0.07
			TEX C2-2784-H3	17.55	17.46	0.228	0.08	2.54	705	5.11	0.201	47.9	0.13
	C2-2784 Three Test Average			17.55	17.47	0.227	0.06	2.58	703	5.13	0.199	54.5	0.10
DAY 2	FL-2783	Neat F-T Diesel	TEX C1-2783-H1	17.55	17.39	0.235	0.06	2.23	717	5.70	0.162	50.0	0.17
			TEX C1-2783-H2	17.55	17.40	0.238	0.03	2.22	724	5.63	0.161	43.0	0.31
			TEX C1-2783-H3	17.55	17.40	0.236	0.06	2.21	718	5.64	0.162	42.2	ND
	C1-2783 Three Test Average			17.55	17.39	0.236	0.05	2.22	720	5.65	0.162	45.1	0.24
	FL-2782	Philips 2004 Diesel Tier 2	TEX R-2782-H4	17.55	17.61	0.231	0.07	3.18	724	5.97	0.236	49.3	0.12
			TEX R-2782-H5	17.55	17.62	0.229	0.11	3.14	716	5.98	0.234	76.2	0.07
			TEX R-2782-H6	17.55	17.63	0.230	0.11	3.12	720	5.91	0.234	97.5	0.11
	R-2782 Three Test Average			17.55	17.62	0.230	0.10	3.15	720	5.96	0.235	74.3	0.10
DAY 3	FL-2782	Philips 2004 Diesel Tier 2	TEX R-2782-H7	17.55	17.62	0.231	0.13	3.08	723	5.95	0.230	65.9	0.27
			TEX R-2782-H8	17.55	17.62	0.227	0.10	3.07	711	5.88	0.233	44.5	0.44
			TEX R-2782-H9	17.55	17.62	0.231	0.14	3.07	723	5.99	0.238	47.4	0.06
	R-2782 Three Test Average			17.55	17.62	0.230	0.12	3.07	719	5.94	0.234	52.6	0.26
	R-2782 Nine Test Average			17.55	17.62	0.230	0.11	3.11	719	5.93	0.235	68.9	0.17
	FL-2785	HCK+HDT Blend Diesel	TEX C3-2785-H1	17.55	17.52	0.226	0.04	2.48	701	5.15	0.198	45.8	ND
			TEX C3-2785-H2	17.55	17.53	0.227	0.04	2.46	703	5.08	0.194	45.7	ND
			TEX C3-2785-H3	17.55	17.53	0.224	0.05	2.47	695	5.18	0.195	35.2	ND
	C3-2785 Three Test Average			17.55	17.53	0.226	0.04	2.47	700	5.14	0.196	42.2	ND

ND = None Detected

* None Detected points were excluded from averaged values

TABLE 6. SUMMARY OF AVERAGE HOT-START EMISSION RESULTS FROM A 1991 DDC SERIES 60 USING FOUR FUELS

Fuel Code	Fuel Description	Actual Work (kW-hr)	BSFC (kg/kW-hr)	Brake-Specific Emission Results: BSHC (g/kW-hr)	BSCO (g/kW-hr)	$BSCO_2$ (g/kW-hr)	$BSNO_x$ (g/kW-hr)	BSPM (g/kW-hr)	SOF (mg/kW-hr)	SO_4 (mg/kW-hr)
FL-2782	Philips 2004 Diesel Tier 2	17.62	0.230	0.11	3.11	719	5.93	0.235	68.9	0.17
COV		0.1%	0.6%	18.8%	1.2%	0.6%	0.9%	1.1%	30.0%	-
FL-2783	Neat Diesel	17.39	0.236	0.05	2.22	720	5.65	0.162	45.1	0.24
COV		0.0%	0.6%	36.3%	0.3%	0.6%	0.7%	0.5%	9.4%	-
FL-2784	Hydrocracked Diesel	17.47	0.227	0.06	2.58	703	5.13	0.199	54.5	0.10
COV		0.0%	0.3%	22.9%	2.3%	0.3%	0.4%	0.9%	11.0%	-
FL-2785	HCK+HDT Blend Diesel	17.53	0.226	0.04	2.47	700	5.14	0.196	42.2	ND
COV		0.0%	0.6%	17.5%	0.5%	0.6%	1.0%	1.0%	14.5%	-

ND = None Detected

(-) COV was not found due to None Detect points.

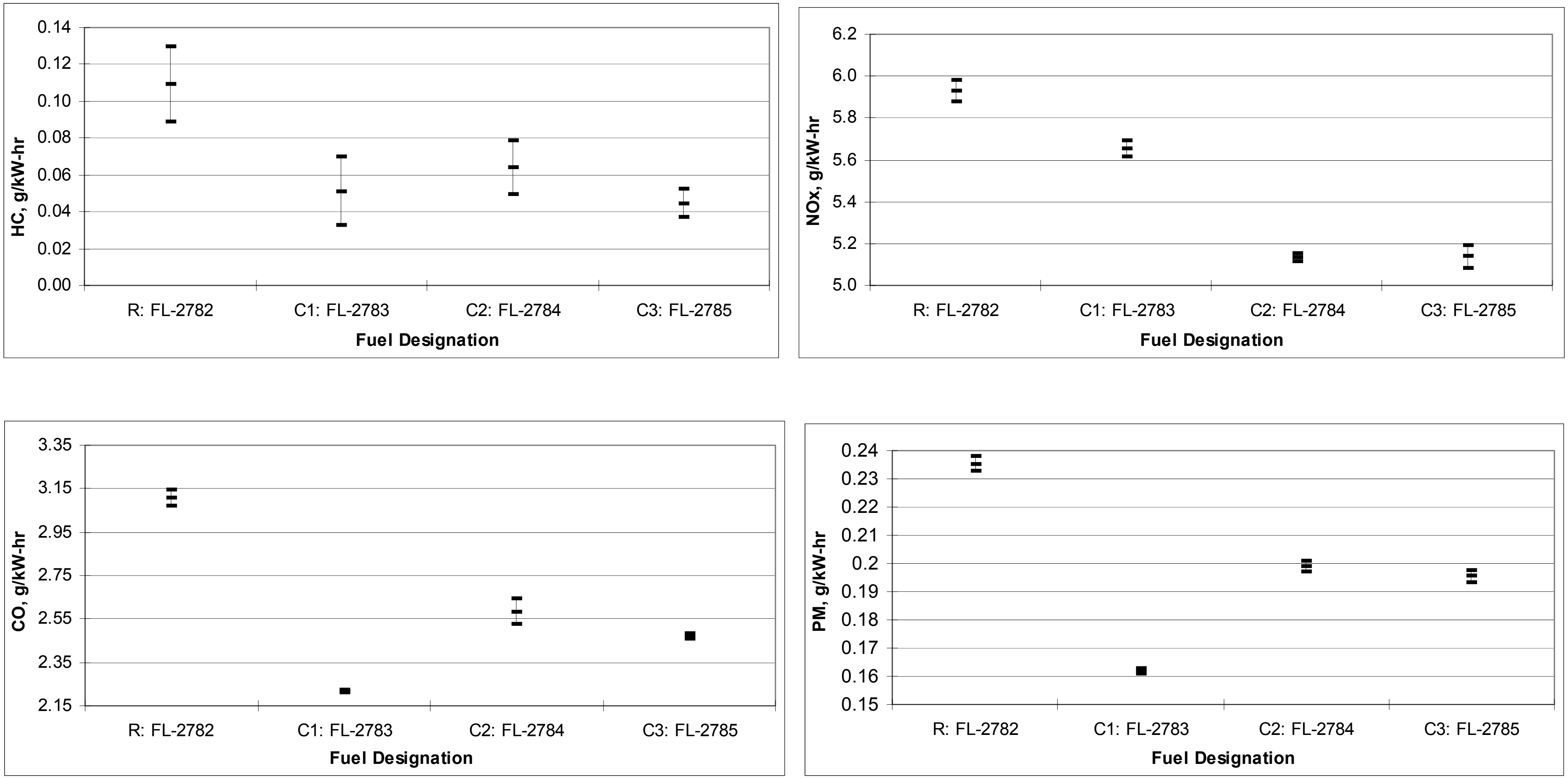

FIGURE 3. COMPARISON OF EMISSION LEVELS (HC, NOx, CO, PM) FROM A 1991 DDC SERIES 60 USING FOUR DIESEL FUELS

Diesel engines play a respected role of providing reliable power in mobile applications in trucks, buses, and other equipment. The engine mechanically processes fuel and air to achieve controlled combustion to deliver rotating mechanical power with reasonable exhaust emissions. Although the levels of exhaust emissions depend largely on the combustion processing of the fuel and air by the engine, fuel properties alone can have significant effects on emissions.

Numerous studies have related changes in fuel properties to changes in engine emissions. Of the many fuel properties that can be used to characterize a diesel fuel, aromatic content and cetane number are respected as two important properties that relate to the hydrogen-carbon components of the fuel and the ignition quality of the fuel, respectively. Many other fuel properties are also important in combustion, such as oxygen and sulfur content. Physical properties, such as density, viscosity, and boiling point distribution, are also important in that they affect how the fuel is delivered, dispersed and ultimately combusted, which also affects engine performance and emissions.

Reducing aromatic content of the fuel, particularly multi-ringed aromatics in favor of more paraffinic fuel has been shown to reduce NO_x. Many diesel engines are sensitive to cetane number, a fuel property closely associated with aromatic content. For the DDC Series 60, increased cetane number, associated with low aromatic or cetane improver additives, has resulted in reductions of NO_x and PM, as well as HC and CO.[1] In addition, it has been recognized that reducing fuel sulfur content not only reduces particulate emissions, it often allows catalyst technology to be implemented to reduce various engine emissions.

Fischer-Tropsch (F-T) fuels generally are defined as having low aromatics (<1%), high cetane number (>70), and essentially sulfur free. Work with Sasol Oil's, "Sasol Slurry Phase Distillate" indicated that heavy-duty diesel engine emissions of NO_x, PM, HC, and CO could be reduced by 14-15 percent, 21-23 percent, 15-28 percent, and 23-25 percent, respectively; from levels obtained with a CARB-like fuel, similar to the reference fuel used in this work.[2] In work with an F-T fuel from Syntroleum Corp., diesel engine emissions of NO_x, PM, HC, and CO were reduced 14, 27, 0, and 27 percent, respectively; again, from levels obtained with a CARB-like fuel.[3,4] Finally, CARB summarized changes to diesel emissions with the use of F-T fuels, relative to CARB-like fuel, as reducing NO_x by 5 percent, PM by 30 percent, HC by 23 percent, and CO by 39 percent.[5]

*Numbers in the text refer to bibliographic entries at the end of the document.

Conclusions

1. The neat F-T diesel reduced NO_x, PM, HC and CO by 4.5%, 31%, 50%, and 29%, respectively; compared to the Tier II CARB-like diesel used as a reference fuel.

2. The hydrocracker F-T diesel product reduced NO_x, PM, HC and CO by 13%, 16%, 38%, and 17%, respectively; compared to the Tier II CARB-like diesel.

3. The blend of hydrocracker and hydrotreater F-T diesel products reduced NO_x, PM, HC and CO by 13%, 17%, 63%, and 21%, respectively; compared to the Tier II CARB-like diesel.

4. Each of the F-T diesel fuel candidates produced lower emission levels than the Tier II CARB-like diesel reference fuel.

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List of Acronyms and Abbreviations

AGR	acid gas removal unit
ASTM	American Society for Testing and Materials
C_1	Compounds with Carbon Number of One
C_2	Compounds with Carbon Number of Two
C_3	Compounds with Carbon Number of Three
CARB	California Air Resources Board
CCR	California Code of Regulations
CFR	Code of Federal Regulations
cm	centimeters
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COV	Coefficients of Variation
DCRP	Delaware City Repowering Project
DDC	Detroit Diesel Corporation
DER	Department of Emissions
DOE	U.S. Department of Energy
EECP	Early Entry Coproduction Plant
EPA	U.S. Environmental Protection Agency
F-T	Fischer-Tropsch
ft	feet
FTP	Federal Test Procedure
g	gram
GC	gas chromatograph
HC	Hydrocarbons or Hydrocracking
HT	Hydrotreater
HFRR	High Frequency Reciprocating Rig
IGCC	Integrated Gasification Combined Cycle
in	inch
kPa	kilo Pascals
mm	millimeter
NO_x	nitrogen oxides
O_2	oxygen
PM	Total Particulate
ppm	parts per million
Psia	ounds force per square inch absolute
SOF	Soluble Organic Fraction
SRU	Sulfur recovery unit
SO4	Sulfate
SwRI	Southwest Research Institute
TGTU	tail gas recovery unit
WTC	Westhollow Technology Center
wt%	weight percent

APPENDIX

COMPUTER PRINTOUTS OF EMISSION RESULTS FOR HOT-START TESTS ON FOUR DIESEL FUELS WITH A 1991 DDC SERIES 60 HEAVY-DUTY DIESEL ENGINE

Southwest Research Institute - Department of Emissions Research
CARB Hot Transient Emission Test Results
Project No. 4786.14.010

Engine Model:	1991 Rebuilt DDC Series	Test No.: TEX C1-2783-H1		DIESEL 2D, FL-2783
Engine Desc.:	12.7 L (775 CID) I-6	Date: 04/16/2003	Time: 09:36	HCR: 2.010 FID Resp: 1.00
Engine Cycle:	Diesel	Program HDT: 4.12-R		H= 0.141 C= 0.836 O= 0.023 X= 0.000
Engine S/N:	06RE001123	Cell: 16	Bag Cart: 1	Oil Code: Delvac15W-40
C1 Fuel, Test 1				

Ambient/Test Cell Conditions

Barometer:	29.02	in Hg	98.3 kPa
Engine Inlet Air			
Temperature:	77.0	°F	25.0 °C
Dew Point:	60.2	°F	15.7 °C
Abs. Humidity:	80.6	gr/lb	11.5 g/kg
Rel. Humidity:	56	%	
Dilution Air:			
Temperature:	80.0	°F	26.7 °C
Abs. Humidity	70.4	gr/lb	10.1 g/kg
Rel. Humidity:	45	%	

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		5.33	ppm	
HC Bckgrd	3.9	2	3.95	ppm	
CO	29.0	2	28.02	ppm	(Dry)
CO Bckgrd	0.5	2	0.47	ppm	
NOx Sample	n/a		42.35	ppm	(Dry)
NOx Bckgrd	0.7	1	0.18	ppm	
CO2 Sample	70.5	1	0.5933	%	(Wet)
CO2 Bckgrd	7.7	1	0.0451	%	

Corrected Concentrations

HC	1.56	ppm
CO	26.84	ppm
NOx	41.25	ppm
CO2	0.5502	%

Mass Emissions

HC			1.126	grams
CO			38.693	grams
NOx			99.129	grams
Particulate			2.821	grams
CO2			12.465	kg
Fuel	9.02	lb	4.09	kg

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,173.0	61.54
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	2.12	0.06
Gas Meter 2:	3.88	0.11
Sample Rate:	1.76	0.05
Total Flow Rate:	2,174.72	61.59

Particulate Data

Filter Number:	4349.0 (pair)	
Weight Gain:	2.282	mg
Sample Multiplier:	1.236	

Correction Factors

NOx Humidity CF:	1.015
Dry-to-Wet CF, Sample:	0.978
Dry-to-Wet CF, Bckgrd:	0.984
Dilution Factor:	22.01

Test Cycle Data

Sample Time:	1,206.30	sec		
Work:	23.32	hp-hr	17.39	kW-hr
Reference Work:	23.54	hp-hr	17.55	kW-hr
Total Volume (Vmix):	43,722.8	scf	1,238.25	scm

Brake-Specific Emission Results

BSHC (Cell)	0.048	g/hp-hr	0.065	g/kW-hr
CO	1.659	g/hp-hr	2.225	g/kW-hr
NOx (Cell)	4.251	g/hp-hr	5.700	g/kW-hr
Particulate	0.121	g/hp-hr	0.162	g/kW-hr
CO2	534.5	g/hp-hr	716.78	g/kW-hr
BSFC	0.387	lb/hp-hr	0.235	kg/kW-hr

Southwest Research Institute - Department of Emissions Research
CARB Hot Transient Emission Test Results
Project No. 4786.14.010

Engine Model: 1991 Rebuilt DDC Series	Test No.: TEX C1-2783-H2		DIESEL 2D, FL-2783
Engine Desc.: 12.7 L (775 CID) I-6	Date: 04/16/2003	Time: 10:16	HCR: 2.010 FID Resp: 1.00
Engine Cycle: Diesel	Program HDT: 4.12-R		H= 0.141 C= 0.836 O= 0.023 X= 0.000
Engine S/N: 06RE001123	Cell: 16	Bag Cart: 1	Oil Code: Delvac15W-40
C1 Fuel, Test 2			

Ambient/Test Cell Conditions

Barometer:	29.03	in Hg	98.3 kPa
Engine Inlet Air			
Temperature:	76.0	°F	24.4 °C
Dew Point:	60.2	°F	15.7 °C
Abs. Humidity:	80.6	gr/lb	11.5 g/kg
Rel. Humidity:	58	%	
Dilution Air:			
Temperature:	81.0	°F	27.2 °C
Abs. Humidity	73.8	gr/lb	10.5 g/kg
Rel. Humidity:	45	%	

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		5.78	ppm	
HC Bckgrd	n/a		5.30	ppm	
CO	29.1	2	28.12	ppm	(Dry)
CO Bckgrd	0.6	2	0.56	ppm	
NOx Sample	n/a		41.87	ppm	(Dry)
NOx Bckgrd	0.5	1	0.13	ppm	
CO2 Sample	71.0	1	0.5997	%	(Wet)
CO2 Bckgrd	7.6	1	0.0445	%	

Corrected Concentrations

HC	0.72	ppm
CO	26.85	ppm
NOx	40.80	ppm
CO2	0.5572	%

Mass Emissions

HC	0.522	grams
CO	38.639	grams
NOx	97.876	grams
Particulate	2.802	grams
CO2	12.604	kg
Fuel 9.12 lb	4.14	kg

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,170.2	61.46
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	2.12	0.06
Gas Meter 2:	3.86	0.11
Sample Rate:	1.74	0.05
Total Flow Rate:	2,171.93	61.51

Particulate Data

Filter Number: 4391.0 (pair)
Weight Gain: 2.239 mg
Sample Multiplier: 1.251

Correction Factors

NOx Humidity CF:	1.015
Dry-to-Wet CF, Sample:	0.977
Dry-to-Wet CF, Bckgrd:	0.983
Dilution Factor:	21.78

Test Cycle Data

Sample Time:	1,206.00	sec		
Work:	23.33	hp-hr	17.40	kW-hr
Reference Work:	23.54	hp-hr	17.55	kW-hr
Total Volume (Vmix):	43,655.8	scf	1,236.36	scm

Brake-Specific Emission Results

BSHC (Cell)	0.022	g/hp-hr	0.030	g/kW-hr
CO	1.656	g/hp-hr	2.221	g/kW-hr
NOx (Cell)	4.195	g/hp-hr	5.626	g/kW-hr
Particulate	0.120	g/hp-hr	0.161	g/kW-hr
CO2	540.2	g/hp-hr	724.47	g/kW-hr
BSFC	0.391	lb/hp-hr	0.238	kg/kW-hr

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Southwest Research Institute - Department of Emissions Research
CARB Hot Transient Emission Test Results
Project No. 4786.14.010

Engine Model: 1991 Rebuilt DDC Series	Test No.: TEX C1-2783-H3		DIESEL 2D, FL-2783
Engine Desc.: 12.7 L (775 CID) I-6	Date: 04/16/2003	Time: 10:55	HCR: 2.010 FID Resp: 1.00
Engine Cycle: Diesel	Program HDT: 4.12-R		H= 0.141 C= 0.836 O= 0.023 X= 0.000
Engine S/N: 06RE001123	Cell: 16	Bag Cart: 1	Oil Code: Delvac15W-40
C1 Fuel, Test 3			

Ambient/Test Cell Conditions

Barometer:	29.04	in Hg	98.3 kPa
Engine Inlet Air			
Temperature:	76.0	°F	24.4 °C
Dew Point:	60.8	°F	16.0 °C
Abs. Humidity:	82.3	gr/lb	11.8 g/kg
Rel. Humidity:	59	%	
Dilution Air:			
Temperature:	81.0	°F	27.2 °C
Abs. Humidity	73.7	gr/lb	10.5 g/kg
Rel. Humidity:	45	%	

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		5.14	ppm	
HC Bckgrd	n/a		3.90	ppm	
CO	28.5	2	27.53	ppm	(Dry)
CO Bckgrd	0.1	2	0.09	ppm	
NOx Sample	n/a		41.72	ppm	(Dry)
NOx Bckgrd	0.4	1	0.10	ppm	
CO2 Sample	70.5	1	0.5933	%	(Wet)
CO2 Bckgrd	7.4	1	0.0433	%	

Corrected Concentrations

HC	1.42	ppm
CO	26.72	ppm
NOx	40.68	ppm
CO2	0.5520	%

Mass Emissions

HC			1.022	grams
CO			38.463	grams
NOx			98.073	grams
Particulate			2.827	grams
CO2			12.487	kg
Fuel	9.04	lb	4.10	kg

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,170.9	61.48
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	2.12	0.06
Gas Meter 2:	3.86	0.11
Sample Rate:	1.73	0.05
Total Flow Rate:	2,172.62	61.53

Particulate Data

Filter Number:	4392.0 (pair)	
Weight Gain:	2.256	mg
Sample Multiplier:	1.253	

Correction Factors

NOx Humidity CF:	1.019
Dry-to-Wet CF, Sample:	0.977
Dry-to-Wet CF, Bckgrd:	0.983
Dilution Factor:	22.01

Test Cycle Data

Sample Time:	1,205.90	sec		
Work:	23.33	hp-hr	17.40	kW-hr
Reference Work:	23.54	hp-hr	17.55	kW-hr
Total Volume (Vmix):	43,666.1	scf	1,236.65	scm

Brake-Specific Emission Results

BSHC (Cell)	0.044	g/hp-hr	0.059	g/kW-hr
CO	1.649	g/hp-hr	2.211	g/kW-hr
NOx (Cell)	4.204	g/hp-hr	5.637	g/kW-hr
Particulate	0.121	g/hp-hr	0.162	g/kW-hr
CO2	535.2	g/hp-hr	717.78	g/kW-hr
BSFC	0.387	lb/hp-hr	0.236	kg/kW-hr

Southwest Research Institute - Department of Emissions Research
CARB Hot Transient Emission Test Results
Project No. 4786.14.010

Engine Model: 1991 Rebuilt DDC Series	Test No.: TEX C2-2784-H1		DIESEL 2D, FL-2784
Engine Desc.: 12.7 L (775 CID) I-6	Date: 04/15/2003	Time: 01:50	HCR: 2.103 FID Resp: 1.00
Engine Cycle: Diesel	Program HDT: 4.12-R		H= 0.150 C= 0.850 O= 0.000 X= 0.000
Engine S/N: 06RE001123	Cell: 16	Bag Cart: 1	Oil Code: Delvac15W-40
C2 Fuel, Test 1			

Ambient/Test Cell Conditions

Barometer:	29.08	in Hg	98.5 kPa
Engine Inlet Air			
Temperature:	77.0	°F	25.0 °C
Dew Point:	59.9	°F	15.5 °C
Abs. Humidity:	79.6	gr/lb	11.4 g/kg
Rel. Humidity:	56	%	
Dilution Air:			
Temperature:	80.0	°F	26.7 °C
Abs. Humidity	65.2	gr/lb	9.3 g/kg
Rel. Humidity:	41	%	

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		5.34	ppm	
HC Bckgrd	n/a		3.90	ppm	
CO	34.2	2	33.15	ppm	(Dry)
CO Bckgrd	0.3	2	0.28	ppm	
NOx Sample	n/a		38.31	ppm	(Dry)
NOx Bckgrd	0.3	1	0.08	ppm	
CO2 Sample	69.5	1	0.5807	%	(Wet)
CO2 Bckgrd	7.3	1	0.0427	%	

Corrected Concentrations

HC	1.62	ppm
CO	32.05	ppm
NOx	37.43	ppm
CO2	0.5399	%

Mass Emissions

HC			1.179	grams
CO			46.317	grams
NOx			89.939	grams
Particulate			3.457	grams
CO2			12.263	kg
Fuel	8.74	lb	3.96	kg

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,177.9	61.68
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	2.13	0.06
Gas Meter 2:	3.79	0.11
Sample Rate:	1.66	0.05
Total Flow Rate:	2,179.59	61.73

Particulate Data

Filter Number:	4346.0 (pair)	
Weight Gain:	2.640	mg
Sample Multiplier:	1.309	

Correction Factors

NOx Humidity CF:	1.012
Dry-to-Wet CF, Sample:	0.979
Dry-to-Wet CF, Bckgrd:	0.985
Dilution Factor:	21.97

Test Cycle Data

Sample Time:	1,206.70	sec		
Work:	23.43	hp-hr	17.47	kW-hr
Reference Work:	23.54	hp-hr	17.55	kW-hr
Total Volume (Vmix):	43,835.1	scf	1,241.44	scm

Brake-Specific Emission Results

BSHC (Cell)	0.050	g/hp-hr	0.067	g/kW-hr
CO	1.977	g/hp-hr	2.651	g/kW-hr
NOx (Cell)	3.839	g/hp-hr	5.148	g/kW-hr
Particulate	0.148	g/hp-hr	0.198	g/kW-hr
CO2	523.4	g/hp-hr	701.86	g/kW-hr
BSFC	0.373	lb/hp-hr	0.227	kg/kW-hr

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Southwest Research Institute - Department of Emissions Research
CARB Hot Transient Emission Test Results
Project No. 4786.14.010

Engine Model:	1991 Rebuilt DDC Series	Test No.: TEX C2-2784-H2		DIESEL 2D, FL-2784
Engine Desc.:	12.7 L (775 CID) I-6	Date: 04/15/2003	Time: 02:30	HCR: 2.103 FID Resp: 1.00
Engine Cycle:	Diesel	Program HDT: 4.12-R		H= 0.150 C= 0.850 O= 0.000 X= 0.000
Engine S/N:	06RE001123	Cell: 16	Bag Cart: 1	Oil Code: Delvac15W-40
C2 Fuel, Test 2				

Ambient/Test Cell Conditions

Barometer:	29.06	in Hg	98.4 kPa
Engine Inlet Air			
Temperature:	78.0	°F	25.6 °C
Dew Point:	59.9	°F	15.5 °C
Abs. Humidity:	79.6	gr/lb	11.4 g/kg
Rel. Humidity:	54	%	
Dilution Air:			
Temperature:	80.0	°F	26.7 °C
Abs. Humidity	65.3	gr/lb	9.3 g/kg
Rel. Humidity:	41	%	

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		5.92	ppm	
HC Bckgrd	n/a		5.00	ppm	
CO	33.2	2	32.16	ppm	(Dry)
CO Bckgrd	0.4	2	0.37	ppm	
NOx Sample	n/a		38.40	ppm	(Dry)
NOx Bckgrd	0.7	1	0.18	ppm	
CO2 Sample	70.0	1	0.5870	%	(Wet)
CO2 Bckgrd	8.1	1	0.0475	%	

Corrected Concentrations

HC	1.15	ppm
CO	30.99	ppm
NOx	37.42	ppm
CO2	0.5417	%

Mass Emissions

HC			0.837	grams
CO			44.722	grams
NOx			89.782	grams
Particulate			3.463	grams
CO2			12.282	kg
Fuel	8.75	lb	3.97	kg

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,176.2	61.63
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	2.12	0.06
Gas Meter 2:	3.79	0.11
Sample Rate:	1.66	0.05
Total Flow Rate:	2,177.87	61.68

Particulate Data

Filter Number:	4347.0 (pair)	
Weight Gain:	2.647	mg
Sample Multiplier:	1.308	

Correction Factors

NOx Humidity CF:	1.012
Dry-to-Wet CF, Sample:	0.979
Dry-to-Wet CF, Bckgrd:	0.985
Dilution Factor:	21.74

Test Cycle Data

Sample Time:	1,205.70	sec		
Work:	23.43	hp-hr	17.47	kW-hr
Reference Work:	23.54	hp-hr	17.55	kW-hr
Total Volume (Vmix):	43,764.3	scf	1,239.43	scm

Brake-Specific Emission Results

BSHC (Cell)	0.036	g/hp-hr	0.048	g/kW-hr
CO	1.909	g/hp-hr	2.560	g/kW-hr
NOx (Cell)	3.832	g/hp-hr	5.139	g/kW-hr
Particulate	0.148	g/hp-hr	0.198	g/kW-hr
CO2	524.2	g/hp-hr	702.98	g/kW-hr
BSFC	0.373	lb/hp-hr	0.227	kg/kW-hr

Southwest Research Institute - Department of Emissions Research
CARB Hot Transient Emission Test Results
Project No. 4786.14.010

Engine Model: 1991 Rebuilt DDC Series	Test No.: TEX C2-2784-H3		DIESEL 2D, FL-2784
Engine Desc.: 12.7 L (775 CID) I-6	Date: 04/15/2003	Time: 03:09	HCR: 2.103 FID Resp: 1.00
Engine Cycle: Diesel	Program HDT: 4.12-R		H= 0.150 C= 0.850 O= 0.000 X= 0.000
Engine S/N: 06RE001123	Cell: 16	Bag Cart: 1	Oil Code: Delvac15W-40
C2 Fuel, Test 3			

Ambient/Test Cell Conditions

Barometer:	29.03	in Hg	98.3 kPa
Engine Inlet Air			
Temperature:	78.0	°F	25.6 °C
Dew Point:	60.2	°F	15.7 °C
Abs. Humidity:	80.6	gr/lb	11.5 g/kg
Rel. Humidity:	54	%	
Dilution Air:			
Temperature:	80.0	°F	26.7 °C
Abs. Humidity	65.4	gr/lb	9.3 g/kg
Rel. Humidity:	41	%	

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		5.94	ppm	
HC Bckgrd	n/a		4.30	ppm	
CO	32.8	2	31.77	ppm	(Dry)
CO Bckgrd	0.2	2	0.19	ppm	
NOx Sample	n/a		38.03	ppm	(Dry)
NOx Bckgrd	0.4	1	0.10	ppm	
CO2 Sample	69.8	1	0.5845	%	(Wet)
CO2 Bckgrd	7.3	1	0.0427	%	

Corrected Concentrations

HC	1.84	ppm
CO	30.79	ppm
NOx	37.14	ppm
CO2	0.5438	%

Mass Emissions

HC	1.336	grams
CO	44.390	grams
NOx	89.261	grams
Particulate	3.515	grams
CO2	12.321	kg
Fuel 8.78 lb	3.98	kg

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,174.0	61.57
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	2.12	0.06
Gas Meter 2:	3.79	0.11
Sample Rate:	1.67	0.05
Total Flow Rate:	2,175.67	61.62

Particulate Data

Filter Number: 4348.0 (pair)
Weight Gain: 2.696 mg
Sample Multiplier: 1.304

Correction Factors

NOx Humidity CF:	1.015
Dry-to-Wet CF, Sample:	0.979
Dry-to-Wet CF, Bckgrd:	0.985
Dilution Factor:	21.83

Test Cycle Data

Sample Time:	1,206.10	sec		
Work:	23.42	hp-hr	17.46	kW-hr
Reference Work:	23.54	hp-hr	17.55	kW-hr
Total Volume (Vmix):	43,734.6	scf	1,238.59	scm

Brake-Specific Emission Results

BSHC (Cell)	0.057	g/hp-hr	0.077	g/kW-hr
CO	1.895	g/hp-hr	2.542	g/kW-hr
NOx (Cell)	3.811	g/hp-hr	5.111	g/kW-hr
Particulate	0.150	g/hp-hr	0.201	g/kW-hr
CO2	526.1	g/hp-hr	705.49	g/kW-hr
BSFC	0.375	lb/hp-hr	0.228	kg/kW-hr

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CARB Hot Transient Emission Test Results
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Engine Model:	1991 Rebuilt DDC Series	Test No.: TEX C3-2785-H1		DIESEL 2D, FL-2785	
Engine Desc.:	12.7 L (775 CID) I-6	Date: 04/17/2003	Time: 02:04	HCR: 2.086	FID Resp: 1.00
Engine Cycle:	Diesel	Program HDT: 4.12-R		H= 0.149 C= 0.851 O= 0.000 X= 0.000	
Engine S/N:	06RE001123	Cell: 16	Bag Cart: 1	Oil Code: Delvac15W-40	
C3 Fuel, Test 1					

Ambient/Test Cell Conditions

Barometer:	29.07	in Hg	98.4 kPa
Engine Inlet Air			
Temperature:	77.0	°F	25.0 °C
Dew Point:	60.2	°F	15.7 °C
Abs. Humidity:	80.5	gr/lb	11.5 g/kg
Rel. Humidity:	56	%	
Dilution Air:			
Temperature:	79.0	°F	26.1 °C
Abs. Humidity	66.9	gr/lb	9.6 g/kg
Rel. Humidity:	44	%	

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		5.60	ppm	
HC Bckgrd	n/a		4.80	ppm	
CO	32.1	2	31.08	ppm	(Dry)
CO Bckgrd	0.1	2	0.09	ppm	
NOx Sample	n/a		38.50	ppm	(Dry)
NOx Bckgrd	0.1	1	0.03	ppm	
CO2 Sample	69.9	1	0.5857	%	(Wet)
CO2 Bckgrd	7.6	1	0.0445	%	

Corrected Concentrations

HC	1.02	ppm
CO	30.18	ppm
NOx	37.65	ppm
CO2	0.5432	%

Mass Emissions

HC	0.740	grams
CO	43.449	grams
NOx	90.320	grams
Particulate	3.463	grams
CO2	12.288	kg
Fuel	8.74 lb	3.96 kg

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,170.3	61.46
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	2.13	0.06
Gas Meter 2:	3.85	0.11
Sample Rate:	1.72	0.05
Total Flow Rate:	2,172.02	61.51

Particulate Data

Filter Number:	4424.0 (pair)	
Weight Gain:	2.744	mg
Sample Multiplier:	1.262	

Correction Factors

NOx Humidity CF:	1.014
Dry-to-Wet CF, Sample:	0.979
Dry-to-Wet CF, Bckgrd:	0.985
Dilution Factor:	21.86

Test Cycle Data

Sample Time:	1,206.10	sec		
Work:	23.50	hp-hr	17.52	kW-hr
Reference Work:	23.54	hp-hr	17.55	kW-hr
Total Volume (Vmix):	43,661.1	scf	1,236.51	scm

Brake-Specific Emission Results

BSHC (Cell)	0.031	g/hp-hr	0.042	g/kW-hr
CO	1.849	g/hp-hr	2.479	g/kW-hr
NOx (Cell)	3.843	g/hp-hr	5.154	g/kW-hr
Particulate	0.147	g/hp-hr	0.198	g/kW-hr
CO2	522.9	g/hp-hr	701.24	g/kW-hr
BSFC	0.372	lb/hp-hr	0.226	kg/kW-hr

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CARB Hot Transient Emission Test Results
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Engine Model:	1991 Rebuilt DDC Series	Test No.: TEX C3-2785-H2	DIESEL 2D, FL-2785
Engine Desc.:	12.7 L (775 CID) I-6	Date: 04/17/2003 Time: 02:43	HCR: 2.086 FID Resp: 1.00
Engine Cycle:	Diesel	Program HDT: 4.12-R	H= 0.149 C= 0.851 O= 0.000 X= 0.000
Engine S/N:	06RE001123	Cell: 16 Bag Cart: 1	Oil Code: Delvac15W-40
C3 Fuel, Test 2			

Ambient/Test Cell Conditions

Barometer:	29.06	in Hg	98.4 kPa
Engine Inlet Air			
Temperature:	77.0	°F	25.0 °C
Dew Point:	59.6	°F	15.3 °C
Abs. Humidity:	78.8	gr/lb	11.3 g/kg
Rel. Humidity:	55	%	
Dilution Air:			
Temperature:	80.0	°F	26.7 °C
Abs. Humidity	70.2	gr/lb	10.0 g/kg
Rel. Humidity:	45	%	

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		5.80	ppm	
HC Bckgrd	n/a		5.10	ppm	
CO	32.0	2	30.98	ppm	(Dry)
CO Bckgrd	0.2	2	0.19	ppm	
NOx Sample	n/a		38.30	ppm	(Dry)
NOx Bckgrd	0.3	1	0.08	ppm	
CO2 Sample	70.1	1	0.5883	%	(Wet)
CO2 Bckgrd	7.6	1	0.0445	%	

Corrected Concentrations

HC	0.93	ppm
CO	29.98	ppm
NOx	37.38	ppm
CO2	0.5458	%

Mass Emissions

HC	0.676	grams
CO	43.062	grams
NOx	89.058	grams
Particulate	3.393	grams
CO2	12.319	kg
Fuel	8.76 lb	3.97 kg

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,165.2	61.32
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	2.12	0.06
Gas Meter 2:	3.78	0.11
Sample Rate:	1.66	0.05
Total Flow Rate:	2,166.82	61.37

Particulate Data

Filter Number:	4425.0 (pair)	
Weight Gain:	2.604	mg
Sample Multiplier:	1.303	

Correction Factors

NOx Humidity CF:	1.010
Dry-to-Wet CF, Sample:	0.978
Dry-to-Wet CF, Bckgrd:	0.984
Dilution Factor:	21.76

Test Cycle Data

Sample Time:	1,206.20	sec		
Work:	23.51	hp-hr	17.53	kW-hr
Reference Work:	23.54	hp-hr	17.55	kW-hr
Total Volume (Vmix):	43,560.2	scf	1,233.65	scm

Brake-Specific Emission Results

BSHC (Cell)	0.029	g/hp-hr	0.039	g/kW-hr
CO	1.832	g/hp-hr	2.456	g/kW-hr
NOx (Cell)	3.788	g/hp-hr	5.080	g/kW-hr
Particulate	0.144	g/hp-hr	0.194	g/kW-hr
CO2	524.0	g/hp-hr	702.68	g/kW-hr
BSFC	0.373	lb/hp-hr	0.227	kg/kW-hr

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CARB Hot Transient Emission Test Results
Project No. 4786.14.010

Engine Model:	1991 Rebuilt DDC Series	Test No.: TEX C3-2785-H3	DIESEL 2D, FL-2785
Engine Desc.:	12.7 L (775 CID) I-6	Date: 04/17/2003 Time: 03:23	HCR: 2.086 FID Resp: 1.00
Engine Cycle:	Diesel	Program HDT: 4.12-R	H= 0.149 C= 0.851 O= 0.000 X= 0.000
Engine S/N:	06RE001123	Cell: 16 Bag Cart: 1	Oil Code: Delvac15W-40
C3 Fuel, Test 3			

Ambient/Test Cell Conditions

Barometer:	29.03	in Hg	98.3 kPa
Engine Inlet Air			
Temperature:	77.0	°F	25.0 °C
Dew Point:	59.2	°F	15.1 °C
Abs. Humidity:	77.7	gr/lb	11.1 g/kg
Rel. Humidity:	54	%	
Dilution Air:			
Temperature:	79.0	°F	26.1 °C
Abs. Humidity	72.0	gr/lb	10.3 g/kg
Rel. Humidity:	47	%	

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		5.50	ppm	
HC Bckgrd	n/a		4.40	ppm	
CO	32.3	2	31.27	ppm	(Dry)
CO Bckgrd	0.2	2	0.19	ppm	
NOx Sample	n/a		39.23	ppm	(Dry)
NOx Bckgrd	0.2	1	0.05	ppm	
CO2 Sample	69.5	1	0.5807	%	(Wet)
CO2 Bckgrd	7.2	1	0.0421	%	

Corrected Concentrations

HC	1.30	ppm
CO	30.24	ppm
NOx	38.31	ppm
CO2	0.5405	%

Mass Emissions

HC			0.939	grams
CO			43.368	grams
NOx			90.866	grams
Particulate			3.425	grams
CO2			12.179	kg
Fuel	8.66	lb	3.93	kg

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,162.4	61.24
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	2.12	0.06
Gas Meter 2:	3.78	0.11
Sample Rate:	1.67	0.05
Total Flow Rate:	2,164.10	61.29

Particulate Data

Filter Number:	4426.0 (pair)	
Weight Gain:	2.639	mg
Sample Multiplier:	1.298	

Correction Factors

NOx Humidity CF:	1.007
Dry-to-Wet CF, Sample:	0.978
Dry-to-Wet CF, Bckgrd:	0.984
Dilution Factor:	22.04

Test Cycle Data

Sample Time:	1,205.80	sec		
Work:	23.51	hp-hr	17.53	kW-hr
Reference Work:	23.54	hp-hr	17.55	kW-hr
Total Volume (Vmix):	43,491.2	scf	1,231.70	scm

Brake-Specific Emission Results

BSHC (Cell)	0.040	g/hp-hr	0.054	g/kW-hr
CO	1.845	g/hp-hr	2.474	g/kW-hr
NOx (Cell)	3.865	g/hp-hr	5.183	g/kW-hr
Particulate	0.146	g/hp-hr	0.195	g/kW-hr
CO2	518.0	g/hp-hr	694.71	g/kW-hr
BSFC	0.369	lb/hp-hr	0.224	kg/kW-hr

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CARB Hot Transient Emission Test Results
Project No. 4786.14.010

Engine Model:	1991 Rebuilt DDC Series	Test No.:	TEX R-2782-H1	DIESEL 2D, FL-2782	
Engine Desc.:	12.7 L (775 CID) I-6	Date: 04/15/2003	Time: 09:31	HCR: 1.940	FID Resp: 1.00
Engine Cycle:	Diesel	Program HDT:	4.12-R	H= 0.140 C= 0.860 O= 0.000 X= 0.000	
Engine S/N:	06RE001123	Cell: 16	Bag Cart: 1	Oil Code: Delvac15W-40	
Ref. Fuel, Test 1					

Ambient/Test Cell Conditions

Barometer:	29.13	in Hg	98.6 kPa
Engine Inlet Air			
Temperature:	75.0	°F	23.9 °C
Dew Point:	58.8	°F	14.9 °C
Abs. Humidity:	76.3	gr/lb	10.9 g/kg
Rel. Humidity:	57	%	
Dilution Air:			
Temperature:	80.0	°F	26.7 °C
Abs. Humidity	70.0	gr/lb	10.0 g/kg
Rel. Humidity:	44	%	

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		7.39	ppm	
HC Bckgrd	n/a		4.90	ppm	
CO	40.0	2	38.89	ppm	(Dry)
CO Bckgrd	0.3	2	0.28	ppm	
NOx Sample	n/a		45.06	ppm	(Dry)
NOx Bckgrd	0.5	1	0.13	ppm	
CO2 Sample	70.7	1	0.5959	%	(Wet)
CO2 Bckgrd	7.4	1	0.0433	%	

Corrected Concentrations

HC	2.71	ppm
CO	37.61	ppm
NOx	43.96	ppm
CO2	0.5546	%

Mass Emissions

HC	1.958	grams
CO	54.451	grams
NOx	104.907	grams
Particulate	4.190	grams
CO2	12.616	kg
Fuel	8.89 lb	4.03 kg

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,182.3	61.80
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	2.13	0.06
Gas Meter 2:	3.76	0.11
Sample Rate:	1.63	0.05
Total Flow Rate:	2,183.89	61.85

Particulate Data

Filter Number:	4341.0 (pair)	
Weight Gain:	3.130	mg
Sample Multiplier:	1.339	

Correction Factors

NOx Humidity CF:	1.003
Dry-to-Wet CF, Sample:	0.978
Dry-to-Wet CF, Bckgrd:	0.984
Dilution Factor:	22.05

Test Cycle Data

Sample Time:	1,206.40	sec		
Work:	23.67	hp-hr	17.65	kW-hr
Reference Work:	23.54	hp-hr	17.55	kW-hr
Total Volume (Vmix):	43,910.7	scf	1,243.58	scm

Brake-Specific Emission Results

BSHC (Cell)	0.083	g/hp-hr	0.111	g/kW-hr
CO	2.300	g/hp-hr	3.085	g/kW-hr
NOx (Cell)	4.432	g/hp-hr	5.943	g/kW-hr
Particulate	0.177	g/hp-hr	0.237	g/kW-hr
CO2	533.0	g/hp-hr	714.78	g/kW-hr
BSFC	0.376	lb/hp-hr	0.229	kg/kW-hr

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CARB Hot Transient Emission Test Results
Project No. 4786.14.010

Engine Model: 1991 Rebuilt DDC Series	Test No.: TEX R-2782-H2		DIESEL 2D, FL-2782
Engine Desc.: 12.7 L (775 CID) I-6	Date: 04/15/2003	Time: 10:11	HCR: 1.940 FID Resp: 1.00
Engine Cycle: Diesel	Program HDT: 4.12-R		H= 0.140 C= 0.860 O= 0.000 X= 0.000
Engine S/N: 06RE001123	Cell: 16	Bag Cart: 1	Oil Code: Delvac15W-40
Ref. Fuel, Test 2			

Ambient/Test Cell Conditions

Barometer:	29.13	in Hg	98.6 kPa
Engine Inlet Air			
Temperature:	75.0	°F	23.9 °C
Dew Point:	59.2	°F	15.1 °C
Abs. Humidity:	77.4	gr/lb	11.1 g/kg
Rel. Humidity:	58	%	
Dilution Air:			
Temperature:	81.0	°F	27.2 °C
Abs. Humidity	68.3	gr/lb	9.8 g/kg
Rel. Humidity:	42	%	

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		7.36	ppm	
HC Bckgrd	n/a		4.60	ppm	
CO	40.3	2	39.19	ppm	(Dry)
CO Bckgrd	0.1	2	0.09	ppm	
NOx Sample	n/a		44.69	ppm	(Dry)
NOx Bckgrd	0.2	1	0.05	ppm	
CO2 Sample	71.1	1	0.6010	%	(Wet)
CO2 Bckgrd	7.5	1	0.0439	%	

Corrected Concentrations

HC	2.97	ppm
CO	38.11	ppm
NOx	43.69	ppm
CO2	0.5591	%

Mass Emissions

HC			2.140	grams
CO			55.060	grams
NOx			104.353	grams
Particulate			4.187	grams
CO2			12.694	kg
Fuel	8.95	lb	4.06	kg

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,177.8	61.68
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	2.13	0.06
Gas Meter 2:	3.76	0.11
Sample Rate:	1.63	0.05
Total Flow Rate:	2,179.45	61.72

Particulate Data

Filter Number:	4342.0 (pair)	
Weight Gain:	3.131	mg
Sample Multiplier:	1.337	

Correction Factors

NOx Humidity CF:	1.006
Dry-to-Wet CF, Sample:	0.979
Dry-to-Wet CF, Bckgrd:	0.985
Dilution Factor:	21.86

Test Cycle Data

Sample Time:	1,206.40	sec		
Work:	23.65	hp-hr	17.64	kW-hr
Reference Work:	23.54	hp-hr	17.55	kW-hr
Total Volume (Vmix):	43,821.4	scf	1,241.05	scm

Brake-Specific Emission Results

BSHC (Cell)	0.090	g/hp-hr	0.121	g/kW-hr
CO	2.328	g/hp-hr	3.122	g/kW-hr
NOx (Cell)	4.412	g/hp-hr	5.917	g/kW-hr
Particulate	0.177	g/hp-hr	0.237	g/kW-hr
CO2	536.7	g/hp-hr	719.78	g/kW-hr
BSFC	0.378	lb/hp-hr	0.230	kg/kW-hr

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CARB Hot Transient Emission Test Results
Project No. 4786.14.010

Engine Model:	1991 Rebuilt DDC Series	Test No.: TEX R-2782-H3		DIESEL 2D, FL-2782	
Engine Desc.:	12.7 L (775 CID) I-6	Date: 04/15/2003	Time: 10:50	HCR: 1.940	FID Resp: 1.00
Engine Cycle:	Diesel	Program HDT: 4.12-R		H= 0.140 C= 0.860 O= 0.000 X= 0.000	
Engine S/N:	06RE001123	Cell: 16	Bag Cart: 1	Oil Code: Delvac15W-40	
Ref. Fuel, Test 3					

Ambient/Test Cell Conditions

Barometer:	29.14	in Hg	98.7 kPa
Engine Inlet Air			
Temperature:	76.0	°F	24.4 °C
Dew Point:	59.3	°F	15.2 °C
Abs. Humidity:	77.7	gr/lb	11.1 g/kg
Rel. Humidity:	56	%	
Dilution Air:			
Temperature:	81.0	°F	27.2 °C
Abs. Humidity	68.3	gr/lb	9.8 g/kg
Rel. Humidity:	42	%	

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		7.43	ppm	
HC Bckgrd	n/a		5.40	ppm	
CO	40.0	2	38.89	ppm	(Dry)
CO Bckgrd	0.2	2	0.19	ppm	
NOx Sample	n/a		43.98	ppm	(Dry)
NOx Bckgrd	0.3	1	0.08	ppm	
CO2 Sample	71.0	1	0.5997	%	(Wet)
CO2 Bckgrd	7.7	1	0.0451	%	

Corrected Concentrations

HC	2.28	ppm
CO	37.72	ppm
NOx	42.97	ppm
CO2	0.5567	%

Mass Emissions

HC			1.640	grams
CO			54.508	grams
NOx			102.704	grams
Particulate			4.185	grams
CO2			12.639	kg
Fuel	8.91	lb	4.04	kg

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,178.2	61.69
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	2.13	0.06
Gas Meter 2:	3.77	0.11
Sample Rate:	1.64	0.05
Total Flow Rate:	2,179.82	61.73

Particulate Data

Filter Number:	4343.0 (pair)	
Weight Gain:	3.151	mg
Sample Multiplier:	1.328	

Correction Factors

NOx Humidity CF:	1.007
Dry-to-Wet CF, Sample:	0.979
Dry-to-Wet CF, Bckgrd:	0.985
Dilution Factor:	21.91

Test Cycle Data

Sample Time:	1,206.30	sec		
Work:	23.60	hp-hr	17.60	kW-hr
Reference Work:	23.54	hp-hr	17.55	kW-hr
Total Volume (Vmix):	43,825.2	scf	1,241.16	scm

Brake-Specific Emission Results

BSHC (Cell)	0.069	g/hp-hr	0.093	g/kW-hr
CO	2.310	g/hp-hr	3.097	g/kW-hr
NOx (Cell)	4.352	g/hp-hr	5.836	g/kW-hr
Particulate	0.177	g/hp-hr	0.238	g/kW-hr
CO2	535.6	g/hp-hr	718.21	g/kW-hr
BSFC	0.377	lb/hp-hr	0.230	kg/kW-hr

Southwest Research Institute - Department of Emissions Research
CARB Hot Transient Emission Test Results
Project No. 4786.14.010

Engine Model: 1991 Rebuilt DDC Series	Test No.: TEX R-2782-H4		DIESEL 2D, FL-2782
Engine Desc.: 12.7 L (775 CID) I-6	Date: 04/16/2003	Time: 02:09	HCR: 1.940 FID Resp: 1.00
Engine Cycle: Diesel	Program HDT: 4.12-R		H= 0.140 C= 0.860 O= 0.000 X= 0.000
Engine S/N: 06RE001123	Cell: 16	Bag Cart: 1	Oil Code: Delvac15W-40
Ref. Fuel, Test 4			

Ambient/Test Cell Conditions

Barometer:	28.98	in Hg	98.1 kPa
Engine Inlet Air			
Temperature:	76.0	°F	24.4 °C
Dew Point:	59.6	°F	15.3 °C
Abs. Humidity:	79.0	gr/lb	11.3 g/kg
Rel. Humidity:	57	%	
Dilution Air:			
Temperature:	80.0	°F	26.7 °C
Abs. Humidity	65.5	gr/lb	9.4 g/kg
Rel. Humidity:	41	%	

Measured Gaseous Data

	* Meter	Range	Concentration		
HC Sample	n/a		8.21	ppm	
HC Bckgrd	n/a		6.80	ppm	
CO	41.4	2	40.28	ppm	(Dry)
CO Bckgrd	0.3	2	0.28	ppm	
NOx Sample	n/a		45.16	ppm	(Dry)
NOx Bckgrd	0.4	1	0.10	ppm	
CO2 Sample	71.5	1	0.6061	%	(Wet)
CO2 Bckgrd	7.4	1	0.0433	%	

Corrected Concentrations

HC	1.72	ppm
CO	39.00	ppm
NOx	44.13	ppm
CO2	0.5648	%

Mass Emissions

HC	1.235	grams
CO	56.028	grams
NOx	105.239	grams
Particulate	4.158	grams
CO2	12.752	kg
Fuel	8.99 lb	4.08 kg

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,166.2	61.35
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	2.12	0.06
Gas Meter 2:	3.73	0.11
Sample Rate:	1.62	0.05
Total Flow Rate:	2,167.84	61.39

Particulate Data

Filter Number: 4393.0 (pair)
Weight Gain: 3.098 mg
Sample Multiplier: 1.342

Correction Factors

NOx Humidity CF:	1.010
Dry-to-Wet CF, Sample:	0.979
Dry-to-Wet CF, Bckgrd:	0.985
Dilution Factor:	21.67

Test Cycle Data

Sample Time:	1,206.10	sec		
Work:	23.62	hp-hr	17.61	kW-hr
Reference Work:	23.54	hp-hr	17.55	kW-hr
Total Volume (Vmix):	43,577.2	scf	1,234.13	scm

Brake-Specific Emission Results

BSHC (Cell)	0.052	g/hp-hr	0.070	g/kW-hr
CO	2.372	g/hp-hr	3.181	g/kW-hr
NOx (Cell)	4.456	g/hp-hr	5.975	g/kW-hr
Particulate	0.176	g/hp-hr	0.236	g/kW-hr
CO2	539.9	g/hp-hr	723.97	g/kW-hr
BSFC	0.381	lb/hp-hr	0.231	kg/kW-hr

Southwest Research Institute - Department of Emissions Research
CARB Hot Transient Emission Test Results
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Engine Model:	1991 Rebuilt DDC Series	Test No.: TEX R-2782-H5		DIESEL 2D, FL-2782
Engine Desc.:	12.7 L (775 CID) I-6	Date: 04/16/2003	Time: 02:48	HCR: 1.940 FID Resp: 1.00
Engine Cycle:	Diesel	Program HDT:	4.12-R	H= 0.140 C= 0.860 O= 0.000 X= 0.000
Engine S/N:	06RE001123	Cell: 16	Bag Cart: 1	Oil Code: Delvac15W-40
Ref. Fuel, Test 5				

Ambient/Test Cell Conditions

Barometer:	28.96	in Hg	98.1 kPa
Engine Inlet Air			
Temperature:	78.0	°F	25.6 °C
Dew Point:	59.6	°F	15.3 °C
Abs. Humidity:	79.0	gr/lb	11.3 g/kg
Rel. Humidity:	53	%	
Dilution Air:			
Temperature:	80.0	°F	26.7 °C
Abs. Humidity	65.6	gr/lb	9.4 g/kg
Rel. Humidity:	41	%	

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		7.94	ppm	
HC Bckgrd	n/a		5.60	ppm	
CO	40.9	2	39.78	ppm	(Dry)
CO Bckgrd	0.2	2	0.19	ppm	
NOx Sample	n/a		45.24	ppm	(Dry)
NOx Bckgrd	0.3	1	0.08	ppm	
CO2 Sample	71.0	1	0.5997	%	(Wet)
CO2 Bckgrd	7.3	1	0.0427	%	

Corrected Concentrations

HC	2.60	ppm
CO	38.60	ppm
NOx	44.23	ppm
CO2	0.5589	%

Mass Emissions

HC			1.858	grams
CO			55.405	grams
NOx			105.395	grams
Particulate			4.120	grams
CO2			12.608	kg
Fuel	8.89	lb	4.03	kg

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,164.8	61.31
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	2.12	0.06
Gas Meter 2:	3.71	0.11
Sample Rate:	1.59	0.05
Total Flow Rate:	2,166.39	61.35

Particulate Data

Filter Number:	4394.0 (pair)	
Weight Gain:	3.031	mg
Sample Multiplier:	1.359	

Correction Factors

NOx Humidity CF:	1.011
Dry-to-Wet CF, Sample:	0.979
Dry-to-Wet CF, Bckgrd:	0.985
Dilution Factor:	21.91

Test Cycle Data

Sample Time:	1,205.80	sec		
Work:	23.63	hp-hr	17.62	kW-hr
Reference Work:	23.54	hp-hr	17.55	kW-hr
Total Volume (Vmix):	43,537.1	scf	1,233.00	scm

Brake-Specific Emission Results

BSHC (Cell)	0.079	g/hp-hr	0.105	g/kW-hr
CO	2.345	g/hp-hr	3.144	g/kW-hr
NOx (Cell)	4.460	g/hp-hr	5.981	g/kW-hr
Particulate	0.174	g/hp-hr	0.234	g/kW-hr
CO2	533.6	g/hp-hr	715.51	g/kW-hr
BSFC	0.376	lb/hp-hr	0.229	kg/kW-hr

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Southwest Research Institute - Department of Emissions Research
CARB Hot Transient Emission Test Results
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Engine Model: 1991 Rebuilt DDC Series	Test No.: TEX R-2782-H6		DIESEL 2D, FL-2782
Engine Desc.: 12.7 L (775 CID) I-6	Date: 04/16/2003	Time: 03:27	HCR: 1.940 FID Resp: 1.00
Engine Cycle: Diesel	Program HDT: 4.12-R		H= 0.140 C= 0.860 O= 0.000 X= 0.000
Engine S/N: 06RE001123	Cell: 16	Bag Cart: 1	Oil Code: Delvac15W-40
Ref. Fuel, Test 6			

Ambient/Test Cell Conditions

Barometer:	28.95	in Hg	98.0 kPa
Engine Inlet Air			
Temperature:	77.0	°F	25.0 °C
Dew Point:	60.2	°F	15.7 °C
Abs. Humidity:	80.8	gr/lb	11.5 g/kg
Rel. Humidity:	56	%	
Dilution Air:			
Temperature:	79.0	°F	26.1 °C
Abs. Humidity	67.3	gr/lb	9.6 g/kg
Rel. Humidity:	44	%	

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		7.28	ppm	
HC Bckgrd	n/a		4.80	ppm	
CO	40.6	2	39.48	ppm	(Dry)
CO Bckgrd	0.2	2	0.19	ppm	
NOx Sample	n/a		44.54	ppm	(Dry)
NOx Bckgrd	0.4	1	0.10	ppm	
CO2 Sample	71.3	1	0.6035	%	(Wet)
CO2 Bckgrd	7.3	1	0.0427	%	

Corrected Concentrations

HC	2.70	ppm
CO	38.27	ppm
NOx	43.51	ppm
CO2	0.5628	%

Mass Emissions

HC	1.933	grams
CO	54.943	grams
NOx	104.169	grams
Particulate	4.130	grams
CO2	12.696	kg
Fuel	8.95 lb	4.06 kg

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,164.2	61.29
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	2.12	0.06
Gas Meter 2:	3.74	0.11
Sample Rate:	1.62	0.05
Total Flow Rate:	2,165.77	61.34

Particulate Data

Filter Number:	4395.0 (pair)	
Weight Gain:	3.086	mg
Sample Multiplier:	1.338	

Correction Factors

NOx Humidity CF:	1.015
Dry-to-Wet CF, Sample:	0.979
Dry-to-Wet CF, Bckgrd:	0.985
Dilution Factor:	21.77

Test Cycle Data

Sample Time:	1,206.30	sec		
Work:	23.64	hp-hr	17.63	kW-hr
Reference Work:	23.54	hp-hr	17.55	kW-hr
Total Volume (Vmix):	43,542.8	scf	1,233.16	scm

Brake-Specific Emission Results

BSHC (Cell)	0.082	g/hp-hr	0.110	g/kW-hr
CO	2.324	g/hp-hr	3.117	g/kW-hr
NOx (Cell)	4.406	g/hp-hr	5.909	g/kW-hr
Particulate	0.175	g/hp-hr	0.234	g/kW-hr
CO2	537.0	g/hp-hr	720.18	g/kW-hr
BSFC	0.379	lb/hp-hr	0.230	kg/kW-hr

Analyzed: 05/05/2003 16:56

Southwest Research Institute - Department of Emissions Research
CARB Hot Transient Emission Test Results
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Engine Model: 1991 Rebuilt DDC Series	Test No.: TEX R-2782-H7		DIESEL 2D, FL-2782
Engine Desc.: 12.7 L (775 CID) I-6	Date: 04/17/2003	Time: 09:40	HCR: 1.940 FID Resp: 1.00
Engine Cycle: Diesel	Program HDT: 4.12-R		H= 0.140 C= 0.860 O= 0.000 X= 0.000
Engine S/N: 06RE001123	Cell: 16	Bag Cart: 1	Oil Code: Delvac15W-40
Ref. Fuel, Test 7			

Ambient/Test Cell Conditions

Barometer:	29.08	in Hg	98.5 kPa
Engine Inlet Air			
Temperature:	73.0	°F	22.8 °C
Dew Point:	59.9	°F	15.5 °C
Abs. Humidity:	79.6	gr/lb	11.4 g/kg
Rel. Humidity:	64	%	
Dilution Air:			
Temperature:	81.0	°F	27.2 °C
Abs. Humidity	78.8	gr/lb	11.3 g/kg
Rel. Humidity:	48	%	

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		7.77	ppm	
HC Bckgrd	n/a		4.90	ppm	
CO	40.1	2	38.99	ppm	(Dry)
CO Bckgrd	0.2	2	0.19	ppm	
NOx Sample	n/a		45.11	ppm	(Dry)
NOx Bckgrd	0.6	1	0.15	ppm	
CO2 Sample	71.8	1	0.6100	%	(Wet)
CO2 Bckgrd	8.2	1	0.0482	%	

Corrected Concentrations

HC	3.10	ppm
CO	37.74	ppm
NOx	43.90	ppm
CO2	0.5640	%

Mass Emissions

HC			2.220	grams
CO			54.247	grams
NOx			104.906	grams
Particulate			4.059	grams
CO2			12.742	kg
Fuel	8.98	lb	4.07	kg

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,167.3	61.38
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	2.12	0.06
Gas Meter 2:	3.75	0.11
Sample Rate:	1.63	0.05
Total Flow Rate:	2,168.89	61.42

Particulate Data

Filter Number:	4396.0 (pair)	
Weight Gain:	3.053	mg
Sample Multiplier:	1.330	

Correction Factors

NOx Humidity CF:	1.012
Dry-to-Wet CF, Sample:	0.976
Dry-to-Wet CF, Bckgrd:	0.982
Dilution Factor:	21.54

Test Cycle Data

Sample Time:	1,206.20	sec		
Work:	23.63	hp-hr	17.62	kW-hr
Reference Work:	23.54	hp-hr	17.55	kW-hr
Total Volume (Vmix):	43,602.0	scf	1,234.83	scm

Brake-Specific Emission Results

BSHC (Cell)	0.094	g/hp-hr	0.126	g/kW-hr
CO	2.296	g/hp-hr	3.079	g/kW-hr
NOx (Cell)	4.440	g/hp-hr	5.954	g/kW-hr
Particulate	0.172	g/hp-hr	0.230	g/kW-hr
CO2	539.2	g/hp-hr	723.10	g/kW-hr
BSFC	0.380	lb/hp-hr	0.231	kg/kW-hr

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Engine Model: 1991 Rebuilt DDC Series	Test No.: TEX R-2782-H8		DIESEL 2D, FL-2782
Engine Desc.: 12.7 L (775 CID) I-6	Date: 04/17/2003	Time: 10:20	HCR: 1.940 FID Resp: 1.00
Engine Cycle: Diesel	Program HDT: 4.12-R		H= 0.140 C= 0.860 O= 0.000 X= 0.000
Engine S/N: 06RE001123	Cell: 16	Bag Cart: 1	Oil Code: Delvac15W-40
Ref. Fuel, Test 8			

Ambient/Test Cell Conditions

Barometer:	29.10	in Hg	98.5 kPa
Engine Inlet Air			
Temperature:	76.0	°F	24.4 °C
Dew Point:	59.9	°F	15.5 °C
Abs. Humidity:	79.5	gr/lb	11.4 g/kg
Rel. Humidity:	57	%	
Dilution Air:			
Temperature:	81.0	°F	27.2 °C
Abs. Humidity	58.6	gr/lb	8.4 g/kg
Rel. Humidity:	36	%	

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		7.80	ppm	
HC Bckgrd	n/a		5.50	ppm	
CO	39.8	2	38.69	ppm	(Dry)
CO Bckgrd	0.2	2	0.19	ppm	
NOx Sample	n/a		44.30	ppm	(Dry)
NOx Bckgrd	0.5	1	0.13	ppm	
CO2 Sample	70.9	1	0.5984	%	(Wet)
CO2 Bckgrd	8.0	1	0.0469	%	

Corrected Concentrations

HC	2.55	ppm
CO	37.60	ppm
NOx	43.33	ppm
CO2	0.5536	%

Mass Emissions

HC			1.830	grams
CO			54.116	grams
NOx			103.651	grams
Particulate			4.107	grams
CO2			12.520	kg
Fuel	8.83	lb	4.00	kg

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,168.7	61.42
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	2.12	0.06
Gas Meter 2:	3.79	0.11
Sample Rate:	1.68	0.05
Total Flow Rate:	2,170.36	61.47

Particulate Data

Filter Number:	4422.0 (pair)	
Weight Gain:	3.171	mg
Sample Multiplier:	1.295	

Correction Factors

NOx Humidity CF:	1.012
Dry-to-Wet CF, Sample:	0.981
Dry-to-Wet CF, Bckgrd:	0.987
Dilution Factor:	21.96

Test Cycle Data

Sample Time:	1,206.70	sec		
Work:	23.63	hp-hr	17.62	kW-hr
Reference Work:	23.54	hp-hr	17.55	kW-hr
Total Volume (Vmix):	43,649.6	scf	1,236.18	scm

Brake-Specific Emission Results

BSHC (Cell)	0.077	g/hp-hr	0.104	g/kW-hr
CO	2.290	g/hp-hr	3.071	g/kW-hr
NOx (Cell)	4.386	g/hp-hr	5.882	g/kW-hr
Particulate	0.174	g/hp-hr	0.233	g/kW-hr
CO2	529.9	g/hp-hr	710.54	g/kW-hr
BSFC	0.373	lb/hp-hr	0.227	kg/kW-hr

Southwest Research Institute - Department of Emissions Research
CARB Hot Transient Emission Test Results
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Engine Model:	1991 Rebuilt DDC Series	Test No.: TEX R-2782-H9		DIESEL 2D, FL-2782
Engine Desc.:	12.7 L (775 CID) I-6	Date: 04/17/2003	Time: 11:00	HCR: 1.940 FID Resp: 1.00
Engine Cycle:	Diesel	Program HDT:	4.12-R	H= 0.140 C= 0.860 O= 0.000 X= 0.000
Engine S/N:	06RE001123	Cell: 16	Bag Cart: 1	Oil Code: Delvac15W-40
Ref. Fuel, Test 9				

Ambient/Test Cell Conditions

Barometer:	29.10	in Hg	98.5 kPa
Engine Inlet Air			
Temperature:	74.0	°F	23.3 °C
Dew Point:	60.2	°F	15.7 °C
Abs. Humidity:	80.4	gr/lb	11.5 g/kg
Rel. Humidity:	62	%	
Dilution Air:			
Temperature:	81.0	°F	27.2 °C
Abs. Humidity	68.4	gr/lb	9.8 g/kg
Rel. Humidity:	42	%	

Measured Gaseous Data

	Meter	Range	Concentration		
HC Sample	n/a		8.18	ppm	
HC Bckgrd	n/a		4.90	ppm	
CO	39.9	2	38.79	ppm	(Dry)
CO Bckgrd	0.2	2	0.19	ppm	
NOx Sample	n/a		45.10	ppm	(Dry)
NOx Bckgrd	0.4	1	0.10	ppm	
CO2 Sample	71.7	1	0.6087	%	(Wet)
CO2 Bckgrd	8.0	1	0.0469	%	

Corrected Concentrations

HC	3.51	ppm
CO	37.62	ppm
NOx	44.04	ppm
CO2	0.5640	%

Mass Emissions

HC			2.515	grams
CO			54.104	grams
NOx			105.524	grams
Particulate			4.198	grams
CO2			12.746	kg
Fuel	8.99	lb	4.07	kg

Sample Flows

	scfm	scmm
Blower 1 Rate:	2,168.6	61.42
Blower 2 Rate:	0.0	0.00
90 mm System:		
Gas Meter 1:	2.12	0.06
Gas Meter 2:	3.78	0.11
Sample Rate:	1.66	0.05
Total Flow Rate:	2,170.22	61.46

Particulate Data

Filter Number:	4423.0, (pair)	
Weight Gain:	3.205	mg
Sample Multiplier:	1.310	

Correction Factors

NOx Humidity CF:	1.014
Dry-to-Wet CF, Sample:	0.979
Dry-to-Wet CF, Bckgrd:	0.985
Dilution Factor:	21.59

Test Cycle Data

Sample Time:	1,206.00	sec		
Work:	23.63	hp-hr	17.62	kW-hr
Reference Work:	23.54	hp-hr	17.55	kW-hr
Total Volume (Vmix):	43,621.5	scf	1,235.39	scm

Brake-Specific Emission Results

BSHC (Cell)	0.106	g/hp-hr	0.143	g/kW-hr
CO	2.290	g/hp-hr	3.070	g/kW-hr
NOx (Cell)	4.466	g/hp-hr	5.989	g/kW-hr
Particulate	0.178	g/hp-hr	0.238	g/kW-hr
CO2	539.4	g/hp-hr	723.34	g/kW-hr
BSFC	0.380	lb/hp-hr	0.231	kg/kW-hr