High Performance Accumulator for Hybrid Power Plant to repower RTG Cranes in Port of Houston

Task 2, 3, 4, and Final Report

for:

New Technology Research and Development Program

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Submitted by:

MJ EcoPower Hybrid Systems

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Abstract/Executive Summary

Conventional rubber-tire gantry cranes (RTGs) utilize a 400 to 700 kilowatt (kW) diesel power plant generator set or genset to provide power to the crane’s electric motor. The engine must supply the required instantaneous power leading to a succession of highly transitory loads. The potential energy released when the crane lowered is converted in electricity through the motor drives and burned in a resistor grid. The engine must idle when the crane is waiting just to fulfill auxiliary loads demand. For example, a 450 kW genset must run in permanence to supply the 12 kW required at idle.

The EcoCrane™ hybrid power plant developed by EcoPower Hybrid Systems replaces the current power plant with a smaller diesel Genset able to deliver 80 kW and a battery pack. The batteries are designed to supply 100% of the requested power including all transitory loads. The small genset provides 100% of the total energy required and runs at constant power only when the batteries required energy. The electricity generated when a container is lowered returns to the battery. The engine is turned off when the battery reaches the defined maximum state of charge (SOC), and the battery supplies all power requirements. The technology is protected under Patent US 7554278 B2 dated June 30, 2009.

This project funded by TCEQ NTRD program has permitted demonstration of an EcoCrane equipped with lithium (Li) ion batteries. The new EcoCrane developed is more efficient and compact enough to fit in space required for actual conventional genset. This opens multiple new possibilities and simplifies greatly the installation procedure. From the concept work, the new Ecocrane was engineered, built and installed; it is currently powering a RTG crane in the port of Houston. This project is a success at technology as well operational levels.

The follow-up phase of this project was to apply for EPA verified status for this new Ecocrane Lithium Ion Hybrid Power Plan. Finally, based on the work performed during this project, the Li-ion Ecocrane configuration was added to the EcoCrane US EPA verification obtained June 18, 2013. In other words, the demonstration Ecocrane delivered in this project have already obtained the verified status.

The emission reduction measured for this project replacing a Cummins QSX15-G7 Tier2 engine with the Ecocrane system powered with a Cummins QSB5-G9 Tier 4i. Based on the duty cycle used for EPA verification, 40% on duty cycle at 15 containers loaded per hour on average and 60% of idling and loitering are presented at Table 1.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Particulate Matter (PM)</th>
<th>Carbon Monoxide (CO)</th>
<th>HydroCarbons (HC)</th>
<th>Oxide of Nitrogen (NOx)</th>
<th>Carbon Dioxide (CO₂) from Fuel Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li-ion EcoCrane</td>
<td>98%</td>
<td>88%</td>
<td>87%</td>
<td>88%</td>
<td>65%</td>
</tr>
</tbody>
</table>

Table 1. Emission reductions (%) from Emission Measurements on repowered crane
Introduction/Background

A Rubber Tired Gantry (RTG) is a mobile gantry crane used for stacking shipping containers within the stacking areas of a container terminal. RTGs are used at container terminals and container storage yards when straddling multiple lanes of rail/road and/or container storage, or when maximum storage density in the container stack is desired.

Conventional RTGs utilize a 400 to 700 kW diesel power plant generator set or genset to provide power to the crane’s electric motor. As no energy buffers are used, the engine must supply the required instantaneous power load leading to a succession of highly transitory loads. Transitory loads lead to increased emissions. The potential energy released when the crane lowered is converted in electricity through the motor drives and burned in a resistor grid. The engine must idle when the crane is waiting just to fulfill auxiliary loads demand. For example, a 450 kW genset must run in permanence to supply the 12 kW required at idle.

The EcoCrane™ hybrid power plant developed by EcoPower Hybrid Systems replaces the current power plant with a smaller diesel generator set (Genset) able to deliver 80kW and a battery pack. The batteries are designed to supply 100% of the requested power including all transitory loads. The small genset provides 100% of the total energy required and runs at constant power only when the batteries required energy. The electricity generated when a container is lowered returns to the battery. The engine is turned off when the battery reaches the defined maximum SOC, and the battery supplies all power requirements.

The difference between the Conventional power plant and the EcoCrane™ hybrid power plant is illustrated in Figure 1.
Figure 1. Difference between conventional power plant and the Ecocrane hybrid power plant for RTG Cranes

Hybrid technology is more expensive than other RTG emissions reduction technology; however, it has the advantage of providing the user with substantial fuel savings, which is, in many instances, a port’s significant operating expense.

The goal of this NTRD project was to develop and demonstrate the technical feasibility and the commercial viability for a new hybrid power plant with a high performance lithium-ion (li-ion) energy accumulator. At the beginning of the project originally propose in 2010, no warranty existed that a Li-ion technology battery would fit the applications and be commercially viable.

The demonstration unit we have delivered in May 2013 is using a battery pack designed and built by EcoPower in combination with a tier 4i engine supplied by Cummins interface and a new electrical interface developed for this project. This unit is currently installed on RTG crane at APM Terminals in Port of Houston. The system is fully functional, important emission reductions in conjunction with very significant improvements in fuel economy are demonstrated.

The hybrid power plant developer, MJ EcoPower Hybrid Systems (EcoPower) was the applicant for the grant. APM Terminals is owner of the equipment on which the new system is installed.


Efficiency Gains with Hybrid Technology

The hybrid power plant enables efficiency gains for the following reasons.

Significantly smaller engine

The conventional RTG cranes idle a significant portion of the time and have no capability for energy storage. Even in a very high duty cycle, a RTG equipped with a conventional genset requires the full power of the genset for only 15 seconds of every 120 seconds, which is equivalent to 12.5% of the time. Thus, a crane can need high power of 400 kW (peak power) for short period of time, while the average power consumed by an RTG crane is less than 50 kW. With the hybrid system, the peak power needed to lift a container is delivered by batteries. A genset is sized to deliver the lower average power required to maintain battery SOC. For the RTG application, the hybrid power plant’s genset size is 4 to 5 times smaller than the original engine sized to cover the maximum peak power demand.

Battery acts as capacitor bank

The conventional RTG diesel power plant is oversized in order to provide enough voltage “stiffness”, i.e., reduced voltage drop during high power demand. In the hybrid system, the batteries can provide the same voltage stiffness while allowing the smaller diesel genset to be used.

Recovering potential energy

Efficiency is increased by the regenerative power captured and stored in the batteries as the crane lowers containers. The potential energy from the container movement is at a maximum when the container is at its highest point. The crane essentially turns the electric motors into generators as the load is lowered, charging the batteries and further reducing the amount of time that the genset must operate.

Reduced engine run time

Depending on application, the batteries’ is set at a SOC level that delivers peak power. The smaller diesel generator installed on the hybrid power plant is turned on and off only as required to maintain batteries’ state of charge. This represents an additional fuel reduction compared to a conventional RTG power plant in which the engine runs all the time.

Project Objectives/Technical Approach

General Timeline

The authorization to proceed was received in June 2011.

Quarter 3 2011:

- The program started with all the preliminary evaluation of Li-ion battery technology, potential suppliers and manufacturers and the scope the entire battery testing plan.
- Ecopower was sold to Mi-Jack
- Decision was made to assemble the battery pack from electrochemical cells.
- To not delay the program Task 2 was started before the authorization requiring the go-no-go of Task 1.

Quarter 4 2011:
- Procurement of all cells
- The testing program of cells was performed

Quarter 1 2012:
- Testing program of preliminary modules was performed.
- All cells manufacturers were audited
- Program demonstrated the possibility to use high energy cells

Quarter 2 2012:
- Task 1 report was completed
- Results shown that the all technical targets could be reached, including:
  - At least two times smaller than the lead acid battery accumulator used on the first prototype version.
  - Safe regarding thermal run-away in over charge and over discharge.
  - Authorizing recharge current at least two times higher with 80% efficiency.
  - Presenting a power (kW)/energy (kWh) ratio of at least 5.
- Authorization to proceed was obtained for the balance of the project.

Quarter 3 2012:
- Design and engineering of battery modules, rack and enclosure including all computational fluid dynamics (CFD) for thermal analysis and finite element analysis (FEA) for mechanical were completed
- Crane in Houston was surveyed for the detail engineering.
- Preliminary electrical design was completed
- Electromagnetic impulse (EMI) sensitivity, communication protocol and module balancing functions from battery management system (BMS) were tested.

Quarter 4 2012
- High self-discharge was detected on batch of cells received. Part of the cells were replaced.
- Final module configuration was tested and validated
- Modules manufacturing was started and tuned.
- A second BMS system was engineered and has been installed for redundancy.

Quarter 1 2013
- Engineering was completed
- Procurement was completed
- All scenario of integration of the existing RTG with the EcoCrane were completed
- BMS development was completed
• Programmable logic control (PLC) programming
• Manufacturing of battery rack enclosure and its installation were completed
• Manufacturing of genset enclosure and installation of the genset and fuel tank were completed.
• Manufacturing of electronic control panel and its installation in enclosure was completed

Quarter 2 2013
• Shop tests were completed
• Transportation authorizations were obtained from both Department of Transportation (DOT) and Transport Canada
• RTG was modified, conventional genset removed and all connections prepared
• EcoCrane was installed, connected and commissioned
• Baseline testing and emission reduction were tested.
• The repowered RTG crane is currently used in operation in port of Houston.
Tasks

Task 1: Selection of battery technology, assembled in sub-pack and tested

Summary
Task 1 represented a go-no-go milestone. Ecopower had to demonstrate the feasibility of the concept and that one tested battery sub pack demonstrated the following characteristics, as compared to the lead acid battery technology:

- at least two times smaller than the lead acid battery accumulator used on the first prototype version;
- safe regarding thermal run-away in over charge and over discharge;
- authorizing recharge current at least two times higher with 80% efficiency;
- presenting a power (kW) to energy (kWh) ratio of at least 5; and
- designed and sized to have a minimal life expectancy of seven years or 4 times the one of a lead acid battery for this type of application.

Three sub tasks were successfully performed: pre-analysis and procurement, fabrication of the sub-packs, and the testing of the sub-packs to demonstrate the feasibility of the project.

Eight different cells were procured and evaluated for capacity, power capability, heat rejection and aging. One cell was rejected because high impedance and poor results at incoming inspection. Two cells were rejected to the poor quality of manufacturing and quality inconsistency during Ecopower visit. Two high end cells were rejected because high price that could not be justified. The three remaining cells were assembled in the following configuration test modules: one in format 26650 and the two prismatic cells of approximately 16 Ah and approximately 40Ah.

The modules were tested under three different duty cycles corresponding to:

- intensive RTG crane operation obtained from direct monitoring to demonstrate cell performance using real operational data,
- standardized very severe duty cycle to show limit of technologies, and
- a model duty cycle use for calculation; as real world operation is too complex to extract required parameters.

All manufacturers that could be used as cells supplier for this project were visited and audited.

From results obtained, the feasible selection for this application was Li-Ion Graphite/LiFePO4.

Task 2: Engineering and Adaptation of Ecopower technology for selected battery technology

From the Grant Activities (Scope of Work):
2.2. Task statement: The PERFORMING PARTY will complete the preliminary and detailed engineering of the battery pack, battery pack controls, and the hybrid power plant.

EcoPower has led the task. EcoPower has performed engineering and drawings using internal resources. EcoPower has built mock-up and performed preliminary testing fabrication. Pack integration, engineering, and technical transfer needed to adapt new battery technology.

Summary
The EcoCrane technology can be retrofitted on existing RTG cranes as well as installed on new cranes. In order to optimize its design, it was important to propose a solution that can be installed on all the commercial RTGs available on the market. A review of RTG cranes’ average and peak power requirements, duty cycles and available space has been completed. Standard models from ZPMC, Kone, Mitsui Paceco, Letourneau, Kalmar, Liebherr and Terex/Nowell were reviewed. Appendix A depicts several specific designs. The design goal was to fit the EcoCrane in the space occupied by any current conventional power plant without exceeding the weight of the current genset and engine cabinet. In parallel, the size of the battery pack required to respect thermal requirements, ventilation, shape factors of the electrochemical cells chosen at Task 1 were estimated. The specifications of the battery pack were determined in order to follow the main recognized standard. Through pre-engineering and detail engineering steps, most of the technical issues were addressed and fixed. The completion of this step led to the prototype manufacturing.

Integrate the chosen battery technology
From the Grant Activities (Scope of Work):

2.2.1. The PERFORMING PARTY will integrate the chosen battery technology with a modular design that permits assembly of the pack indifferent sizes and for different applications. The concept must be easily transferable to other types of applications where this hybrid concept can be applied.

Following our original strategy we have determined that using Li-ion technology a single size EcoCrane could fit all current commercial RTG crane applications. This represents a major advantage for the commercialization.

The final mechanical design was based on the KONE RTG Crane to be repowered at APMT in the port of Houston.

The entire assembly including two cabinets: one for the engine, the controls, and the power electronics, and a second cooled cabinet dedicated to batteries. The two cabinets were designed to fit within the volume of the conventional genset original cabinet.

We are illustrating the high level concept at Figures 2 and 3. Figure 2 presents a drawing of the original crane and Figure 3 is a picture of actual crane before repowering. The blue oval circle the original generator’s cabinet to be replaced.
Figure 2. Drawing and pictures of the RTG crane to be repowered in APMT at Port of Houston.
Figures 4, 5, and 6 show various views of the EcoCrane model obtained after all design iterations between the battery module and pack design and the genset/electronic cabinet sized to receive the smallest and cleanest generator commercially available for the application. The primary input of the iteration was the 3D model of the engine used to optimize the packaging of the engine and maximize space kept for the battery module final design and packaging.

The first view Figure 4 shows an external view (outside the crane). EcoCrane is installed between the wheels replacing the original generator cabinet. Electronic control are behind the white doors at the left. The battery rack is installed in the green cabinet. The inverter to supply AC power required for auxiliary equipment and control operation are installed being the grey wall in between.
The two other views, Figures 5 and 6, show the internal view of the EcoPower (under the crane). They are illustrating clearly the final design of the demonstration unit of the Li-ion EcoCrane. The packaging of the generator equipped with the qsb5-g9 tier4i Cummins engine can be seen as well as the module arrangement within the battery rack.
Choose and adapt an energy management system

From the Grant Activities (Scope of Work):

2.2.2. The PERFORMING PARTY will choose and adapt an energy management system specific to the accumulator technology, including a control strategy to maximize both energy balance and fuel efficiency.

From various monitoring we have evaluated that average power required to sustain RTG crane duty cycle is 40 kW. During intensive work it can reach 60 kW average over 10 minutes. We have determined that in average 15 containers are loaded every hour.

For this project we have chosen to work with a generator powered by a tier 4i Cummins engine model QSB5-G9. The engine can deliver up to 100 kW in continuous power and covers the need to maintain the battery SOC. Figure 7 illustrates data power from a generator on RTG crane. The blue thin line presenting peak up to 370 kW represents the instantaneous power requirement of the crane to perform the work load. The pink bold line represents the average power required over 10 minutes. A conventional generator must supply the instantaneous power. The generator of the EcoCrane just needs to supply the average power as batteries are supplying required instantaneous power.
Figure 7. Illustration of instantaneous power requirement compared to average power.

Figure 8 illustrates the energy management strategy for the Ecocrane. A conventional generator needs to constantly adjust to the power peak shown and just idle between power demand. All the negative power peaks in the shaded area are burned into breaking grid resistors. With Ecocrane, all power peaks are supplied by the batteries and negatives power peak in the shaded area are returned to batteries. The five shaded squares represent the power coming out of the Ecocrane generator to maintain the level of energy in the batteries when required. When required the generator is turned on and maintain a constant power output until the SOC of the batteries reach the maximum targeted. The generator is then turned off until SOC reached the minimum target point. This ensures that the engine is running at constant regime, avoiding high emission transitory power demand and never passively idles.
Select and interface the battery monitoring system

From the Grant Activities (Scope of Work):

2.2.3. The PERFORMING PARTY will select and interface the battery monitoring system and the control system used for thermal management, cell balancing, and state of pack detection.

BMS selected is manufactured by Elektromotus and modified following EcoPower requirements. Five versions of BMS firmware and hardware modifications were required. For safety and redundancy two BMS are used in parallel to monitor and equilibrate modules. The interface between the battery monitoring system and the control system was designed and packaged by Ecopower for the applications.

Define hardware configuration of the EcoCrane cabinets

From the Grant Activities (Scope of Work):

2.2.4. The PERFORMING PARTY will enhance hardware configuration of the EcoCrane cabinets to optimize battery cabinet volume and thermal management.

Hardware configuration of the EcoCrane cabinets was designed to optimize volume and thermal management. A forced convection analysis of battery module was conducted using computational. The objective of the analysis was to determine the flow rates required to achieve acceptable battery temperature as well as the associated pressure drop. Finally a forced air flow of 50 cubic feet per minute (cfm) with an ambient temperature of 15 degrees Celsius considering...
power dissipation due to resistance at 208 W per module (i.e., 40 cells per module x 5.2W per cell) permits to obtain a temperature difference of 2 degrees Celsius within the module. Results of simulation are presented at Figure 9. Temperature mapping of a transverse cut of the third cell bundle of 10 cells.

![Temperature mapping of a transverse cut of the third cell bundle of 10 cells.](image)

**Figure 9. Simulation of temperature equilibrium at continuous 1C discharge rate within a module. A transversal cut of the 3rd cell bundle is shown.**

As presented in Figure 10, the CFD analysis was applied to the complete battery rack to confirm that cooling was sufficient and to analyze air flow balancing.
Figure 10. CFD results of the thermal analysis of the battery rack.

Based on worst case scenario, it was calculated that in case of thermal events, if more than one cell vented the internal pressure of the cabinet could be too high for the doors. In this context an explosion proof opening was designed to open to release internal pressure. Figure 11 presents result of the FEA stress analysis performed during the design.
Figure 11. Simulation and evaluation of the explosion proof door.

FEA stress analysis was conducted for mechanical resistance evaluation of enclosure. Considering that each battery module weighs 175 pounds (lb). The operational loads were simulated to confirm that the stresses on the rack structure were below yield strength. The criteria applied were:

- 1g down + 2g lateral (X+, X-),
- 1g down + 2g longitudinal (Z+, Z-),
- 3g down, and
- 80,000 lb tire change load.

To validate that the cabinet could be lifted with all modules installed the conditions tested were:

- 3g down (lifting load) - stresses to be below yield strength, and
- 6g down (lifting load) - stresses to be below tensile strength.

Reaction loads and moments for weld calculations were based on a simplified model including only the structural components.

The battery modules were assumed not to contribute to the stiffness of the structure, which is a conservative assumption.
All welds are assumed to be through welds covering the complete rectangular section for all structural parts.

The rails are assumed welded as shown below (front and back). Weld thickness was 0.25 inch. Typical results are presented at Figure 12.

![Equivalente Stress](image)

**Figure 12. Example of FAE results obtained during design structure validation.**

**Define the safety layer to prevent thermal events and estimate life expectancy.**

From the Grant Activities (Scope of Work):

2.2.5. *The PERFORMING PARTY will ensure that the assembly is designed to present multiple layers of protection against fire hazards; and designed and sized to have a minimal life expectancy of 7 years or 4 times that of a lead acid battery for this type of application.*

For safety reason, we have researched solutions and focus on technology using LiFePO₄ active material as cathode. This technology is safer and resists higher temperature, is not susceptible to thermal runaway in over charge. Overall this technology is recognized as a safer alternative than other technologies but presents a lower energy density. We have demonstrated that Li-ion technology using LiFePO₄ invented by Goodenough at University of Texas in Austin and patented by Hydro Quebec represents a safe solution and can be used as energy accumulator in the RTG Crane to be retrofitted at APMT port of Houston.
Over this intrinsic safety characteristic the following safeties were added.

- Software is designed to disconnect the battery safely in case of off specification voltage or temperature.
- A grid is connected to burn energy if the fixed maximum voltage is reach on the system.
- The system is fused based on short circuit information from supplier testing.
- Electrolyte was sprayed on module to validate electronic won’t short in case of a cell venting electrolyte.
- A second BMS is connected in parallel for safety and redundancy purposes.
- Electromagnetic interference testing was performed and confirm that electromagnetic noise does not affect communication.
- Insulating blankets to put around the batteries to prevent arc were tested with success during hi-pot testing.
- Vibration test with updated design was completed without failures.
- Immersion test was done on individual cell.
- Explosion proof doors and vent panels are installed.
- Every single module is contained in a metal box limiting potential fire propagation.

Knowing that LiFePO₄ technology loses 20% of capacity at every 2000 full cycles, considering an average power of 40 kW during operation we calculate 13.3 hybrid cycles of 24 kWh in average every day. This corresponds to 640 full cycles per year. By extrapolation, the remaining energy of the pack would be around 90 kWh after the seventh year. This does not take into account that the life will be extended considering that the pack is never discharged under 50% and operates on less than 20% of the capacity.

**Selection of resources**

From the Grant Activities (Scope of Work):

2.2.6. *The PERFORMING PARTY will select subcontractors for the following roles: battery pack integrator(s), power electronics engineer(s), and drafters.*

After contract modification on July 2012, Ecopower was acting as battery pack integrator. Specific services of simulation and drafting were contracted and were performing services under the close supervision of Ecopower. List of specific consultants and rates are available in the financial reports.

**Task 3: Manufacturing of prototype power plant**

From the Grant Activities (Scope of Work):

2.3. *Task statement: The PERFORMING PARTY will manufacture, commission and complete preliminary testing of the prototype battery pack and power plant.*

2.3.1. *The PERFORMING PARTY will manufacture the battery pack and new EcoCrane hybrid power plant using Li-ion technology.*
2.3.2. The PERFORMING PARTY will complete commissioning and debugging of the prototype systems, including preliminary testing and bench validation.

2.3.3. The PERFORMING PARTY will select subcontractors for the following roles: environmental analysis and emissions monitoring engineer(s); and EcoCrane installer, maintenance, and operation.

2.3.4. Schedule: The PERFORMING PARTY shall complete this task within 23 months of the signed Notice to Proceed Date as issued by TCEQ.

2.3.5. Deliverables: The PERFORMING PARTY shall submit a report to the TCEQ upon completion of this task. This report will include but is not limited to documentation, including pictures, of the manufactured battery pack and hybrid power plant and results of the preliminary testing and bench validation.

Prototype battery pack
Module final configuration is presented at Figures 13 and 14. Each module is composed of 40 cells of 3.2 V at 44 Ah. The connections are five cells connected in parallel in 8 series (5P 8S) for a module of 25.6V of 220 Ah. General connection configuration is presented at Figure 13. Figure 14 shows an external view of the module.

Figure 13. View of cells arrangement and connections inside the modules.
The Figure 15 presents an internal view of the battery pack. The battery pack is composed of a rack in which 27 modules are inserted, 14 on one side and 13 on the other. The pack is protected by a cooled enclosure. An explosion proof panel is installed at the top of the enclosure to prevent deflagration in case of serious thermal event. Positive and negative posts are protected by red and black insulating material. We can see the modules serial interconnections, the black cable connecting red post to black post to add the voltage of each modules to reach a total voltage of 690 V nominal.
Figure 15. Interior view of the Li-ion battery pack installed on the EcoCrane hybrid power plant.

Figure 16. Generator Cummins QSB5-G9 tier 4i installed and connected inside the new EcoCrane enclosure.
The entire system was assembled at Ecopower manufacturing facility. Standard start-up procedure was followed: input/output check, functionality, and software validation were performed. All communication, BMS system, genset controls, battery charging and discharging were tested using external resistor grids.

Emisstar was contracted as environmental analysis services and monitoring engineers. Emisstar was in charge of the testing of the previous generation of Ecocrane testing. A unit equipped with lead acid battery was manufactured and installed under an emerging technology DERA grant. That unit was used in the US EPA verification process. Emisstar was familiar with the duty cycle and testing methodology.

The installation, maintenance and operation services were supplied by APMT and Ecopower personnel.

**Task 4: Retrofitting of the power plant on existing RTG and demonstration**

From the Grant Activities (Scope of Work):

2.4. **Task statement:** The PERFORMING PARTY will retrofit an existing RTG crane with the prototype hybrid Ecopower power plant using Li-ion battery power pack.

Detailed graphic presentation of the mechanical interface between EcoCrane and KONE crane is presented at Appendix B.

**Modify RTG Crane for the retrofit**

From the Grant Activities (Scope of Work):

2.4.1. **The PERFORMING PARTY will modify the existing RTG crane for the retrofit, install and integrate the EcoCrane prototype power plant with Li-ion battery pack, and commission the retrofitted RTG crane.**

The conventional power plant from RTG crane was disconnected and removed.

**Install and integrate EcoCrane**

From the Grant Activities (Scope of Work):

2.4.2. **The PERFORMING PARTY will install acquisition data modules on the RTG crane and perform preliminary testing of its operation after it has been retrofitted with the EcoCrane prototype power plant with Li-ion battery pack. The PERFORMING PARTY will continue testing the performance during operation and request any supplementary testing indicated from performance results.**

Interface brackets and attachments were welded on RTG structure following the engineering supplied by EcoPower. The Ecocrane was installed and secured in positions. Power connections were done. Kone drive software was modified for communication with the Ecocrane. Figures 17, 18, 1nd 19 depict the assembled crane.
Figure 17. Outside crane width view of the li-ion EcoCrane installed on the Kone crane; view of the control panel.

Figure 18. Inside crane width front view (inside the crane) of the Li-ion EcoCrane Hybrid power plant. View of the genset cabinet and the second side of the battery rack.
Commission RTG

From the Grant Activities (Scope of Work):

2.4.2.1. The PERFORMING PARTY will ensure that testing analyzes: the hours of crane operation; percentage of time the generator is turned on during crane operation; voltage, power and current produced by the batteries; power and current from the genset as well as from regeneration; and fuel consumption.

The RTG crane newly repowered with the lithium ion EcoCrane Hybrid System was debugged and commissioned in May 2013. The crane was tested in operation. It performs as well as the conventional system but reacts a little more rapidly because the batteries do not need to be loaded as the generator does.

Perform preliminary testing of operation

From Grant Activities (Scope of Work):

2.4.2.2. The PERFORMING PARTY will ensure that NOx emissions testing is conducted using a Portable Emissions Measurement System using the standard EPA and CARB duty cycle for RTG cranes.

Emission testing was performed. The emission reductions measured for this project replacing a Cummins QSX15-G7 Tier2 with the Ecocrane system powered with a Cummins QSB5-G9 Tier 4i
based on duty cycle used for EPA verification (40% on duty cycle at 15 containers loaded/hour in average and 60% of idling and loitering) are presented in Table 1.

Apply for verification

The second phase of project was to apply for certification for the new Li-ion EcoCrane prototyped with the support of the NTRD grant program.

In parallel with this project, Ecopower was seeking verification for the lead Acid battery version of the EcoCrane. Based on US patent 7,554,278 obtained June 2009, the basic EcoCrane equipped with VRLA batteries was placed on emerging technology list on December 2009. EcoCrane was verified in June 2013. The preliminary results of this project were good enough to extend the EPA verification to the Li-ion cranes.

This TCEQ project has permitted a demonstration using Li-ion batteries to be completed. All information related to battery life and long term performances are still to be collected. From a technical standpoint, it was shown that the Li-ion accumulator reduced the overall size of the lead acid hybrid power plant by more than a factor 2. This will permit Ecopower to apply the technology to other diesel electric applications where peak power need is much higher than the average power required. Examples of such applications include other lifting equipment and drilling rigs for example.
Discussion/Observations

Objectives vs. Results

The EcoPower’s hybrid power plant replaces conventional existing diesel gensets on existing RTGs and is supplied as an original engine manufacturer (OEM) package on newly manufactured RTGs. This project has demonstrated a new concept of energy efficiency for container handling equipment at marine port facilities. The project met the TCEQ NTRD Program objectives by contributing to significant reductions in diesel emissions in terms of tons of pollution produced and diesel emissions exposure, particularly from fleets operating in an area designated as a poor air quality area. Furthermore, the EcoCrane is the only repowering permitting significant level of emission reduction added to 60% fuel reduction.

The Li-ion EcoCrane hybrid power plant had to be manufactured to make a demonstration in operation and required funding to show its potential to reduce emissions as well as fuel usage by 60%. The demonstration of functionality in operation was excellent. The demonstration unit founded in part by TCEQ already received its verification from US EPA. Based on current results, US EPA has included other battery technology to the verification process that was completed June 18, 2013 with the official verification letter presented in Appendix C.

The hybrid power plant delivers power while maintaining higher fuel efficiency and substantially reducing emissions. The hybrid power plant can convert diesel fuel to electrical energy more efficiently with lower emissions, as its diesel engine is sized more appropriately for the average demand. It operates at all times under optimal conditions, mostly under steady state conditions with very few transients, as power not needed for operation is used to recharge the batteries.

As expected this project confirmed that RTG cranes spend a significant amount of time idling. The batteries offer energy storage capability and provide the opportunity to reduce required engine size and to turn off the generator when the RTG crane is idling. All ports are facing a similar crisis of high fuel costs and the challenge of reducing emissions with minimal impact on operation and maintenance costs. The hybrid power plant provides an efficient solution to maximize operational performances and meet environmental demands.

Overall the project went without huge surprises. All problems were addressed on a daily basis and mitigation actions were taken in due time to respect timeline and the ultimate deliverable a working Li-ion hybrid power plant installed on a RTG crane Barber cut’s APM terminal in Port of Houston. The schedule was extended to accommodate contractual phase as well as availability of the final user for the installation.
Technical and commercial viability of the proposed approach

The EcoCrane hybrid power plant can be used as original power source on new machine and is design to be retrofit on existing equipment. Figure 20 presents the number of existing equipment in use in North America. With the new compact design achieved during this project, a more significant part of this market is now accessible to EcoCrane technology.

Figure 20. Existing cranes in use in North America.

EcoCrane technology offers a full return on investment (ROI) on entire investment with ongoing savings extending for life. No other retrofit or repower options offer a ROI based on absolute fuel savings, reduces ongoing maintenance costs and reduced engine rebuild frequency.

With the new verification status obtained June 18, 2013, EcoCrane is now admissible to Diesel Emissions Reduction Act (DERA) funding. We also expect that the focus on greenhouse-gas reduction will help to position EcoCrane as an efficient transition between conventional generator and zero emission equipment.

The goals of this project were achieved. The technical barriers identified were mainly related to BMS and interfacing existing older equipment often equipped with proprietary software and technology. All identified barriers were addressed. Planned technological improvements will overcome these barriers and will ease the retrofit process. This project already reduces by a factor of four the manpower and the time required to retrofit the EcoCrane. We can do in one week what was requesting one month before. As we do not have to modify the crane structure and we do not add weight to the original equipment we can now also avoid crane structural engineering validation and complex steering adjustments required in the past.
**Scope for future work**

Future work planned was to obtain a US EPA verified status for the Li-ion EcoCrane. As mentioned, we already obtained this verification in extension to our verification request for the first lead acid battery. The next steps will be related the optimization and improvement of the system. This demonstration project with Li-Ion batteries will permit to retrofit smaller applications where lead acid batteries could not be used because the volume required and the weight of the batteries.

We are planning to engineer and build An EcoCrane equipped with a fuel cell as prime power using the new Li-ion battery pack. That will be the first unplug zero emission RTG crane.

**Intellectual Properties/Publications/Presentations**

US patent 7,554,278/June 2009

The patent covers the entire concept use in EcoCrane power management and was obtained before the beginning of the project. As this patent covers all lifting apparatus equipped with all prime power system(s) (generator, fuel cell, induction, grid, etc) and energy storage system(s) (battery, super cap, flywheel, etc.) when the prime power is sized at 20 to 70% of the peak power.

**Summary/Conclusions**

This project funded by TCEQ NTRD program has permitted demonstration of an EcoCrane equipped with Li-ion batteries. The new EcoCrane developed is more efficient and compact enough to fit in space occupied by actual conventional genset. This opens multiple new possibilities and simplifies greatly the installation procedure. From the concept work, the new Ecocran was engineered, built and installed; it is currently powering a RTG crane in the port of Houston. This project is a success at technology level as well as at operational level.

The follow-up phase of this project was to apply for EPA verified status for this new Ecocrane Lithium Ion Hybrid Power Plan. Finally, based on the work performed during this project, the Li-ion Ecocrame configuration was added to the EcoCrane US EPA verification obtained June 18th 2013. In other words, the demonstration Ecocrame delivered in this project have already obtained the verified status.

We are currently adapting new and improve version of this verified li-ion Ecocrame and installing it on four supplementary RTG cranes at APM terminal in port of Houston.
Acknowledgements

EcoPower thanks AMP terminal in Houston to make this demonstration possible in supplying the RTG crane to be repowered and time and resources to support the testing and the operation.

Ecopower thanks TCEQ for its funding, its support and advice since the acceptance of the project. We specially thank Kate Williams for her professionalism, her support, and her clear explanations regarding rules and procedures.

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Appendices
Appendix A: RTG Crane Layout review used for New EcoCrane design

Drawings and pictures of all RTG Crane models considered in the design of the Li-ion EcoCrane. The final solution could be installed on any of these machines. This is related to the power and the reduce size of the new units.
Appendix B: Overview of Mechanical installation of EcoCrane on KONE RTG Crane

The following sequence of drawings illustrates the installation of the EcoCrane on the Kone RTG Crane. These drawings were supplied to the installation team to illustrate the sequence of installation.
Actual genset volume is 146” length x 79” height x 55” depth
Actual two genset supports to grind off

Install 6 new mounting brackets (welded to sill beam)
Bolt the two enclosures to the sill beam (each with four mounting bolts)
All interfacing cables exit the EcoCrane at this location.

Actual E-room cables bottom entries will be used.

Cut exhaust pipe and hook up to new exhaust line.
Additional components to install: Transformer and Resistor Grid

Transformer 30.5" width x 22" depth x 36" height with supplied supporting bracket to be bolted or welded in this area
Transformer weight = 1000 lbs

To be wired to CPMP and E-room

Additional components to install: Resistor Grid

In the same area (maybe same bracket as transformer)
Resistor Grid 29" width x 20" depth x 22.5" height
Resistor Grid weight = 250 lbs
To be wired to Inverter beside CPMP
Appendix C: Verification letter
(see PDF version for copy of letter – page 1 out of 3)
(see PDF version for copy of letter – page 3 out of 3)