IPRO It takes a team
INTERPROFESSIONAL PROJECTS PROGRAM

IPRO 310: Conversion of a Commercial-Grade Riding Lawnmower to Hydrogen Fuel

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Final Report: Melissa Lemons, Nate Gates, Nathan Knopp, Joel Fenner
Poster: Chungyun Kim, Minjoong Kim, Frank Costanzo
Presentation: Yewon Gim, Dan Taulbee, Minsuk Jung

Recorder of Minutes: Jason Neale

Project Introduction:

IPRO 310 is responsible for researching the safe and efficient conversion of a John Deere Mid-Z Trak 757 gasoline-powered riding lawnmower to run on gaseous hydrogen.. This semester's work is a continuation of last semester's benchmarking information and research gathered. According to last semester's testing, with the blades engaged and a full 10-gallon tank of gasoline, the lawnmower can operate for approximately 6 hours, and according to eNature, per hour of operation, a lawnmower emits 10-12 times as much emissions gas as does a typical automobile. Due to the Bush administration's push for alternative and more efficient fuel sources and the unacceptable lawnmower emissions information, the Chicago Parks District (CPD), which is responsible for maintaining over 7300 acres of parkland in and around Chicago, contacted the IPRO office two semesters ago and challenged them with the task of investigating a more environmentally friendly fuel option – gaseous hydrogen – and its possible application to lawnmowers. However, earlier this semester it was announced that due to concerns about the team's ability to complete the project the Chicago Parks District was no longer interested in funding IPRO 310's research. The IPRO 310 team is currently investigating alternative sources of funding.

Revised Objectives:

The objectives established in the Project Plan have not been altered though the timeline for their completion has been changed as needed (see the attached adjusted Gantt chart in Appendix 1). The tasks have been further broken down and assigned to each of the three sub-teams:

Conversion Sub-Team

- Calculate the power output and compare the cost to benefit ratio for each type of fuel
- Research, select, and purchase the components necessary for the conversion process
- Develop detailed conversion guidelines that comply with the safety standards proposed by the lab safety sub-team
- Convert the engine to use gaseous hydrogen as its fuel
- Establish a testing and tuning procedure
- Integrate the converted engine with the lawnmower
- Design a safe and convenient tank mounting system

Lab Safety Sub-Team

- Maintain a safe environment in the testing lab
- Research safety requirements for hydrogen use in motor vehicles
- Develop a thorough and complete safety code for hydrogen use both in the testing lab and on the lawnmower.

- Work closely with Testing and Conversion sub-teams to help implement safety codes and protocols in their work
- Install hydrogen detection and safety equipment in the testing lab

Testing Sub-Team

- Remove the engine from the lawnmower and get it into the testing laboratory
- Learn how to operate and repair the DYNO-Max 2000
- Perform engine tests using the dynamometer to obtain a power curve and other useful parameters that will be compared to that of the converted engine
- Perform gas analyzer test to compare before- and after-conversion emissions
- Analyze the results obtained from testing and compare the pre-and post-conversion test results

Throughout the semester, each sub-team will also be responsible for keeping the entire team up to date on its progress through reports and presentations.

Results to Date:

Each sub-team has been working diligently throughout the semester to reach their objectives and ultimately the final goal. Listed below is each of the sub-teams' progress thus far this semester.

Conversion Sub-Team

The conversion sub-team created thermodynamic models for the Kawasaki FH721D engine used by the John Deere lawnmower for both gasoline and hydrogen. These were developed using the Otto cycle (see Figure 1), which is the idealized internal combustion engine cycle, and taking into account power losses due to friction and appropriate heat losses.

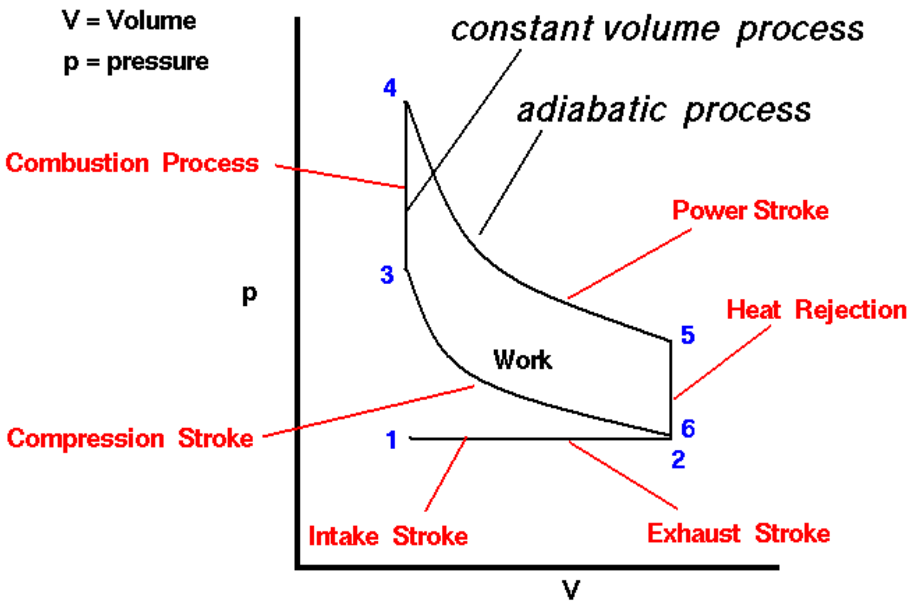


Figure 1: The Otto Cycle

To find the value of the ideal net work expected from the lawnmower engine, the formula for the thermal efficiency, η_{th}, of the Otto cycle, expressed by Equation 1, is used.

$$\eta_{th} = 1 - \frac{1}{\left(r^{k-1}\right)}$$

Equation 1. Thermal Efficiency of the Otto Cycle

In Equation 1, *r* is the compression ratio, which is the ratio of the greatest displacement to the least displacement in the cylinder, and k is the ratio of constant pressure specific heat of the air-fuel mixture to the constant volume specific heat of the same mixture.

However, thermal efficiency is also defined in a more general manner by Equation 2.

$$\eta_{th} = \frac{W_{net}}{Q_{in}}$$

Equation 2. General Form of Thermal Efficiency

In Equation 2, W_{net} is the net work output and Q_{in} is the heat added to the cycle due to combustion.

Combining Equations 1 and 2, an expression for net work output is obtained. Q_{in} can be calculated from the heat of combustion of the fuel and the quantity of the fuel in the cylinder during combustion.. Thus, a value of net work output is obtained for both the gasoline- and hydrogen-powered engines. Net power output values are then calculated using the engine rpm (revolutions per minute) value at the peak power output as specified on the engine data sheet.

In order to calculate the real power outputs, empirical friction and heat loss factors found in reference materials from similar engines are used. The real values of the power outputs are 26.6 hp for the gasoline engine and 18.275 hp for the hydrogen engine. The predicted power output for the gasoline engine is close to 25 hp provided by Kawasaki specifications. This confirms the validity of the sub-team's thermodynamic model.

Despite hydrogen having a higher heat of combustion per unit mass, the hydrogen engine will have a lower power output than the gasoline engine because gasoline is much denser than hydrogen.

After constructing the thermodynamic models, the conversion sub-team began researching engine conversion procedures that would result in a safe hydrogen engine that was approximately as powerful as the current gasoline engine. Some of the issues that needed to be addressed were hydrogen embrittlement, gaseous fuel delivery, improved cooling, abnormal combustion, and the management of combustion products.

Hydrogen needs to be stored in special tanks, because it causes embrittlement in ordinary steel tanks or the gasoline tanks currently on the lawnmower. Hydrogen embrittlement occurs when hydrogen molecules, which are much smaller than the gasoline hydro-carbon molecule, are absorbed by surrounding material. Once the hydrogen enters metal crystal lattices, it reduces the ductility and load-bearing capacity of the material, making it susceptible to cracking and brittle failures at low stresses such as the normal vibrations of an operating lawnmower. Also, the hydrogen can eventually migrate all the way through surrounding metal into the air. The materials that can be used in contact with hydrogen safely are 316 and 304 Stainless Steels, aluminum, and composite materials. Aluminum is more resistant to embrittlement than the stainless steels, and it costs less and is stronger than composites. However, composites are safer and lighter than aluminum. Therefore the conversion sub-team decided on composite tanks for the actual converted lawnmower model.

One of the largest problems associated with hydrogen-fuel engines is pre-ignition or backfire. This is when the fuel ignites before it is supposed to in the combustion cycle. The carburetor system used to regulate the air-fuel mixture needed to be adapted for use with a gaseous fuel. An adapter and various components between the hydrogen tanks and the carburetor are necessary. The new system also adds the hydrogen to the air closer to the cylinder to prevent backfire thus making the old fuel intake port useless. Also, as larger amounts of heat would be produced during hydrogen combustion, an improved cooling system would be helpful in preventing overheating, a precursor to pre-ignition.. Another way of preventing backfire would be to use stainless-steel-tipped spark plugs instead of the platinum-tipped spark plugs that are currently used. Because hydrogen can explode at a variety of concentrations and even with small heat sources, a stainless-steel-tipped spark plug that will dissipate heat faster than a normal platinum-tipped spark plug, preventing unwanted ignition in the cylinder. Furthermore, piston rings with a better seal between the piston wall and the cylinder would be needed to prevent leakage of the excess water produced during combustion into the oil pan and to prevent oil from seeping into the top of the cylinder, another condition encouraging pre-ignition. All of these component changes were researched thoroughly by the members of the conversion sub-team.

The starting point of the conversion research was last semester's equipment list. The team examined individual components that would be used during conversion, talked to vendors for price quotes of these items, and put together a conversion budget for the proposal to possible new funding sources.. The task of researching different components was assigned to different conversion sub-team members.

Dan was assigned the task of researching, designing and pricing the carburetion system. Through contacts with Swagelok, Inc. and Rick Nordstrom at IMPCO Technologies, a design which allows for use of the existing carburetor was chosen. This aspect of the design would result in a lesser cost for the overall project. The fuel delivery system is ready for ordering. Another component researched by Dan was the cooling system. While larger engines use liquid cooling systems, the Kawasaki engine on the mower uses a simple air cooled system consisting mainly of an engine fan. This design does not allow for simple or expensive modifications. Therefore, an improved cooling system has been deemed uneconomical.

Preeti's task was to look into hydrogen tanks, regulators, and tubing for the hydrogen supply on the lawnmower. After researching products from various companies, she found Swagelok, Inc. had a product line designed exclusively for gaseous alternative fuel technologies. The regulators, hoses, and tubing for the hydrogen fuel system were chosen from Swagelok's product line, and are made mostly out of 316 Stainless Steel.
The conversion sub-team decided on Luxfer Composites' A360W Type 2 Hoop Wrapped cylinder for hydrogen storage on the lawnmower. This cylinder features an aluminum-magnesium-silicon alloy with carbon fiber or fiberglass hoop wrapping.

Steffany was charged with assisting in the carburetor research and selecting piston rings and spark plugs. After extensive research and calling numerous suppliers, it was determined that high performance rings are not manufactured for such a small engine. Custom made rings were deemed uneconomical. A vendor that provided stainless steel plugs (for marine applications) was located and a quote was produced.

Yewon's task was to locate a hydrogen supplier. Currently, the most convenient hydrogen source would be Mittler Supplies. As IIT's Chemical Engineering Department is currently ordering hydrogen from Mittler, the delivery costs would be reduced. The cylinder would also be supplied by Mittler at a rental fee of $0.13 per day. The team decided on using industrial grade hydrogen which Mittler produces for about $0.33 per liter. If tanks from other sources were used, it would take at least a week to get the tanks filled and, at this moment, the cost can not be estimated. The cylinder provided by Mittler will be sufficient for testing. A protective casing for the cylinder and the connection area will be necessary. The casing would be made out of an impact-resistant polymer. The most viable casing supplier is Vision technology but local suppliers have yet to respond.

Lab Safety Sub-Team:

The principal goal of the lab safety sub-team is to obtain information about the safe use of hydrogen in the context of a laboratory environment and in the more practical context of a motor vehicle. The lab safety sub-team has thoroughly reviewed five separate codes for hydrogen and compressed fuel gas safety: one from the National Aeronautics and Space Administration (NASA), one from the National Fire Protection Association (NFPA), one from the Occupational Safety and Health Administration (OSHA), and two from the International Code Council (ICC). Using the information from those five codes, a more concise summary set of safety requirements directly applied to the use of gaseous hydrogen in the context of the conversion project have been developed. Necessary safety equipment for the lab to detect hydrogen leakage, and warn personnel in the event of a leak, have been identified. The maximum safe quantity of hydrogen that may be kept in the lab at any given time to comply with safety codes has been determined.

As far as the specifics of hydrogen safety in the laboratory are concerned, the NASA and OSHA documents have proven most applicable. The codes specify strict restrictions on the volumetric concentration of hydrogen in the air (as hydrogen is likely to leak at some slight rate). For general purposes, no more than a 1% concentration of hydrogen by volume is permissible, this value being ¼ of the concentration required to pose a combustion hazard. To comply with this restriction, members of the lab safety sub-team took measurements of the dimensions of the room and calculated the maximum safe quantity of hydrogen which, if leaked, would cause that 1% concentration to develop. This value was calculated as 0.41 pounds of hydrogen. Therefore, for the purposes of engine testing in the laboratory, no more than 0.41 pounds of hydrogen shall be allowed in the lab at any given time to prevent even the possibility of exceeding the 1% volumetric concentration in the event that all the hydrogen is inadvertently leaked.

As a further safety concern in the lab, nearly all the codes specify the use of a hydrogen detector to warn personnel if the hydrogen concentration should reach the 1% volumetric threshold. The detector must give audible and visible warning so personnel may perform a shutdown of the hydrogen equipment and then evacuate the lab until the concentration drops to safer levels. The team has selected a detector and associated warning lights and alarms to be installed in the lab to comply with this specification.

Some of the work of the lab safety sub-team has bearing on the work of the conversion team. This is very much the case as far as the issues of hydrogen embrittlement and diffusion are concerned. The various codes (particularly NASA and ICC) discuss the effects of hydrogen on metals. In general, the codes recommend the use of stainless steels or aluminum alloys as these substances tend to show the least effects of hydrogen embrittlement. The NFPA compressed gas codes, however, suggest that certain DOT certified grades of ordinary chromium-molybdenum steels are acceptable for pressure vessels, provided that those vessels are produced in compliance with DOT specifications.

As an additional safety concern, the NASA codes point out that plastic deformations in metals tend to serve as an initiation mechanism for accelerated hydrogen embrittlement.

For example, if a pressure vessel or a hydrogen-carrying component (pipe, pressure regulator, etc.) becomes dented or malformed in some way, hydrogen embrittlement is likely to become accelerated at the site of that damage. The insidious part of the problem is that the embrittlement will occur at the interface between hydrogen and metal (i.e., on the inside), making visual detection of crack development nearly impossible until a crack has propagated to the outside of the component. This means that any component damaged in use should be taken out of service and replaced because, if left in service, it may fail suddenly after a long period of time.

While it is the goal of the lab safety sub-team to prevent any sort of hydrogen accident, the issue of a hydrogen fire should be considered. In the event that a hydrogen leak should develop and ultimately begin to burn in a controlled manner (like a gas torch or Bunsen burner), the safety codes insist that the utmost priority is to disable the hydrogen supply. In our case, this should simply entail closing off the supply valve from a hydrogen tank. Furthermore, while it may seem counter-intuitive, the safety codes indicate that it is unsafe to extinguish such a hydrogen fire if the hydrogen supply has not been disabled. The reasoning behind this is that a controlled fire is, in a certain sense, stable. If the hydrogen fire should be extinguished with the hydrogen supply still active, hydrogen gas may simply begin to concentrate in a cloud. If accidentally ignited, that hydrogen cloud may pose an explosion hazard, whereas the prior hydrogen flame posed no such explosion hazard.

Information regarding the safe use of hydrogen on motor vehicles is vaguer. The codes are quite clear about the high diffusion rates of hydrogen in air. Hydrogen is lighter than air (as opposed to other fuel gases like propane or methane) and naturally diffuses upward. Hydrogen also naturally diffuses horizontally at high rates. These two factors suggest that hydrogen use in motor vehicles is somewhat safer (computer modeling presented in the NFPA codes confirms this) than other fuel gases as it is less likely to become concentrated in the event of a leak.

Testing Sub-Team:

The current accomplishments of the testing team subgroup include removal of the engine from the John Deere 757 ® Commercial Lawn Mower (see Figures 1 and 2 in Appendix 2), mounting the engine in order to make important measurements utilizing the DYNO-Max 2000, and starting the engine. Removal of the Kawasaki type FH271B 25 hp engine, involved the simple technique of removing each bolt that connected the engine to the lawnmower, as well as disconnecting each belt on the engine that was connected to the lawnmower. Mounting the engine involved simply placing four bolts through both the engine stand and the engine mount that is on the DYNO-Max 2000. Starting the engine was a process solved by making the proper electrical connections with the engine, and providing sufficient fuel to the engine. The proper connections for starting the engine were made after carefully analyzing the schematics of all the electrical leads (see Figure 3 in Appendix 2).

Updated Assignments:

As the CPD is no longer financing this project, a proposal writing team, consisting of one member from each sub-team, was formed to create a proposal for alternate funding. The overall team leader, Steffany Evanoff, will be heading the team in conjunction with the IPRO's advisor Dr. Al-Hallaj. The proposal team members are Dan (Conversion sub-team), Jim (Testing sub-team), and Minjoong (Lab Safety sub-team).

Conversion Sub-Team:

Now that the component research for the engine conversion is completed, the entire conversion sub-team will work together to determine step-by-step conversion and testing and tuning guidelines, and design the tank mounting system to comply with the lab safety sub-team's recommendations.

Lab Safety Sub-Team:

Up to the present, the specific tasks of examining and summarizing hydrogen safety standards have assigned somewhat arbitrarily. Minsuk and Minjoong (working as a pair) were responsible for the NASA and NFPA (compressed gas) codes. Jason was responsible for the OSHA & NFPA (fuel gas) codes. Chungyun was responsible for both ICC codes (fire safety and fuel gas). Joel (as sub-team leader) oversaw the efforts of the individual sub-team members in the summarization and did much of the ultimate compilation of the information from the various codes into one coherent document. Since each team member has specific familiarity with specific safety codes, the entire team as a collective must work together on the remaining tasks to ensure that all aspects of the various safety codes are incorporated into decisions.

Testing Sub-Team:

Over the remainder of the semester, the testing sub-team will perform a fuel flow test on the engine, determine the power output versus engine rpm of the engine while running on gasoline, and do the same tests on the engine after the conversion as taken place to compare the results.

A fuel flow test must be done on the engine to determine if the fuel pump and filter are functioning properly. This can be done following the given procedure in the John Deere manual.

To test the power output of the engine, it must be connected to the DYNO-Max 2000. The testing sub-team has been and is continuing to work under the assumption that the DYNO-Max 2000 will receive the required maintenance to become operational. After the required maintenance, the engine can be connected to the DYNO-Max 2000 and the tests can be performed. This task will be undertaken by first connecting the throttle linkage and the choke linkage by utilization of the throttle linkage built into the DYNO-Max 2000 console. Then, the choke must be removed from the lawnmower. Also, a portion of the testing team has been devoted to studying and learning the DYNO-Max 2000 manual in order to get as much knowledge about the software and testing instrument to ensure proper usage and to use this instrument to its fullest potential during testing to obtain applicable and useful results.

After the engine is connected to the DYNO-Max 2000 a measurement of the engine power under gas power can be obtained and the data can be analyzed and compared to the specifications stated in the manual.

When each of these steps has been completed, the actual conversion process of the engine can be done. At that point, the engine and DYNO-Max 2000 may need to be modified. However, the modifications are not known at this time.

Barriers and Obstacles:

Conversion Sub-Team:

One of the major obstacles encountered by the conversion sub-team was a lack of familiarity with the Otto Cycle. This resulted is several errors made while during the early development of the thermodynamic models, such as impossibly high calculated temperatures inside the engine during combustion. However, these errors were corrected with the help of Prof. Ruiz. Also, as the power loss factors are empirical and not theoretical in nature, it was difficult to find a reliable source for them.

While researching conversion procedures, several obstacles were encountered. Not many companies make high-quality alternative fuel products, so choices were limited. Detailed information and price quotes were not readily available, and the companies had to be contacted by telephone during regular business hours. Alternative spark plugs and piston rings were difficult to find as they are not made for small engines. Locating a hydrogen supplier in the Chicagoland area, who meets the team’s requirements, was also very challenging.

Lab Safety Sub-Team:

Strict requirements for hydrogen use in confined spaces (from the codes reviewed) would have required major modifications to the testing lab if a large hydrogen quantity was to be kept there. As an alternative, by carefully controlling the amount of hydrogen stored in the lab, most of the hazardous issues that the lab modifications were meant to address can be avoided, thereby making it possible to safely use hydrogen in the lab without major modifications.

The lab safety-team expects to encounter many obstacles in the future. Permanent hydrogen tanks, as opposed to rented tanks, pose a greater safety hazard as they must be refilled and inspected. These will likely be a necessity for the finished hydrogen lawnmower, as the gas supplier only offers one pressure-vessel size for rental. This issue is currently unresolved. With the present constraint on the quantity of hydrogen which can be stored in the lab, the theoretical run-time of the engine on a single charge of hydrogen is on the order of 5 minutes. This may be too short a time to obtain useful test data from the dynamometer in a single run. Should this constraint be a problem, it may be possible to move the equipment to another location (temporarily) where a larger quantity of hydrogen can be used. Safety codes pertinent to the use of hydrogen specifically on motor vehicles have been somewhat vague thus far. The codes reviewed do provide a wealth of information about hydrogen safety in any environment, but it would be helpful to have more definitive information about the motor vehicle context.

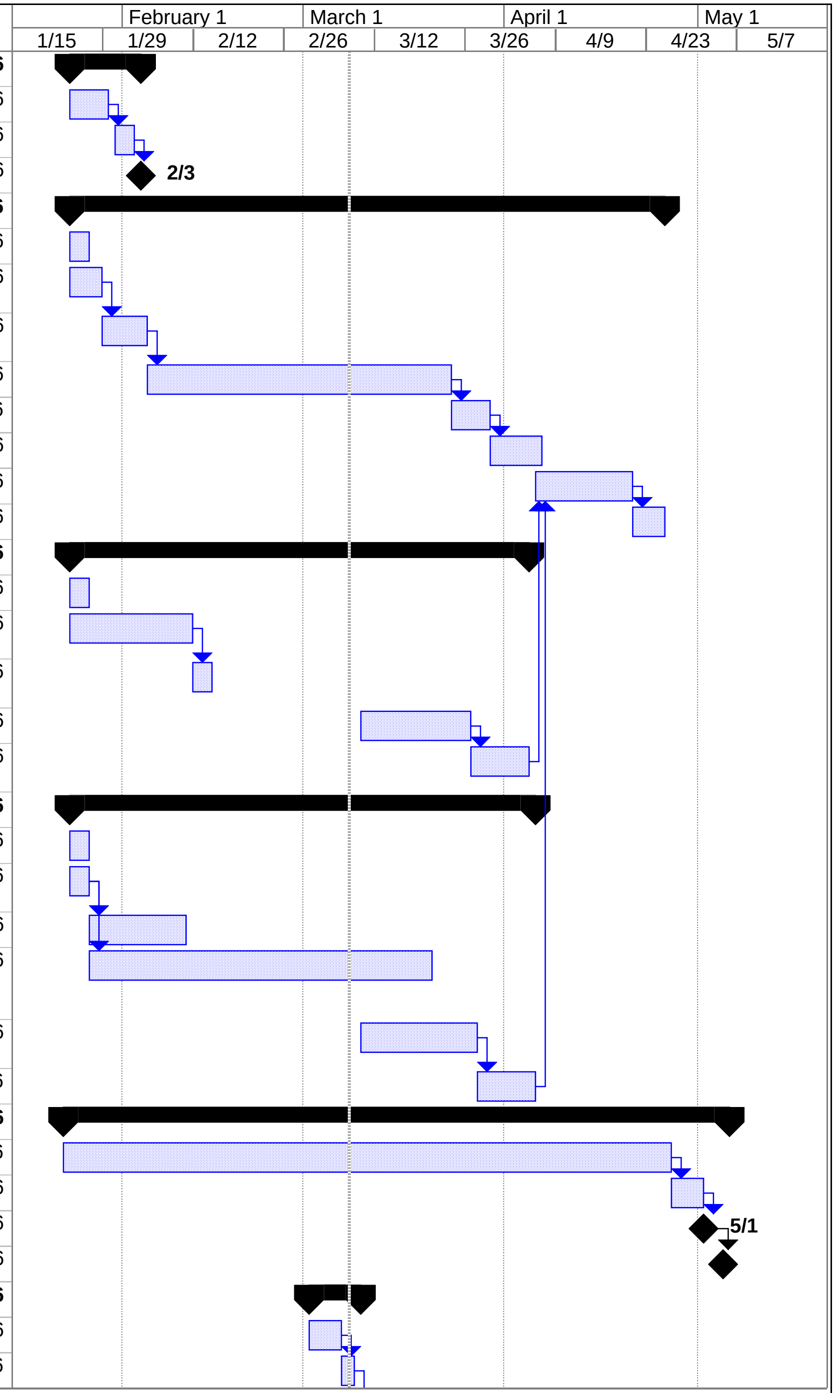
Testing Sub-Team:

The immediate task that the testing subgroup had decided to undertake was repairing the DYNO-Max 2000. In order to do any testing on the engine, it must be properly connected to the DYNO-Max 2000. At this point, the DYNO-Max 2000 is not ready for testing for various reasons. First, most of the wires that connect to the sensors do not have the mating sensors. These parts must be missing due to projects performed on the DYNO-Max 2000 in the past. Secondly, water will not flow through the DYNO-Max 2000. The water is needed to provide the load to the load cell for engine testing. Third, some necessary wires on the DYNO-Max 2000 have been cut and misplaced. Altogether, it is unknown how to prepare the DYNO-Max 2000 to test the engine. Therefore, we are taking the proper steps to purchase a service plan for the DYNO-Max 2000.

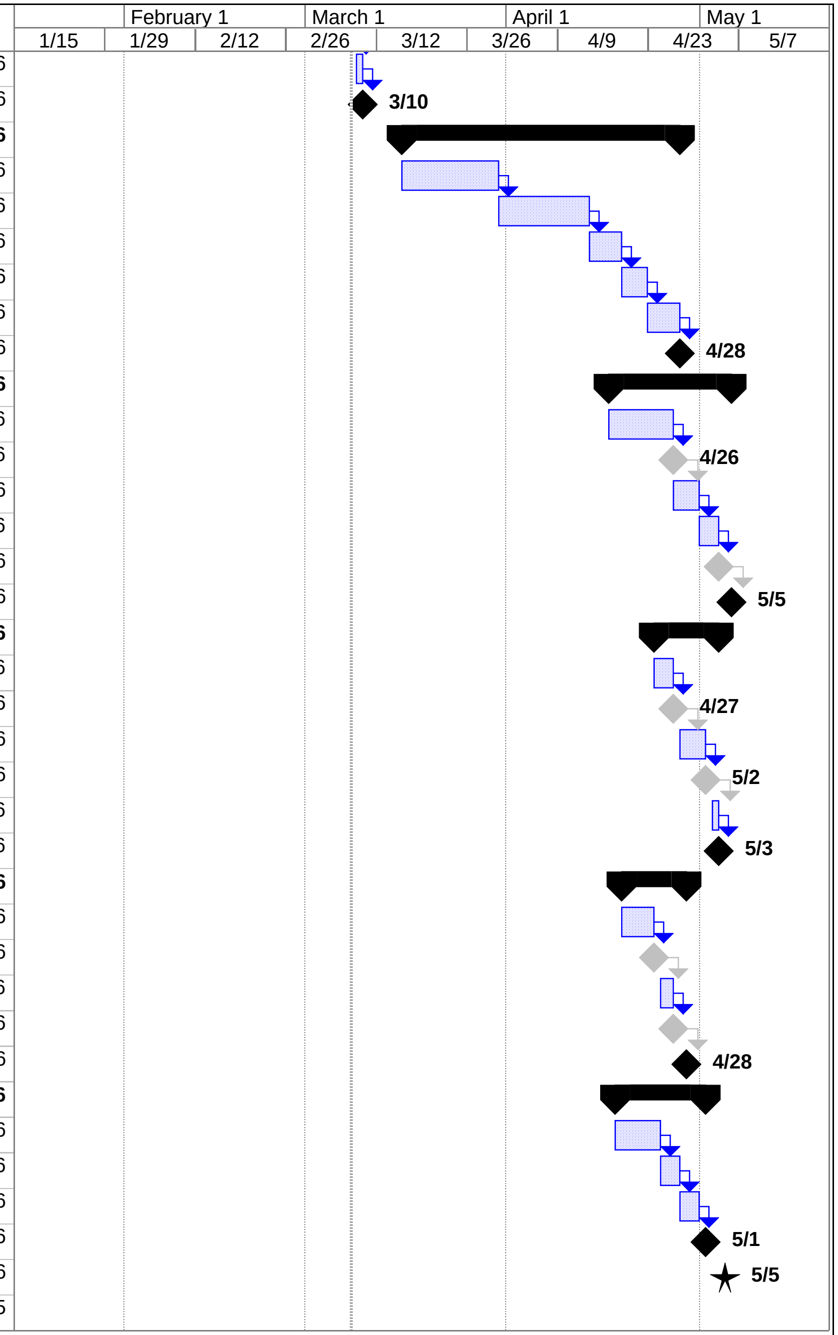
Conclusion:

Depending on the time frame for obtaining the appropriate parts and maintenance for the dynamometer's operation the remaining tasks can be performed as scheduled. Conversion and lab safety components are currently being ordered. The parts list can be seen in Appendix 3. Despite all the possible contingencies and various barriers foreseen, the IPRO 310 team is willing to adapt and work through any obstacles that may arise in order to achieve its goals.

ID		Task Name	Start	Finish
1		**Project Plan**	**Tue 1/24/06**	**Fri 2/3/06**
2		Draft	Tue 1/24/06	Sun 1/29/06
3		Review	Tue 1/31/06	Thu 2/2/06
4		Proposal Due	Fri 2/3/06	Fri 2/3/06
5		**Testing Team**	**Tue 1/24/06**	**Tue 4/25/06**
6		Team scheduling	Tue 1/24/06	Thu 1/26/06
7		Review previous IPRO's recommendations and critique	Tue 1/24/06	Sat 1/28/06
8		Spend time in test lab and become familiar with test equipment/operating procedures	Sun 1/29/06	Sat 2/4/06
9		Repair dyno	Sun 2/5/06	Thu 3/23/06
10		Perform testing on existing engine	Fri 3/24/06	Wed 3/29/06
11		Write performance report and present results	Thu 3/30/06	Thu 4/6/06
12		Perform engine testing on converted engine	Thu 4/6/06	Thu 4/20/06
13		Write performance report and present results	Fri 4/21/06	Tue 4/25/06
14		**Lab Safety Team**	**Tue 1/24/06**	**Tue 4/4/06**
15		Team scheduling	Tue 1/24/06	Thu 1/26/06
16		Research safety codes, define specific actions necessary to prepare testing lab and identify vendors	Tue 1/24/06	Sat 2/11/06
17		Write safety codes report and present results of research	Sun 2/12/06	Tue 2/14/06
18		Order equipment (order earlier if possible)	Fri 3/10/06	Sun 3/26/06
19		Install equipment and ensure that systems are operational	Mon 3/27/06	Tue 4/4/06
20		**Conversion Team**	**Tue 1/24/06**	**Wed 4/5/06**
21		Team scheduling	Tue 1/24/06	Thu 1/26/06
22		Review previous IPRO's recommendations and critique	Tue 1/24/06	Thu 1/26/06
23		Further develop thermodynamic model	Fri 1/27/06	Fri 2/10/06
24		Establish conversion methodology including testing/tuning procedure for converted engine an dlocate vendors	Fri 1/27/06	Mon 3/20/06
25		Order conversion equipment	Fri 3/10/06	Mon 3/27/06
26		Reassemble engine with modifications	Tue 3/28/06	Wed 4/5/06
27		**Information and Documentation**	**Mon 1/23/06**	**Fri 5/5/06**
28		Collect Data/ Links	Mon 1/23/06	Wed 4/26/06
29		Create Final Porfolio w/ All Data and Save to CD	Thu 4/27/06	Mon 5/1/06
30		Database Complete	Mon 5/1/06	Mon 5/1/06
31		Team Information and CD Due	Fri 5/5/06	Fri 5/5/06
32		**Midterm Report**	**Thu 3/2/06**	**Fri 3/10/06**
33		Draft	Thu 3/2/06	Mon 3/6/06
34		Review Report	Tue 3/7/06	Wed 3/8/06



ID		Task Name	Start	Finish
35		Final Revision	Thu 3/9/06	Thu 3/9/06
36		Report Due	Fri 3/10/06	Fri 3/10/06
37		**Website**	**Thu 3/16/06**	**Fri 4/28/06**
38		Review Existing Website Layout and Design	Thu 3/16/06	Thu 3/30/06
39		Determine Changes to be Made	Fri 3/31/06	Thu 4/13/06
40		Write Text and Develop Graphics	Fri 4/14/06	Tue 4/18/06
41		Upload to Website	Wed 4/19/06	Sat 4/22/06
42		Final Review of Website	Sun 4/23/06	Thu 4/27/06
43		Website Complete and Due	Fri 4/28/06	Fri 4/28/06
44		**Final Report**	**Mon 4/17/06**	**Fri 5/5/06**
45		1st Draft	Mon 4/17/06	Wed 4/26/06
46		1st Draft Review	Wed 4/26/06	Wed 4/26/06
47		2nd Draft	Thu 4/27/06	Sun 4/30/06
48		Last Revisions	Mon 5/1/06	Wed 5/3/06
49		Final Report Complete	Thu 5/4/06	Thu 5/4/06
50		Final Report Due	Fri 5/5/06	Fri 5/5/06
51		**Presentation**	**Mon 4/24/06**	**Wed 5/3/06**
52		1st Draft of Presentation	Mon 4/24/06	Wed 4/26/06
53		1st Run of Presentation	Thu 4/27/06	Thu 4/27/06
54		2nd Draft of Presentation	Fri 4/28/06	Mon 5/1/06
55		2nd Run of Presentation	Tue 5/2/06	Tue 5/2/06
56		Final Draft of Presentation	Wed 5/3/06	Wed 5/3/06
57		Presentation Due	Wed 5/3/06	Wed 5/3/06
58		**Poster**	**Wed 4/19/06**	**Fri 4/28/06**
59		Determine Poster Layout and Content	Wed 4/19/06	Sun 4/23/06
60		1st Draft of Poster Due	Mon 4/24/06	Mon 4/24/06
61		1st Revision	Tue 4/25/06	Wed 4/26/06
62		Final Draft of Poster Due	Thu 4/27/06	Thu 4/27/06
63		Poster Due (if IPRO office is to print poster)	Fri 4/28/06	Fri 4/28/06
64		**Abstract**	**Tue 4/18/06**	**Mon 5/1/06**
65		1st Draft	Tue 4/18/06	Mon 4/24/06
66		1st Revision	Tue 4/25/06	Thu 4/27/06
67		Final Draft	Fri 4/28/06	Sun 4/30/06
68		Abstract Due	Mon 5/1/06	Mon 5/1/06
69		IPRO Day	Fri 5/5/06	Fri 5/5/06
70		Debriefing	Mon 12/5/05	Fri 12/16/05

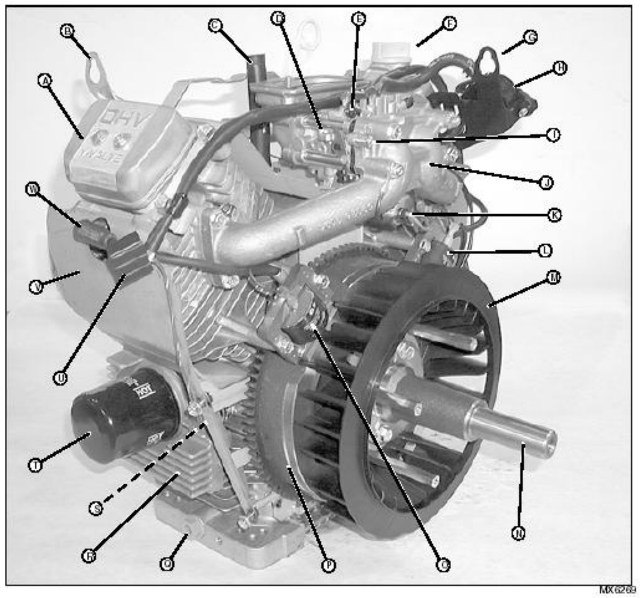


Appendix 2

Figure1. The engine removed from the John Deere Commercial Grade Lawnmower

ENGINE COMPONENT LOCATION

Component Location **External Engine Components**



Picture Note: S.N. (-040000) Shown

A - Rocker Cover
B - Lifting Bracket
C - Crankcase Breather Hose
D - Carburetor
E - Idle Mixture Screw
F - Oil Fill
G - Lifting Bracket
H - Fuel Pump
I - Idle Speed Screw
J - Intake Manifold
K - Fuel Shutoff Solenoid
L - Ignition Coil - No. 1 Cylinder
M - Cooling Fan
N - Crankshaft extension
O - Ignition Coil - No. 2 Cylinder
P - Flywheel
Q - Oil Drain
R - Oil Cooler (Model FH721D only)
S - No-Oil Pressure Switch
T - Oil Filter
U - Engine Harness-to-Main Harness Connector
V - Air Shroud
W - Spark Plug - No. 2 Cylinder

Engine Component Location - 32

Figure 2. Engine part locations from John Deere Lawn Mower manual

Electrical Schematic - S.N. (030001-)

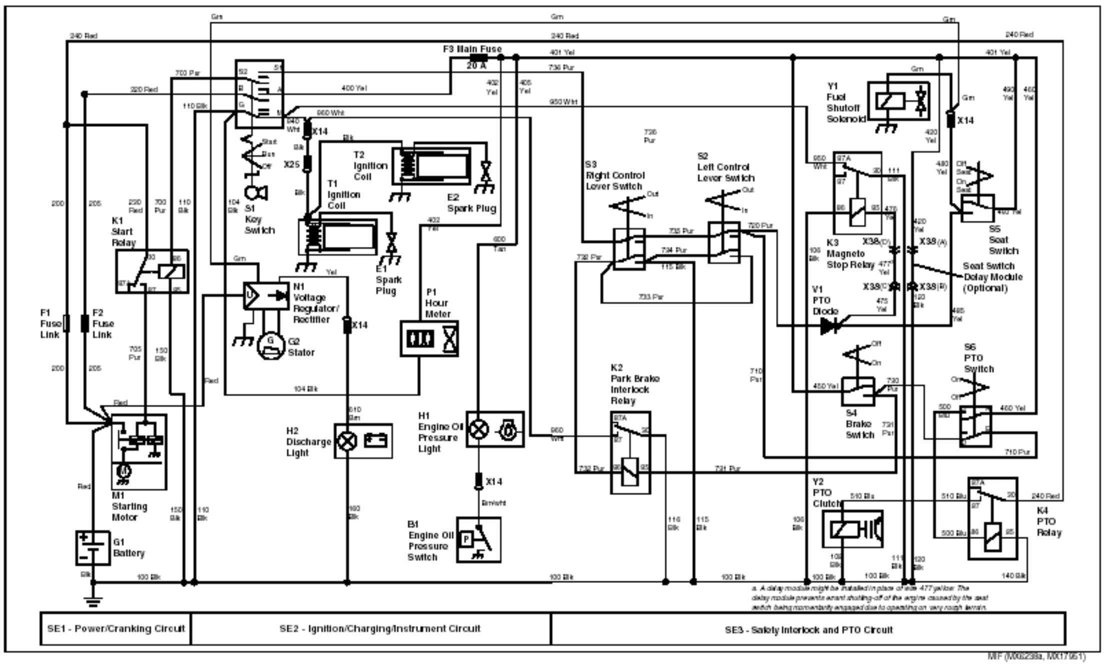


Figure 3. Electrical Schematic diagram of the John Deere Commercial Lawn Mower

Appendix 3

Conversion Team Equipment List

Necessary conversion components:

Quote from Swagelok, Gas Technologies

Item	*Part Number*	*Quantity*	*Unit Price*	*Amount*
Union Elbow	SS-600-9	4	16.50	66.00
Union Tee	SS-600-3	3	24.50	73.50
Tubing	SS-T6-S-049-20	20’	4.53	90.60
Flex Metal Hose	SS-FM6TA6TA6-36	1	210.30	210.30
Flex Metal Hose	SS-FM6TA6TA6-18	4	178.30	713.20
High-P Regulator	KPR1JRF417A20010	1	399.50	399.50
Valve	SS-43GS6	1	69.70	69.70

Quote from IMPCO Systems

Item	*Part Number*	*Quantity*	*Unit Price*	*Amount*
Low-P Regulator	T60-G	1	93.23	93.23
High-P Regulator	HPR-3600	1	223.88	223.88
Lock-Off Solenoid	4004A-12V	1	29.83	29.83
Venturi	200-1532	1	36.13	36.13
Load Adj. Elbow	42EA	1	8.65	8.65

Necessary for the actual conversion:

Quote from Luxfer Composites

Item	*Part Number*	*Quantity*	*Unit Price*	*Amount*
3000 PSI Tank	A360W	4	578.00	2312.00

Subtotal: $4375.52 (plus the Cost of Hydrogen)

Necessary for our purposes:

Quote from Mittler Chemical Supplier

Item	*Part Number*	*Quantity*	*Unit Price*	*Amount*
Hydrogen		8400L	0.32	2688

Subtotal: $4751.52 (including the Cost of Hydrogen)

Reductions (included in the total cost for our purposes):

Item	*Part Number*	*Quantity*	*Unit Price*	*Amount*
Union Elbow	SS-600-9	-3	16.50	- 49.50
Union Tee	SS-600-3	-2	24.50	- 49.00
Flex Metal Hose	SS-FM6TA6TA6-18	-2	178.30	-356.60

Lab Safety Team Equipment List

Quote from All Electronics Corp.

Item	*Part Number*	*Quantity*	*Unit Price*	*Amount*
Strobe Warning Light-Red	STROBE-3R	1	8.95	8.95
Strobe Warning Light-Amber	STROBE-3A	1	8.95	8.95
Piezo Alarm	SBZ-365	2	3.95	7.90
12V Switching Power Supply	PS-1214	1	12.75	12.75
SPDT 30A Relay	RLY-351	2	2.40	4.80
Relay Socket	SRLY-2	1	2.00	2.00
SPST Momentary Toggle Switch	STS-28	1	2.00	2.00
20A AGC Fuses	FS-20	1	0.75	0.75
AGC Fuseholder	FHP-2	2	0.50	1.00

Quote from Aerion Technologies, Inc., Macurco.

Item	*Part Number*	*Quantity*	*Unit Price*	*Amount*
12/24V Hydrogen Detector with Low/High Relays	HD-12	1	300	300

Quote from Digi-Key.

Item	*Part Number*	*Quantity*	*Unit Price*	*Amount*
Economy ESD Wrist Strap	16-1021-ND	3	14.14	42.42

Subtotal: $391.52

Testing Team Equipment List

Dynamometer parts prices are currently being researched. An annual maintenance fee costs $250. As the dynamometer is currently not operational, engine testing before conversion must be outsourced at a cost of $200 per hour. It is estimated that the engine testing will take approximately 5 hours.

Subtotal: $1250 (excluding dynamometer parts)

Total: $6393.04 (excluding dynamometer parts)