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EVALUATION OF CATALYTIC PYROLYSIS PROCESS FOR PRODUCTION OF BIO-FUELS FROM SOLID BIOMASS

Summary of a Comprehensive Report by Texas A&M University

Edited to remove confidential information
Submitted by the SSTP Scientific Advisory Board
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Complete TAMU report was submitted to

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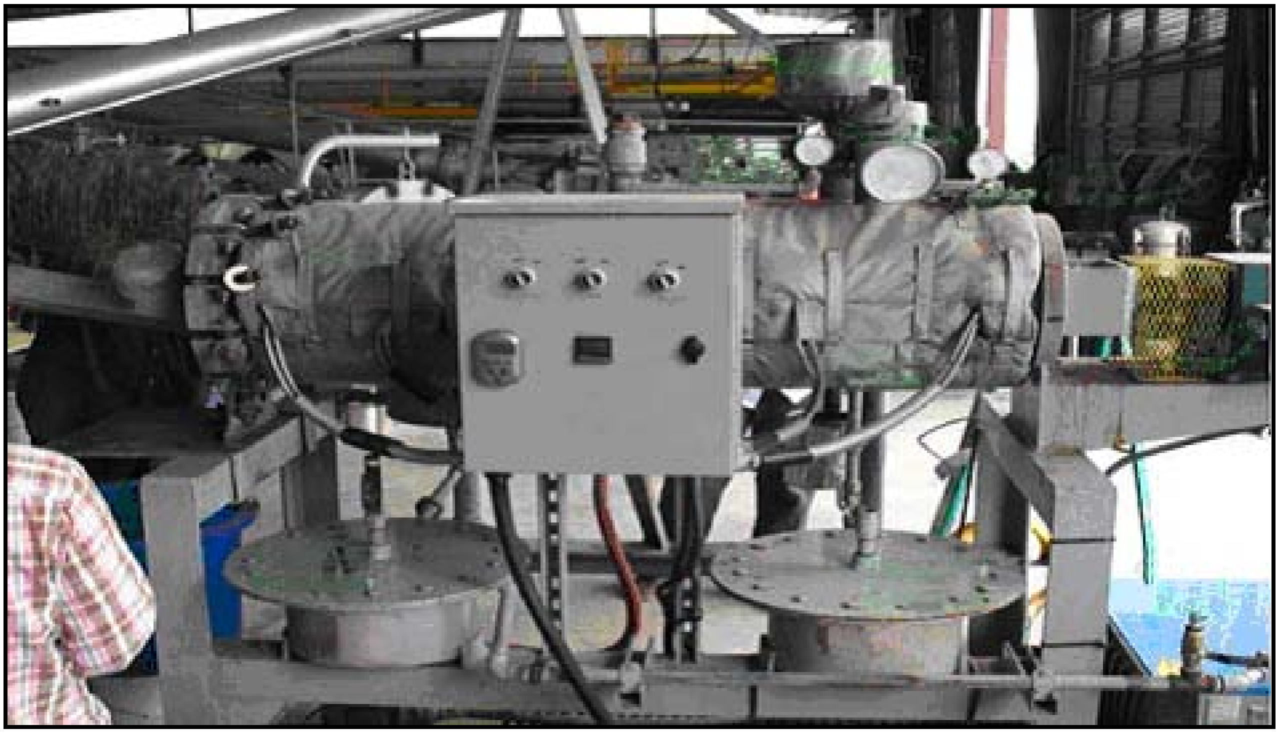
A team of Texas A&M University (TAMU) graduate students and research personnel visited Sustainable Power Corp. ("SSTP") on April 24, 2009. The team conducted two experiments at SSTP's Baytown facility with the assistance of SSTP personnel and collected required samples for further analysis. The two experiments consisted of placing biomass feedstock into SSTP's batch reactor. One experiment included 30 lbs of soybeans with 0.8 lb of proprietary catalyst provided by SSTP (Case 1 or CAT) and the second experiment included 30 lbs of soybeans without the proprietary catalyst (Case 2 or NO CAT).

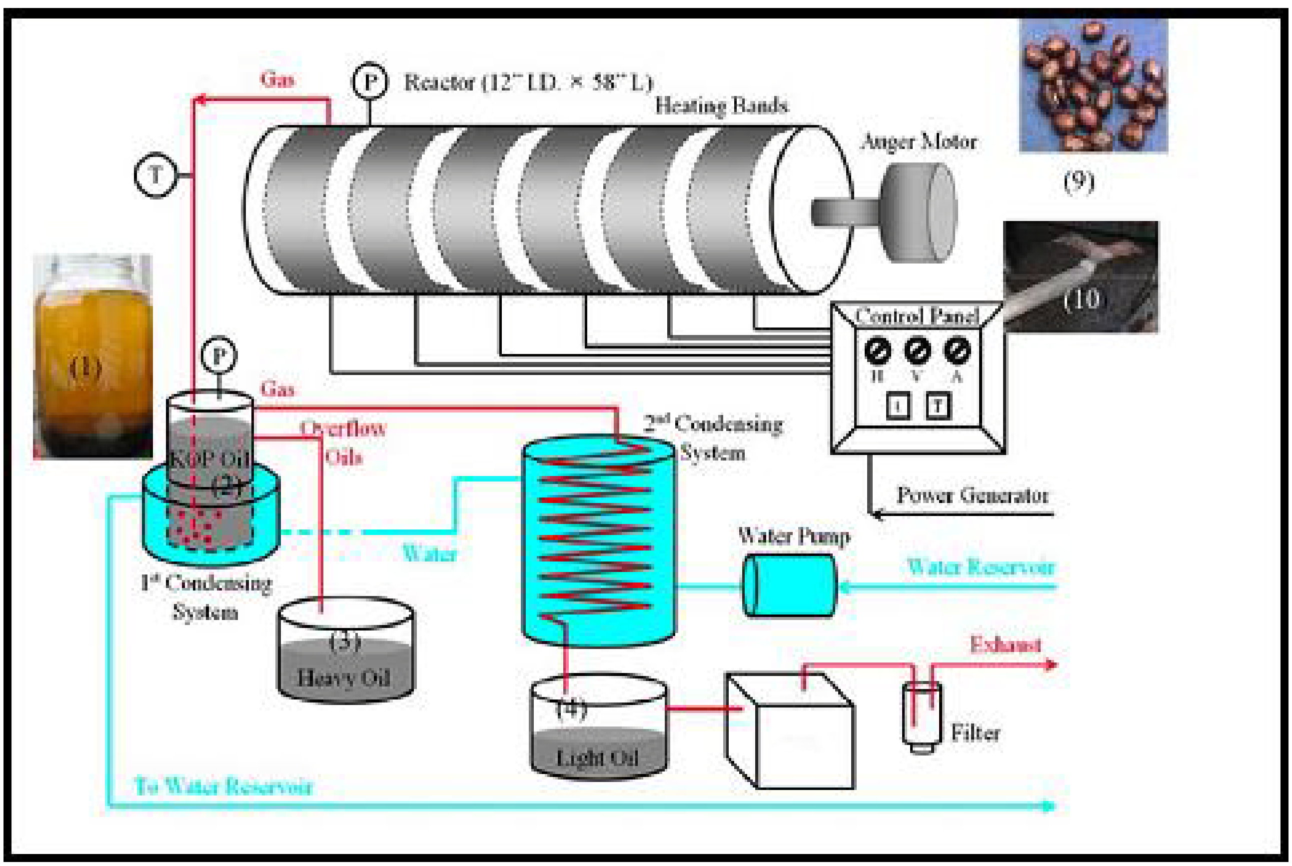
After the reactor was closed and sealed, the atmosphere inside of the reactor was adjusted to SSTP's proprietary specifications involving significantly less oxygen than is present at ambient conditions. Then the reactor's internal head gas temperatures were raised to a process temperature of less than 1000 degrees Fahrenheit.

Front and rear photographs of the laboratory scale reactor are below:

SSTP Batch Reactor – Front View



SSTP Batch Reactor – Rear View



Schematic diagram of Sustainable Power's Portable Reactor

Mass Input vs. Mass Output

With SSTP's licensed proprietary process involving heating biomass in a reactor vessel with the presence of the Company's proprietary catalyst, Texas A&M reported a yield of 54.4% oil in addition to 25.3% flammable gas and 20.3% biochar. The results are in the table below:

Input	Pounds	Percent
Soybeans (not counting 0.8 pounds of catalyst)	30.0	100.00
Output	Pounds	Percent
Heavy Oil	1.11	3.70
Light Oil	15.21	50.70
Char	6.09	20.30
Gas	7.59	25.30
Total Output	**30.00**	**100.00**

Table 1

The Texas A&M report states, "SSTP demonstrated that the oil yields with pyrolysis are much higher than simple mechanical squeezing process of soybeans."

Among Texas A&M's other findings in the Confidential Report was that "Sustainable Power Corporation…invented a proprietary catalytic process which produces bio-fuels in the form of what is essentially a heavy crude and light crude oil by a thermo-chemical pyrolysis …process as opposed to conventional pyrolysis…which typically occurs at…higher pressures." The report added, "The tests conducted with blow torch indicated that oils produced with catalysts readily ignited while oils produced without catalysts did not ignite easily." Eyewitnesses to this burn test report that the oils produced without catalysts simply evaporated and did not burn at all.

Moisture Content

Burn tests indicated that oils produced using SSTP's licensed catalyst driven Rivera process (CAT) readily ignited compared to non-catalyst oils (NO CAT) which did not easily ignite or which did not ignite at all. Differences in moisture contents could be one of a number of factors contributing to this difference in quality. The TAMU report indicated there was significantly less moisture in the CAT light oils and CAT biochar produced by the catalyst driven process than those of the NO CAT oils and biochar. Although the CAT heavy oil did have more moisture than the NO CAT heavy oil, this could be a result of the larger amount of moisture present in the condenser oil at the start-up of the CAT test. At the start of the tests, the condenser is filled with a carefully measured amount of oil through which the process output gases are bubbled, causing those gases to condense into SSTP's heavy or light oils. The TAMU team used two diffferent oils to charge the condenser and the difference in moisture contents of those oils, as reported below, could impact the tests.

The outputs of solids and liquids as previously reported by TAMU in Table 1, above, included the moisture contents of the solid and liquid inputs and outputs of the catalyst driven process. TAMU scientists then evaluated those materials for their moisture content as reported in Table 2, below.

The moisture content for the CAT tests was as follows: Soybean Input-13.95%, Condenser Oil- 9.95%, Heavy Oil Output – 11.70%, Light Oil Output – 18.70%, and Char Output – 2.65% . By subtracting the moisture content of the outputs from that of the inputs, the final dry weights for the CAT tests are reported as: Soybean Input-25.82 lbs, Heavy Oil Output – .98 lbs, Light Oil Output – 12.37 lbs, and Char Output – 5.93 lbs.

The data for the NO CAT tests are as follows: Soybean Input-13.95%, Condenser Oil- 0%, Heavy Oil Output – .22%, Light Oil Output – 38.80%, and Char Output – 9.66% . By subtracting the moisture content of the outputs from that of the inputs, the final dry weights are reported as: Soybean Input-25.82 lbs, Heavy Oil Output – 3.502 lbs, Light Oil Output – 7.950 lbs, and Char Output – 5.881 lbs.

Comparison of Moisture Content of Inputs and Outputs
Catalyst Driven (CAT) vs Non-Catalyst (NO CAT) Driven Process

Input Soybeans & Condenser Oil	Initial Weight (Pounds)	Moisture (Percent)	Moisture Weight (Pounds)	Dry Weight (Pounds)
Soybeans (CAT)	30.00	13.95	4.185	25.815
Soybeans (NO CAT)	30.00	13.95	4.185	25.815
Condensor Oil (CAT)	11.00	9.95	1.051	9.949
Condensor Oil (NO CAT)	11.00	.00	.000	11.000
Output Materials	Output Weight (Pounds)	Moisture (Percent)	Moisture Weight (Pounds)	Dry Weight (Pounds)
Heavy Oil (CAT)	1.11	11.70	.130	.980
Heavy Oil (NO CAT)	3.51	.22	.008	3.502
Light Oil (CAT)	15.21	18.70	2.844	12.366
Light Oil (NO CAT)	12.99	38.80	5.040	7.950
Char (CAT)	6.09	2.65	.161	5.929
Char (NO CAT)	6.51	9.66	.629	5.881

Table 2

Information from SSTP's CTO that is not included in the TAMU report: *Although there is some moisture content in the oils and char, most will be extracted and added to the char. Thus, the moist weight of the initial char output of 6.09 lbs will be increased to a moist char weight of about 8.25 lbs. This is done because it is beneficial in a number of ways.*

The moisture which condenses as water in oils has valuable elements it absorbs from the process, including but not limited to, nitrogen. By adding that water to the char, it increases the value of the char as a fertilizer and helps to cool the hot char as it is withdrawn from the reactor.

This further helps to standardize the activity level of the output char. Other manufacturers of lower quality and lower activity biochars report that their chars retain heat or even increase their temperature when stored in large quantities. Some manufacturers allow the char to remain open to the atmosphere in order to allow natural oxidization to reduce the activity level of the char. This adds costs, increases process time, and reduces efficiencies. By adding nutrient laden moisture to our chars, SSTP eliminates that problem while enhancing the value of the char.

Another benefit of the process derived moisture is its use as a vehicle to inoculate the biochar with other amendments such as mycorrhizal fungi or other materials to produce a higher value char that will accelerate benefits to the soils to which it is added. ~MG

Comparative Yields

Table 3 reports the final output weights of oils and char when using various amounts of inputs. Comparisons are: the 30 pound batch as tested, a standard sixty pound bushel of soybeans, and a ton of soybeans.

Weights of Outputs in Pounds
Remaining Moisture in Oils is Minimal
Excess Moisture Content of Oils added to Char

	Test Batch	**Per Bushel (60 lbs)**	**Per ton**
Soybeans - In	**30**	**60**	**2000**
Heavy Oil-Out	1.04	2.07	69.07
Light Oil-Out	13.13	26.26	875.33
Total Oil-Out	**14.17**	**28.33**	**944.40**
Char-Out	8.25	16.50	550.00
Gas-Out	7.59	15.18	506.00

Table 3

Flammable Gaseous Outputs

The TAMU scientists began their work on the test with the proprietary catalyst at 9:08 AM. They recorded the outputs of flammable gas by igniting a flare produced by gases being output as the process temperatures increased. The below Table 4 reports their results. Clock times and process descriptions are indicated in Columns 1 and 2 respectively. Duration of each level of gaseous ignition is indicated in Column 3 while the cumulative time of gaseous ignition is reported in Column 4.

Time-Line for Gaseous Output With Catalyst

Time	Description	Duration (Minutes)	Cume Time (Minutes)
9:08	Reactor Started Up (RSU)	0	0
10:05	Lit the flame (RSU+57 min.)	8	8
10:13	Visible large orange flame(RSU+65 min)	32	40
10:45	Flame became weak (RSU+97 min)	15	55
11:00	Very weak flame (RSU+112 min.)	20	75
11:20	No flame (RSU+132 min.)		
12:03	Shut down (RSU+175 min.)		

Table 4

The data in Table 4 shows that enough flammable gas to support a flame was emitted fifty seven minutes after the reactor became operational. After eight minutes, the flame became large and visible. That phase lasted for 32 minutes until the flame began to weaken during the next 15 minutes. At that time, the flame became very weak until it went out 20 minutes later. Total duration of the flame was 75 minutes between 10:05 AM and 11:20 AM.

The same data as presented in Table 4 for CAT tests is reported below in Table 5 for NO CAT tests. The data indicates that the CAT tests produced flammable gases for ten minutes longer than the NO CAT tests.

Time-Line for Gaseous Output Without Catalyst

Time	Description	Duration (Minutes)	Cume Time (Minutes)
3:00	Reactor Started Up (RSU)	0	0
4:13	Lit the flame (RSU+73 min.)	7	7
4:20	Visible large orange flame(RSU+80 min)	31	38
4:51	Flame became weak (RSU+111 min)	27	65
5:18	No flame (RSU+138 min.)		
5:48	Shut down (RSU+168 min.)		

Table 5

The TAMU team did not measure the total volume of the gas directly, nor did it analyze the chemical composition of the gas. The team did measure the weight of the gas by subtracting the weights of the outputs of solids and liquids from the weight of the original soybeans. This subtraction quantified the weight of the gas to be 7.59 pounds, as indicated in Table 1.

Energy Balance

The TAMU team measured the heat energy values in the inputs and outputs in two ways. The first was "as received", meaning that the incombustible moisture and ash contents of the materials were not removed from the calculations. The second calculation removed the moisture and ash components which then gave the dry, ash free (DAF) weights. Table 6, below, reports those DAF results for all inuts and outputs of the catalyst driven process , with the exception of the gaseous output. The TAMU team reported heat energy as kilojoules per kilogram. One kilojoule equals .948 BTU's, and one kilogram equals 2.2 pounds. Table 6 reports the TAMU kilojoule amount and converts the energy to BTU's per pound of dry, ash free material for convenience of the reader.

Energy Balance of Dry, Ash Free Inputs and Outputs – With Catalyst

Item	Weight (Pounds)	Energy 1 Kilojoules/Kg	Energy 2 BTU/lb	Total Energy BTU
Soybeans In	**24.980**	**24,747**	**10,669**	**266,520**
Heavy Oil - Out	0.971	36,180	15,599	15,149
Light Oil - Out	12.333	37,451	16,147	199,139
Char - Out	4.388	33,223	14,32 4	62,848
Gas - Out	7.590	**	**	**
			Total Output	277,137

Table 6

It will be noted that the total energy input reported in Table 6 is 266,520 BTUs, while the total energy output is 277,137 BTUs, not including the heating value of the gas. Thus, the energy outputs exceed the energy inputs by 10,617 BTUs plus the energy of the gas. This disparity may be caused by the fact that the heat energy value of the catalyst was not measured due to its proprietary nature. Thus the catalyst, which weighed .8 pounds, could be contributing the excess heat energy.

Table 7, below reports the same data as Table 6 for the process without the use of the catalyst. Note that the total energy of the outputs is now lower than the input energy by an amount equal to 16,781 BTUs.

Energy Balance of Dry, Ash Free Inputs and Outputs – Without Catalyst

Item	Weight (Pounds)	Energy 1 Kilojoules/Kg	Energy 2 BTU/lb	Total Energy BTU
Soybeans In	24.980	24,747	10,669	266,520
Heavy Oil - Out	3.498	39,558	17,055	59,665
Light Oil - Out	7.935	36,405	15,696	124,547
Char - Out	4.481	33,914	14,622	65,526
Gas - Out	7.590	**	**	**
			Total Output	249,739

Table 7

**The team did not qualify the components of the gas nor the heat energy value other than to note its combustibility as reported in Tables 4 and 5.

NOTE from SSTP's CTO: The TAMU team did not test the gas for content or energy value thus could make no definitive conclusions about it. Therefore the following information must not be considered as part of the TAMU report: *It cannot go without some comment that the tests indicate an excess of BTUs out over the BTUs input by the soybeans. For the purposes of reporting the TAMU data, we offer the possibility that the catalyst contributes this 10,617 BTU surplus, plus whatever energy is contributed by the gas. However, aside from the TAMU report data, I must note that independent tests of the gas done by Alchem Labs of Ruston, LA on January 7, 2006 show it to be a complex mixture of more than ten flammable gases, including but not limited to hydrogen, methane, ethane, propane, butanes, pentanes, and hexanes. The BTU value measured by Alchem was 25, 181 BTUs per pound which is equivalent to 1904 BTUs per cubic foot, which compares very favorably to natural gas which averages about 1050 BTUs per cubic foot. This represents an additional 191,000 BTUs of output energy resulting in total outputs of 468,260 BTUs, which is more than 200,000 BTUs greater than the soybean input of 266,520 BTUs. While this may be controversial, I believe further testing and discussion will show that the soybeans contribute only a portion of total inputs. Additional BTU inputs are available including, but not limited to, energy from the catalyst, the hydrogen in the four pounds of soybean moisture, and the initial energy inputs used to heat the soybeans. More research will be done at some future time to address this issue. ~**MG***

TAMU Summary Statement
Excerpted from Complete TAMU Report
As submitted to SSTP – October 7, 2009

1. SSTP demonstrated that the oil yields with pyrolysis are much higher than simple mechanical squeezing process of soybeans. Texas A&M conducted tests of the Rivera Process in the batch reactor and measured the yield of liquid and gas produced and analyzed same. All the liquid and gas yields obtained by both SSTP and Texas A&M are reasonable within the expected values as observed from literature using biomass feed stocks and flash pyrolysis.

2. Based on the quantity produced for soybeans with catalysts, the mass yield percentages of heavy oil, light oil, char and gas are 3.7, 50.7, 20.3, and 25.3 respectively; they were similar for both sample sizes of 20 lb (experiments on Feb 23, 2009, TAMU faculty visit) and 30 lb (experiments: April 24th, 2009). Total oil and gas yield percentages are 54.4 and 25.3 indicating volatile matter of percentages 79.7 of sample mass. The percentage yield is based only on sample mass and does not include mass of catalyst.

3. When flammability tests were conducted using a torch, the …soybean gases from tests with the catalyst and which were condensed using volatile and flammable SSTP bio-oils …are readily flammable while the process without catalysts but employing non-volatile and non-flammable vegetable KOP oils are difficult to ignite. It is difficult to state one or other way regarding flammability unless tests are conducted using vegetable oil in both cases.

4. The chars for case 1(with catalyst) were homogenously blackened and were relatively dry while the chars for case 2 (without catalyst) were not homogeneously blackened and were noticeably wetter than the catalytic chars.

5. The mass percentages calculated includes moisture from oil; for the light oil without catalyst has more moisture than that of light oil produced with catalysts. A better comparison should be based on dry ash free mass (or combustibles) of heavy oil and light oil produced by both cases 1(with catalyst) and 2 (without catalyst). Looking at a glance, it appears that the total oil yield is 58% for case 1 with catalysts but only 47% for case without catalysts. Note that catalyst mass is not accounted in estimations. But this mass is only 0.8 lb and increase is more than that could be accounted by the mass of conclusively catalyst.

Summary Note from SSTP's CTO:

We would like to acknowledge the entire Texas A&M University on-site team of scientists for their diligence. Our appreciation is also extended to the administration of Texas A&M University for their efforts. It is our honor to collaborate with such a highly respected research institution and we look forward to further collaborations.

As is prominently and clearly stated in the TAMU report, " The ultimate goal of the research is to complete a fair, scientific and objective evaluation of the pyrolysis process and to extract valuable scientific information useful to industries and energy scientists in Texas and the nation. The objective of the current project is to evaluate and conduct a thermo-chemical analysis on the yields of oil, gas, and char produced from the batch reactor. There are two aspects of evaluation: 1) quantity of oil produced and 2) quality of oil produced. The evaluation of quantity is straight forward using the mass units. However quality of oil and gas produced is rather subjective. The quality is typically measured in terms of heat value of fuel produced, combustible content, volatility of liquid fuels produced and the flammability characteristics."

In light of the above stated objectives, it is important to note that the SSTP licensed process results in economically viable yields that far exceed that associated with other biofuel processes. More importantly, although heat energy values are reported for all inputs and outputs, the most crucial factor is whether these are available for use in an economically viable manner.

One of the most compelling components of the tests was the blow torch burn test for oils done in the presence of the TAMU team and SSTP witnesses. This test showed that the SSTP Vertroleum produced using catalysts burned readily and was volatile and flammable. Further, the Vertroleum in the condenser is described in numerous other parts of the report as "volatile and flammable" compared to the condenser vegetable oil which was "non-flammable".

When the torch was applied to the oils produced without catalysts, they did not burn. Even after heating them enough to remove any moisture, combustion was never achieved although the torch flame remained in contact with the material until it was incinerated. Thus, regardless of the reported heating values, the oil produced without the catalyst is not a commercially viable product.

In addition to this dramatic difference in oil quality and economic viability, the TAMU team reported that the biochars produced with the catalyst " were homogenously blackened and were relatively dry while the chars without catalyst were not homogeneously blackened and were noticeably wetter than the catalytic chars." As with the oils, only the biochar produced with the catalyst has commercial value.

The true brilliance of the SSTP licensed process is that it produces very significant amounts of both oil AND biochar. Other processes produce only limited amounts of oil with no biochar or lesser quality biochar with lesser amounts or no oils. This is the defining difference of the SSTP process. By creating both biofuels and biochar, SSTP will go forward to help power the world, revitalize depleted soils, help our planet's farmers produce nutrient rich foods, and last, but certainly not least – to help reverse global warming by removing carbon from the atmosphere and returning it to the earth.

We express our greatest thanks to those members of the SSTP family - our founder, employees, investors, and others who have maintained their faith in SSTP and who are committed to helping create a more sustainable planet and community. ~MG

This summary report was submitted by SSTP Scientific Board to the SSTP Board of Directors on January 31, 2010. Additional content was added from original TAMU report by SSTP's Chief Technology Officer to provide clarification for layman readability.