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Recapture of Energy and Metals from MSW and ASR

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ABSTRACT

CarbonTech, LLC is the business vehicle to commercialize the licensed CATO Research Corporation process (US Patent No. 7,425,315) to generate an energy rich source of carbon from wastes such as municipal solid waste (MSW) and automobile shredder residue (ASR). With a focus on renewable energy technology, CarbonTech is in a unique position to reduce waste to landfills by 90%, generate a coal equivalent source of sustainable fuel to help reduce our dependence on fossil fuels, and recover metals for scrap recycling purposes.

INTRODUCTION

The Colorado School of Mines verified the CATO process in an eighteen-month demonstration of the technology where they processed an assortment of ASR and MSW components at a 50-200 gram scale. Harmful gases such as furans and dioxins were not detected in their testing. The low temperature process preserves metals, such as aluminum foil, allowing them to pass through the process unaltered. The carbon generated from the process has potential BTU content equivalent to coal and can be utilized as a coal substitute, while steam generated during the process can be used to drive turbines that generate electricity. Following the CSM tests, Hazen Research performed confirming tests at ten (10) pounds scale and achieved comparable results to those at CSM.

The unique aspect of the process is that the inert gases CO_2 and CO are utilized as oxidizing agents to achieve energy conversion in a self-sustaining exothermic reaction due to the significant amounts of plastics and rubber in the raw feed material. At commercial scale of twenty-five (25) tons reacting per hour the CATO process will generate more than 58 MM BTU. It is important to realize that this is not an incineration process, but rather a chemical process. The key reactions include:

Chloride Capture /Vinyl Chloride i.e.:

$$2\{C_2H_3Cl\} + MgCO_3 = 5C + MgCl_2 + 3H_2O\ (g)$$

Hydrocarbon Oxidation:

$$2\{-CH_2-\} + CO_2 = 3C + 2H_2O\ (g)$$

The carbon produced will be collected by screening and eddy current separation equipment which will remove the metals and other solids. A combined-cycle gas/steam turbine envisioned for power production from this process can achieve 1.2 Mw/ton versus mass burn-incineration that achieves 560 kW/ton. This suggests that our process can be twice as efficient as traditional waste to energy plants. We assume steam to electricity at 30% efficiency and carbon, an intense heat source, at 35%.

Existing waste to energy (WTE) incineration methods oxidize much of the recoverable metals in the MSW/ASR. The CATO process preserves these recyclable resources resulting in a greater economic yield per ton of MSW/ASR processed; the scrap metal recovered can be sold as secondary materials for reclamation or as primary metals, i.e. aluminum, copper, etc. Markets at the end of 2008

valued these metals at a conservative price of $30/ton on an aggregated basis. An important added benefit is the conservation of energy in processing reclaimed metals versus metals derived from virgin ore.

Revenue streams include waste tipping fees, the sale of carbon obtained for electricity generation, captured steam and related gases for power generation, and metals reclamation. A typical facility processing 100,000 tons of ASR/MSW will generate 120,000 useable megawatts, when credited at $30/Mw from the utility, yields $3,600,000 annually. Another financial consideration is global carbon credits. As our process recovers sustainable carbon, compared to fossil coal we are well positioned to realize carbon credit trading opportunities.

ECONOMIC VALUE

With most of the world focused on global warming, replacing fossil fuels with renewable, sustainable resources also reduces carbon emissions, such as CO_2 which is suspected of being a leading contributor to greenhouse gases. Recycling of metals and all other material which can be recycled is another opportunity where we can reduce emissions as well as save energy.

We also see a significant economic value to the implementation of our process. There are multiple revenue streams available which include:

- Tipping fees for acceptance of MSW/ASR
- Carbon as a coal/BTU equivalent
- Efficient electricity generation
- Metals recycling

MSW has the following metallic content: 7.6% metallic per ton (EPA 2006)

- 1.3% of Aluminum (Al)
- 0.35% of Copper (Cu)
- 0.35% Other Non-Ferrous metals
- 5.6% Ferrous (Fe)

200,000 tons of MSW will generate 15,200 tons of metals with a value of $39/ton of waste processed, or $7,800,000. These values are based on conservative sales prices for metals contained at year end 2008.

Table 1 illustrates the financial benefit to a company operating a "mega-shredder" to produce ferrous (Fe) and non-ferrous metals from feedstock containing obsolete scrap such as automobiles, appliances and other household items, commercial and industrial metallic offal, prompt scrap from manufacturing operations, and heavier grades of scrap, e.g. demolition materials. These items are processed for recycling purposes where the metallic content is recaptured and sent to ferrous and non-ferrous mills for remelting into new products. Despite the best available current technology, metals remain in the waste stream and are recovered by the CATO process without the severe oxidation degradation caused by incineration methods.

TABLE 1

Shredder Operator ASR Revenue Example

ASSUMPTIONS:

1) 8,000 -10,000 Hp Mega-Shredder
2) Assume 10 hours shredder operation per day
3) Assume 25 TPH for CarbonTech process per reactor. One reactor should process 600 tons per day at 25 TPH; volume above that level requires additional reactor(s). Reactors operate 24 hours/day, 330 days/year.
4) Assume 1,500 MwH per month used by shredder
5) Assume 22 days/mo and 10 hrs per day
6) Assume 10 cents/kWH charged to operator
7) Assume 5% metals in ASR at $30/ASR ton.

Shredding Process	Per Hour	Per Day	Per Year
Ferrous Tons	200	2,000	528,000
ASR Tons	67	667	176,000
CarbonTech Process	**Per Hour**	**Per Day**	**Per Year**
MwHours from CBT process (1.2 Mw/ton, 25T/hr)	30.00	720.00	237,600
Shredder MwHours Consumed	7	70	18,480
MwHours Sold	23.00	650	219,120
Sale Price/MwH	$30.00	$30.00	$30.00
Revenue	$690.00	$19,500.00	$6,573,600.00
Shredder Electrical Savings ($3.50/Fe ton)	$700.00	$7,000.00	$1,848,000.00
Shredder ASR Disposal Savings (10:1 volume reduction @ $20/T)	$1,020.00	$10,200.00	$2,692,800.00
One month purchased electricity for annual reactor shut down.	($700.00)	($7,000.00)	($154,000.00)
Metals Recovered @ $30/ASR ton	$2,000.00	$20,000.00	$5,280,000.00
Total Economic Value to Shredder	$3,710.00	$49,700.00	$16,240,400.00

NOTE: Does not include any capital or operating costs.

Table 2 illustrates the financial benefit to a community utilizing the CATO process to convert MSW into electrical power either by generating power directly or selling the carbon to a coal fired plant.

TABLE 2

Urban MSW Benefit Example

Assumptions
220,000 population, 100,000 homes (2.2 people per household)
4.54 pounds MSW/day/person = 182,500 tons/year
Average electric bill = $1,200 annually
Average charge kWh = $0.10 (MwH = $100)
Metal credit = $39/MSW ton

Annual Community Electric	$120,000,000.00
Savings per MwH	$70.00
Total MwH generated	267,042
Total Electric Savings	$18,692,940.00
% Credit of Community Electric	15.58%
Metal credit	$7,117,500.00
Total Value (electric plus metal)	$25,810,440.00
Total Return	21.51%

NOTE: Does not include any capital or operating costs.

TECHNICAL DATA

The following tables provide technical data for both ASR and MSW.

Exhibit ASR-1

ASR Contents & Products

INPUT	Pounds Used
PVC	181
PE,PP,PS	363
Urethane	213
Cellulosics	322
Rubber	231
Sub Total - Organics	1,310
Glass & Dirt	190
Metals	300
Total	1,800
CO_2	570
$MgCO_3$	107
Input Total	2,477

Metal Content	Coarse	Fines
Fe	2	26
Al	58	58
Cu	44	22
Zn	42	28
SS	20	
Total Metals	166	134
Glass & Dirt	56	134
Total	222	268

Products	Carbon	Water	BTU/1800 lb	NOTES
PVC	78	30	175,000	Chloride
PE,PP,PS	414	374	281,000	
Urethane	98	147	184,000	Nitrogen
Rubber	158	116	132,000	Zn oxide and sulfur
Cellulose	139	110	175,000	
Total	887	777	947,000	
$MgCl_2$	117			
CH_4	128			
N_2	57			
Output Total	2,456			

Exhibit ASR-2
Auto Shredder Residue
Heat Balance Per Ton

Reaction

Reactor In:	Pounds	Specific Heat	Temp °F	BTU	Cu Ft of Solids	Cu Ft of Gas
Solids (from ASR)	1,800	0.21	70	(26,460)	14.40	
Water (from ASR)	200	1.00	70	(14,000)	3.20	
$MgCO_3$	104	0.25	70	(1,820)	0.80	
CO_2	570	0.26	996	(147,607)		14,615
N_2	1,516	0.27	996	(407,683)		60,640
Net	4,190			(597,570)	18.40	75,255
Delta H (estimated)				(947,000)		
Gasify	200			194,000	(970 BTU's/lb H_2O to achieve gassification)	
			Sum of Heat In	(1,350,570)		

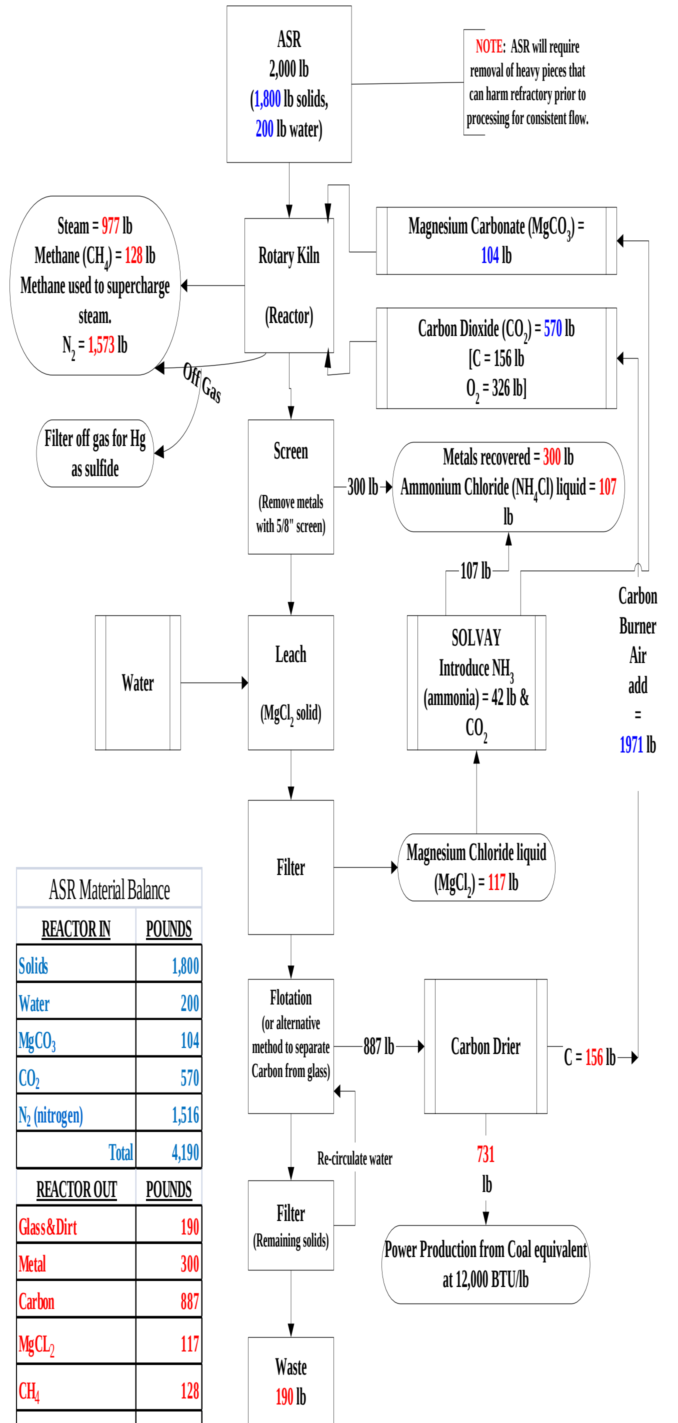
Reactor Out:	Pounds	Specific Heat	Temp °F	BTU	Cu Ft of Solids	Cu Ft of Gas
Glass&Dirt	190	0.25	752	(35,720)	1.50	
Metal	300	0.15	752	(33,840)	2.00	
Carbon	887	0.36	752	(240,129)	7.10	
$MgCL_2$	117	0.25	752	(21,996)	0.90	
CH_4	128	0.90	752	(86,630)		7,111
Steam	977	0.50	752	(367,352)		48,850
N_2	1,573	0.29	752	(343,040)		49,156
Net	4,172			(1,128,707)	11.50	105,117
Heat Loss				(221,863)		
			Sum of Heat Out	(1,350,570)		
					Averages	
					14.95	90,186

Carbon Burner

Carbon	156	0.31	70	(3,385)
Air	1,974	0.26	70	(35,927)
Delta H				(1,872,000)
			Sum of Heat In	(1,911,312)
CO_2	570	0.29	2,600	(429,780)
N_2	1,516	0.29	2,600	(1,143,064)
Heat Loss				(338,468)
			Sum of Heat Out	(1,911,312)

Heat Available				BTU
Gases From Reactor				(575,159)
Carbon Burner		(1,234,376)	(555,290)	(679,086)
CH_4	128			(2,754,560)
Carbon	731			(8,772,000)
			Total	(12,780,805)

Exhibit ASR-3
Demonstration Flow Sheet Per Ton



ASR Material Balance

REACTOR IN	POUNDS
Solids	1,800
Water	200
$MgCO_3$	104
CO_2	570
N_2 (nitrogen)	1,516
Total	4,190
REACTOR OUT	**POUNDS**
Glass&Dirt	190
Metal	300
Carbon	887
$MgCL_2$	117
CH_4	128
Steam	977
N_2	1,573
Total	4,172

Exhibit MSW-1
Revised MSW Amounts

In:	EPA2005 Pounds Used		
Solids (from MSW)	1,667		
Water (from MSW)	333		
Total	2,000		
Metals (see below for breakdown)	123		
Inorganics	137		
Organics (items incl. below)	1,407		
		Cellulosics	1,089
		Plastics	241
		Rubber	57
		PVC	20
Metals		Iron	83
		Aluminum	28
		Copper	6
		Zinc	6

Out:	Carbon	Water	BTU Delta H
Cellulosics	514	504	544,500
Plastics	257	368	186,534
Rubber	50	29	32,547
PVC	9	3	18,780
Totals	830	904	782,361

Exhibit MSW-2A
Municipal Solid Waste
Heat Balance per Ton

Reactor In:	Pounds	Specific Heat	Temp °F	BTU	Cu Ft of Solids	Cu Ft of Gas
Solids	1,667	0.21	70	(24,505)	16.70	
Water	333	1.00	70	(23,310)	5.30	
Gasify				323,010		
$MgCO_3$	10	0.25	70	(175)	0.10	
CO_2	586	0.29	1,118	(189,993)		15,025
N_2	1,604	0.29	1,118	(520,049)		66,833
Net				(435,022)		
Delta H				(782,361)		
			Total	(1,217,383)	22.10	81,855

Reactor Out:	Pounds	Specific Heat	Temp °F	BTU	Cu Ft of Solids	Cu Ft of Gas
Carbon	830	0.33	752	(205,973)	6.60	
Glass&Dirt	137	0.25	752	(25,756)	1.10	
Metal	123	0.15	752	(13,874)	0.80	
$MgCl_2$	12	0.25	752	(2,256)	0.10	
CH_4	79	0.90	752	(53,467)		4,388
N_2	1,604	0.29	752	(349,800)		50,425
CO_2	138	0.29	752	(30,095)		2,760
Steam	1,237	0.50	752	(465,112)		61,850
Net				(1,146,334)		
Losses				(71,049)		
			Total	(1,217,383)	8.60	119,423
					Averages	
					15.35	100,639

Carbon Burner	Pounds	Specific Heat	Temp °F	BTU
Carbon	160	0.31	70	(3,472)
Air	2,030	0.26	70	(36,946)
Delta H				(1,920,000)
Net				(1,960,418)
CO_2	586	0.29	2,600	(441,844)
N_2	1,604	0.29	2,600	(1,209,416)
Losses				(309,158)
Net				(1,960,418)

Heat Available	Pounds			BTU
Gases From Reactor				(862,589)
Carbon Burner				(1,406,786)
CH_4	79			(1,700,080)
Carbon	670			(8,040,000)
			Total	(12,009,455)

Exhibit MSW-2B

MSW Heat Balance per Ton

With Drier

Drier	Drier In: Pounds	Specific Heat	Temp °F	BTU	Drier Out: (295°F) Pounds	BTU
Solids (from MSW)	1,667	0.21	70	(24,505)	1,667	(103,271)
Water (from MSW)	333	1.00	70	(23,310)	87	(12,833)
Gasify (246 lb)				238,620		
CH_4	79	0.90	752	(53,467)	79	(16,314)
N_2	1,225	0.29	752	(267,148)	1,225	(97,571)
Steam	991	0.50	752	(372,616)	1,237	(182,458)
Net	4,295				4,295	(412,445)
					Losses	(89,981)
				(502,426)	Net	(502,426)

Reactor In:	Pounds	Specific Heat	Temp °F	BTU	Cu Ft of Gas
Solids	1,667	0.21	295	(103,271)	
Water	87	0.50	295	(12,833)	
$MgCO_3$	10	0.25	70	(175)	
CO_2	448	0.29	651	(84,578)	11,487
N_2	1,225	0.29	651	(231,268)	51,040
		Net		(432,124)	
		Delta H		(782,361)	
			Total	(1,214,485)	62,527

Out:	Pounds	Specific Heat	Temp °F	BTU	Cu Ft of Gas
Carbon	830	0.33	752	(205,973)	
Glass&Dirt	137	0.25	752	(25,756)	
Metal	123	0.15	752	(13,874)	
$MgCL_2$	12	0.25	752	(2,256)	
CH_4	79	0.90	752	(53,467)	4,388
N_2	1,225	0.29	752	(267,148)	52,619
Steam	991	0.50	752	(372,616)	49,550
		Net		(941,090)	
			Losses	(273,395)	
			Total	(1,214,485)	106,557
			Average Gas Ft^3		84,542

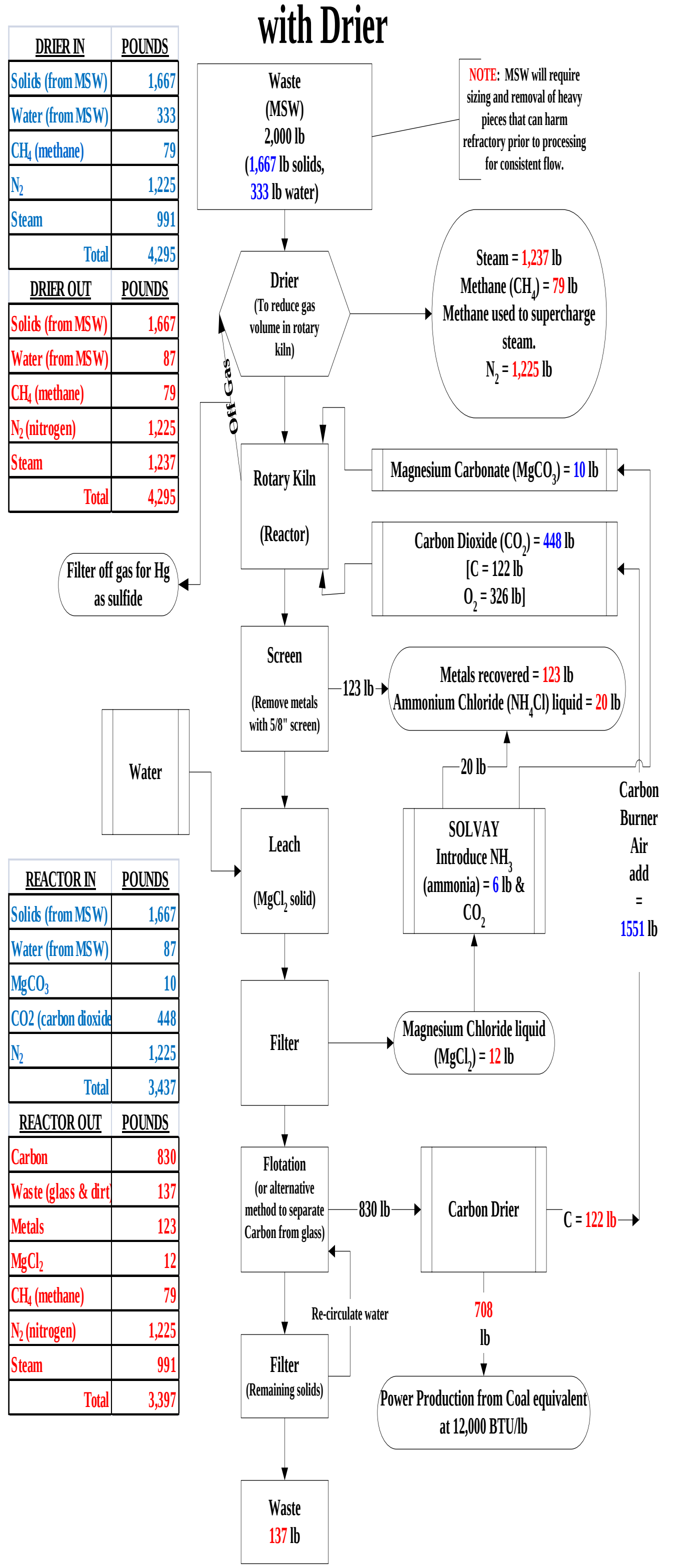
Carbon Burner	Pounds	Specific Heat	Temp °F	BTU
Carbon	122	0.31	70	(2,647)
Air	1,551	0.26	70	(28,228)
Delta H				(1,464,000)
CO_2	448	0.29	2,600	(337,792)
N_2	1,225	0.29	2,600	(923,650)
			Losses	(233,434)

Heat Available	Pounds			BTU
Drier Out				(263,715)
Carbon Burner				(945,596)
CH_4	79			(1,700,080)
Carbon	708			(8,496,000)
			Total	(11,405,392)

Exhibit MSW-3

Demonstration Flow Sheet Per Ton

with Drier



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[1] P.R. Taylor, S.A. Shue and J.W. Hohn, December, 2005, "An Experimental Investigation of the Reaction of Plastics and Related Organic Materials in Automobile Shredder Residue (ASR) with Magnesium or Calcium Carbonate, Water and Carbon Dioxide", Kroll Institute for Extractive Metallurgy, Colorado School of Mines, Golden, Colorado.

[2] M.J. Castaldi and J.P. Dooher, June, 2007, "Investigation into a catalytically controlled reaction gasifier (CCRG) for coal to hydrogen", International Journal of Hydrogen Energy, vol. 32 (2007), pp. 4170-4179.

ADDENDUM

Following is the commentary from Reviewer 1 of the CarbonTech paper and the responses from the inventor, Mr. Paul Kruesi. Mr. Kruesi's comments have been utilized to revise this paper.

Reviewer Comments

Reviewer 1:

The vinyl chloride equation presented as example is feasible but it is only slightly exothermic (0.34 MJ/mol of vinyl chloride) so the process will require an external heating source. This source and also the needed quantity of external energy per ton of MSW/ASR is not mentioned in the extended abstract. The process is supposed to produce carbon which, according to authors can be used to produce 1200 kWh per ton of ASR/MSW, vs. the 600 kWh of combustion in a WTE, but the authors do not indicate how will the carbon produced be separated from the other solid residues in the products and how the carbon will be used to produce electricity. There is no mention of the scale in which this process was tested (lab, pilot, prototype). It appears that the material and energy balances included in the abstract were derived theoretically. Prof. Marco Castaldi is mentioned in the references and he may be able to provide more information as to this process.

Paul Kruesi Response

Reviewer 1 comments "slightly exothermic" translating, 0.34Mj per gram mole is 1168 BTU per pound. Close to what we used. That this is insufficient heat for an autothermic process is wrong. First: PVC is one of the lesser exothermic materials; plastics and rubber are higher. Second: 30 tons in a reactor reacting in less than an hour is 70,000,000 BTU if all PVC. Plenty of heat. He is correct that the reaction was tested at only ten pounds an hour (Hazen). That does not imply "theoretical"; it implies that scale up will be required before large scale plants are built. The process generates high temperature steam and carbon. We assumed steam to electricity at 30% efficiency and carbon an intense heat source at 35%. Conservative estimates are that 50% combined cycle plants have been demonstrated. We have not chosen to go into the details of carbon separation nor on the particular properties of our carbon as this would involve a very substantial technical paper beyond that being presented.