

WHERE MIDSTREAM MEANS BUSINESS APRIL 10 - 13 • NEW ORLEANS

Scot Smith, Director, Zeeco, Inc. Flare Division

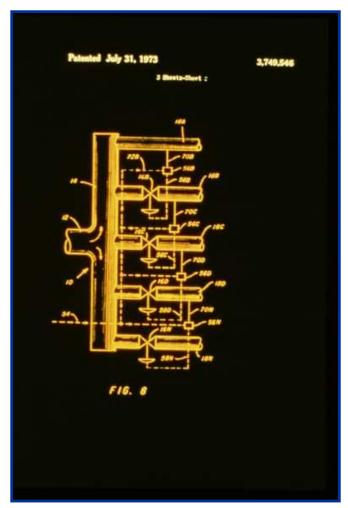
EMISSIONS TESTING OF SONIC FLARES

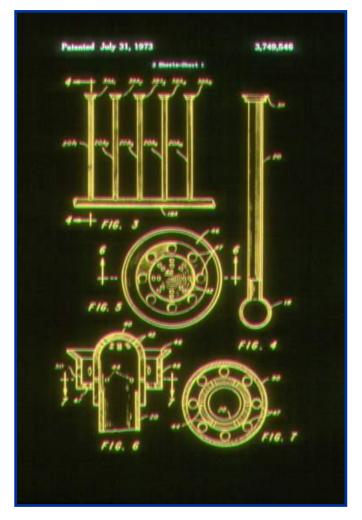
Multipoint Ground Flare History

- Developed early 1970's
- Zeeco founder was one of the original inventors and listed on original patent
- Original installation in 1972
- Many improvements over past 35 years in burner technology
- Basic overall concept today is same as original



Original Multipoint Flare Drawings







Burner Development Over 35 Years



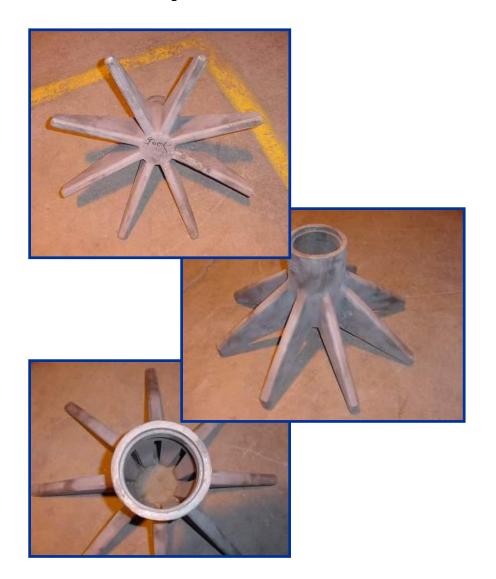
Common Burner Characteristics

- Use jet action of gas to entrain air for smokeless burning
- Smokeless burning over wide pressure ranges
- Low radiation
- Stable operation at sonic velocity
- Multiple burners for unobstructed air access



Modern Sonic Velocity Burners

- Variable arm area
- Investment cast
- Pressure tested at factory
- 310 SS cast material
- Inherently stable on wide range of gases





Common MPGF Design Concept

- Many small burners
- Staging system ensures operation in optimum pressure band
- Number of burners in service are proportional to gas flow
- Typically used for high pressure, heavy hydrocarbon service
- Allows for controlled flame length from burners



















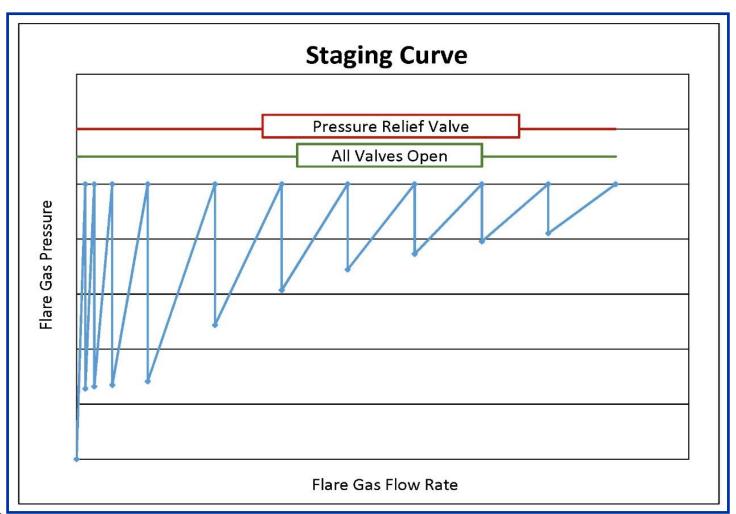








Typical Staging Curve





Typical Installations



Typical Installations





1983 CMA Testing

- Air-assisted flare
- Un-assisted flare
- Steam-assisted flare
- Extractive sampling
- EPA involvement
- Basis for current flare regulations, 40 CFR 60.18



1983 CMA Testing

- Subsequent to all CMA sponsored testing of flare systems, there was a separate test using the same equipment on a pressure-assisted flare tip
- Results of that test were submitted to the EPA
- Results showed very high destruction efficiency



1983 CMA Test Data on Pressure-Assisted Tip Testing, Crude Propylene Firing

						TEST 81 ST DATA SUMM GROUND CORE						
OVERALL COMBUSTION EFFICIENCY = 99.82%												
TIME	PROBE HGT(FT)	PROBE TEMP(C)	802	NOX	CO	C02	THC	02 (X)	WS (MPH)	WD (DEG)	AMBIENT TEMP(C)	OBS CE X
30/18:01:34	37:00	157 • 7	0.085	2.05	0.6	2867.	-1-1	20.85	4.9	198.	36.52	100.02
30/18:01:46	37:00	155.6	0.016	4.16	-1 - 1	5037.	-1.2	20.30	4.6	183.	36.47	100.04
30/18:01:58	37:00	153.3	0.001	2.94	1.9	4112.	-1.2	20.37	5.6	214.	36.38	99.98
30/18:02:15	37:00	186.1	006	1.50	2.6	2982.	-1.4	20.60	3.2	202.	36.51	99.96
30/18:02:27	37:00 37:00	221.8	0.101	1.18	5.3	2722•	-1.4	20.76	3.4	214.	36.55	99.86
30/18:02:40 30/18:02:52	37:00	194.6 190.0	0.092	4.98 4.92	10.0	5647. 6347.	-1-3	20.40	5.6	206.	36.41	99.85
30/18:03:08	37:00	257.1	0.138	1.72	6.6 2.2	3932.	-1.3	19.95	2.7	198.	36.53	99.92
0/18:03:21	37:00	273.8	0.070	7.69	3.9	7652•	-1.4 -1.3	20.47	4.9	193.	36-51	99.98
30/18:03:33	37:00	303.8	0.267	7.34	5.4	9157•	-1.1	20.15 19.62	2.4	228.	36.61	99.97
30/18:03:45	37:00	276.1	0.131	12.63	4.8	12967.	0.3	19.72	4 • 0 3 • 5	208.	36.66	99.95
30/18:03:57	37:00	274.1	0.050	9.22	5.5	11632.	0.6	18.64	3.4	221.	36.71 36.71	99•96 99•95
30/18:04:14	37:00	258 • 2	0.019	4.34	5.3	7322.	0.6	19.61	4.4	203.	36.79	
30/18:04:26	37:00	233.8	0.081	2.37	11.9	5232•	0.6	19.99	5.0	209.	36.68	99.92 99.76
30/18:04:59	37:00	224.3	0.007	3.11	14.6	4917.	0.4	20.06	3.7	195.	36.64	99.76
0/18:04:51	37:00	210.5	0.030	1.84	12.0	3732.	-0.1	20.20	3.9	223.	36.57	
0/18:05:07	37:00	175.5	003	1.24	4.1	2772.	-0.3	20.33	4.2	215.	36.53	99.68 99.86
0/18:05:20	37:00	188.3	009	0.41	4.0	1852.	-0.4	20.47	4.4	213.	36.55	99.81
0/18:05:32	37:00	180.2	0.046	0.06	1.8	1322.	-0.5	20.58	4.3	224.	36.58	99.90
0/18:05:44	37:00	185.8	0.093	0.72	2.7	1727.	-0.9	20.51	3.7	223.	36.51	99.89
0/18:05:56	37:00	205.4	0.004	2.80	4.5	3362.	-0.8	20.24	4.0	217.	36.55	99.89
0/18:06:13	37:00	289.1	0.132	3.39	0.6	4272.	-1.1	20.15	5.8	206.	36.56	100.01
30/18:06:25	37:00	242.4	0.123	8.86	1.2	8487.	-1.2	19.59	3.8	194.	36.46	100.00
30/18:06:38	37:00	272.8	0.015	8.01	1.7	9262.	-1.1	19.05	4.9	219.	36.41	99.99
0/18:06:50	37:00	292.6	0.159	4.94	2.3	7312.	-0.9	19.59	4.1	207.	36.40	99.98
30/18:07:06	37:00	341.3	0.113	10.26	-2.2	10547.	-0.7	19.01	2.7	214.	36.67	100.03
0/18:07:19	37:00	368.9	0.187	11.57	-1.5	12027.	-0.8	18.94	3.5	208.	36.81	100.02
0/18:07:31	37:00	433.3	0.216	17.08	-0.9	16557.	-0.5	18.20	2.6	193.	37.01	100.01
0/18:07:43	37:00	453.6	0.246	19.01	1.3	19732.	-0.2	17.61	2.9	222.	37.05	99.99
0/18:07:55	37:05	409.1	0.230	21.17	3 • 2	22267.	1.7	17-16	3.7	223.	37.01	99.98
0/18:08:12	37:06	382.2	0.116	15.37	9.7	18737.	2.2	17.56	2.9	202.	37.11	99.94
0/18:08:24	37:06	386.4	0.040	10.06	25.2	14212.	2.0	18.38	2.9	225.	37.19	99.81
0/18:08:37	37:06	418.1	0.108	6.10	45.1	10367.	1.3	19.25	3.1	215.	37.17	99.55
0/18:08:49	37:06	402.1	0.164	9.54	48.4	11617.	1.4	19.29	2.2	202.	37.34	99.57
0/18:09:05	37:06	425 • 2	0.178	11.72	41.3	13552.	1.4	18.64	2.0	203.	37.54	99.69
0/18:09:18	37:06	492.9	0.269	14.38	28.0	15462.	1.1	18.43	2.8	202.	37.66	99.81
0/18:09:30	37:06	493.7	0.720	24.20	19.1	22712.	2.6	17.46	4 - 1	193.	37.55	99.90
0/18:09:42	37:06	454.2	0.701	26.47	23.0	26847.	8.0	16.23	4.3	187.	37.33	99.88
0/18:09:54	37:06	395.7	0.266	18.35	21.6	22017.	10.6	16.83	2.2	208 •	37.41	99.85
0/18:10:11	37:06	400.5	0.244	6.92	37.4	12767.	10.3	18.71	3.3	210.	37.49	99.63
0/18:10:23	37:06	378.1	0.161	9.30	52.7	12527.	9.1	18.95	3.3	251.	37.45	99.51
0/18:10:36	37:06	274.5	0.137	6.73	53.5	10692.	8.0	19.08	5.1	235.	37.32	99.43
0/18:10:48	37:06	293.7	0.056	6-24	44-8	9287•	7.0	19.35	3.7	207.	37.28	99.45
0/18:11:04	37:06	274.4	0.030	2.37	37.6	5727.	6+1	19.88	4.5	204.	37.18	99.24
0/18:11:17	37:06	256.0	0.021	0.91	31.8	3702.	5.0	20 + 23	3.2	187.	37.07	99.01
0/18:11:29	37:06	306.2	0.017	0.21	25.9	2447.	4.3	20.42	3.4	198.	37.08	98.78
0/18:11:41	37:06	276.7	0.141	3.84	21-1	4667.	3.6	20.34	3.9	192.	37.06	99.47
0/18:11:53	37:06	247.4	0.034	7.54	16.0	7927•	3.1	19.44	4.2	218.	37.02	99.76



1986 EER Testing for EPA

- Further EPA sponsored testing on different type of flare tips
- Testing intended to analyze further gas mixtures, alternative gas types, etc.
- 3-inch nominal flare tip size for most tests
- Testing was performed on pressure-assisted commercially available high velocity flare tips,
 Commercial tips "E" and "F"



1986 EER Testing on Pressure-Assisted Flare Tips, Propane in Nitrogen

Table 2-2

COMMERCIAL 1.5 INCH DIAMETER PRESSURE-ASSISTED HEAD E. TEST RESULTS

		Actual Exit Velocity ¹ (ft/sec)	%Propane in Nitrogen	Low Htg Val (Btu/ft ³)	ΔP			Observations						Hydro
	Test No.				Across Head (psig)	Ht ³	Wind Speed (mph)	Flame Length (ft)	Lift Off (in)	Color	Smoke	Sound	Comb Eff (%)	Carbon Dest Eff (%)
2-5	207 208A 208B 209 210 211 212 214 216 217 218 219 220	14.3 112 94.7 472 78.5 12.4 95.9 238 384 14.2 470 109 761	15.8 20.2 23.9 23.9 26.0 18.1 21.9 48.1 29.6 23.7 35.2 28.4 28.1	371 474 562 562 612 426 514 1130 696 557 828 668	0)	ability C 6 7 12 16 6 16 7 20	Lucainead		2 2 1 4 0 3 0 4	dim orange yellow-purple base yellow-blue yellow-blue yellow blue base orange-blue yellow-blue	none none none none none none none none	none dull rumble- roar roar roar none jet low rumble	97.0 94.2 99.3 98.3 99.1 96.2 98.8 97.7	98.4 95.1 99.8 98.9 99.6 98.0 99.2 98.5
	221	907	36.6	870	10	30	6	20	3	yellow-blue	none	load roar	99.4	99.7



Testing by DOW for Two Installations

- Sonic velocity multipoint ground flares
- Two different applications, 2007 and 2014
- Nominal 4-inch spider type sonic burners
- General test results presented at AFRC Meetings



DOW Pressure-Assisted Tip Testing, AFRC Presentation 2007, Propylene / N2 mix

	Technology (Annual Control of Con	Target Flow	Y	Fuel	A COLUMN TO THE REAL PROPERTY OF THE PROPERTY
Test	Flare Burner	Lbs/hr	Kg/hr	HC	HC+N2
A	Large	5,000	2,270	V	The second secon
В	Large	8,000	3,640	7	
C	Large	5,000	2,270		√ √
D	Small	1,200	550	V	
E	Small	1,200	550		√ √

Combustion stability is a major factor in flare burner performance. A well designed and properly operated pressure-assisted flare burner with a stable flame will achieve 99+% DRE, which is the same or better than the efficiency of those flares that meet the requirements of Code of Federal Regulations, Title 40, Part 60.18.

Wind velocities up to 16 MPH (26 kph) had no identifiable impact on DRE results.



DOW Pressure-Assisted Tip Testing, AFRC Presentation 2014

Parameter		Pressure Assisted Tests							
Test ID	P1H	P1L	P2H	P2L	P3H	P3L			
Combustion Efficiency (%)	99.98	99.98	99.96	99.89	99.92	99.95			
THC DE (%) (Based on O2 F-Factor)	99.98	99.99	99.98	99.95	99.96	99.98			
Propylene DE Direct (%) (Based on O2 F-Factor)	99.91	99.95	99.93	99.96	99.95	99.98			
Propylene DE Bag (%) (Based on O2 F-Factor)	99.92	99.98	99.98	99.95	99.93	99.98			
Critical Pressure (psig)	10.7	10.7	11.5	11.6	11.7	11.7			
Pressure at Flare Tip (psig)	13.5	5.2	13.4	5.0	14.0	4.9			
Exit Velocity at Flare Tip (ft/s)	880	597	1,017	669	1,101	706			
Fuel Gas LHV (BTU/SCF) (GC Analysis)	2,145	2,133	776	711	698	690			
Fuel Gas Flow Rate (lb/hr)	8,307	5,422	7,914	4,898	7,512	4,592			
Combustion Efficiency (%) via PFTIR	99.8	99.7	99.8	99.8	99.7	99.3			

⁵ Tables JZ-2 and JZ-4, Report on Emissions Testing of Pressure Assisted LRGO-HC and Steam Assisted SKEC Burners, Document: 9136991-GP0-P07-0002, Rev 0



Approved for External Release

Sonic Flare Full Scale Testing for Smokeless / Flame Length / Crosslighting







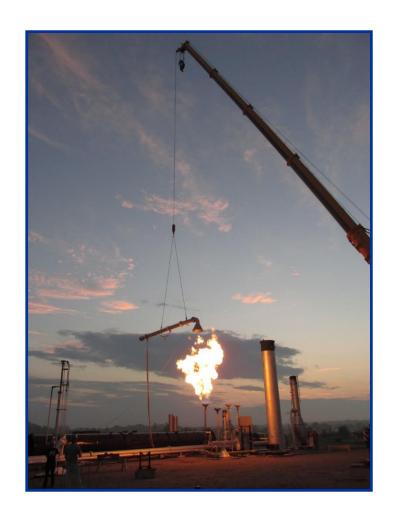
Multipoint Flare Burner Testing





Multipoint Sonic Flare Testing at Zeeco for DRE

- Natural Gas
- Propylene
- Propane
- Inert / H2 Mixtures
- Consistently over 99.5% DRE
- Summer 2013 Spring 2015





Multipoint Sonic Flare Testing

at Zeeco



Several Methods Used for Data Verification:

- 1. Extractive Sampling
- 2. PFTIR Analysis
- Optical Efficiency Monitor Device (FlareSentry™)



1. Extractive Sampling

- Sample hood with venturi suction
- Same design as TCEQ / TU tests 2010
- Temperature and FLIR camera for positioning







2. PFTIR Analysis

- Common industry test-method
- Monitoring relies on operator control





3. Optical Efficiency Monitor Device (FlareSentry™)

- New technology to directly, autonomously, and continuously monitor flare performance in real time
- Requires no operator input



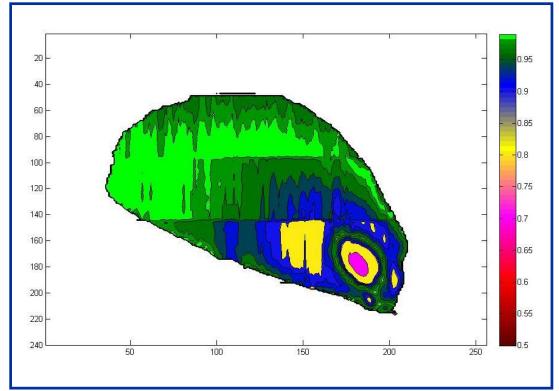


Imager for FlareSentry™; (Developmental platform; not final product)



Testing Methods Used 3.Optical Efficiency Monitor Device (FlareSentry™)







Test Area Video



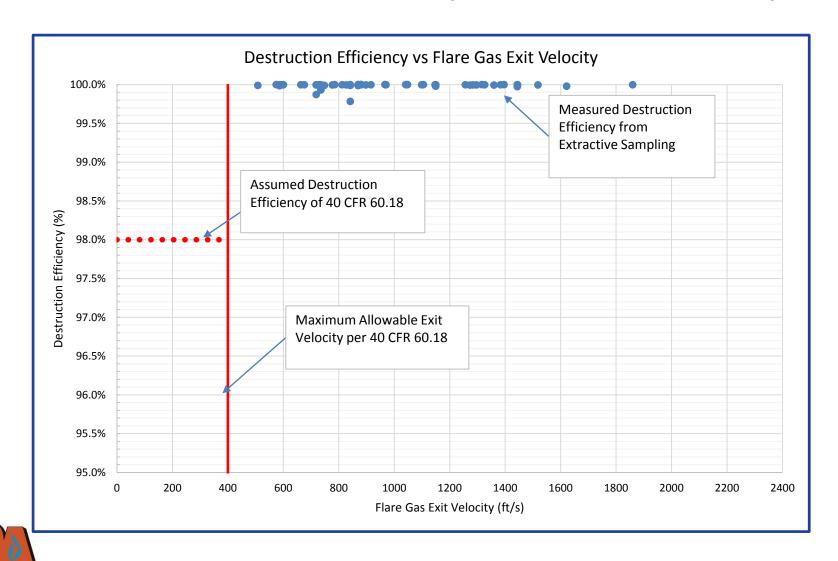


Details for Zeeco's Recent Sonic Testing

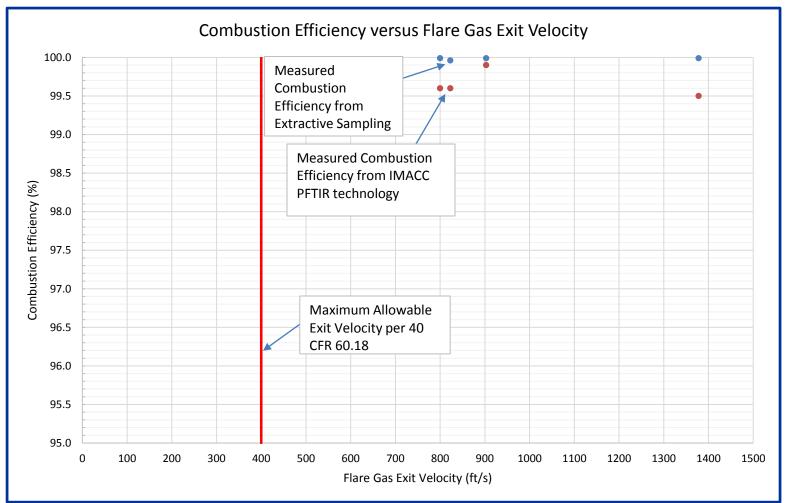
- Over 70 test points run
- Test gases ranged from 6 to 44 MW
- NHV ranged from 440 to 2316 BTU/SCF
- Operating pressures ranged from 3 to 30 psig
- Mixtures included Propylene, Natural Gas, Propane, H2, CO2, N2



Destruction Efficiency, Sonic Velocity



Combustion Efficiency, Sonic Velocity





Comparison of FlareSentry, PFTIR, and Extractive Sampling Data

Gases	СЗН8	C3H8/N2	C3H6	NG
NHV (BTU/SCF)	2316	1251	2183	937
40 CFR Maximum Allowable (ft/s)	400	400	400	400
Exit Velocity (ft/s)	841.4	969.9	869.8	1443.5
Mach Number	1.00	1.00	1.00	1.00
Flare Operating Pressure (psig)	16.0	10.3	16.9	15
CE (%) from Extractive Sampling	99.99%	99.99%	99.96%	99.99%
CE (%) from PFTIR	99.60%	99.90%	99.60%	99.50%
DRE (%) from Extractive Sampling	99.99%	99.99%	99.99%	99.99%
DRE (%) from FlareSentry™	99.80%	99.55%	99.90%	99.70%



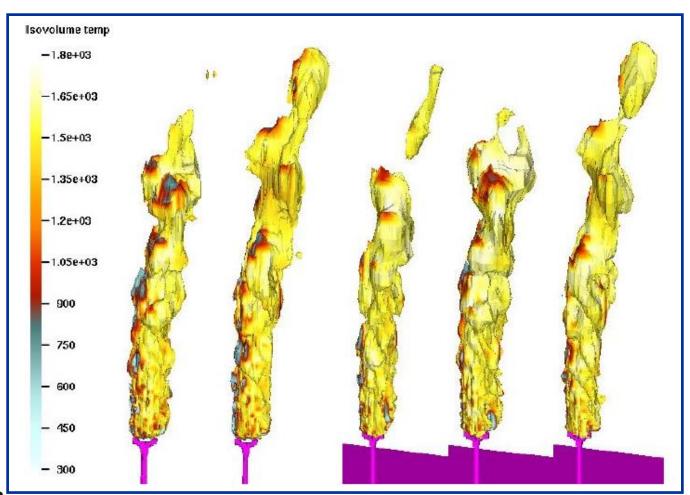
CFD Analysis





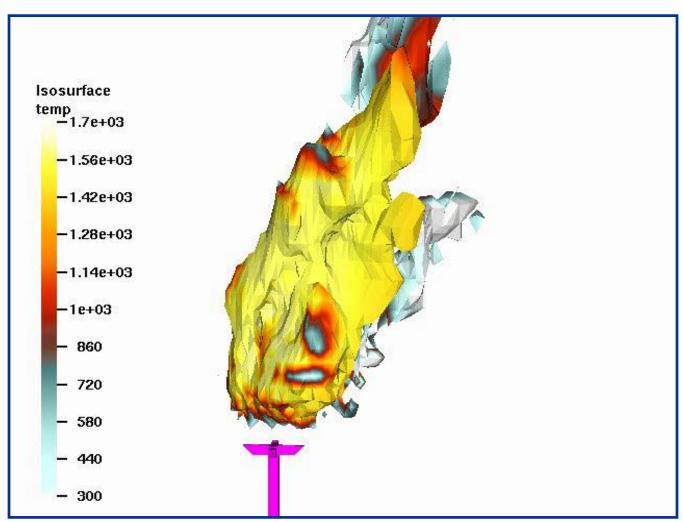


CFD Analysis





CFD Analysis





General Benefits for MPGF

- <u>High destruction</u> efficiencies
- Maximum <u>smokeless capacity</u> possible
- Low utility usage and cost
- Minimizes impact to your neighbors
 - Radiation fence
 - Smoke eliminated
- Easy access for maintenance
- Small plot space



Questions?

