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High Density Plasma Tools

Plasma Abatement: Moving from Research and Development to Production

A Presentation for the
Engineering Research Center
2001 July 12

Rusty Jewett, Ph.D.
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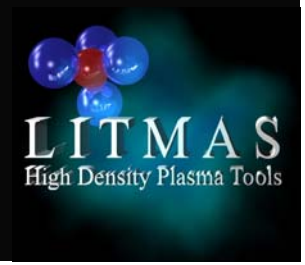

Outline:

- *Introduction (a brief history of Litmas, Inc.)*
- *Low Pressure Plasma Abatement of PFC's*
  - *Research Review*
  - *Engineering Considerations*
  - *Business Outlook*
- *High Pressure Plasma Abatement of PFC's*
  - *Research Review*
  - *Engineering Considerations*
  - *Business Outlook*
- *Litmas - Future Outlook*

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Introduction

January 1998: David Graves' Group at the UC Berkeley Department of Chemical Engineering Sponsored by the ERC to Investigate Plasma Treatment of Perfluorinated Compound Exhaust from a Lam Research Corporation 9100 Series Oxide Etcher

Prior Work:

V. Mohindra, H. Chae, H.H. Sawin, M.T. Mocella, "Abatement of Perfluorocompounds (PFC's) in a Microwave Tubular Reactor Using O_2 as an Additive Gas," IEEE Transactions on Semiconductor Manufacturing, V10(3), 1997, pp. 399-411.

January 1998: Rusty Jewett (Lam Research) and Curtis Camus (Advanced Energy Industries) complete prototype of an Integrated Power Converter and Plasma System

Prior Work:

Nathan Sokal and Alan Sokal, "Class-E, A New Class of High-Efficiency Tuned, Single-Ended Switching Power Amplifiers," IEEE Journal of Solid State Circuits, Vol SC-10, June 1975, pp 168-175

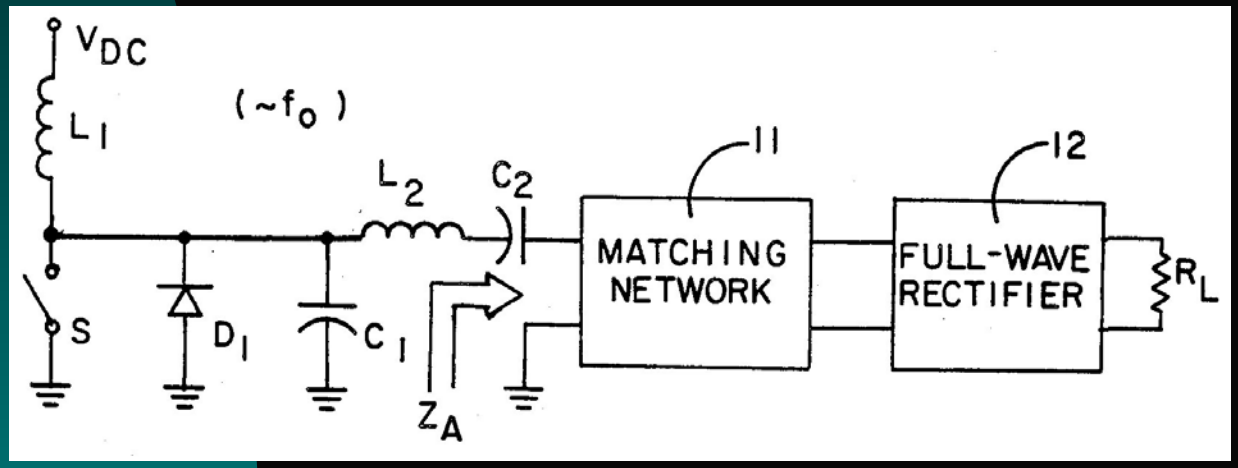
Nathan Sokal, Richard Redl, Bela Molnar, "Class-E High Efficiency DC/DC Power Converter," US Patent Number 4,607,323. August 19, 1986

Class E Switching Power Converters

Resonant Switching: Energy Stored in an Inductor is used to power a resonant load. A switch alternately allows current to go to a load, where energy is dissipated, or to ground, to charge the Inductor. The load is made to be resonant so that it rings. Switch cycles are performed when the current in the load crosses goes to zero.

High Frequency, High Density Plasma Sources used in the Semiconductor Industry have High Q, (resonant) loads.

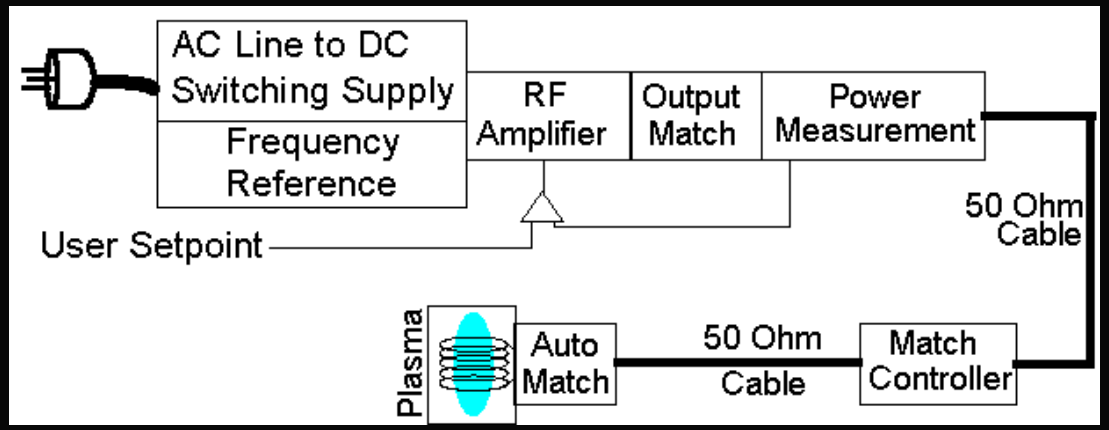
Litmas' Idea: Integrate the resonant induction plasma loads into an efficient Class E switching converter.



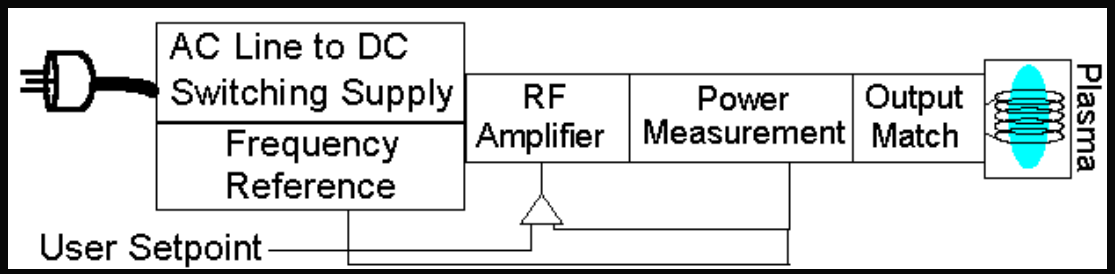
Stated another way…

Redundant Pieces of Existing RF Delivery Schemes were Combined…

Old Way…



New Way…

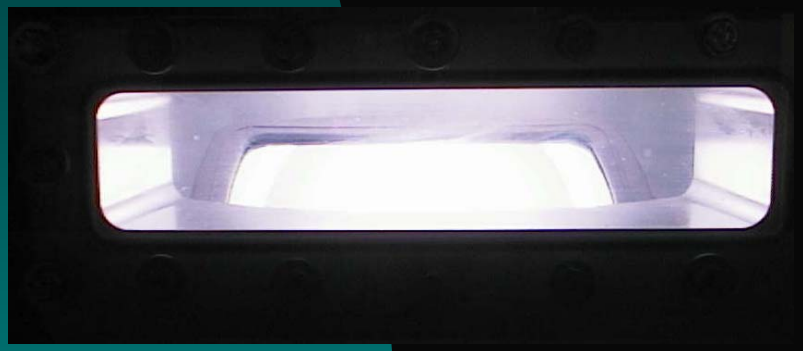


Litmas Planar Source

All-in-one plasma/match/power supply design

Patent-pending coil design ensures high uniformity, minimally-capacitive, planar plasma over a wide process window.

WIDE operating range of pressures and gases allows maximum process development freedom



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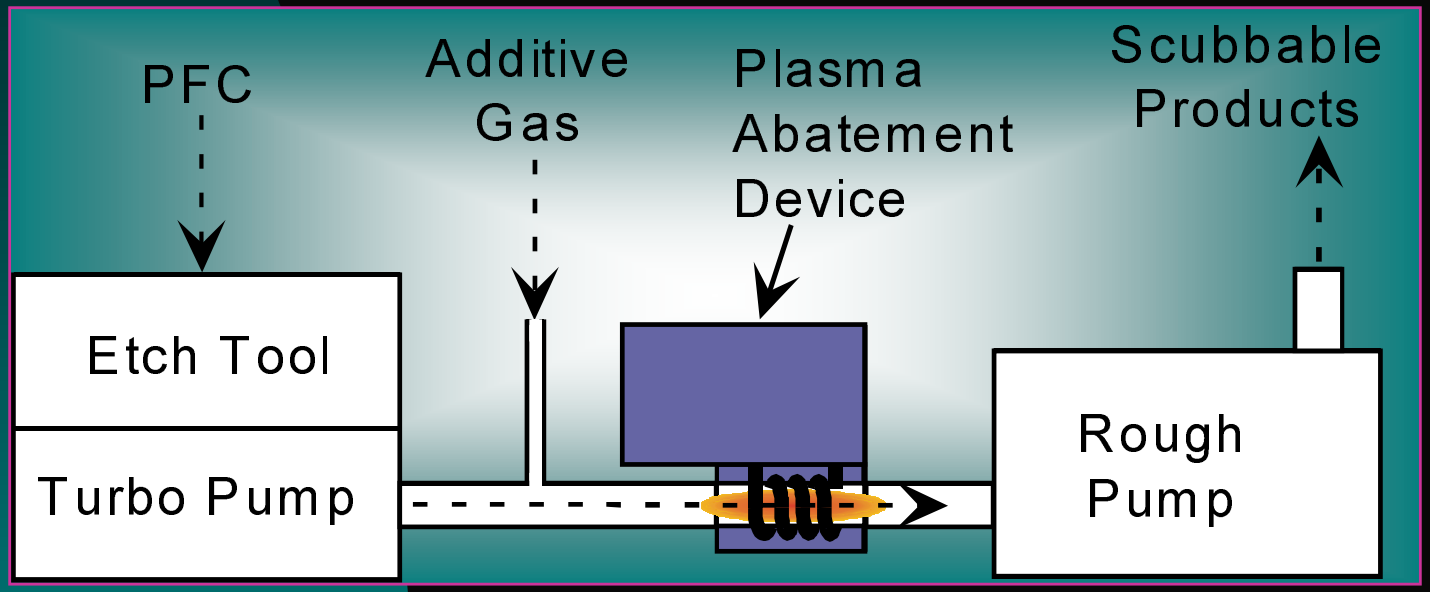
Foreline Plasma Abatement of Etch Exhaust

Strategy:

- Place high density plasma source in tool foreline to destroy PFC's before they are diluted in the rough pump.
- Use reaction gas additive such as O_2, H_2, H_2O to prevent PFC reformation and produce scrubbable products.



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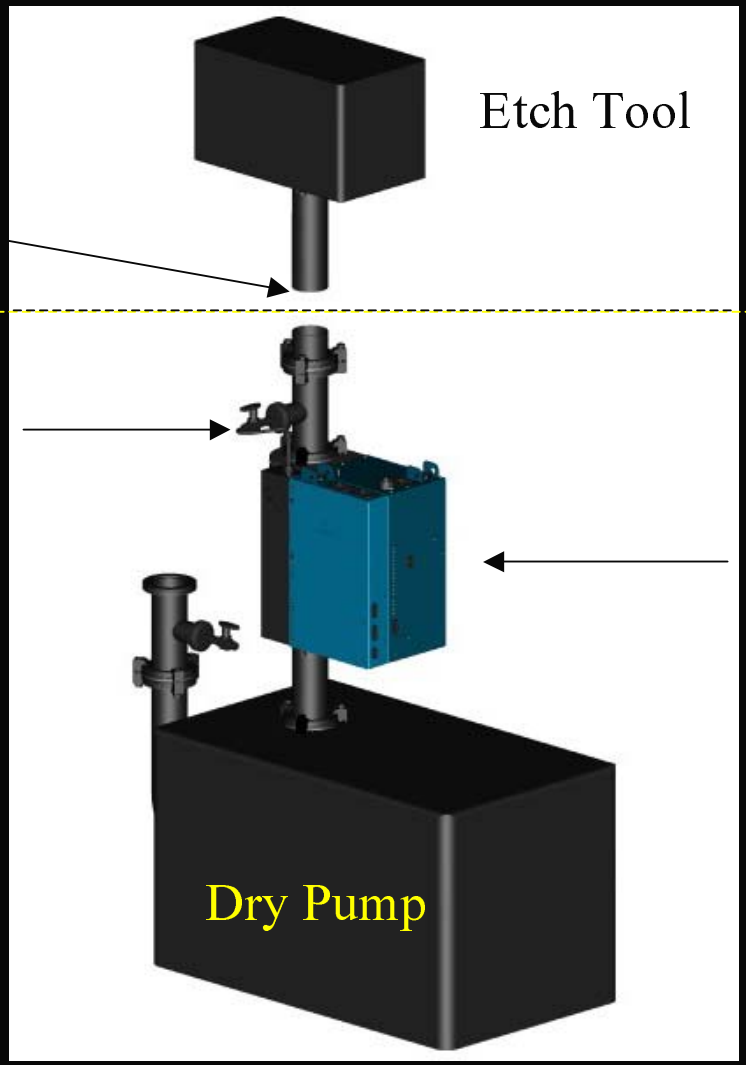
Typical Foreline Abatement System Installation Schematic



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The Litmas LB1200 Plasma System

- The LB1200 is an “all-in-one” inductively-coupled plasma source, power supply and matching network.
- Integration of all necessary components leads to significant cost and reliability increases and significantly reduces system size.

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Accessories: Automatic Water Delivery System (GDS-AF and GDS-O2)

- Newly available accessory
- Mounts directly on side of LB1200
- Just connect DI H_2O supply

- Pressure interlock
- Mass flow meter, control valve, and flow interlock
- LON interface and 15-pin analog interface
- -Ar option adds secondary flow of Argon to boost performance by an additional 5-10%

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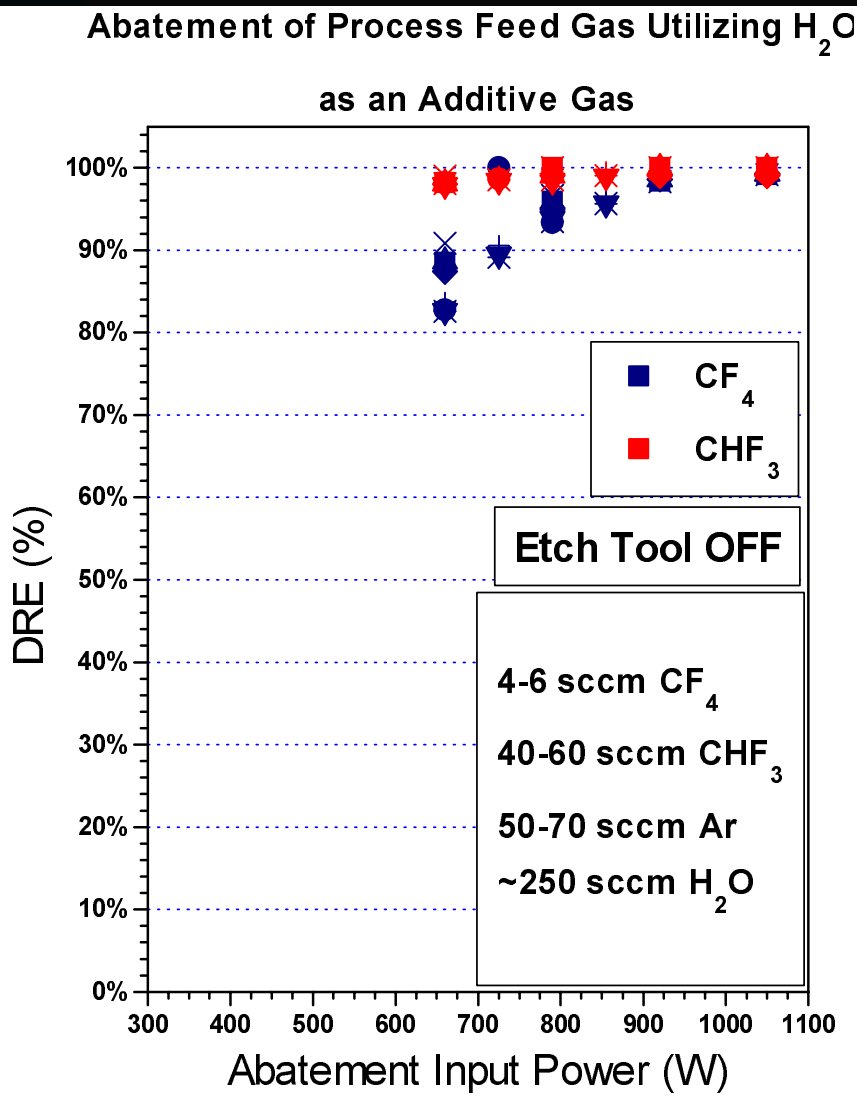
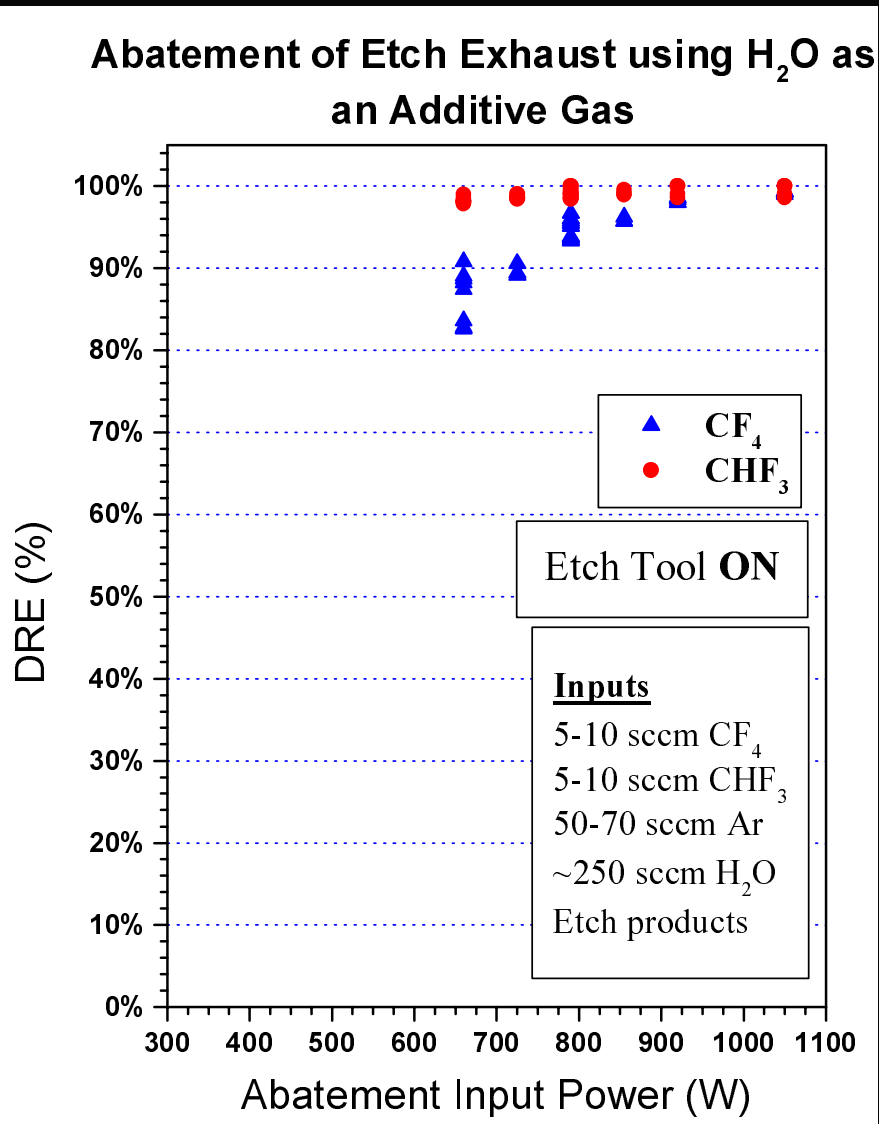
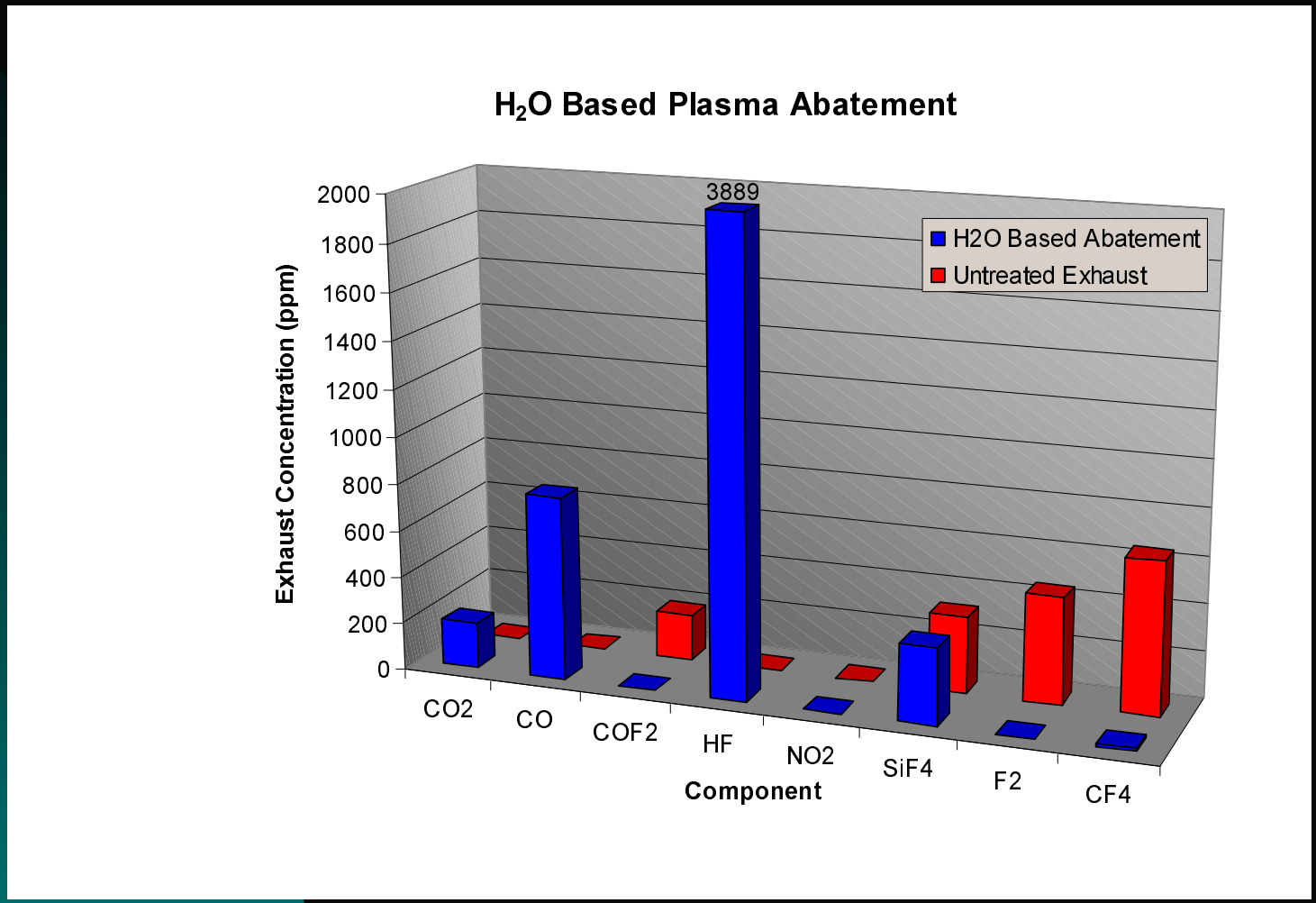
H_2O-based Abatement of an AMAT Etch Recipe

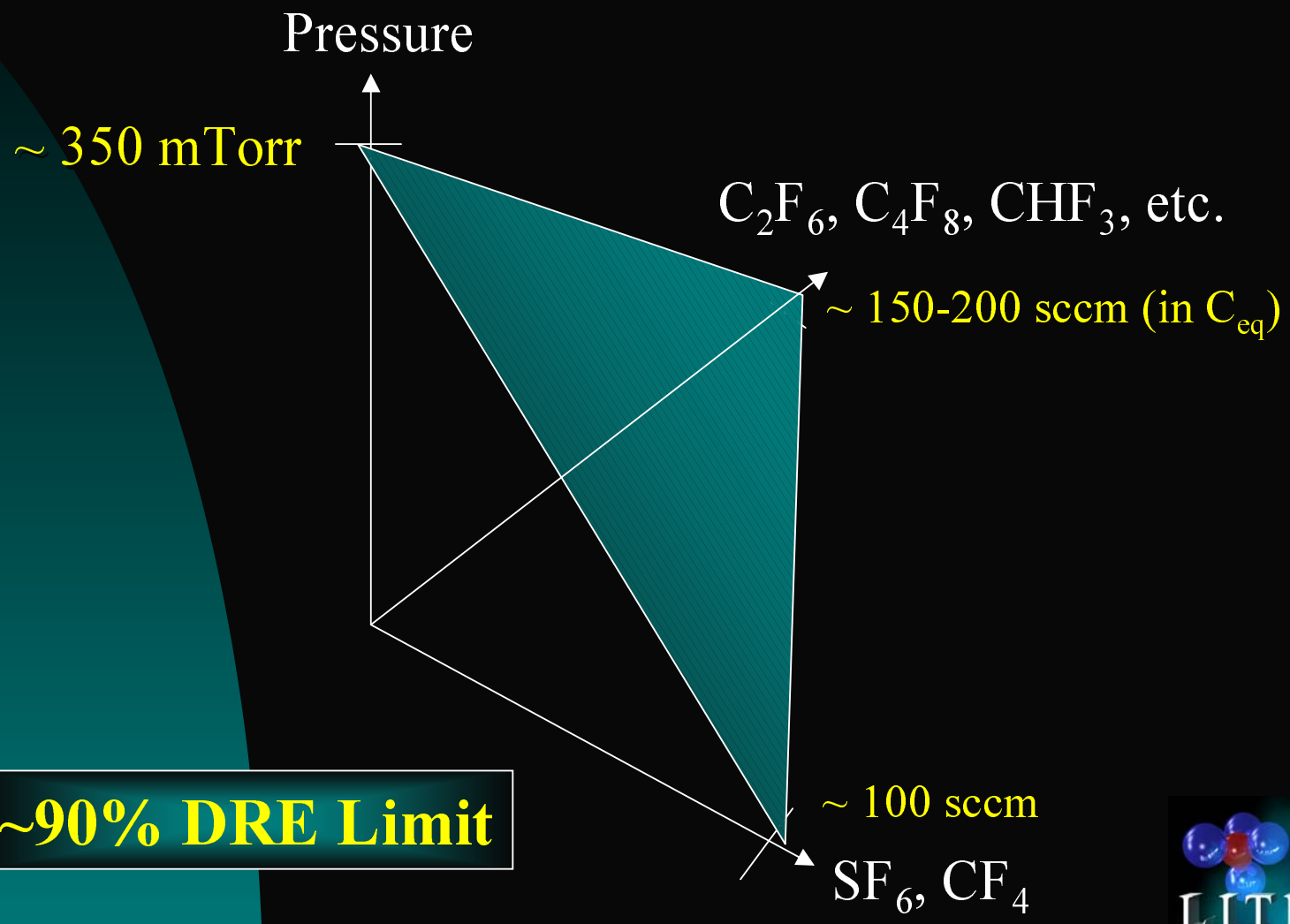




Changes in Exhaust Composition using the Litmas Blue System



LB1200 Process Window



~90% DRE Limit

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Abatement Additive: O_2 or H_2O?

- Choice of additive gas has little effect on PFC destruction efficiency.
- Abatement by-product distribution changes significantly with additive choice.

H_2O*	O_2
HF	CO_2
CO	CO (minor)
CO_2 (minor)	COF_2
H_2O (unreacted)	F_2
SiF_4 (from etcher)	HF (if HFC is abated)
	O_2 (unreacted)
	SiF_4 (from etcher)

*** Recommended for most applications**

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LB1200 Abatement Performance: Other PFCs

- *PFCs other than CF_4 are much easier to abate*

PFC	Max Flow for DRE > 90%	DRE at Max Tested Flow
CHF_3	> 200 sccm	> 99%
CH_3F	> 100 sccm**	> 95%
C_2F_6	~ 200 sccm	~90%
C_3F_8	~75 sccm**	~ 90%
c-C_4F_8	> 30 sccm**	> 99%
C_5F_8	~100 sccm	> 95%
NF_3	> 250 sccm**	> 99%
SF_6	100 sccm**	~95%

** This is the maximum flow tested to date for these gases
-All data reported here was taken without Ar dilution.

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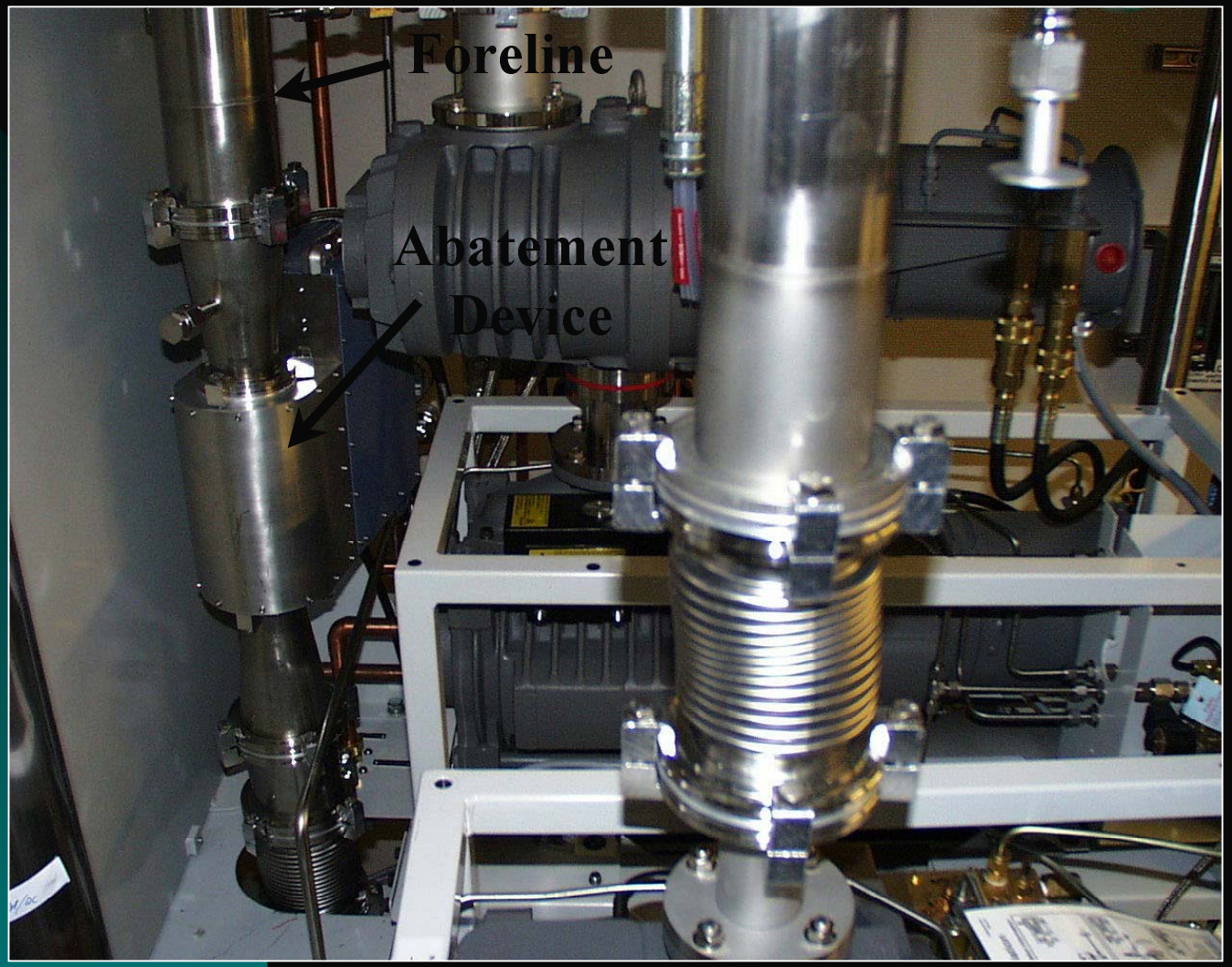
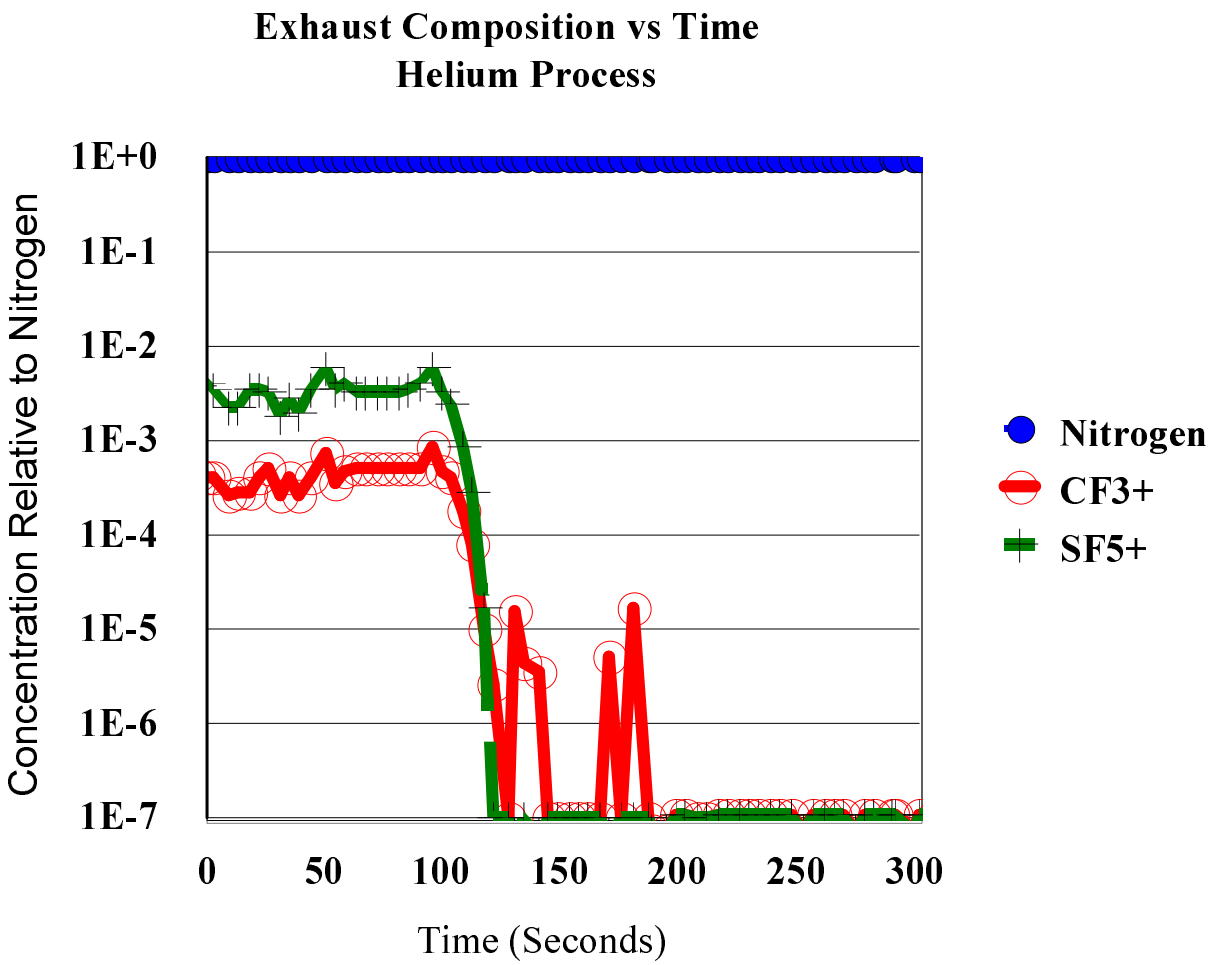
Motorola Installation



Performance in Hard Disk Manufacturing Installation
(Courtesy IBM Almaden Research Center)



Engineering Advantages of Foreline Plasma Abatement

- **Flexible solution**… install only as needed. Install phase-in possible.
- **No process impact**… No process requalifications.
- **Zero (or negligible) sub-fab footprint**
- **Easily controllable**… turn on only as needed. No start-up/warm-up time required.
- **Retrofittable to installed base and easily integrated to next generation tool set.**
- **Energy and water efficient** … low operating costs.
- **No fuel required. Improved fab safety and lower fire risk. (Requires only power, ICW, and low flow distilled water lines)**
- **It is independent of the type of HF scrubber employed (if any).**
- **Cost is proportional to # of chambers serviced (unlike multi-chamber systems)**
- **The lowest CoO of any PFC abatement solution for etch**

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Litmas Blue Technology Roadmap

LB3000 3kW Plasma Abatement Source

- Currently in beta testing (through Q3-Q4 2001)
- Some power supply design modification underway to reduce size and cost.
- Final release expected late Q4 2001
- Compatible with Litmas Gas Delivery Systems
- Will handle **all** 300 mm recipes (>300 sccm CF_4 based on preliminary data)
- Semi S2-2000 compliance planned

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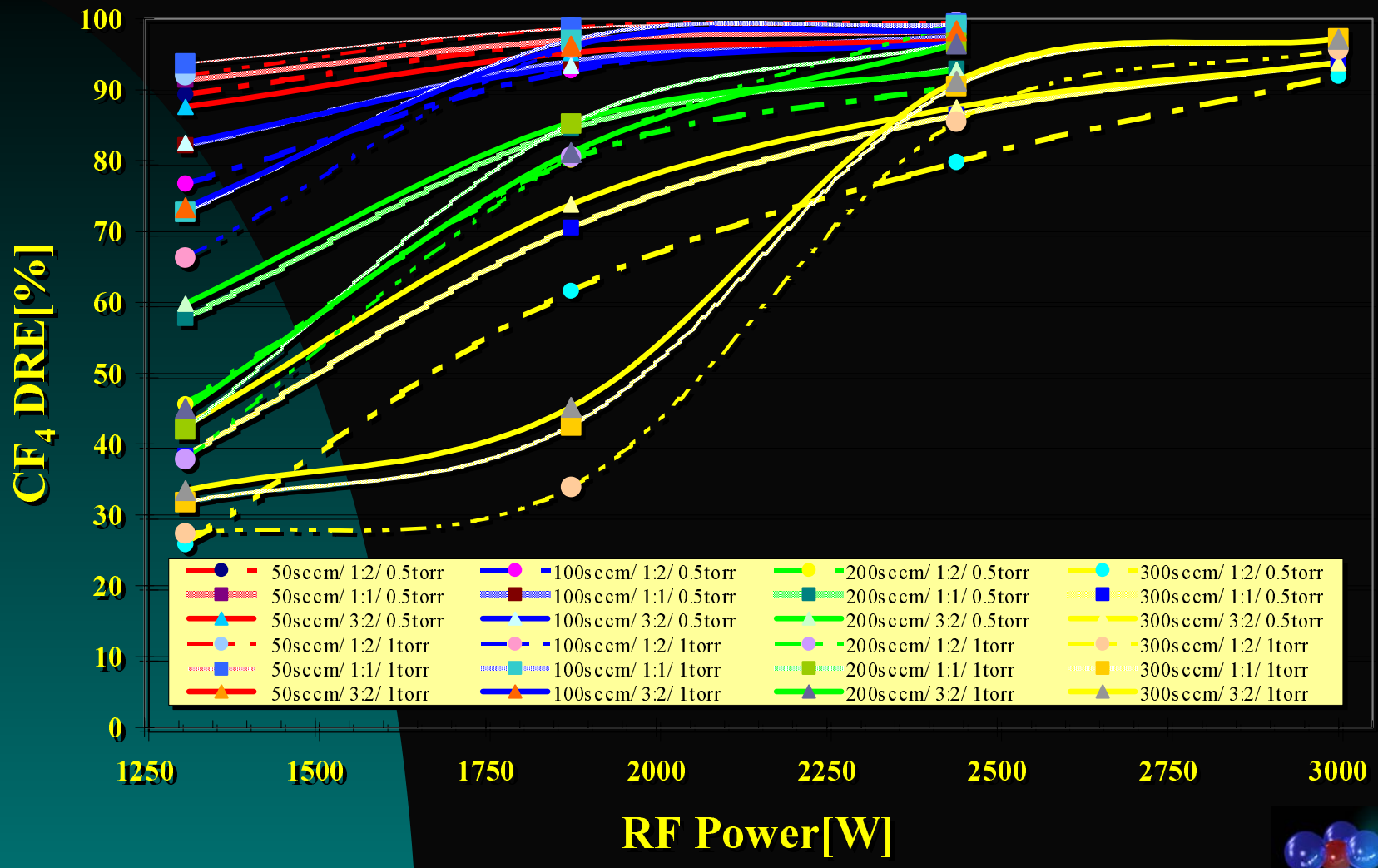
Litmas Blue LB3000 Performance Data



*Data collected using O_2 as an additive

**Water additive was found to be more effective

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High Flow, Atmospheric Pressure Plasma Abatement

Litmas Red LR3000

High flow oxide etch, asher, non-turbo etchers

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Atmospheric Pressure Abatement

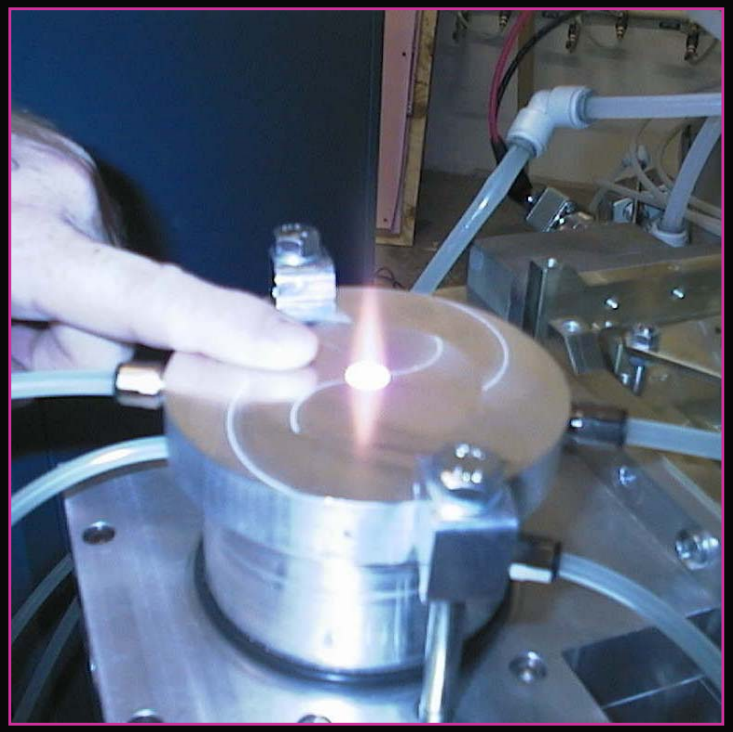
August 1999: Some applications are unsuitable for foreline abatement, as the act of treating the exhaust gas could perturb the process in the chamber. Work begins at Litmas on an Atmospheric pressure treatment system.

Prior Work:

J. D. Cobine and D. A. Wilbur, "The Electronic Torch and Related High Frequency Phenomena", Journal of Applied Physics, Volume 22, Number 6, June, 1951, pp. 835-841.

Thomas B. Reed, "Induction-Coupled Plasma Torch", Journal of Applied Physics, Volume 32, Number 5, May 1961, pp. 821-824

Early Atmospheric Work at Litmas



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Litmas Red: Product Specifications

- Atmospheric pressure plasma torch
- Microwave plasma generation at 2.45 GHz
- Based on Early Work by Cobine, et. Al.
- Instantaneous start-up & no warm-up time
- 5 kW maximum power utilization
- Additive gases
  - *Requires delivery of Hydrogen-containing compounds (e.g. CH_4 or H_2) and O_2 < 1 slm (below flammability limits)*
  - *EtOH, MeOH, IPA manual delivery also available*

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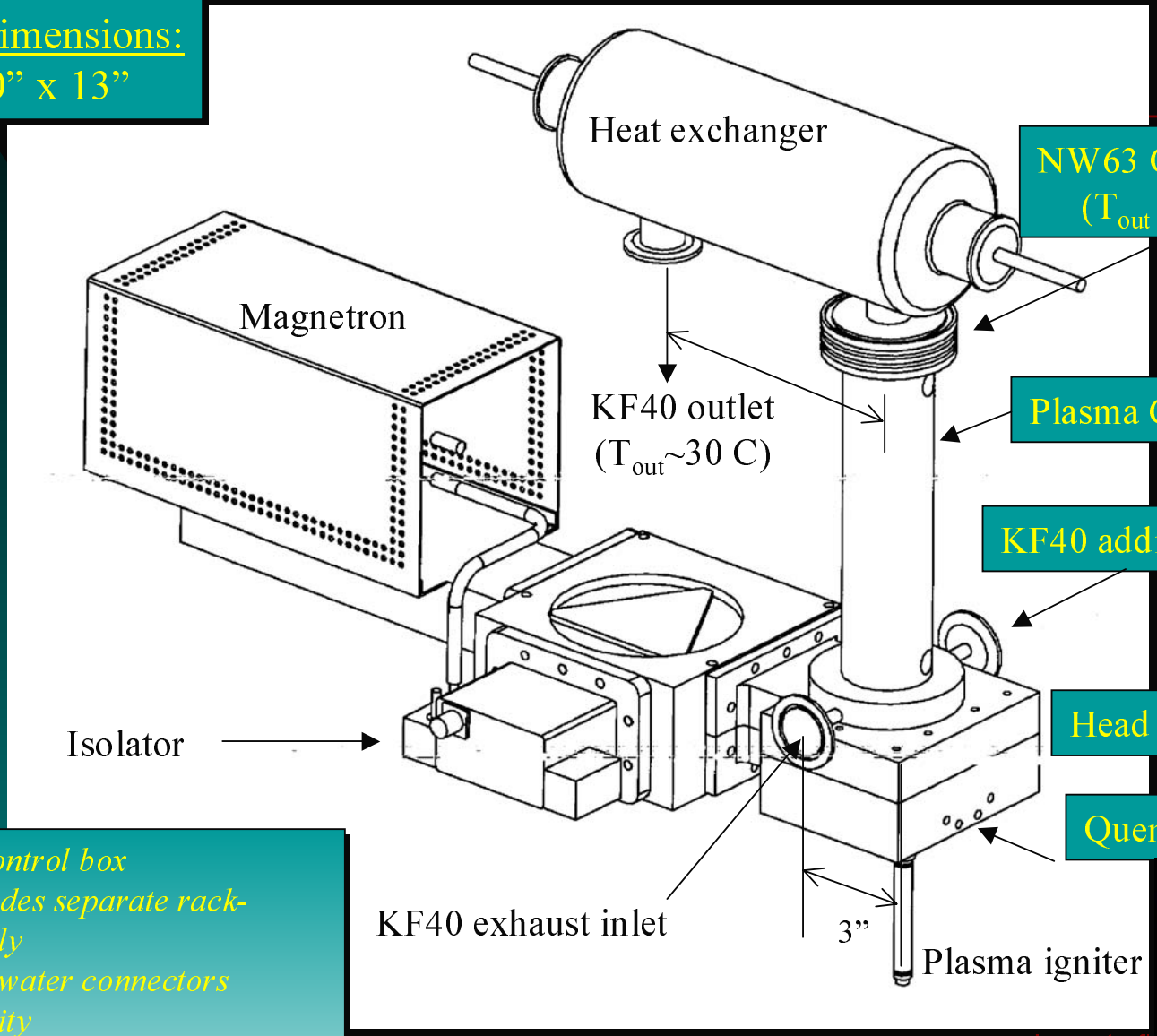
Litmas Red: OEM System Configuration

Outer Dimensions:
30” x 30” x 13”



*Shown without control box
*System also includes separate rack-mount power supply
*Gas and cooling water connectors not shown for clarity

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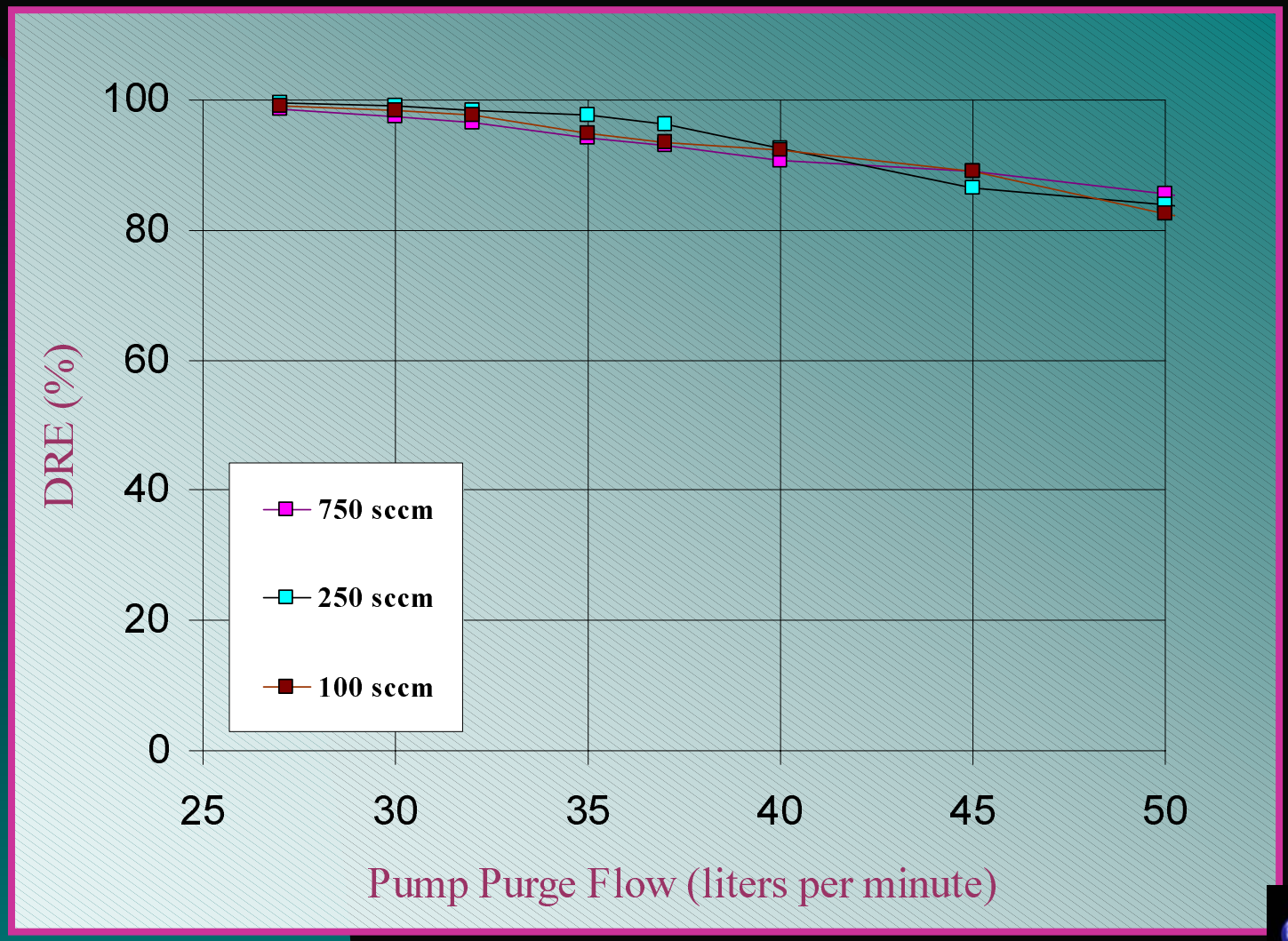
Jump to fi

LR3000 CF_4 Abatement Chart



***Abatement performance is a function of total flow, not PFC flow

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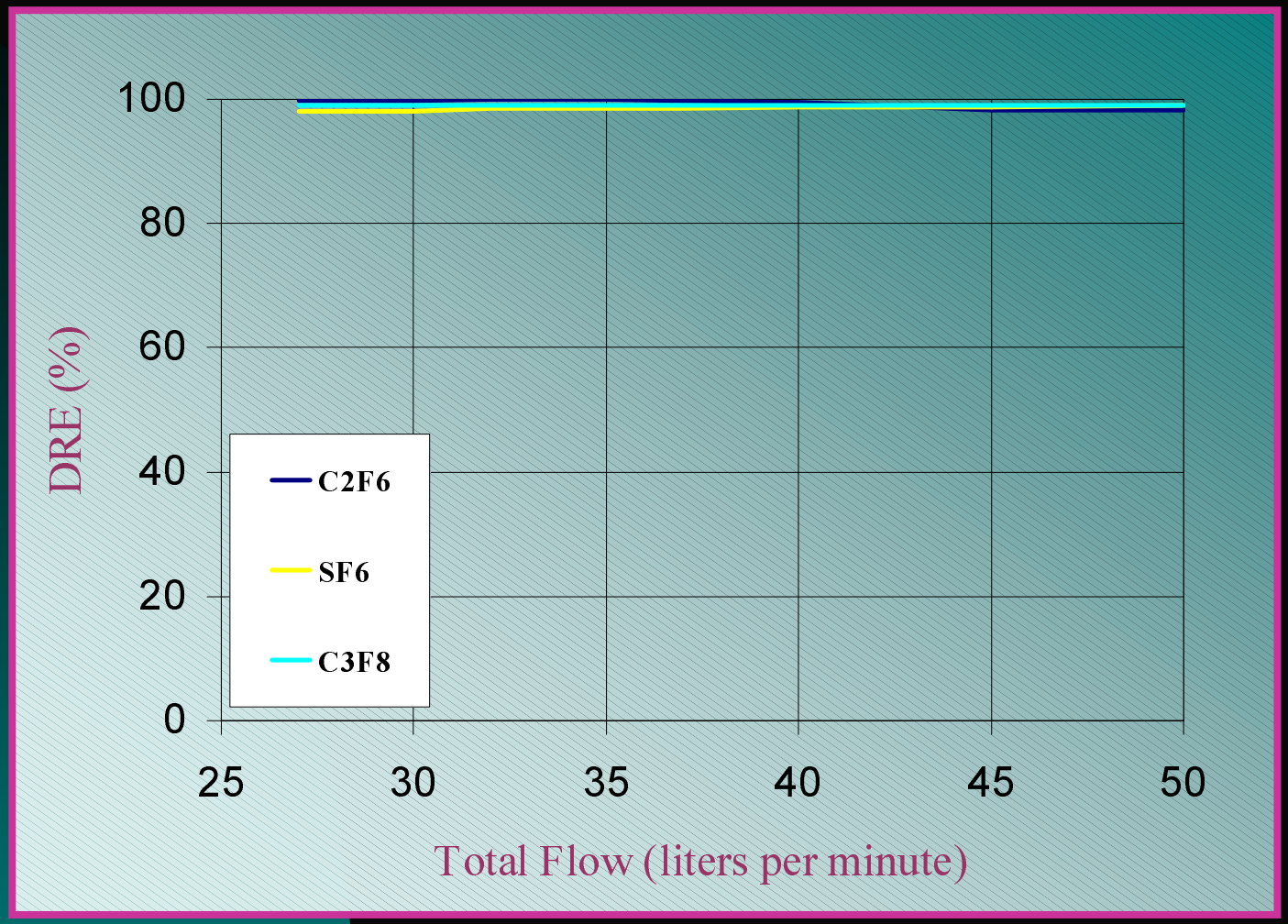
LR3000 Non-CF_4 PFC Abatement Chart



***Non-CF_4 PFCs destroyed VERY easily

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Advantages of Atmospheric Plasma Abatement

- **Flexible solution**… install only as needed. Install phase-in possible.
- **high PFC flow capacity (1 slm PFC flow)**
- **high destruction efficiencies**
- **No process impact**… No process requalifications.
- **Small sub-fab footprint**
- **Retrofittable to installed base and easily integrated to next generation tool set.**
- **Low operating costs (lower than thermal or catalytic systems)**
- **No solid wastes to dispose.**
- **It is independent of the type of scrubber employed (if any). (Can use wet or dry scrubbing technology)**
- **Safety**…Additives are kept below flammability limits.

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Litmas Red: Technology Roadmap

- The Litmas Red is currently in beta testing in France
  - *Good destructive performance*
  - *A couple of materials issues yet to be resolved*
- Initial applications will be for high flow & non-turbo oxide etch, and asher systems. (clog-free applications)
- 2-3 chamber capability depending on pump purge rates and gas to be abated
- 20-60 slm total flow capability
- Final release of Litmas Red expected Q4, 2001.

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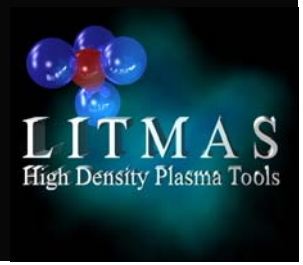
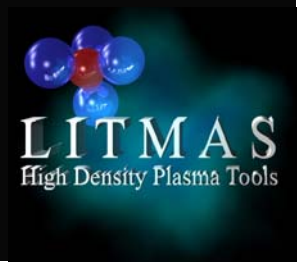
Competitive Cost of Ownership and technical analysis of other PFC abatement options



Primary Competitive Technologies

- Hitachi CDS Catalytic Decomposition System (Japan) *Catalytic-Thermal*
- Edwards TPU (UK, USA) *Thermal-Combustion*



Competitive Analysis
Hitachi CDS™

- Catalytic Thermal Abatement system with Integrated Water Scrubber
- Capital cost (~$160,000) and operating cost ($20-30 k per year)
- 120 slm total flow capacity (4-6 chambers max)
- Solid waste disposal necessary every 6-8 months
- Large size (20 ft^2 footprint)

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LB1200 CoO Analysis

LB1200	
LB1200 (ea. List price)	$25,000
GDS-AF	$5,800
Installation cost (capital, est.)	$5,000
Installation Cost (20 hours, est.)	$2,000
Installed Cost per chamber	$37,800
Total operating costs per year	$729
5 year discouted cost per chamber	**$40,784**
5 year discounted cost for 4 chambers	$163,135.74
5 year cost per chamber with scrubber	**$50,181**
5 year cost (4 Ch. With scrubber)	$200,722.68
Cost per Wafer	$0.067

Assumptions:

1. 10% discount compounded on yearly operating costs
2. Scrubber Cap. Cost = $40,000, Op. Cost = $4,000/yr.
3. Maintenance cost = $100/hr.
4. 40% tool PFC utilization rate.
5. $0.075/kWhr electricity rate
6. 20 wafers/hr., 70% Tool Utilization

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LB3000 CoO Analysis

LB3000	
LB3000 (estimated list)	$30,000
GDS-AF	$5,800
Installation cost (capital)	$5,000
Installation Cost (hours)	$2,000
Installed Cost per chamber	$42,800
Op Cost per year (1st year)	$1,482
5 year discouted cost per chamber	**$48,867**
5 year discounted cost for 4 cham.	$146,601.90
LB3000 w/ HF Scrubber (per cham.)	**$55,915**
Cost per Wafer	$0.080

Assumptions:

1. 10% discount compounded on yearly operating costs
2. Scrubber Cap. Cost = $40,000, Op. Cost = $4,000/yr.
3. Maintenance cost = $100/hr.
4. 40% tool PFC utilization rate.
5. $0.075/kWhr electricity rate
6. 20 wafers/hr., 70% Tool Utilization

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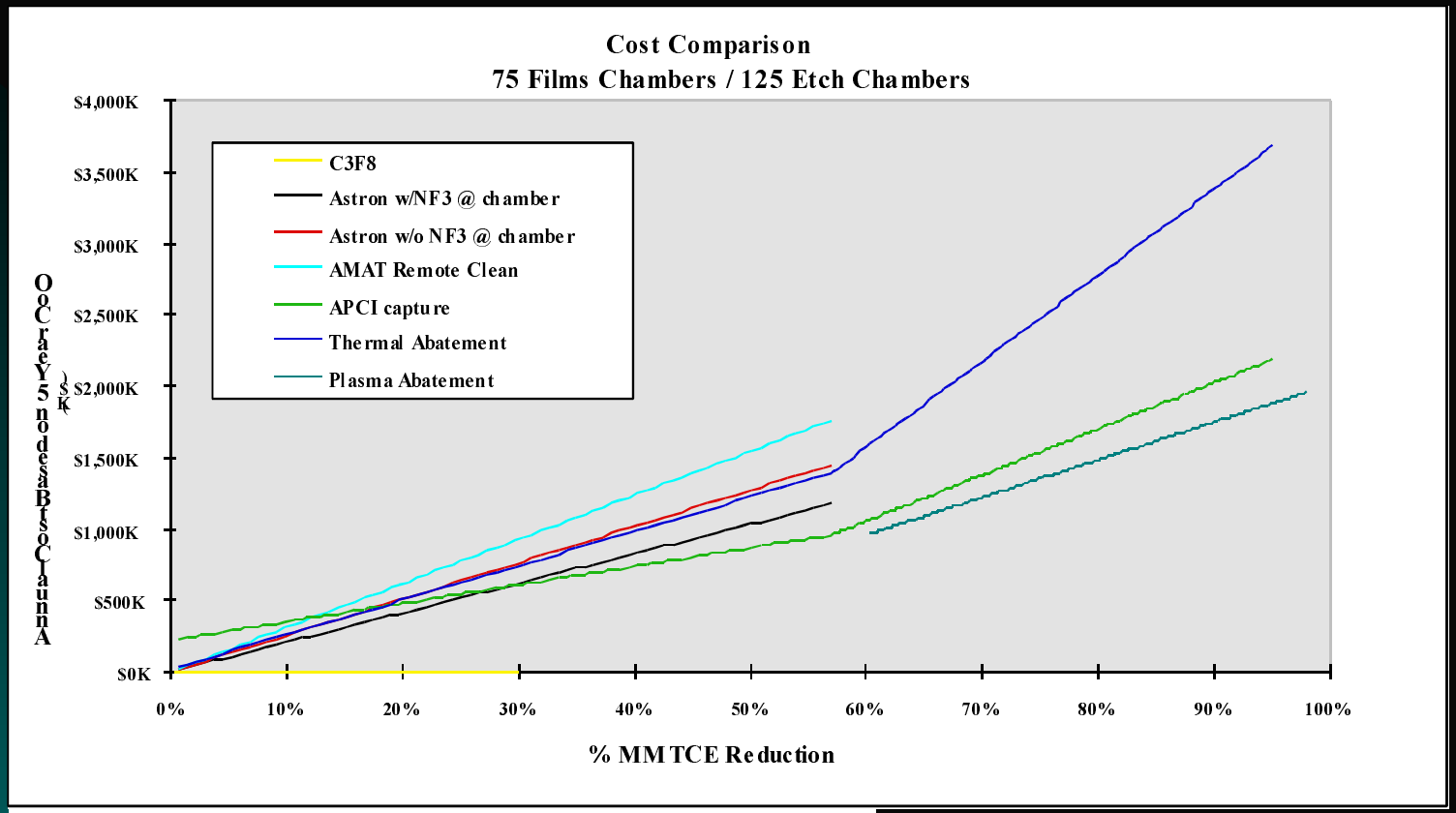
POU Abatement Economics



COO Summary (5 year annualized)

Capital Expenses:	$15,000/ fixed
Installation Expenses:	$6,500/ fixed (+$3,000 using O_2)
Operating Expenses:	$296/yr. x 5 yrs = 5,990$
Maintenance Expenses:	$80/yr. x 5 yrs. = $400
Total 5-Year Cost Estimate:	**$ 23,380(water), $26,380 ($O_2$)**
Annualized COO	**$ 4,676/yr. (water), $5,276 /yr. ($O_2$)**

Analysis courtesy of Paul T. Brown, Motorola ESIH & Laurie Beu, Motorola APRDL

Litmas Red LR3000 CoO Analysis (stand-alone model)

Litmas Red	
Litmas Red (estimated list)	$70,000
Electrical Usage (kW)	5
Installation cost (capital)	$3,000
Installation Cost (hours)	$3,000
# of Chambers	2
Installed Cost per chamber	$38,000
Op Cost per year (1st year)	$6,102.00
5 year discouted cost per chamber	**$50,494**
5 year discounted cost for 4 chambers	$75,741.23
5 year cost with HF scrubber	**$57,542**
5 year cost for cluster with HF scrubber	$115,083.40
Cost per Wafer	$0.082

Assumptions:

1. 10% discount compounded on yearly operating costs
2. Scrubber Cap. Cost = $40,000, Op. Cost = $4,000/yr.
3. Maintenance cost = $100/hr.
4. 40% tool PFC utilization rate.
5. $0.075/kWhr electricity rate
6. 20 wafers/hr., 70% Tool Utilization

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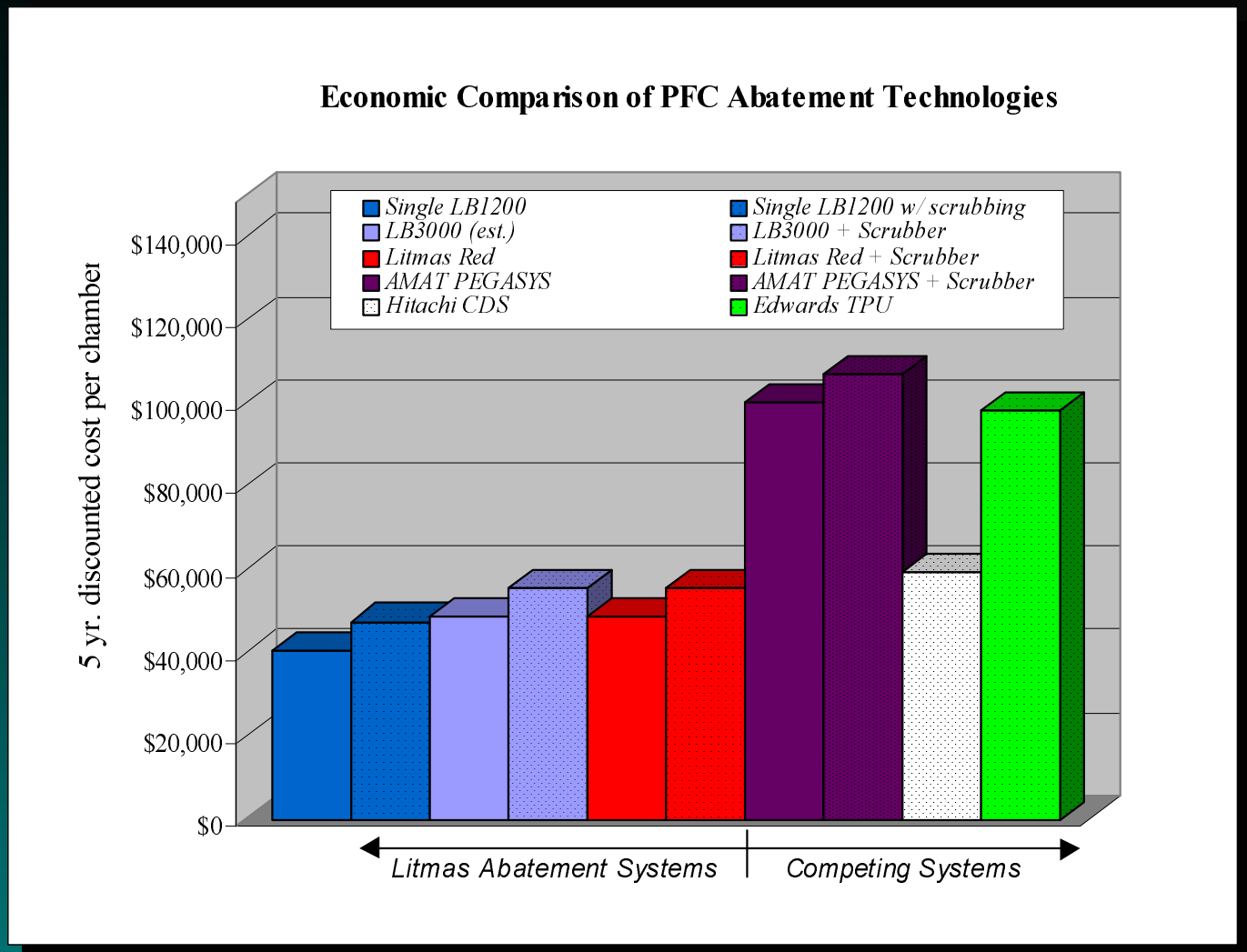
Abatement Options Economic Comparison



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Manufacturing Information

- Manufacturing Location: Charlotte, NC (10,000 ft^2 facility)
  - *Site of final assembly, testing, R&D*
- Components are sub-contracted to large suppliers capable of quickly ramping production without added cost
- Quality improvement programs are underway.
  - New power supply board revs will improve reliability
  - Strict inspection of all suppliers for quality
- Current manufacturing capacity: 30-35 units/month
  - expected to ramp up to 40-45 units/mo. in coming months
  - can ramp to ~100 units/mo. in 3-5 months time
  - manufacturing lead time < 6 weeks

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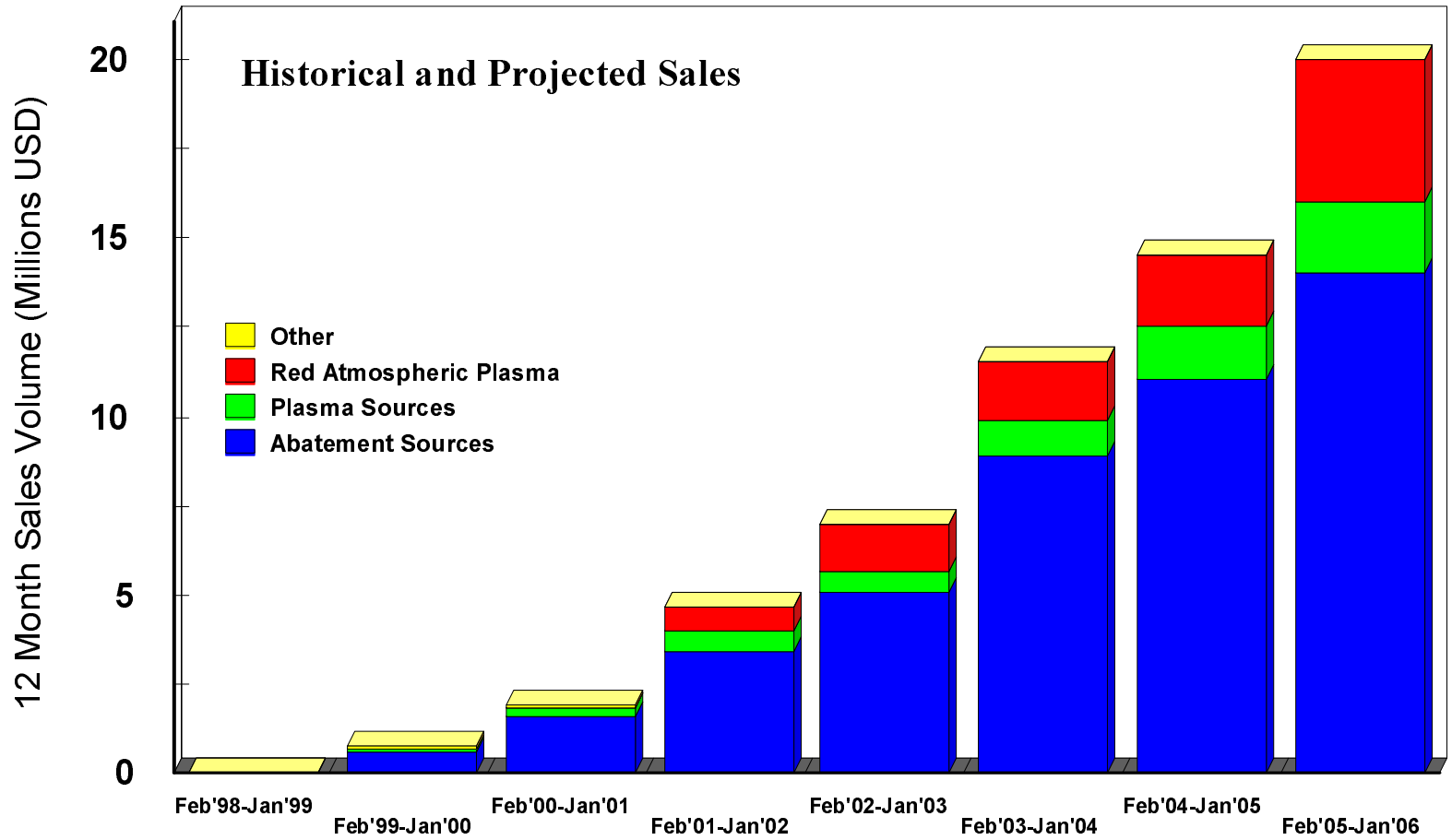
Past Financial Performance, and Projections

Profit and Loss Historical and Projected	Feb'98-Jan'9	Feb'99-Jan'0	Feb'00-Jan'0	Feb'01-Jan'0	Feb'02-Jan'0	Feb'03-Jan'0	Feb'04-Jan'0	Feb'05-Jan'0
Ordinary Income/Expense	Historical	Historical	Historical	Projected	Projected	Projected	Projected	Projected
Income								
Sales								
LB1200 Abatement+Accessories (Blue)	55,000	657,535	1,599,992	3,390,631	5,068,564	8,913,425	11,000,000	14,000,000
Plasma Sources	0	34,580	220,886	650,000	560,000	960,000	1,500,000	2,000,000
LR3000 Atmospheric (Red)	0	0	54,000	665,000	1,330,000	1,680,000	2,000,000	4,000,000
Engineering Services+Miscellaneous	0	86,196	40,710	0	0	0	0	0
Total Sales	55,000	778,311	1,915,588	4,705,631	6,958,564	11,553,425	14,500,000	20,000,000
Total Income	55,000	778,311	1,915,588	4,705,631	6,958,564	11,553,425	14,500,000	20,000,000
Cost of Goods Sold								
Total COGS	1,783	199,837	572,448	1,529,330	2,435,497	4,390,302	5,800,000	8,600,000
Gross Profit	53,217	578,475	1,343,140	3,176,301	4,523,067	7,163,124	8,700,000	11,400,000
Expense								
Total Research and Development	172,324	237,086	471,224	799,957	1,113,370	1,501,945	1,595,000	2,000,000
Total General and Administrative	413,408	442,870	445,572	517,619	695,856	1,039,808	1,160,000	1,400,000
Total Sales and Marketing	4,388	74,587	306,305	517,619	695,856	1,155,343	1,450,000	2,000,000
Total Expense	590,120	754,543	1,223,101	1,835,196	2,505,083	3,697,096	4,205,000	5,400,000
Net Ordinary Income	(536,903)	(176,068)	120,039	1,341,105	2,017,984	3,466,028	4,495,000	6,000,000
Other Income/Expense								
Total Other Income	4,734	2,365	0	0	0	0	0	0
Total Other Expense	0	1,861	1,225	0	0	0	0	0
Net Other Income	4,734	504	(1,225)	0	0	0	0	0
Net Income	(532,169)	(175,564)	118,814	1,341,105	2,017,984	3,466,028	4,495,000	6,000,000
Gross Profit Ratio	0.97	0.74	0.70	0.68	0.65	0.62	0.60	0.57
R&D Ratio	3.24	0.41	0.35	0.17	0.16	0.13	0.11	0.10
G&A Ratio	7.77	0.77	0.33	0.11	0.10	0.09	0.08	0.07
S&M Ratio	0.08	0.13	0.23	0.11	0.10	0.10	0.10	0.10

Past and Projected Performance, continued.



Summary and Observations

The university and field performance measurement work was invaluable to Litmas -- it showed the initial viability of the concept, and gave us analytic resources unavailable to small companies.

Traditional methods of exciting plasmas would not have been economically competitive against thermal or catalytic abatement systems. The integrated power conversion and plasma excitation concept makes plasma a viable choice for a Semiconductor factory.

As of 2001 June 30, Litmas has shipped over 210 foreline plasma POU scrubbers, mostly to end users.

We expect plasma abatement to emerge as the choice of treatment solutions not just for PFC's, but for many other types of hard-to-treat gases.

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LITMAS
High Density Plasma Tools