Improving the Environmental Performance of *In Situ* PECVD Chamber Cleaning Processes by studies of CVD Reactor Clean Performance and Field Evaluation of Optimised processes.

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Air Products and Chemicals Inc.

Introduction

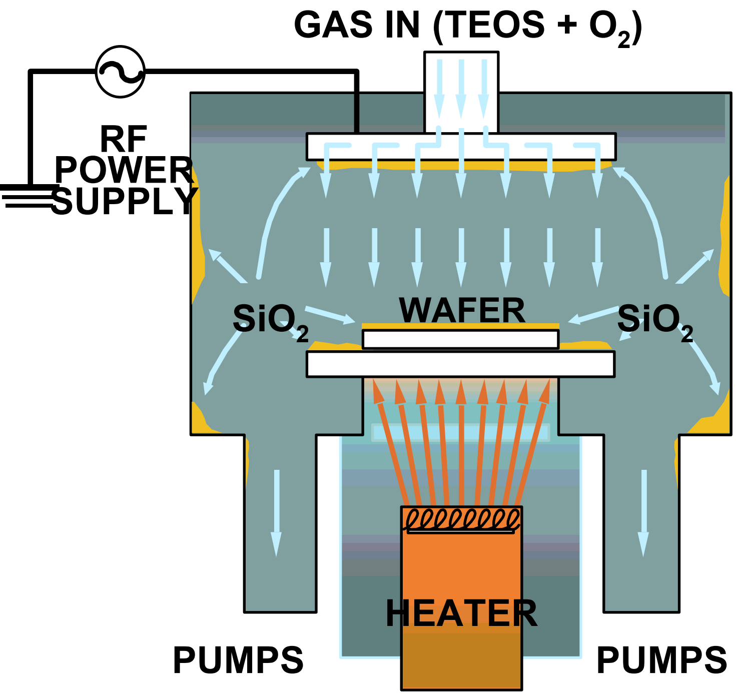
- Through the World Semiconductor Council (WSC) the semiconductor industry has committed to reduce PFC emissions.
- 10% reduction over 1995 baseline by 2010.
- ~ 70% of PFC emissions from PECVD cleaning processes
  - Undestroyed PFC and CF4 bi-product

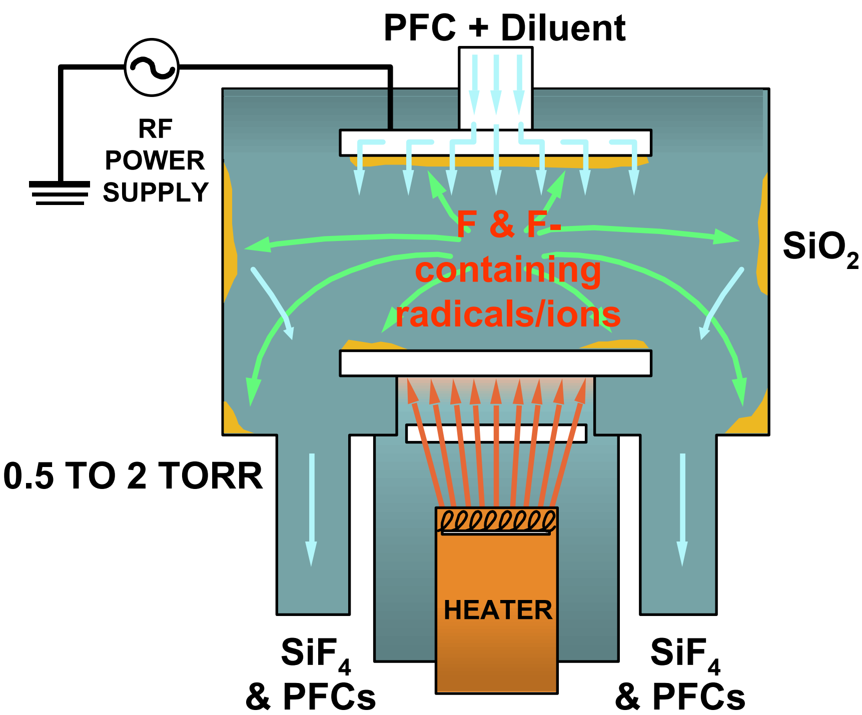
Gas	*Atmos. res. time (yrs)	*GWP_{100}
CO_2	150	1
CF_4	50,000	6,500
C_2F_6	10,000	9,200
C_3F_8	7,000	7,000
c-C_4F_8	3,200	8,700
C_4F_8O	unknown	8,700 §
CHF_3	250	11,700
SF_6	3,200	23,900
NF_3	740	8,000

$$MMTCE = \sum_{PFC} \frac{Q(kg) \cdot \left(\frac{12}{44}\right) \cdot GWP_{100}}{10^9}$$

* Data source (except C4F8O): "Climate Change 1995", Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK (1996).
§ C4F8O: from 3M estimation

PECVD- Chamber Clean Process:





- Deposition
- Clean

Options available to the Semiconductor Industry

- Optimisation of existing C_2F_6 -based in situ cleaning process.
- Replacement of C_2F_6 with alternative PFC for in situ cleaning.
- Utilise dilute NF_3 for in-situ cleaning.
- Adopt NF_3-based remote downstream cleaning.

Project Objectives

- Optimise various chamber cleaning gases on a common production platform
  - AMAT P-5000 DxL chamber (lamp heated)
  - 1.0 μm PE-TEOS based depositions
- Optimise standard C_2F_6 chamber clean
- Evaluate dilute NF_3 in situ clean
- Evaluate alternative fluorocarbon gases
- Compare results with standard C_2F_6 process
  - Perform Design of Experiments (DOE) over wide parameter space
    - Flow rate — Pressure
    - O_2/PFC — Power
  - Minimise emissions
  - Acceptable clean time
- Review alongside field optimisation studies at major Semiconductor manufacturers

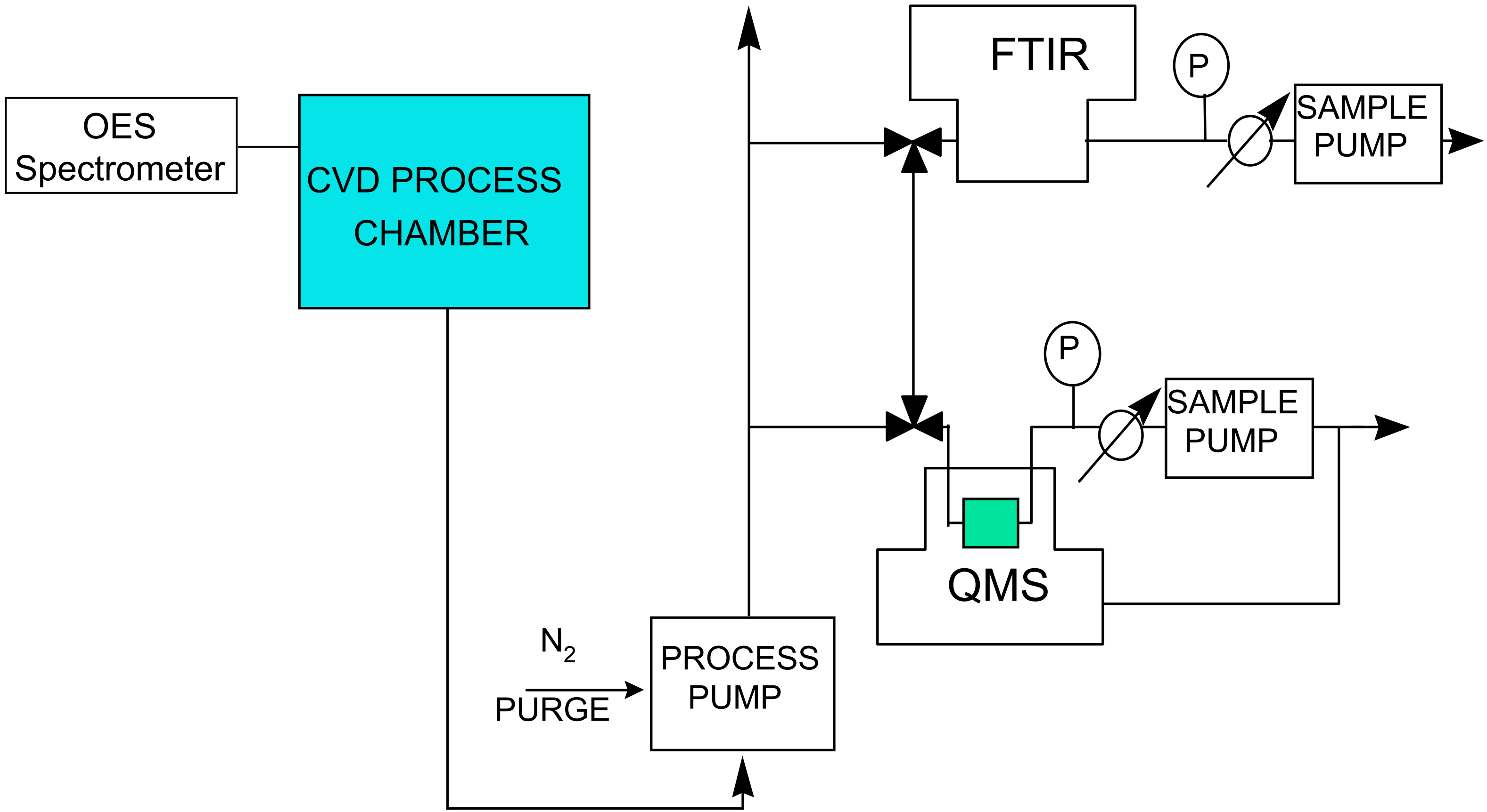
Project Background

- **PFC emissions reduction is a balancing act**
  - Trade-offs between MMTCE and clean time
  - MMTCE

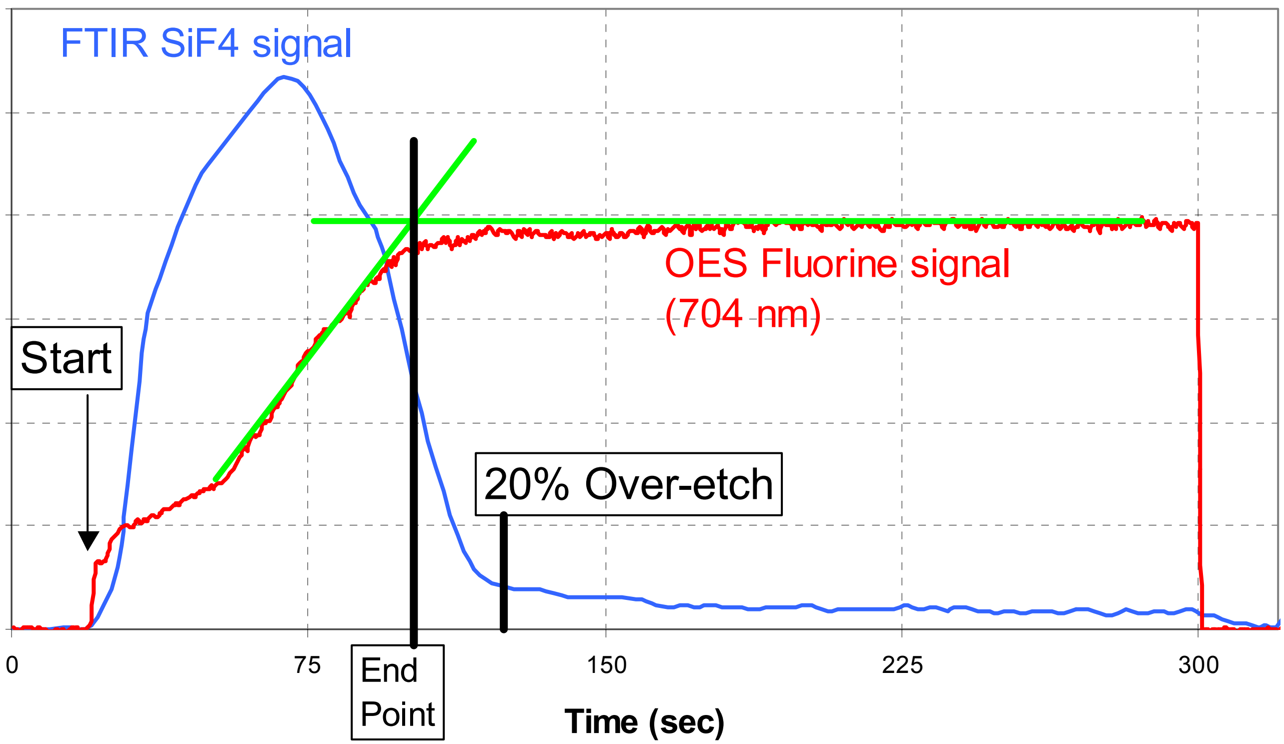
    ***f*(tool, film, power, pressure, flow, concentration, …)**
  - Clean time

    ***f*(tool, film, power, pressure, flow, concentration, …)**

Process Analytical System

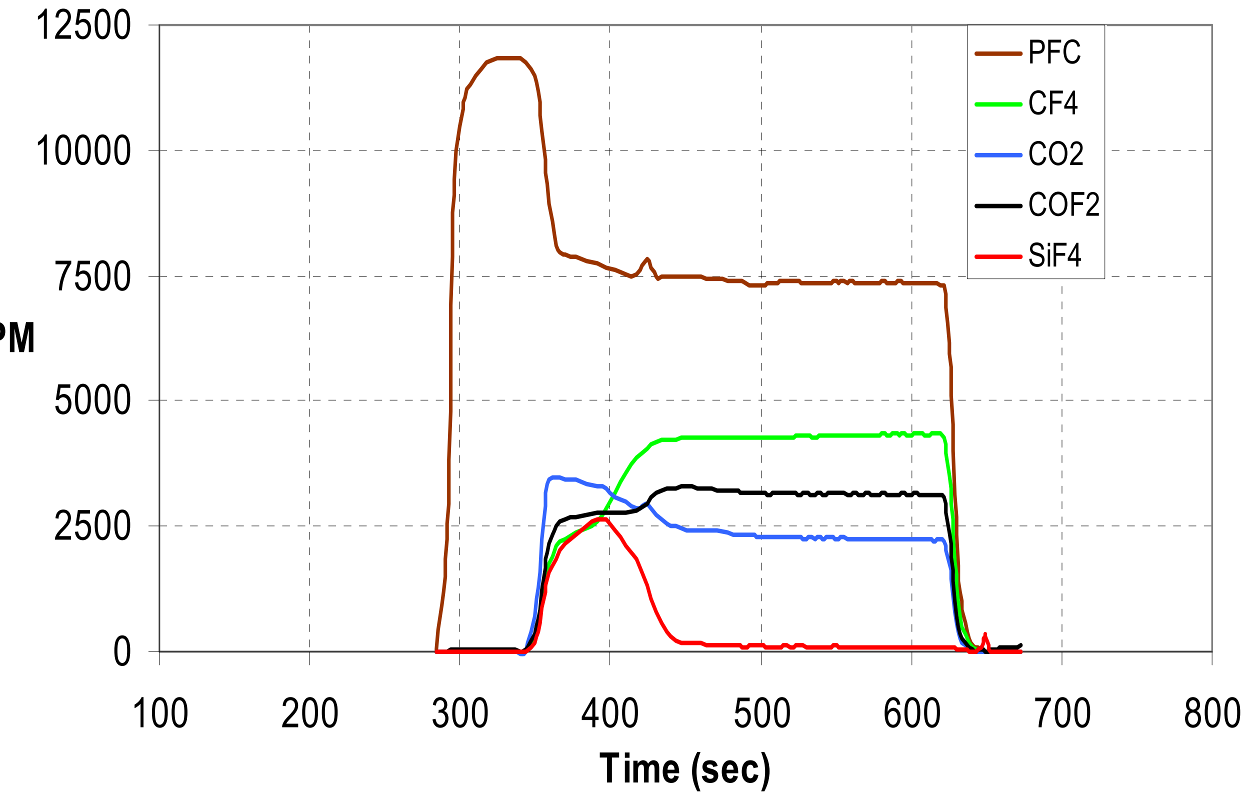


Endpoint Monitoring



- Clean time = OES endpoint + 20% over-etch

Effluent Monitoring by FTIR



- Gas Analysis
  - PFC Clean gas
  - CF_4
  - CO_2
  - COF_2
  - SiF_4

C_2F_6 process space evaluated

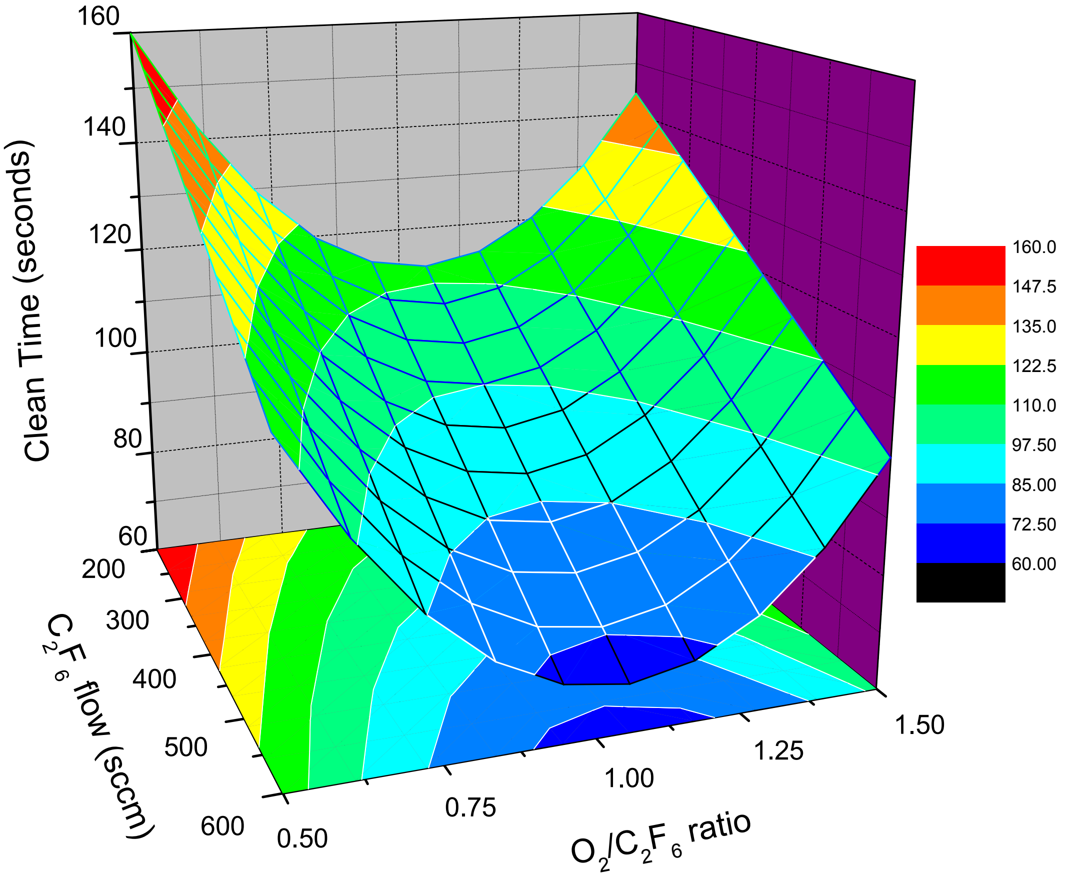
DOE Parameters

C_2F_6 Flow (sccm)	O_2/PFC	Pressure (Torr)	Power (W)
200 - 600	0.5 - 1.5	4 - 6	650 – 950

C_2F_6 Standard Recipe

C_2F_6 Flow (sccm)	O_2/PFC	Pressure (Torr)	Power (W)
600	1	4	950

Clean Time vs. Flow Rate and O_2/C_2F_6 Ratio

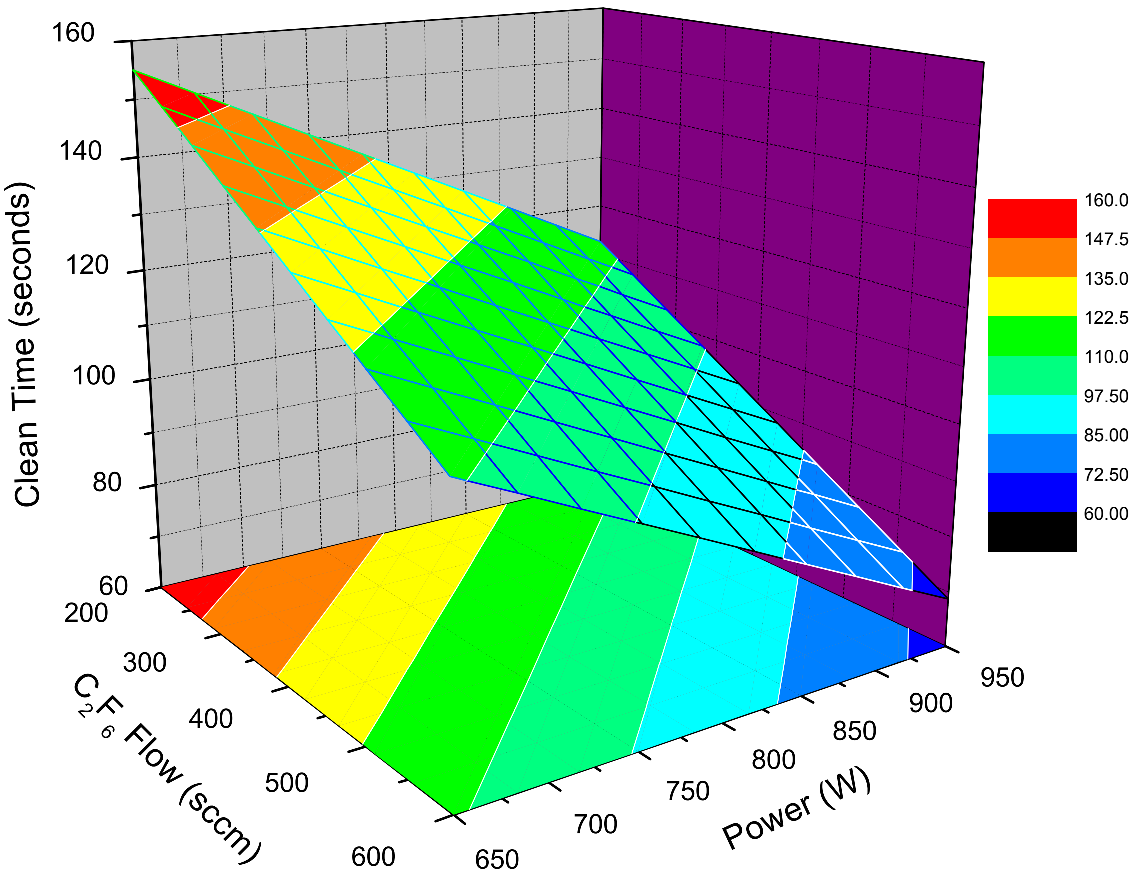


Increased C_2F_6 flow decreases clean time

950 W

5 Torr

Clean Time vs. Flow Rate and Power



Increased power shortens clean time

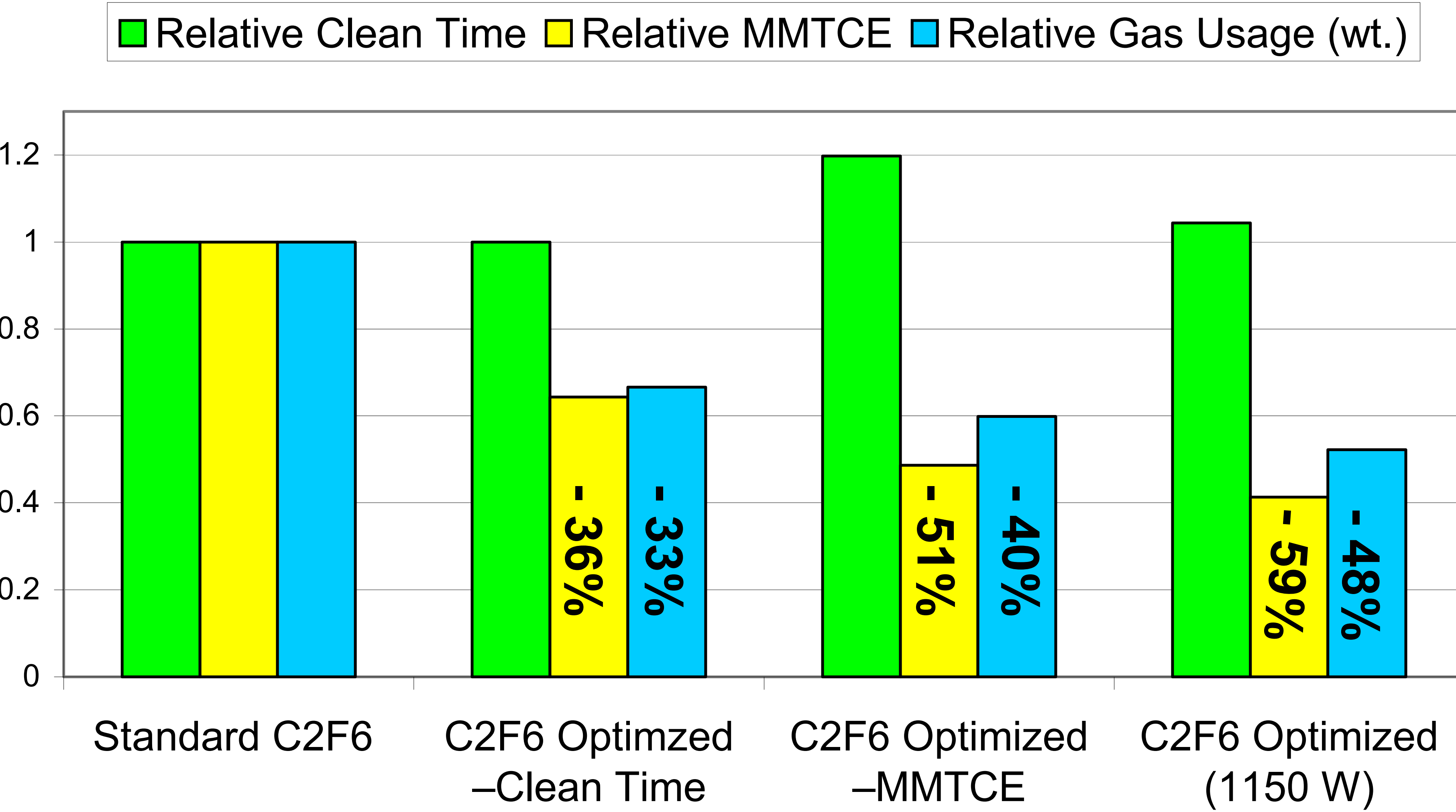
5 Torr

O_2/C_2F_6 =1

C_2F_6 Optimisation Trade-Offs

		Clean Time	MMTCE
C_2F_6 flow rate	↑	↓↓	↑↑
Power	↑	↓↓	↓↓
O_2/PFC	↑	↓↑	↓↑
Pressure	↑	↓	↑

Results of C_2F_6 Optimisation



Dilute NF_3 Optimisation Study

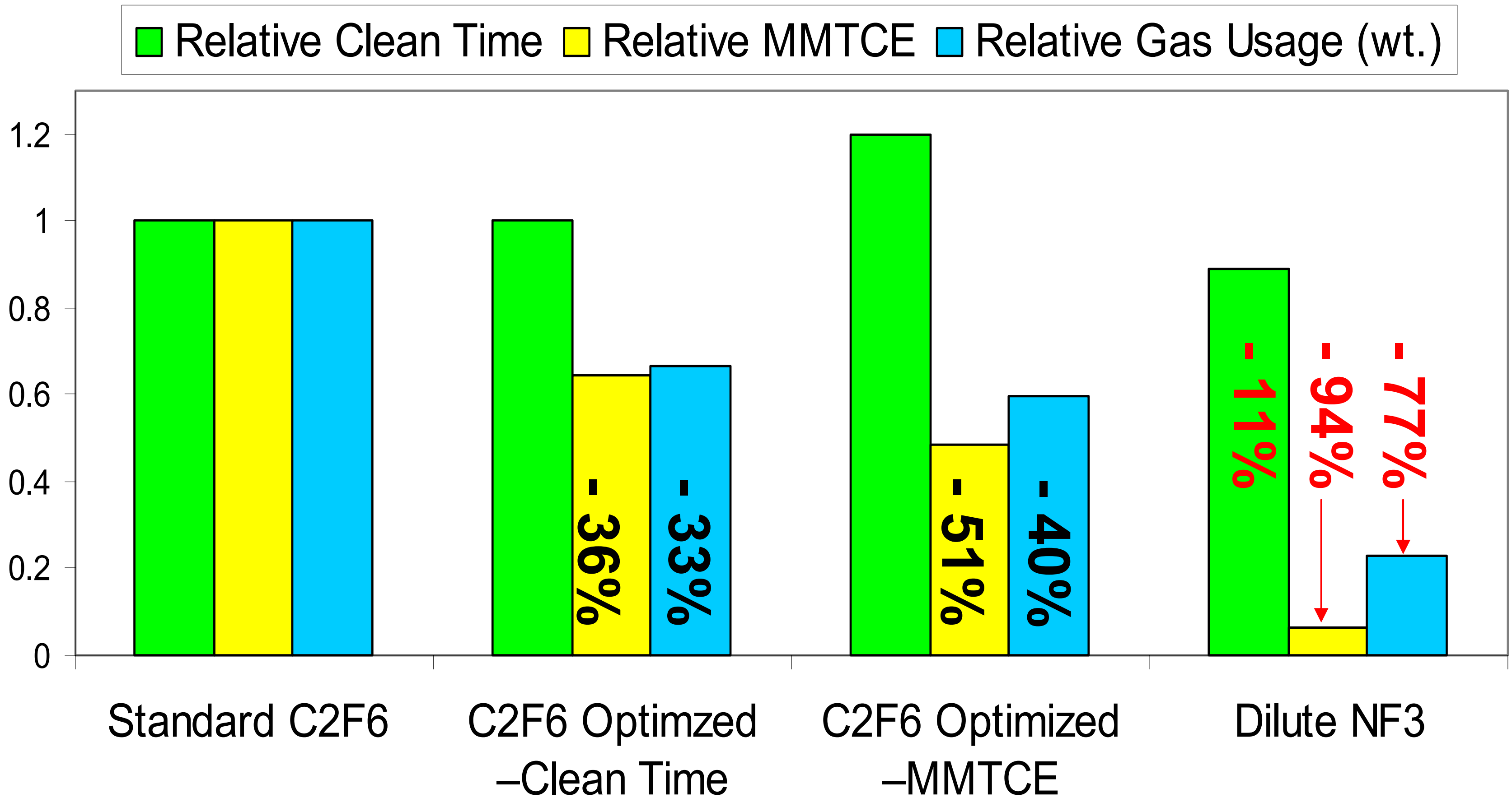
DOE Parameters

NF_3 Flow (sccm)	% NF_3 (balance He)	Pressure (Torr)	Power (W)
200 - 400	10 - 25%	2 - 4	950

NF_3 Optimisation Trade-Offs

		Clean Time	MMTCE
NF_3 flow rate	↑	↓↓	↑↑
Power	↑	↓↓	↓↓
NF_3 %	↑	↑	↑
Pressure	↑	↓↑	↓↑

Results of NF_3 Optimisation



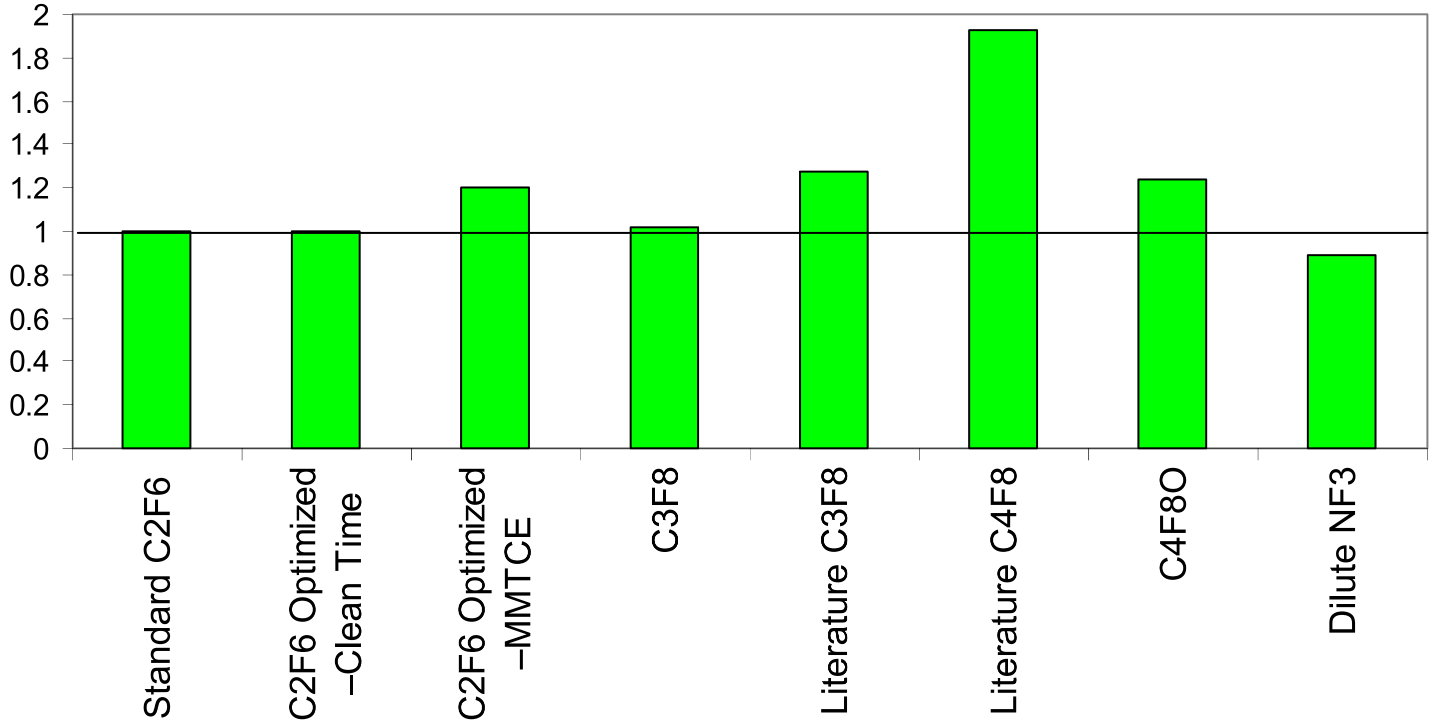
Alternative Fluorocarbon Optimisation Study

DOE Parameters

	PFC Flow (sccm)	O_2/PFC	Pressure (Torr)	Power (W)
C_3F_8	100 – 400	1 – 5	4 – 6	650 – 950
C_4F_8	100 – 400	3 – 5	4 – 6	650 – 950
C_4F_8O	100 - 400	2 - 5	4 - 6	650 – 950
Lit.-C_3F_8 *	211	2.13	5	750
Lit.-C_4F_8*	169	4.56	5	750

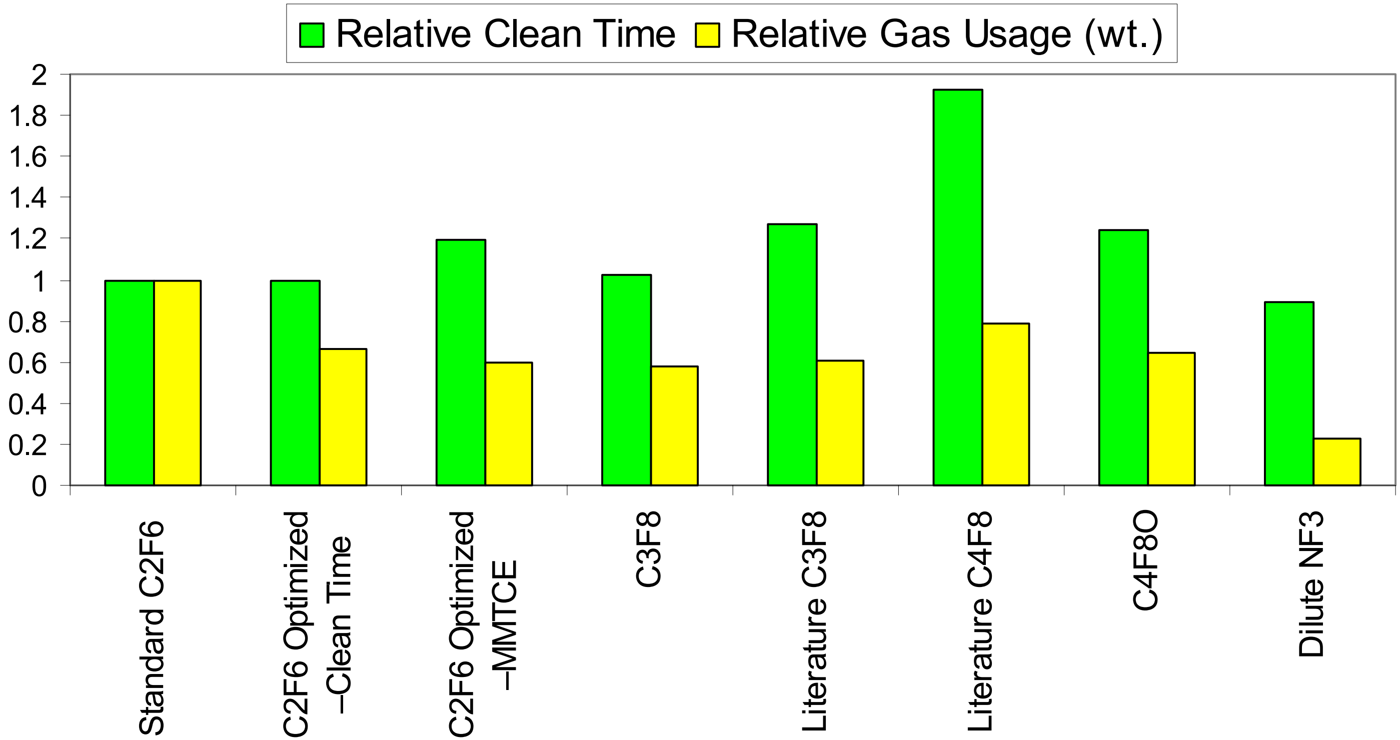
* C. C. Allgood, S. Hsu, B. Birmingham, J. Soucy. *SEMICON SW 2000.*

Summary for Optimised Recipes: Cleaning Time



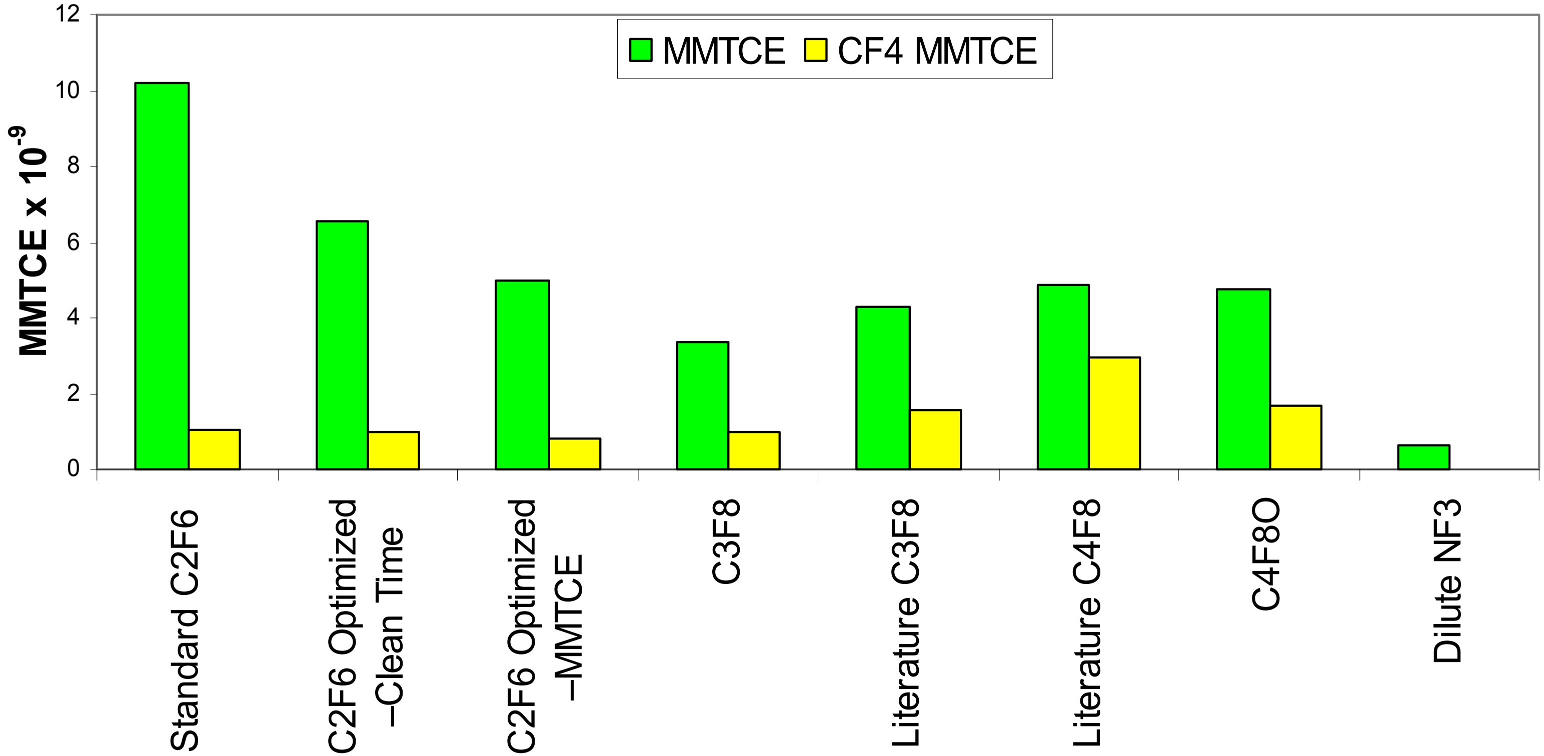
Alternative fluorocarbon gases offer comparable or longer clean times relative to the optimised C_2F_6 recipe.

Summary: Clean Time and Gas Usage



Gas usage among fluorocarbons is similar.

Summary: Effluent Emissions



Alternative fluorocarbon gases: Similar emissions to an optimised C_2F_6 recipe.

Field Optimisation Studies

- Silane based PECVD films
  - Replacement of CF_4 by optimisation of C_2F_6 and C_4F_8 processes.
  - 95 % non-utilisation of CF_4 (GWP$_{100}$ 6500/ Lifetime > 50000 years)
- Optimisation of legacy C_2F_6 cleans
  - Installed base traditionally uses non-optimised C_2F_6 recipes
- Provide an appreciation of the scope of environmental benefits from optimisation of C_2F_6 chemistry

Cleaning Silane Based PECVD Films

- Replacement of CF_4 with C_2F_6 or C_4F_8
  - DOE carried out for both candidate gases
- C_2F_6 found to be a true drop in replacement
  - >60% emissions and gas usage reduction
  - 18% faster cleans
  - Confirmed by marathon
- C_4F_8 was unsuitable due to MFC instability, weak EPD and need for higher power to give equivalent performance.

	CF_4 base	C_4F_8	C_2F_6
PFC (sccm)	1500	300	300
Power (W)	800	1000	800
Clean time (s)	101	76	82
MMTCE	20×10^{-9}	7.54×10^{-9}	7.78×10^{-9}
Gas used (g)	11.8	5.4	3.7

Field C_2F_6 Optimisations

- Installed base traditionally uses non-optimised C_2F_6 recipes
- Novellus Concept 2 (USG, BPTEOS, SiNx)
  - 42% MMTCE reduction
  - 37% gas cost saving
  - Confirmed by marathon testing
- Novellus Concept 2 (Tungsten)
  - 17% to 49% MMTCE reduction
  - 8% to 42% gas cost savings
  - Up to 25% faster cleans
  - Demonstrates the flexibility of a C_2F_6 optimisation programme.

Overall conclusions

- Comparison of relative clean performance of cleaning gases confirms
  - C_2F_6 optimisation delivers significant environmental and cost saving benefits
  - Alternative fluorocarbon gases exhibited no significant benefits over an optimised C_2F_6 process
  - Optimised dilute NF_3 process offers further step change improvement
- For existing tools, the best solution is to optimise the current chemistry:
  - Simplifies the qualification process
  - Eliminates hardware changes
  - Achieves substantial emissions reductions and cost savings.
  - For CF_4 processes: The benefits of C_2F_6 clean without hardware changes are also demonstrated.

Thank you

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