NOx Adsorber Regeneration Phenomena In Heavy Duty Applications

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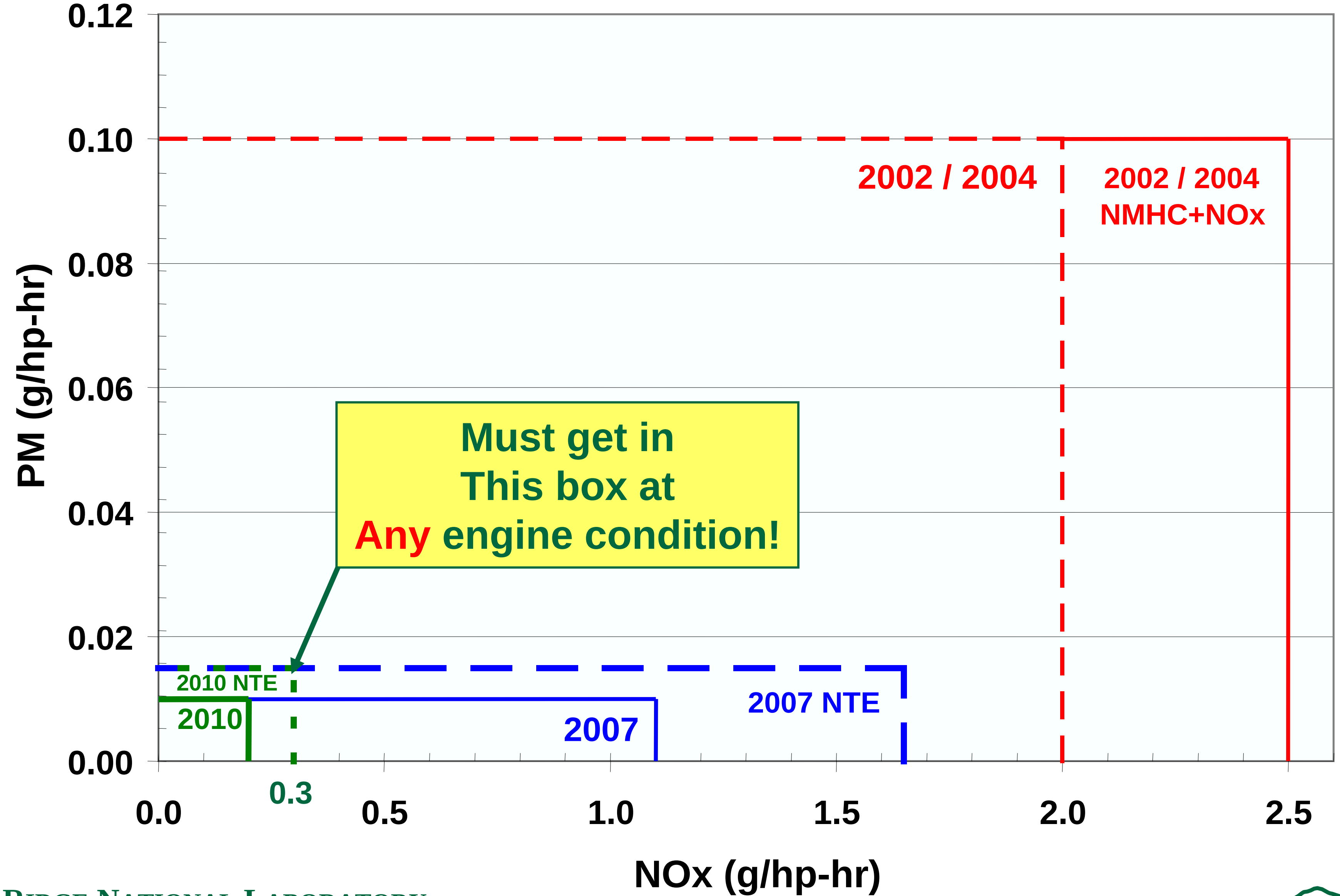
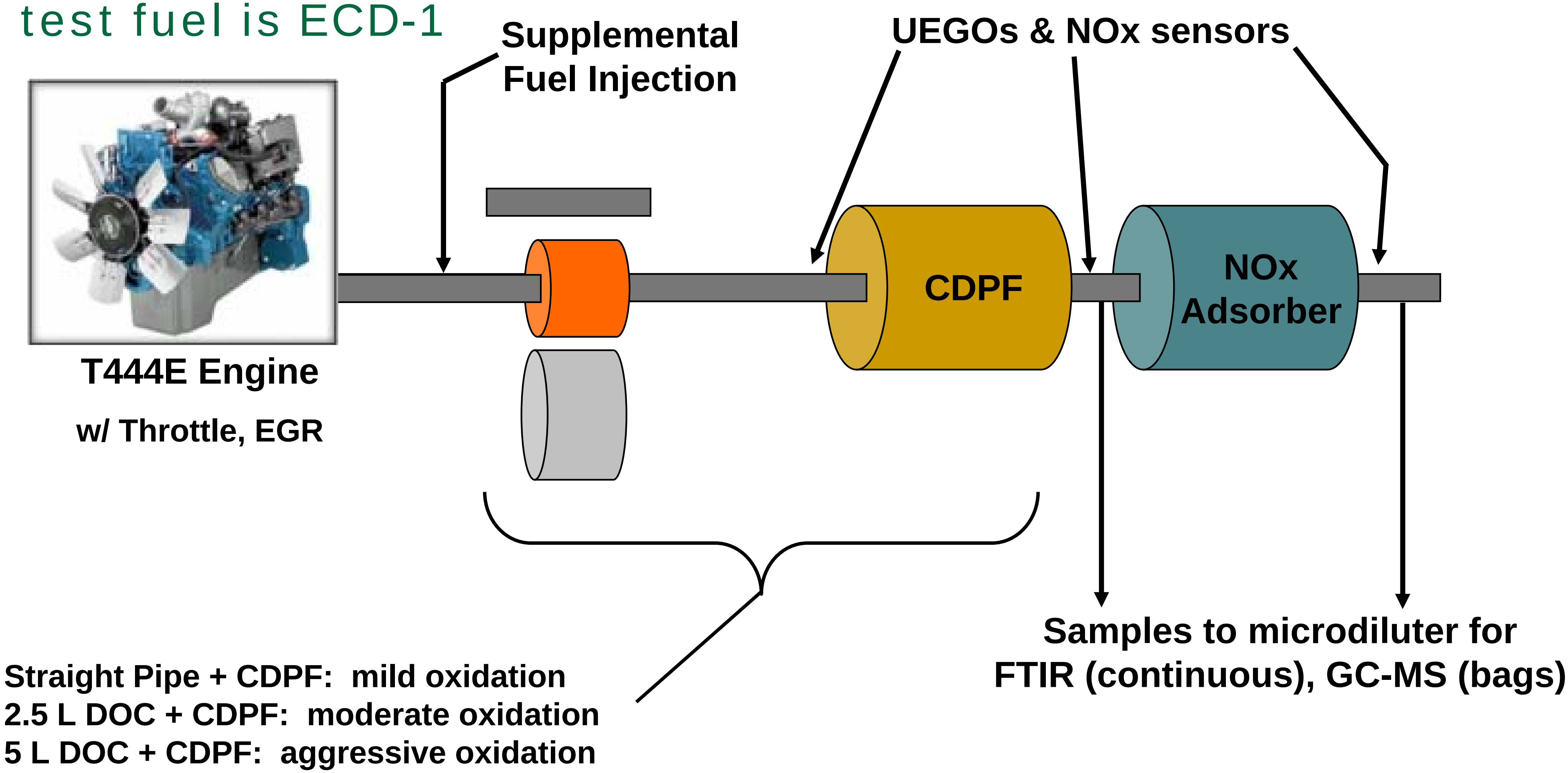
Impending HD standards call for drastic emissions reductions. NTE limits impose significant challenge

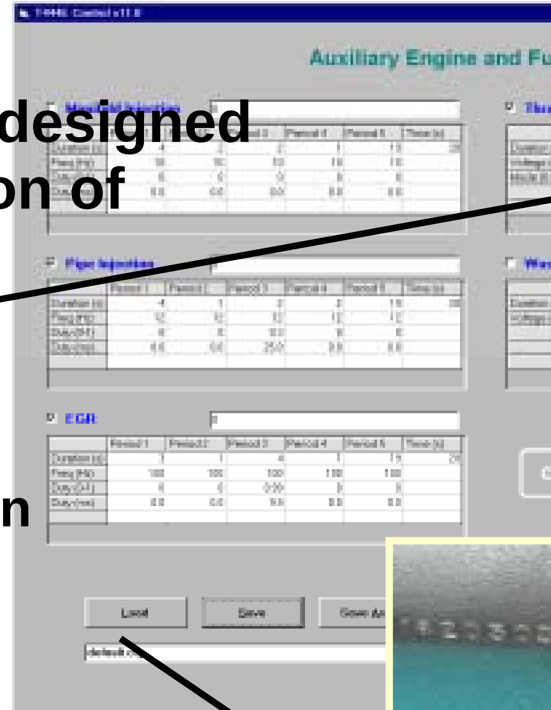


Diesel oxidation cats inserted downstream of injection site. CDPF and NOx adsorber in all experiments. Unless otherwise specified, test fuel is ECD-1



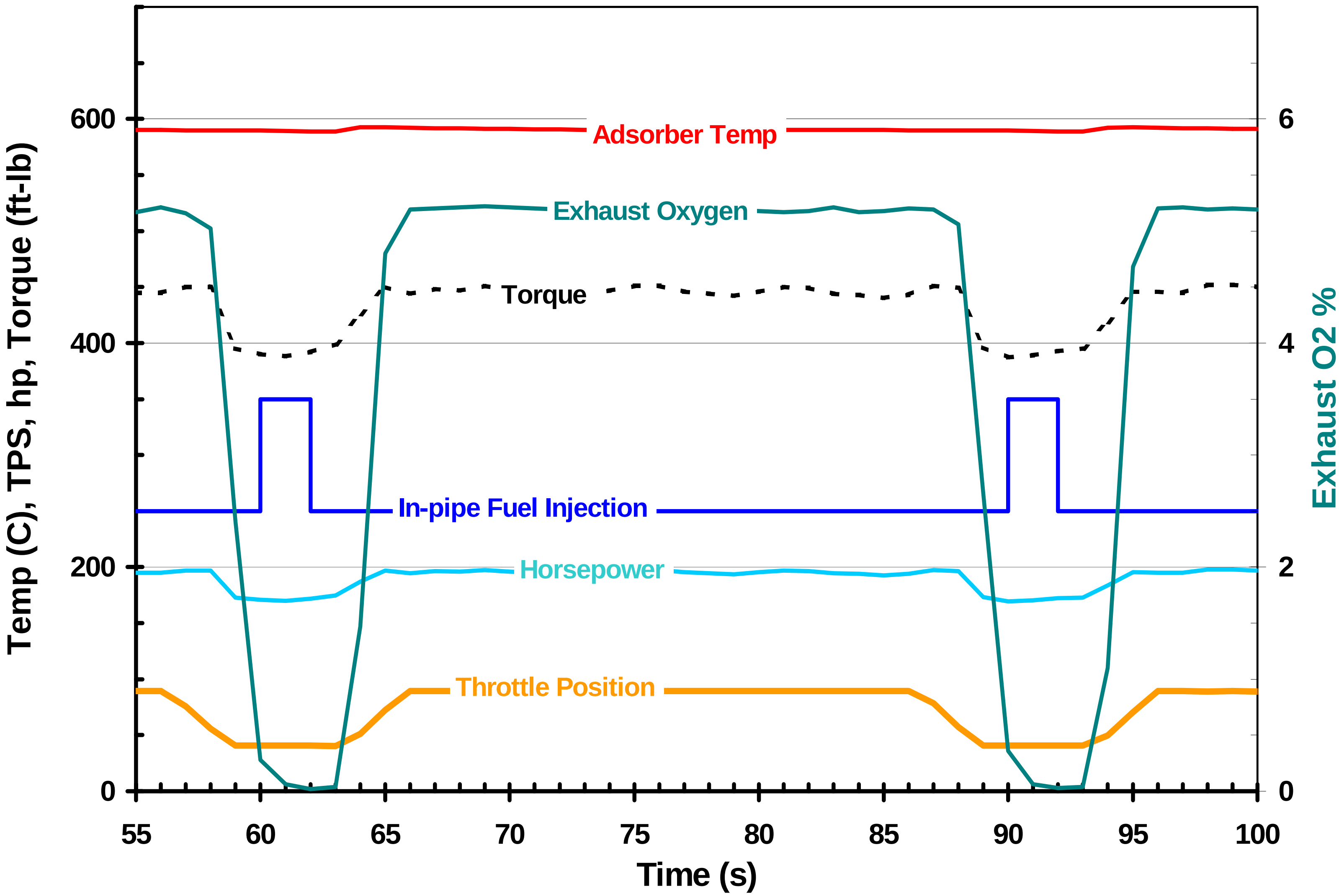
ITEC T444E Engine modified to control aftertreatment system

- **PC-based auxiliary controller designed and built for transient operation of**
  - **Electronic throttle**
  - **Electronic EGR valve**
  - **Wastegate**
  - **Post-combustion fuel injection**
    - **In-manifold (pre-turbo)**
    - **In-pipe (after turbo)**



- **Aftertreatment system includes diesel oxidation catalyst(s), catalyzed diesel particulate filter, and NOx adsorber**

Sample strategy for regeneration with in-pipe injection



2300 RPM, 450 ft-lb

Adsorber temperature 600C

30 s cycle time

2 s throttle ramp to 40%, hold 5 s

3 s rich pulse

No attempt to mitigate torque loss

All experiments used same NOx adsorber with CDPF upstream. CDPF augmented with DOCs

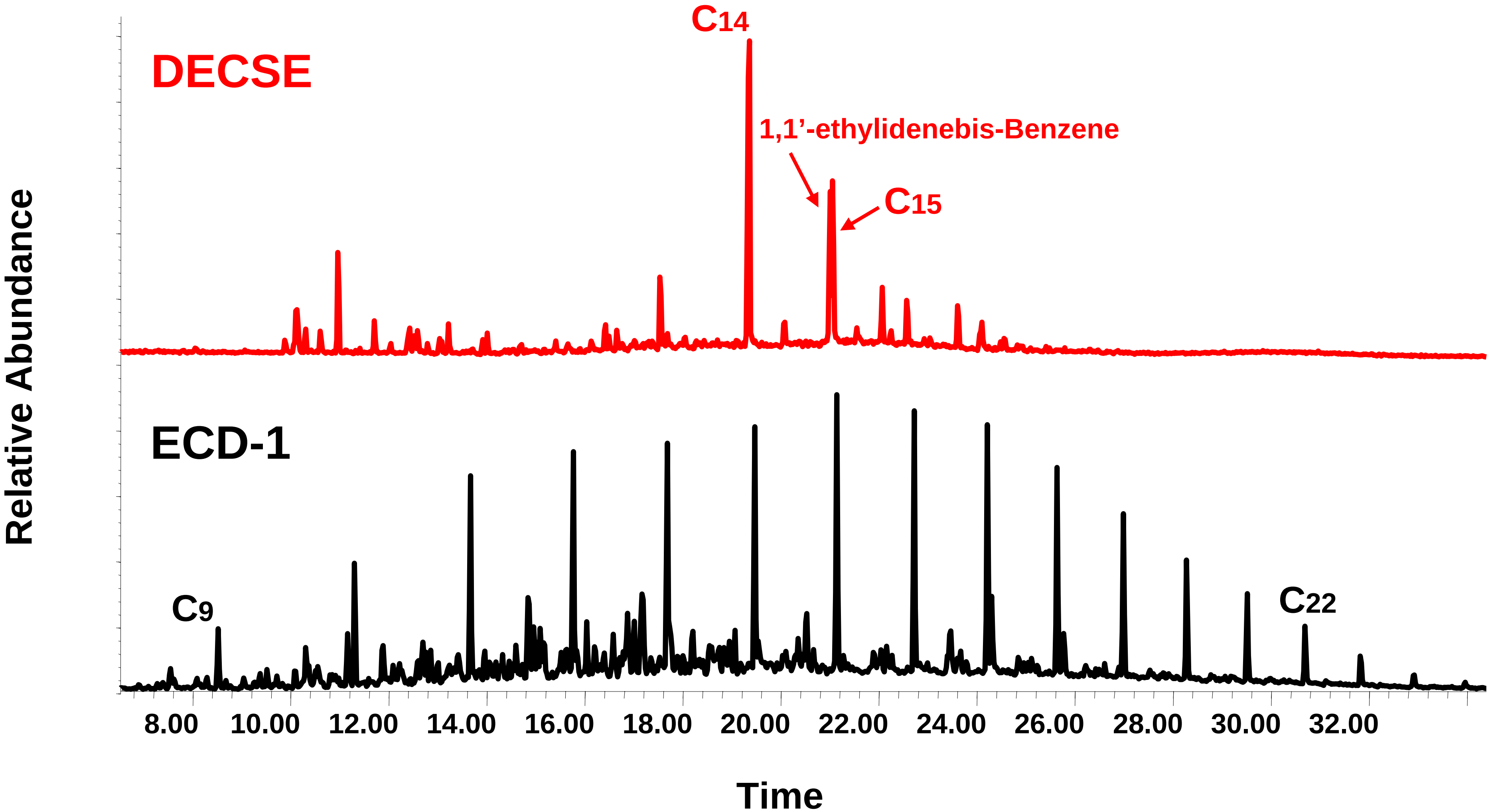
Device	Volume (L)	Min SV (1000/hr) (Regen)	Max SV (1000/hr) (Lean operation)	PGM g/ft^3
Small DOC	2.5	204	307	70
Large DOC	5	102	154	70
CDPF (not Delphi part)	15	34	51	75
NOx Adsorber (Ba-K type)	14	36	55	100

Fuel used in this study is largely BP (Arco) ECD-1. Cursory look at DECSE

- **EPA's 2006 Diesel Fuel spec differs from today's only in sulfur level**
- **EPA and CARB certification fuel specs differ in aromatics (EPA >27; Cal <10) and cetane**
- **BP (Arco) ECD-1 "looks" like CARB fuel**
- **"DECSE" (Chevron Phillips ULS), BP15, and S-zorb™ "look" like 2006 EPA fuels**
  - **Aromatics, boiling range, sulfur**

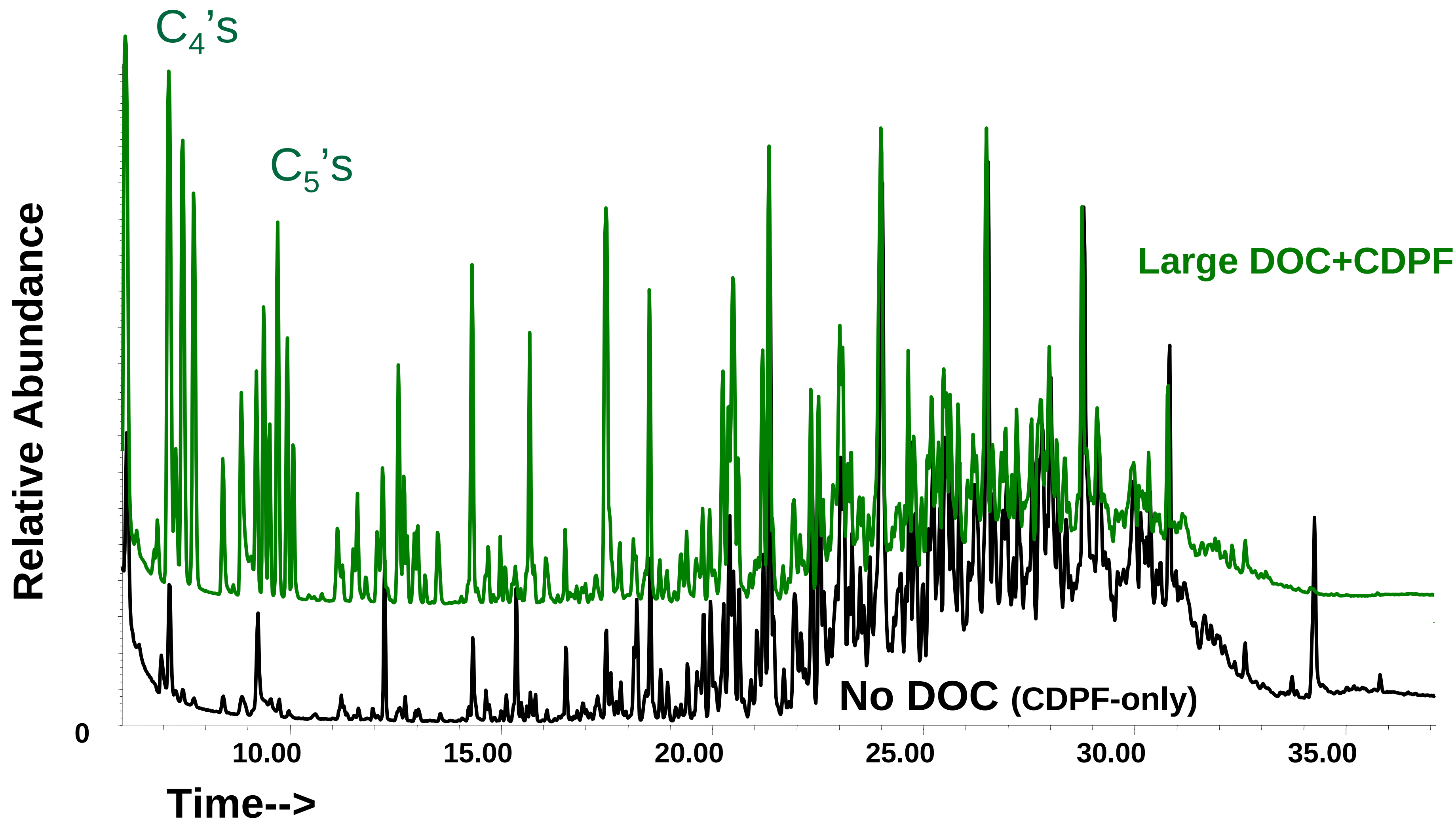
DECSE fuel meets all specs, but contains narrow range of HCs

Chromatogram shows individual compounds in DECSE and ECD-1 fuel



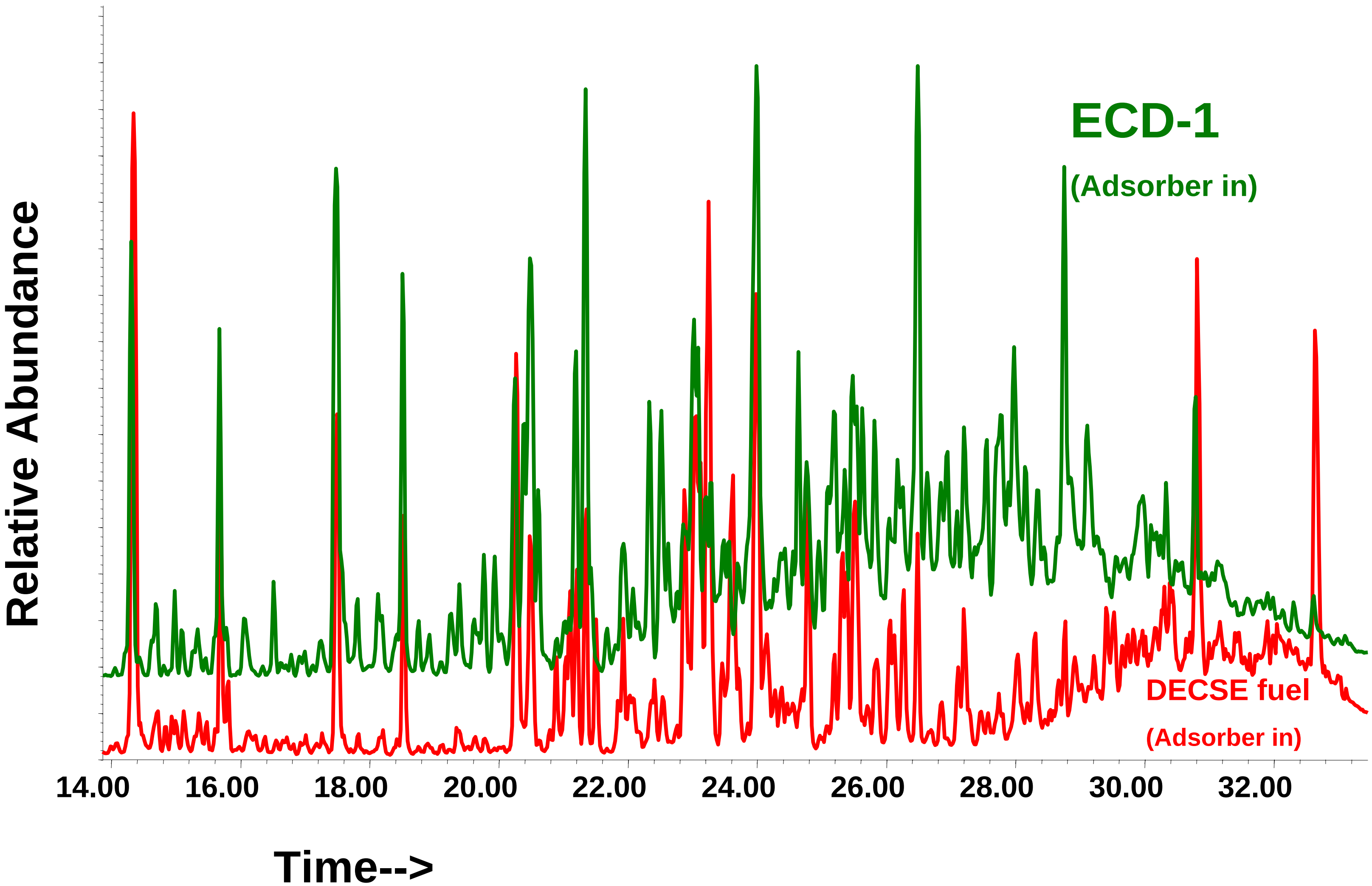
Large DOC provides extensive HC cracking and lighter HCs to Adsorber

Large DOC vs no DOC, 0.4 DC, ECD-1, Adsorber in



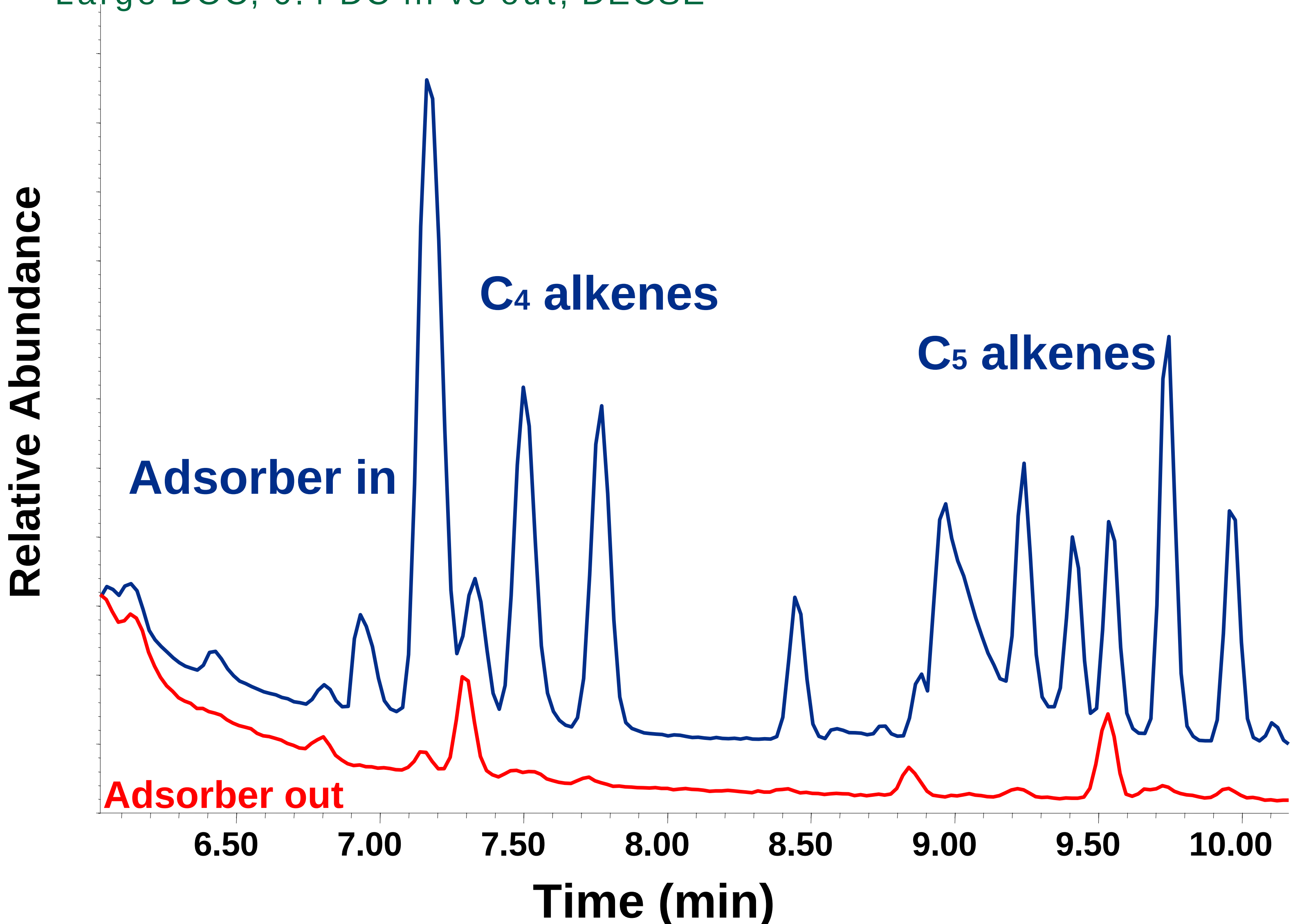
ECD-1 Fuel yields broader range of HCs at Adsorber inlet than DECSE fuel

Large DOC, 0.4 DC, DECSE vs ECD, Adsorber in

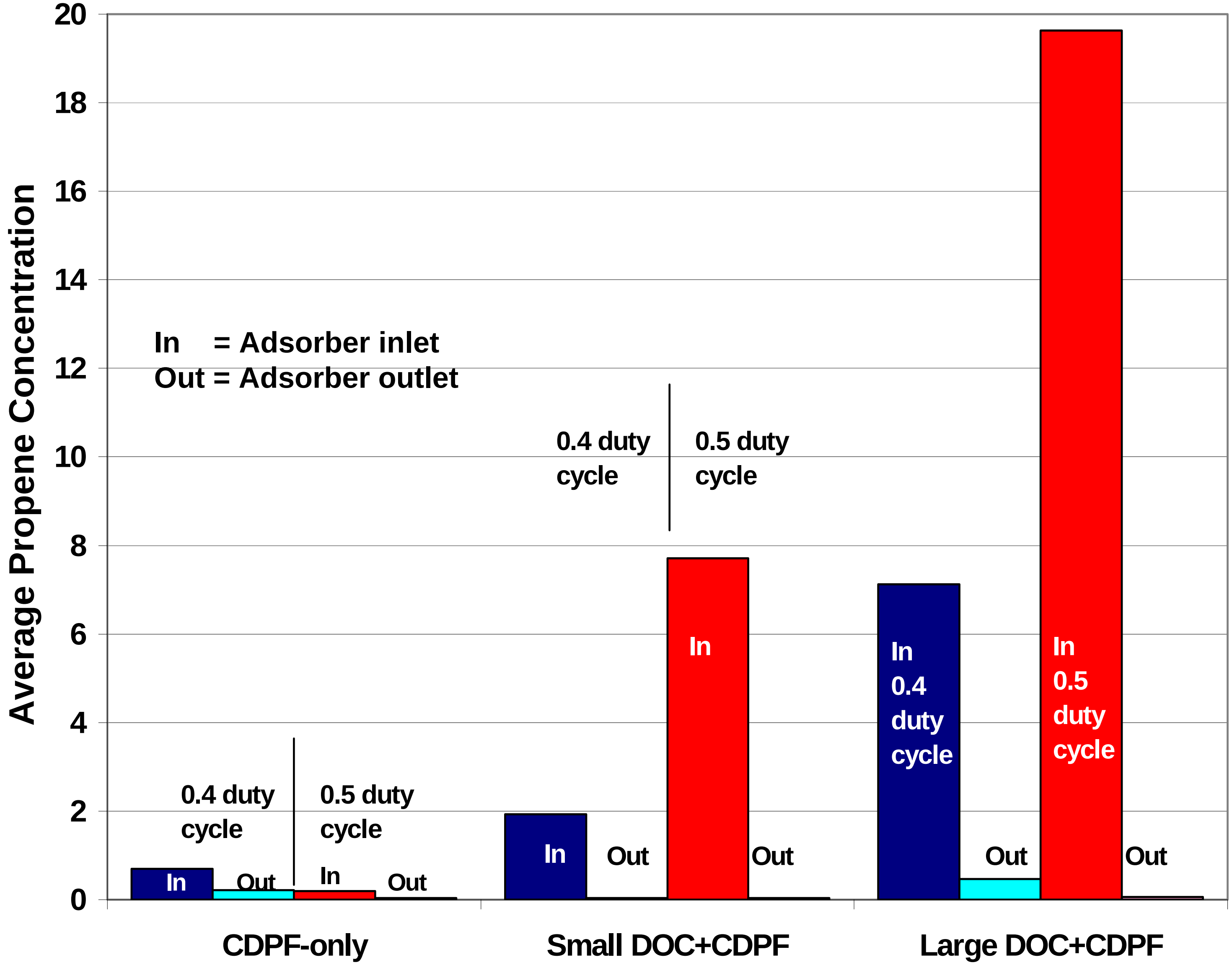


GC-MS shows C_4 and C_5 HCs at adsorber inlet, all utilized by NOx adsorber catalyst. Light alkenes are formed in upstream catalysts.

Large DOC, 0.4 DC in vs out, DECSE



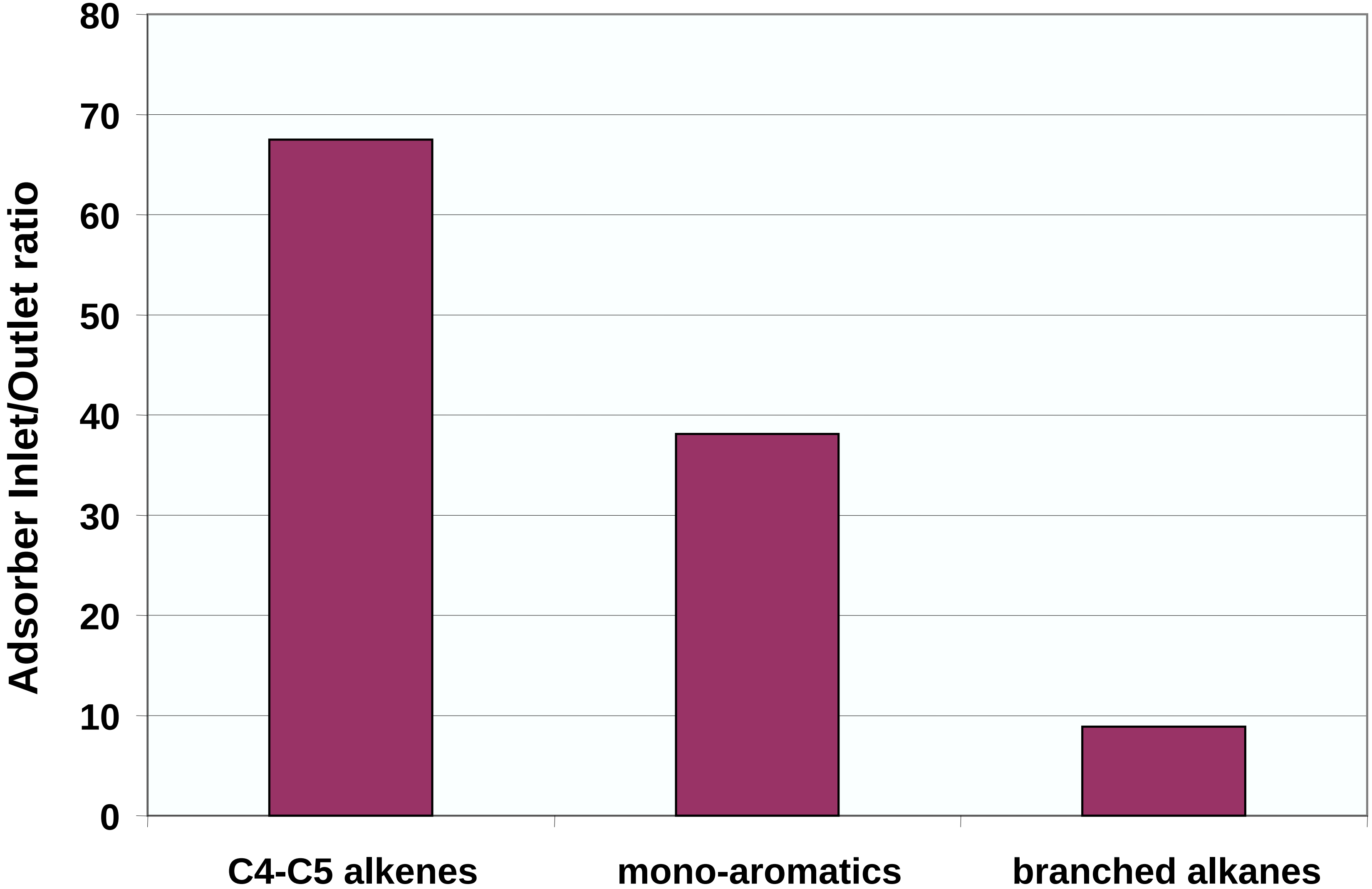
Oxidation catalysts promote propene formation, readily utilized by NOx adsorber



- **Data from FTIR**
- **Larger diesel oxidation catalyst (DOC) makes most propene**
- **Richest calibration produces most propene w/ DOC**
- **Duty cycle is fractional on time for periodic in-pipe injector**

Light alkenes and mono-aromatics are readily utilized by NOx adsorber. Branched alkanes are less preferred. Are aromatics *good*?

Average adsorber inlet/outlet concentration of families of compounds shown for several cases, both ECD-1 and DECSE fuels, with oxidation catalyst and CDPF upstream of NOx adsorber.



- **Monoaromatics and light alkenes**
  - **Formed in exhaust from raw fuel**
  - **Well utilized by NOx adsorber**

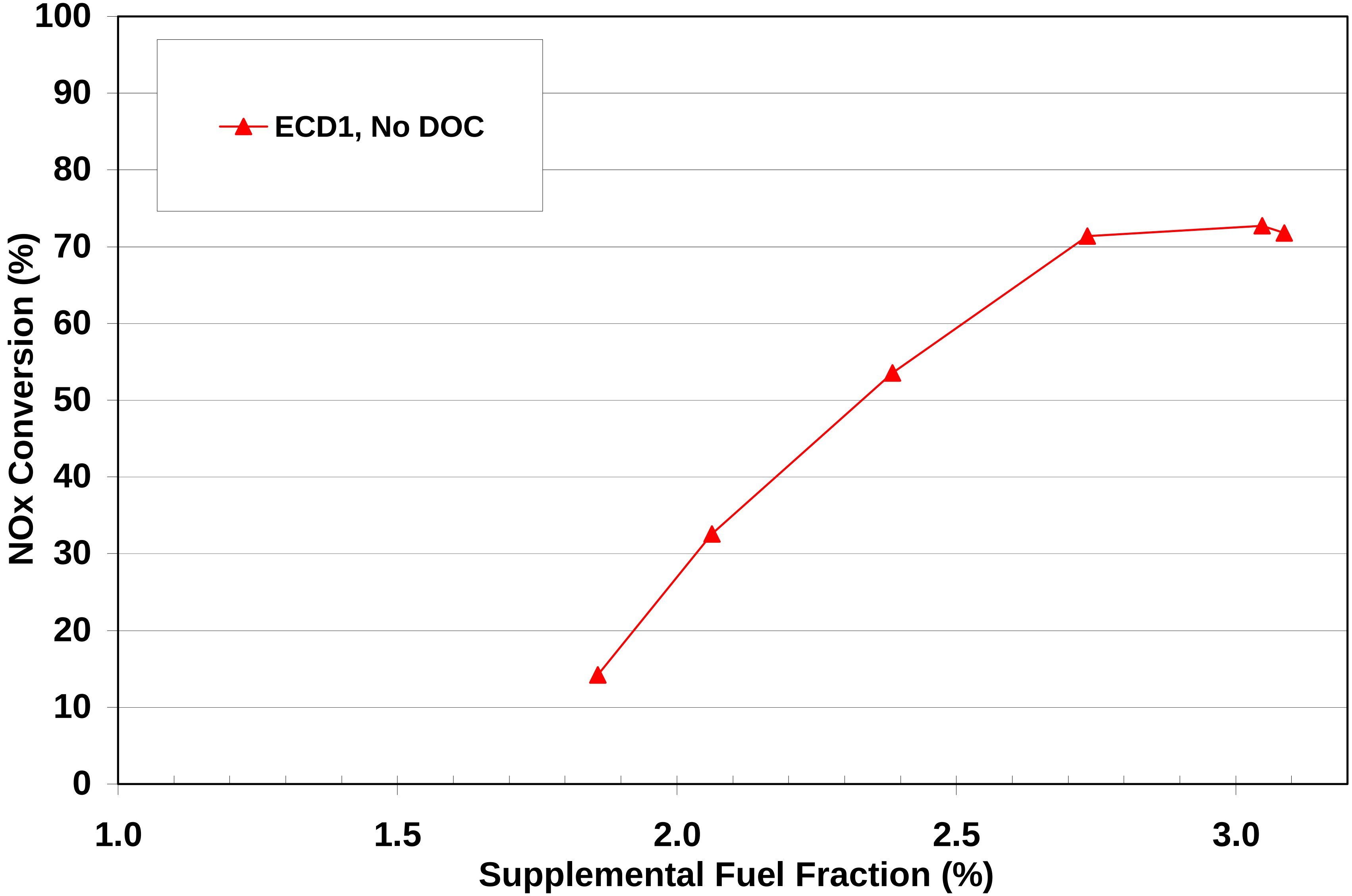
- **All tailpipe HC emissions are below NTE limit of 0.21 g/hp-hr**

We have shown that fuel cracking in DOCs provides different species to the NOx adsorber.

What affect does this have on NOx reduction?

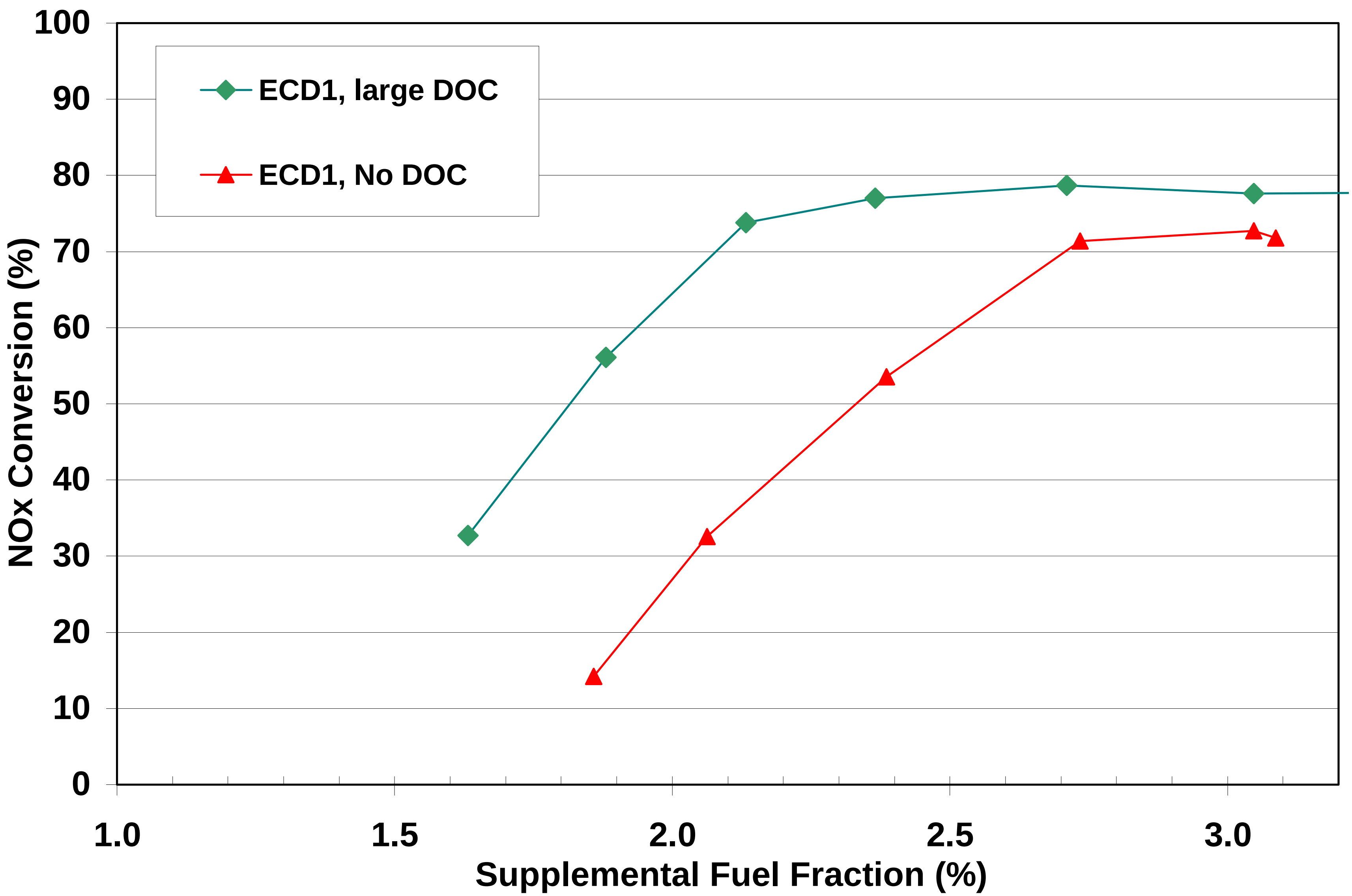
With no upstream DOC, 70% NOx reduction achieved at ~2.7% excess fuel

Full Load, Rated Speed condition, 600C Catalyst temperature



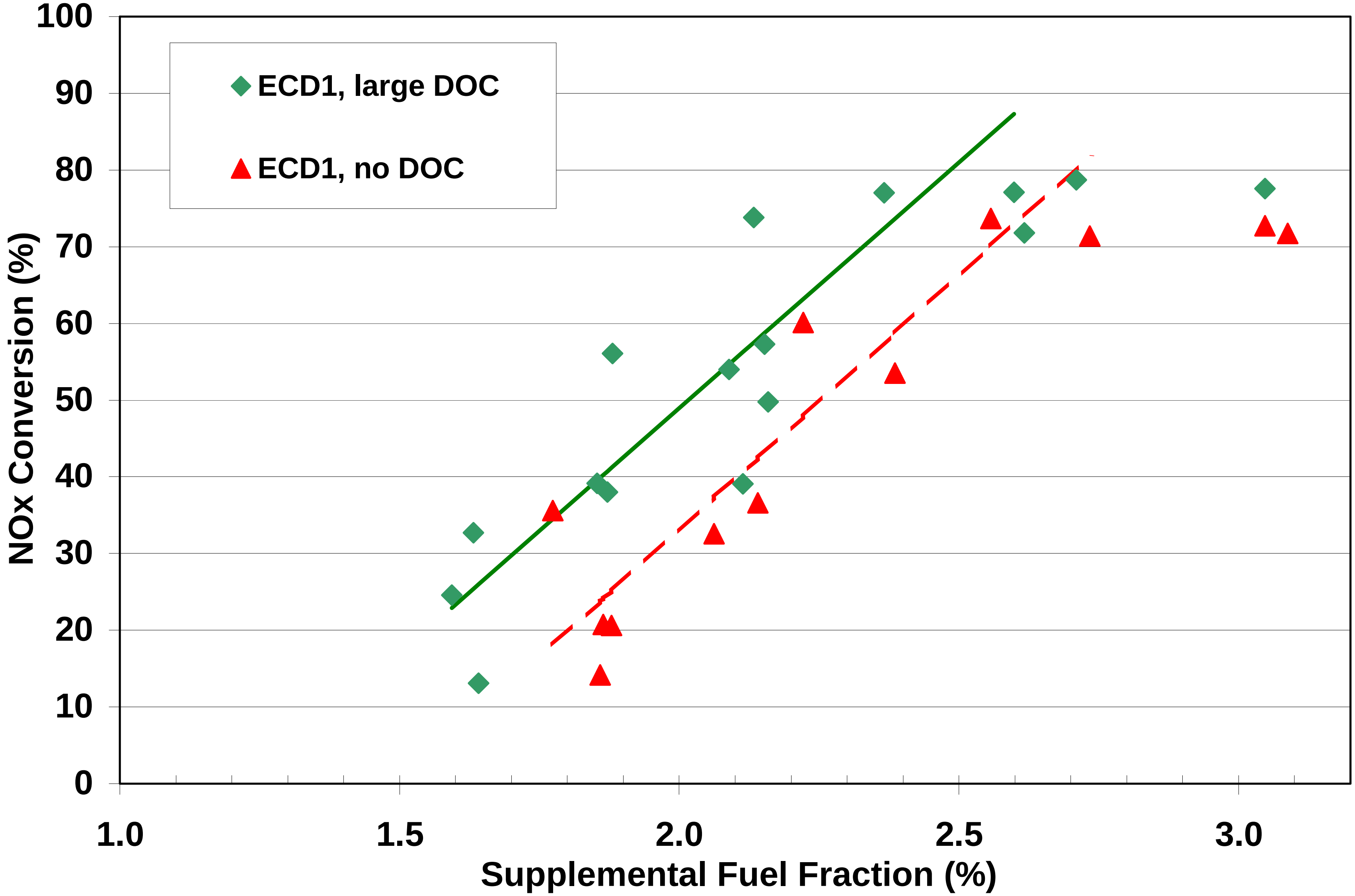
Fuel cracking in DOC lowers fuel penalty for equivalent NOx reduction

Full Load, Rated Speed condition, 600C Catalyst temperature



Data from multiple runs shows consistent 10% reduction in fuel penalty with DOC

Full Load, Rated Speed condition, 600C Catalyst temperature



Summary and Conclusions-1

- **Light alkenes, mono-aromatics preferred by NOx adsorber**
  - **Branched alkanes not as good**
  - **Suspect an increase in HC sensitivity at lower temperatures (we were at 600°C)**
  - **Understanding preferred HC species may help choose "best" certification fuel**
    - **Many "clean" diesel fuels are low aromatic**

Summary and Conclusions-2

- **~70% NOx reduction achieved at 600 °C NTE condition**
  - **Caveats:**
    - **Large, "young" catalyst (150-200 hours)**
      - **Negligible sulfur poisoning, no desulfations as yet**
    - **High engine-out NOx (~5 g/hp-hr)**
    - **Only 2 - 2.5% excess fuel**
  - **70% NOx reduction will require <1.0 g NOx/hp-hr engine-out in 2010 to meet NTE**
  - **2.0 g NOx/hp/hr engine-out will require >85% reduction**
    - **Larger/improved adsorber, more frequent regen, best reductant**
- **NTE imposes *significant* challenge**

Acknowledgments

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- **Industrial Partners:**

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