FPC2015

Future Powertrains Conference

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Brunel UNIVERSITY LONDON

CLEAN AIR POWER

MicroPilot - The New Generation of Compression-Ignited Natural Gas Engines

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Developers & Tier 1 suppliers of compression-ignited natural gas engine systems that enable heavy duty trucks to operate on diesel and natural gas

62	$90m	>2,700	~70	>1bn	>200 man yrs
patents	invested in R&D	vehicles delivered	employees	miles in use	of knowledge

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Conventional Natural Gas Engines

Natural Gas Engines

Compression-Ignited

Base Engine Retained

Dual-Fuel™

FUEL ECONOMY	
Substitution of 80%+	X
Engine efficiency	?
OPERATIONS	
Power of 450-500 BHP	✓
Range	✓
Diesel fall-back	✓
COSTS	
Low purchase and running costs	✓
Maintain residuals	✓

Base Engine Modified

HPDI

FUEL ECONOMY	
Substitution of 80%+	✓
Engine efficiency	?
OPERATIONS	
Power of 450-500 BHP	✓
Range	?
Diesel fall-back	X
COSTS	
Low purchase and running costs	?
Maintain residuals	?

Spark-Ignited

New Base Engine

Spark-Ignited

FUEL ECONOMY	
Substitution of 80%+	✓
Engine efficiency	X
OPERATIONS	
Power of 450-500 BHP	X
Range	X
Diesel fall-back	X
COSTS	
Low purchase and running costs	?
Maintain residuals	?

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A New Natural Gas Engine Option:

Natural Gas Engines

Compression-Ignited

Spark-Ignited

Base Engine Retained	Flexible	Base Engine Modified	New Base Engine
Dual-Fuel™	***MicroPilot***	**HPDI**	**Spark-Ignited**
FUEL ECONOMY	FUEL ECONOMY	FUEL ECONOMY	FUEL ECONOMY
Substitution of 80%+ X	Substitution of 80%+ P	Substitution of 80%+ P	Substitution of 80%+ P
Engine efficiency ?	Engine efficiency P	Engine efficiency P	Engine efficiency X
OPERATIONS	OPERATIONS	OPERATIONS	OPERATIONS
Power of 450-500 BHP P	Power of 450-500 BHP P	Power of 450-500 BHP P	Power of 450-500 BHP X
Range P	Range P	Range ?	Range X
Diesel fall-back P	Diesel fall-back P	Diesel fall-back X	Diesel fall-back X
COSTS	COSTS	COSTS	COSTS
Low purchase and running costs P	Low purchase and running costs P	Low purchase and running costs ?	Low purchase and running costs ?
Maintain residuals P	Maintain residuals P	Maintain residuals ?	Maintain residuals ?

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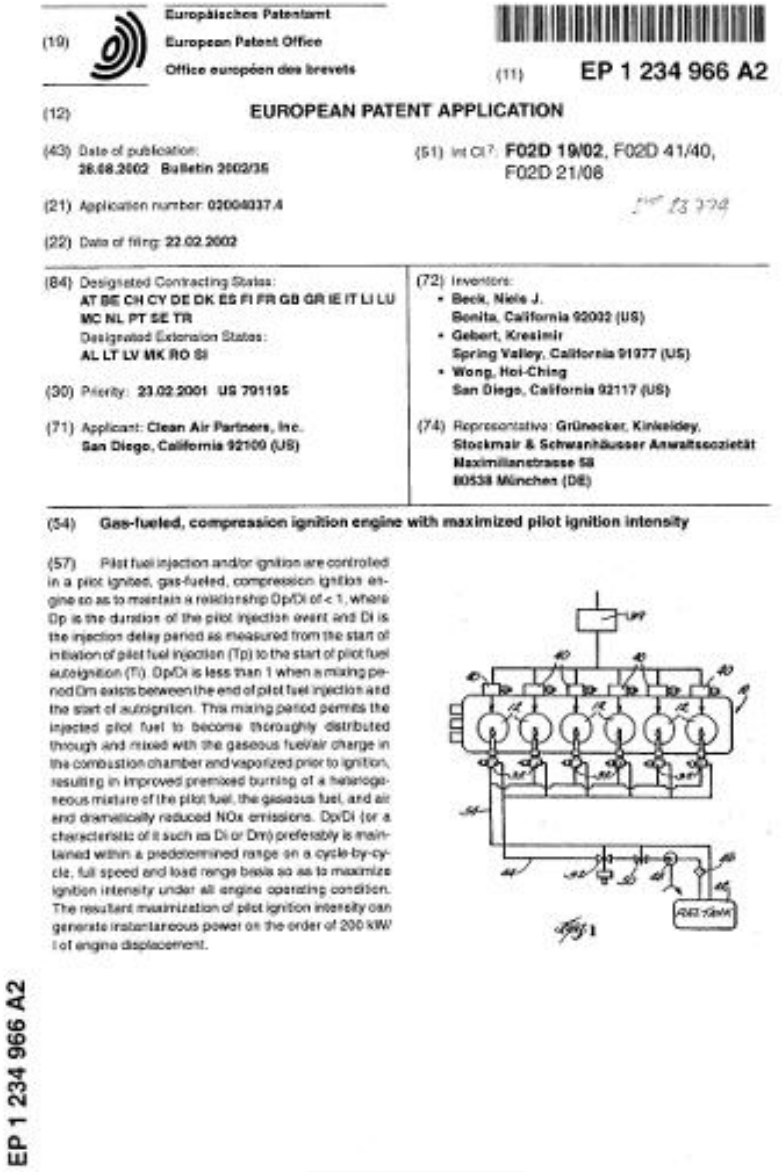
What is MicroPilot?

- Compared to “classic” Dual-Fuel technology it uses a much SMALLER pilot injection of <10% diesel
- MicroPilot is also an INTENSE injection, defined as having a short injection period
- MicroPilot is enabled by today’s advanced high pressure “common-rail” diesel systems
- MicroPilot is patented technology, developed by CAP 15 years ago!
- Today’s advanced heavy-duty diesel engines are now equipped with diesel common-rail that enables MicroPilot
- CAP are now engaged in commercial programs to exploit the benefits of MicroPilot and have a research partnerships with Brunel University London to develop the technology to its full potential



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(54) Gas-fueled, compression ignition engine with maximized pilot ignition intensity

(57) Pilot fuel injection and/or ignition are controlled in a pilot ignited, gas-fueled, compression ignition engine so as to maintain a relationship Dp/Di of < 1, where Dp is the duration of the pilot injection event and Di is the injection delay period as measured from the start of initiation of pilot fuel injection (Tp) to the start of pilot fuel autoignition (Ti). Dp/Di is less than 1 when a mixing period Dm exists between the end of pilot fuel injection and the start of autoignition. This mixing period permits the injected pilot fuel to become thoroughly distributed through and mixed with the gaseous fuel/air charge in the combustion chamber and vaporized prior to ignition, resulting in improved premixed burning of a heterogeneous mixture of the pilot fuel, the gaseous fuel, and air and dramatically reduced NOx emissions. Dp/Di (or a characteristic of it such as Di or Dm) preferably is maintained within a predetermined range on a cycle-by-cycle, full speed and load range basis so as to maximize ignition intensity under all engine operating condition. The resultant maximization of pilot ignition intensity can generate instantaneous power on the order of 200 kW / of engine displacement.

EP 1 234 966 A2

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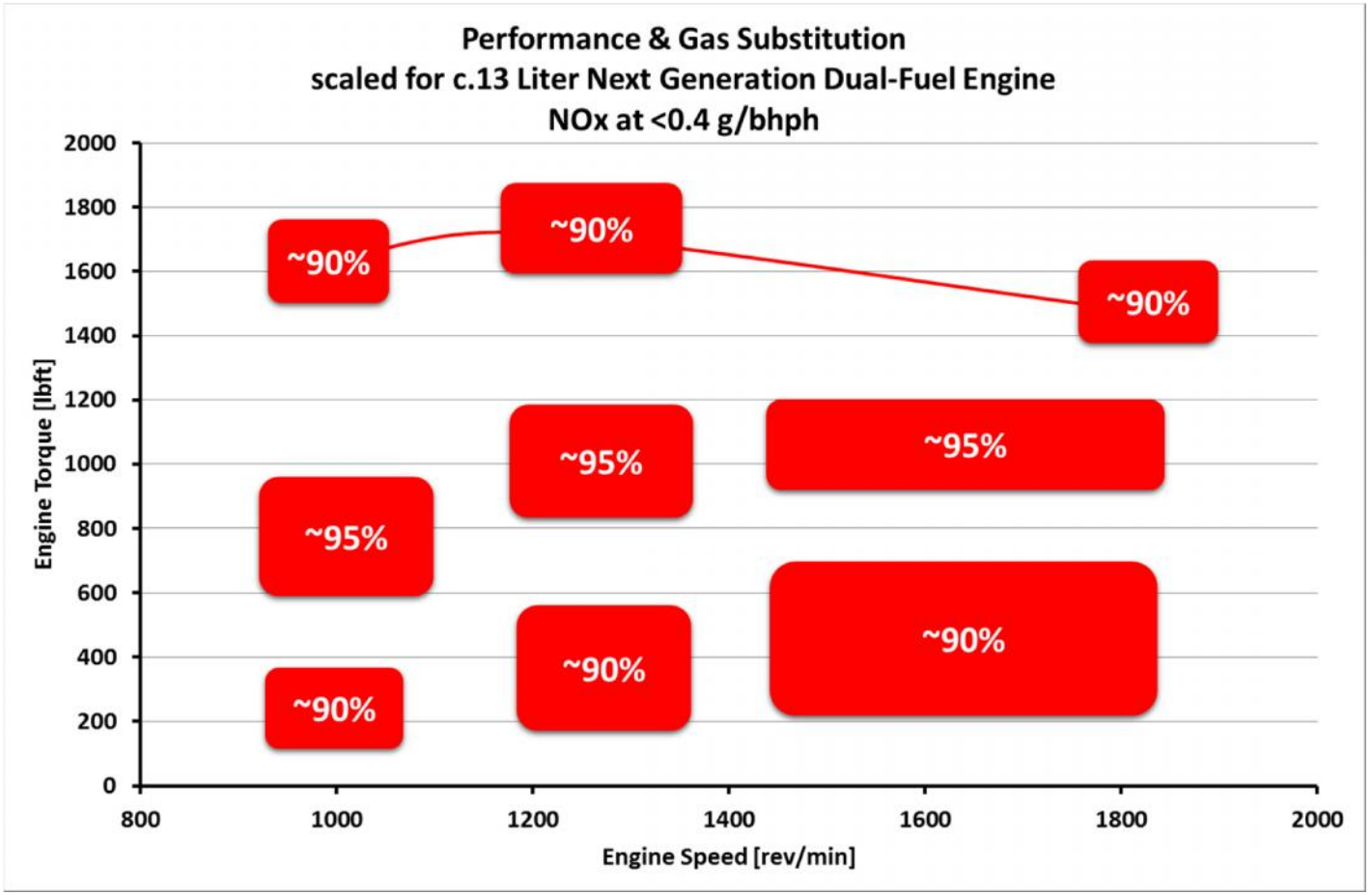
MicroPilot in Action - Substitution



- MicroPilot has the potential to deliver >90% gas substitution on test and real-world duty cycles

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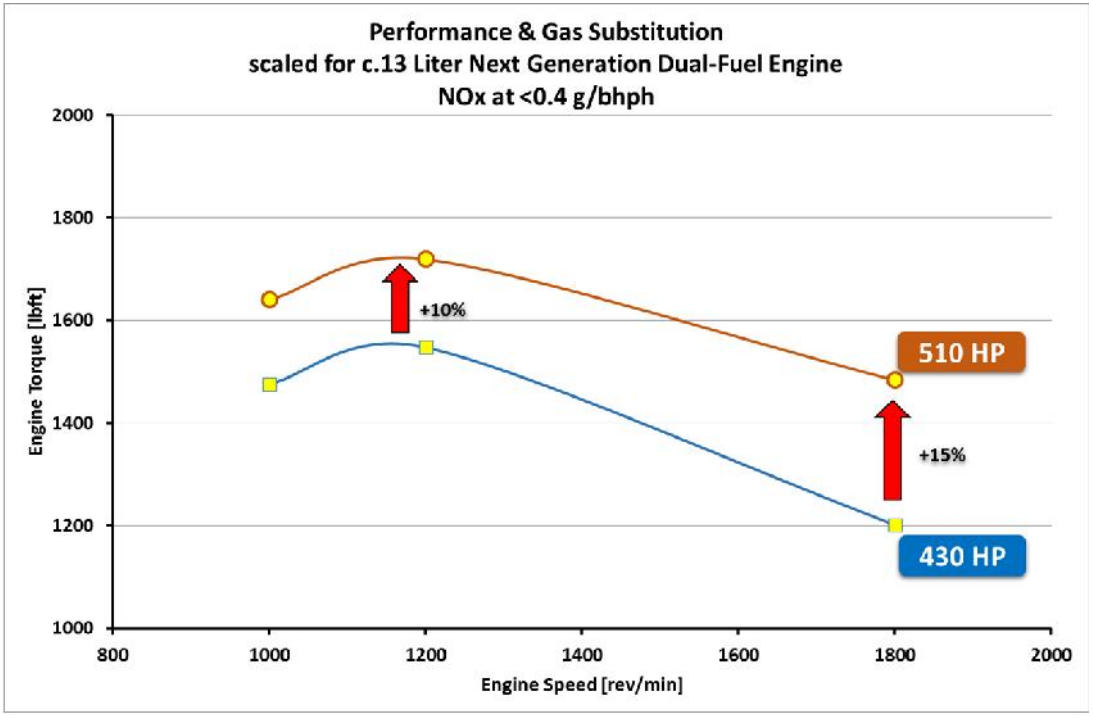
MicroPilot in Action - performance

- MicroPilot has potential to deliver improved performance
- Engine tests have demonstrated significantly higher power-density from a prototype MicroPilot research engine using exhaust-gas recirculation
- MicroPilot has demonstrated the highest power-density of any CAP Dual-Fuel application

Application	Emission Level	Power Density (HP/Liter)
Next Gen	US2010	40.0
CAT 3126	US1998/2002	34.7
CAT C-10	US1998/2003	30.6
CAT C-12	US1998/2004	34.5
CAT C-15	US1998/2005	34.2
Volvo MD13	Euro V	35.9
Volvo MD13	Euro V	37.5



- Compared to a leading low-emissions Dual-Fuel engine application, MicroPilot has demonstrated significant improvement in performance at comparable emissions levels
- 15% increase in rated power
- 10% increase in peak torque

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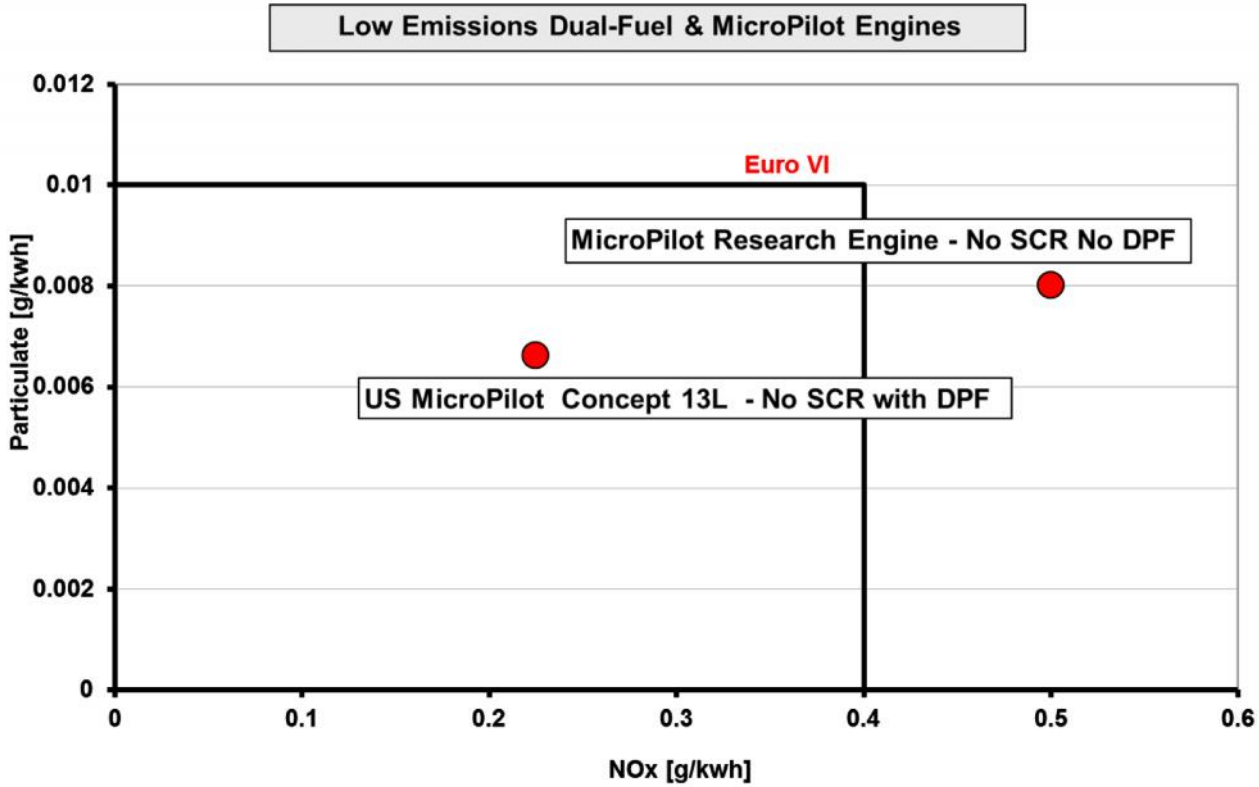
MicroPilot in Action - Emissions

- MicroPilot technology shows strong potential to meet Euro VI
- Recent R&D has demonstrated sub-Euro VI without SCR
- Recent R&D is showing potential to eliminate expensive diesel exhaust aftertreatment systems



- However, like all natural gas combustion systems, methane remains an issue
- Methane is a GHG, not a pollutant, but the UN and EU persist in including it in the pollutant regulation. Additionally, Dual-Fuel systems have been forced to comply with Spark-Ignited engine methane limits which did not consider lean-burn (low carbon) systems

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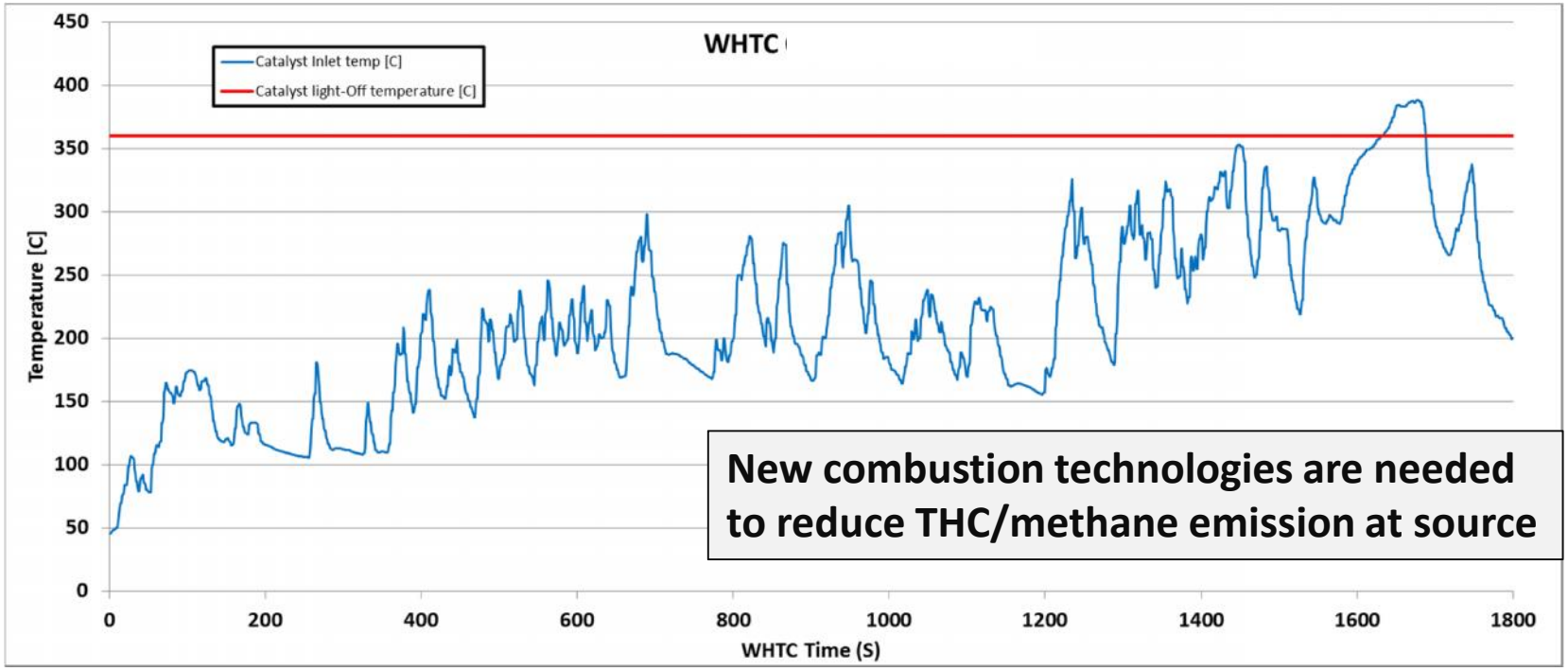
The Euro VI Problem For Lean-Burn NG Engines

- Euro VI regulations prevent lean-burn/dual fuel gas engine technologies
- Oxidation catalysts are required to meet the THC and methane limits (~0.5 g/kWh)
- Oxidation catalyst technology does not exist for <350 C light-off or >700,000km ISC
- **WHTC is too cold for methane oxidation catalysts**



Engine data measured from 13L US2010 engine with pre-cat/DPF/SCR – similar to Euro VI. Temperature is measured at the inlet to the pre-cat.

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MicroPilot Research- PMPC (patent pending)

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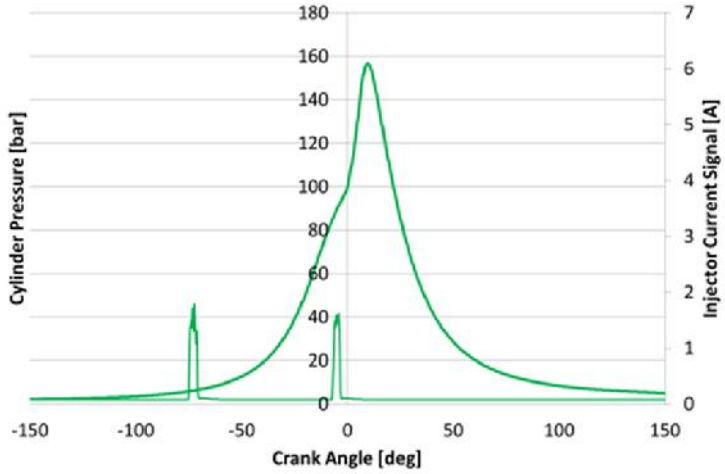
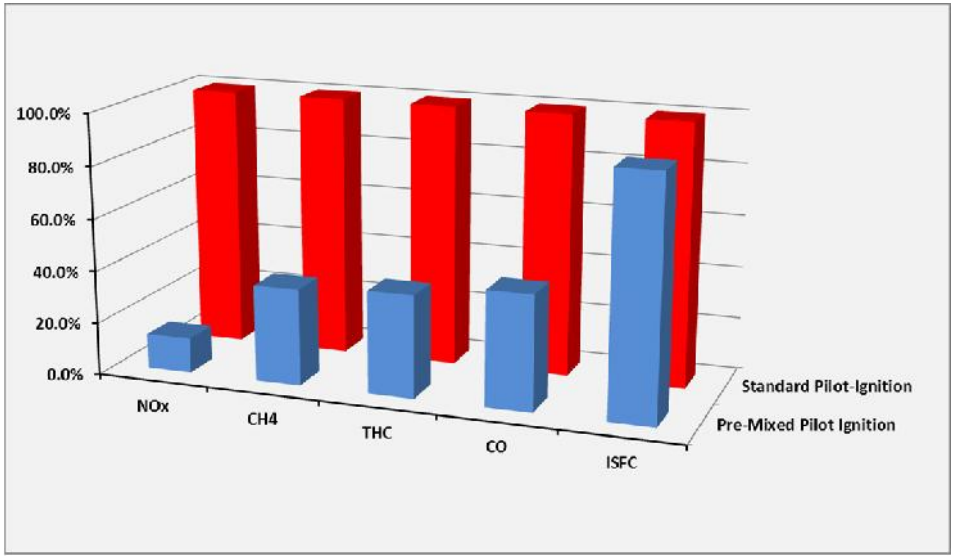
Premixed MicroPilot Combustion (PMPC)

- MicroPilot enables the use of multiple pilot injections that deliver *PMPC*
- *PMPC* is a new combustion strategy that has been developed by CAP with patents pending
- Significant improvements in emissions can be made from engines equipped PMPC





- Research partnership with Brunel University London has shown that PMPC can deliver significant emissions reductions
- >60% methane reduction
- >60% NOx reduction
- Potential to deliver Euro VI NOx without SCR

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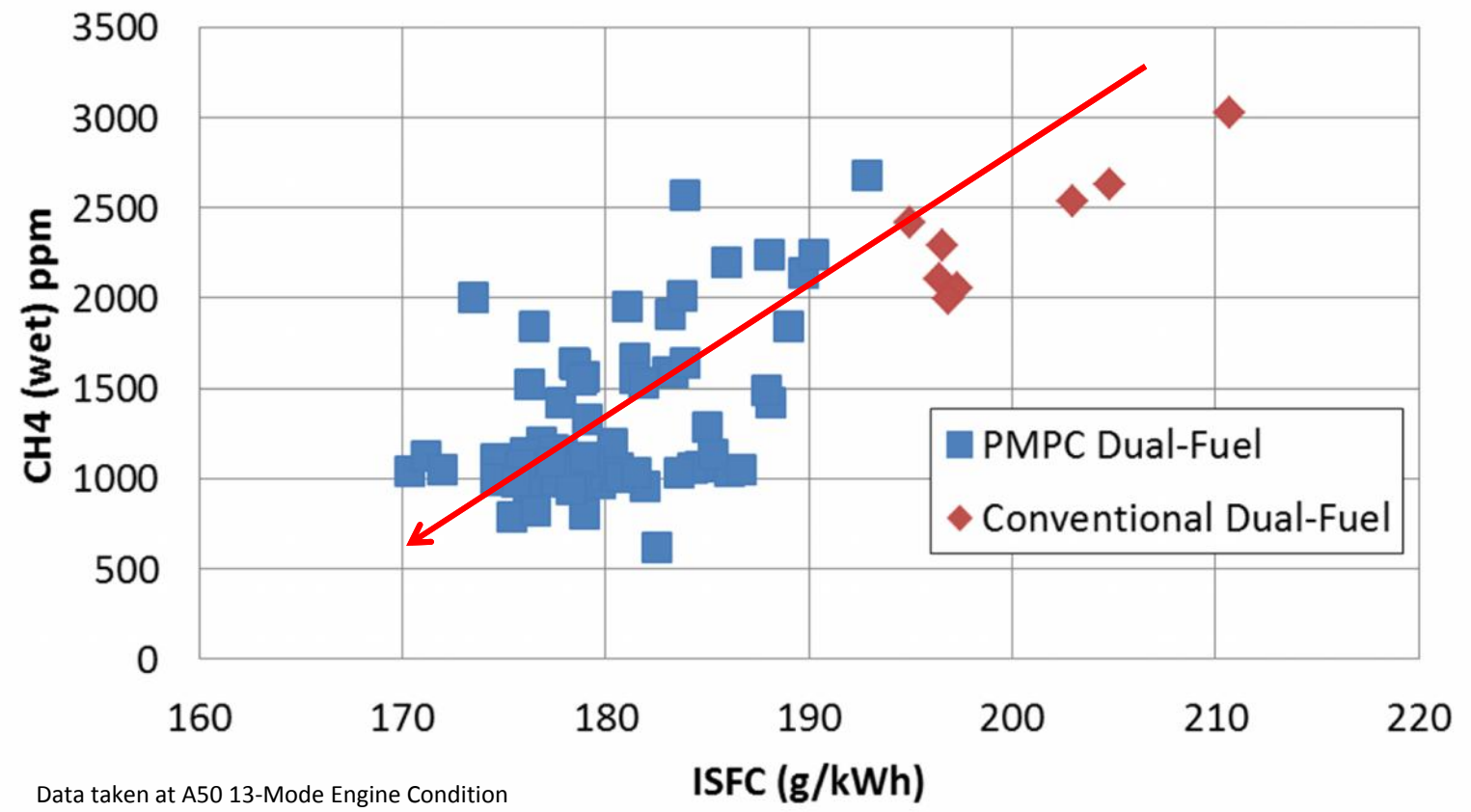
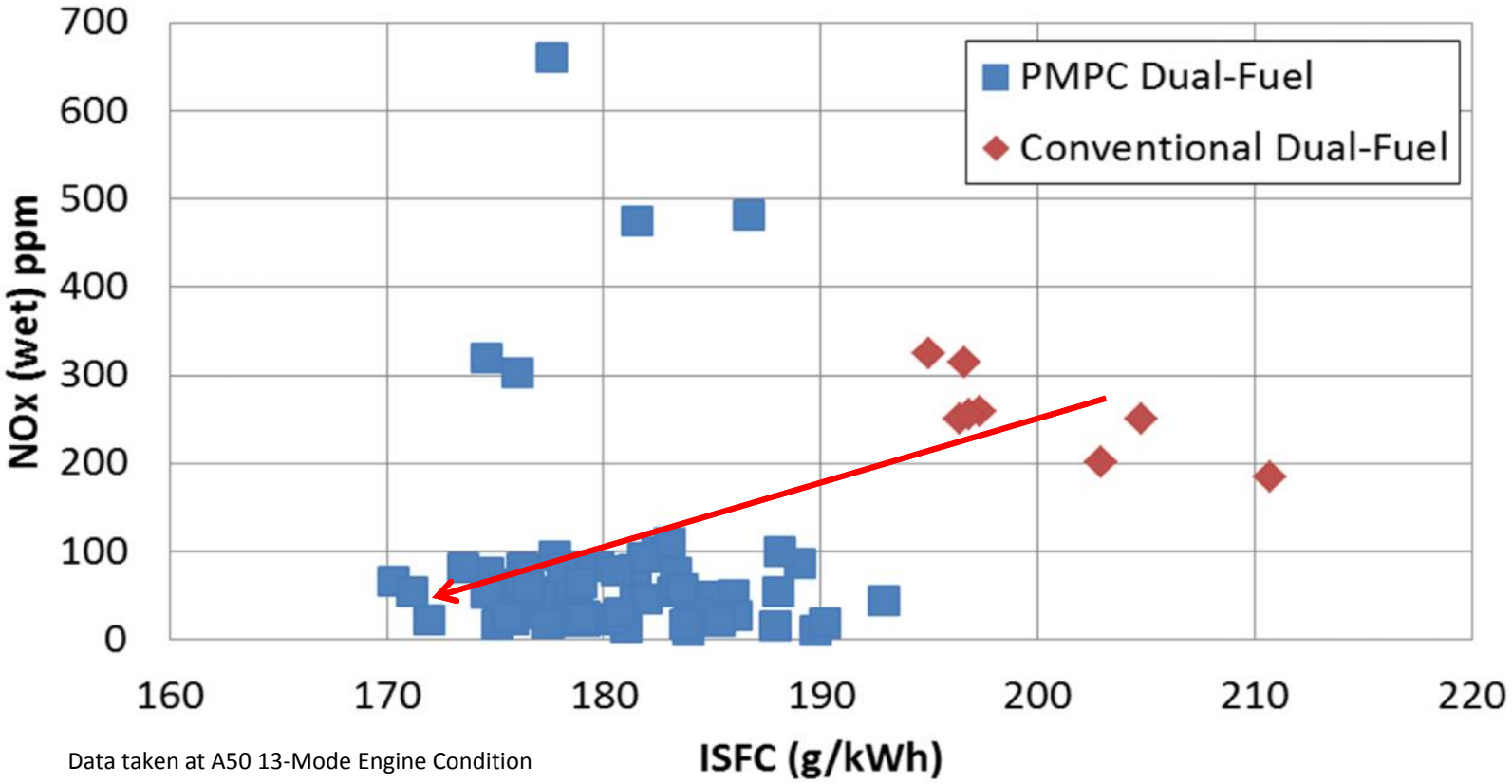
MicroPilot Research – PMPC (patent pending)



Data taken at A50 13-Mode Engine Condition

- Significant increase in methane combustion delivers lower fuel consumption and low methane emissions

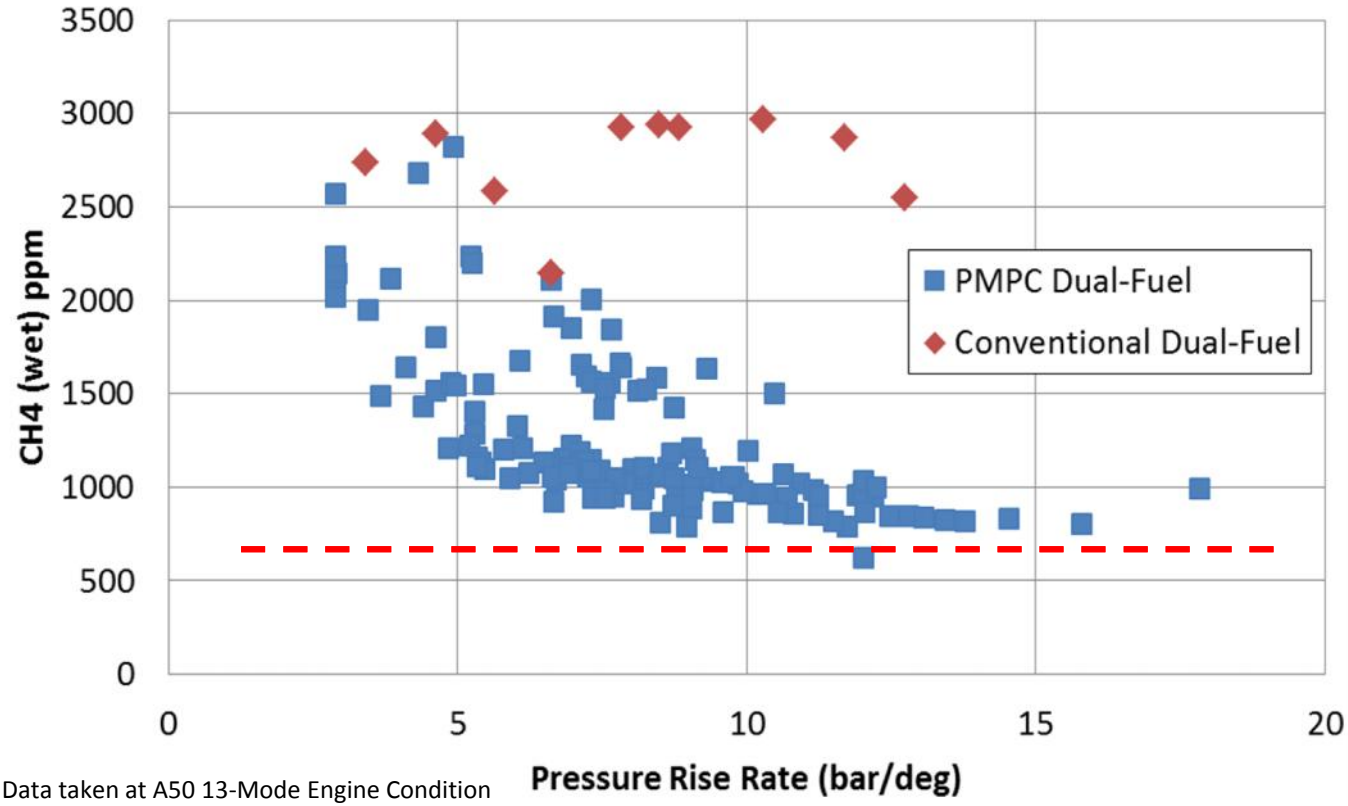
MicroPilot Research – PMPC (patent pending)



Data taken at A50 13-Mode Engine Condition

- Significant reduction in NOx and ISFC due to low-temperature, efficient combustion

MicroPilot Research – PMPC (patent pending)



Data taken at A50 13-Mode Engine Condition

- Significant increase in methane combustion efficiency reaches a limit of methane emission reduction
- Results indicate effect of crevice volume and combustion quenching effects of combustion system hardware
- Further countermeasure to be investigated

MicroPilot Potential

- In comparison with conventional natural gas-diesel combustion, MicroPilot shows significant improvements in gas utilisation, performance, efficiency, emissions and GHG's
  - 90+% replacement of diesel fuel with natural gas or bio-methane
  - 40HP/litre = 510HP 13 litre HD engine
  - US2010 / Euro VI NOx & PM achieved more readily than with diesel
  - Advanced combustion systems – PMPC - benefits of HCCI with full controllability
- MicroPilot is enabled by advanced diesel common-rail systems deployed on contemporary premium heavy duty engines with minimum change to the base engine
  - 100% diesel fall-back still possible & 100% diesel residual value guaranteed
  - Diesel-like operation, servicing & maintenance
- HD MicroPilot will deliver a natural gas powertrain that is attractive and acceptable to operators of HGV fleets and should be part of a National strategy to de-carbonise heavy road transportation
- UK & EU should be supporting realistic and achievable regulation to encourage lean-burn and efficient natural gas / bio-methane powertrain technology

Thank You !

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