Euromot position on regulating gaseous-fuelled non-road, inland waterway & rail engines under 97/68/EC

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Structure of following slides

- Engines & fuel types to be included in-scope
- Definition of SI & CI
- Source of core limit values
  - Inland waterway, locomotive & railcar
  - Non-road
- Test cycles
- Operation on liquid fuel
- Basis of HC measurement
  - SI engines < 56 kW
  - All engines other than SI engines < 56 kW
- CH_4 limit value
- Adaptation of test procedures

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ENGINE TYPES & FUELS IN-SCOPE

The following are proposed to be in scope:

- Inland waterway, locomotive, railcar & mobile non-road engines either operated on compressed or liquefied natural gas or bio-methane, or on liquid petroleum gas (LPG), irrespective of power class & ignition method (includes mono-fuel, dual-fuel, CI & SI)

Fuel specifications:

- Gaseous type approval test fuel specifications are to be determined in a further round of discussion taking into consideration available reference fuels and the use of pipeline fuel where appropriate
- Successful introduction of gaseous-fuelled engines into service depends upon on availability of market gaseous fuels of appropriate specification and quality

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DEFINITION OF SI & CI

For the purpose of this document the following apply:

- Spark ignition (SI) gas engine shall mean an engine which works on the spark-ignition principle
  - engines fitted with spark plugs to provide ignition source irrespective as to whether the gas engine has been derived from a petrol or diesel engine

- Compression ignition (CI) gas engine shall mean an engine which works on the compression-ignition principle
  - includes dual-fuel engines that use compression to provide ignition, irrespective of the proportion of gaseous and liquid fuel used

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SOURCE OF CORE LIMIT VALUES
Inland waterway, locomotive and railcar

- One set of limit values & test cycles for each engine power/displacement class irrespective of diesel fuel, gaseous fuel or dual-fuel operation and irrespective of ignition method (CI or SI)

- Core limit values & cycles for all engines taken from corresponding diesel CI engine requirements *

* See also later slides on basis of HC measurement and CH_4 limit value

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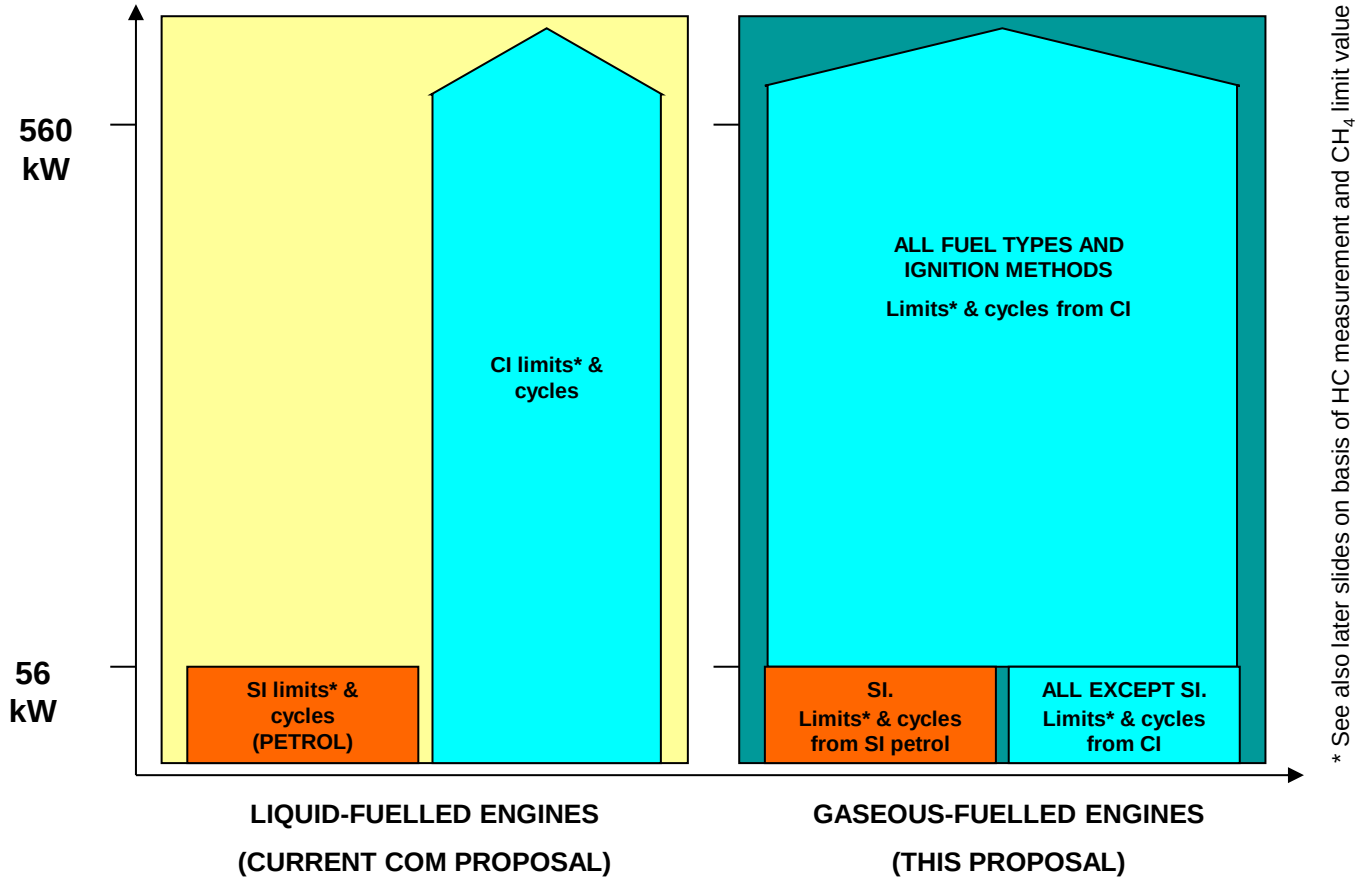
SOURCE OF CORE LIMIT VALUES
Non-road



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TEST CYCLES

- Engines operated on gaseous fuels shall comply with the respective limit values when operated on the test cycle(s) appropriate to the corresponding category of liquid-fuelled engine

- Non-road engines operated on gaseous fuel where the corresponding liquid-fuelled power class is subject to both steady-state and transient test cycles shall be tested on both cycles.

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OPERATION ON LIQUID FUEL

- Engines operated on gaseous fuels, that are also intended to be capable of full operation solely on liquid fuel (‘liquid mode’), shall additionally be tested operating in liquid mode on the relevant cycles(s)

- Engines operated on gaseous fuels, that are capable of restricted operation solely on liquid fuel for repairing or moving the machine/vessel to safety when operation on gaseous fuel is not possible (‘service mode’) shall not be required to be tested operating in liquid mode

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BASIS OF HC MEASUREMENT
SI engines < 56 kW

- No requirement to change existing basis for HC measurement assuming adoption of limit values proposed by Euromot (COM option 2)

- The basis of the HC measurement shall be total hydrocarbons (THC) regardless of liquid or gaseous fuel

- Consequently no CH_4 limit shall apply

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BASIS OF HC MEASUREMENT
All engines other than SI engines < 56 kW
Current Status

- 97/68/EC currently regulates HC on basis of total HC (THC)
- Engines in these categories fuelled using natural gas/bio-methane unable to comply with current THC limits due to methane slip
- For lean-burn engines ability of catalyst to reduce ethane is also limited
  - Second most difficult primary hydrocarbon to catalyse with similar temperature requirements as for methane catalysis (T_{50}: 400 – 450 deg C)
  - No concern for operation on reference fuel with low ethane content
  - Potential issue for operation on R49.06 reference fuel G_R and for testing using commercial/pipeline fuel due to proportion of ethane (eg G_R: 11 – 15% ethane)
  - Regulating HC on basis of non-methane hydrocarbon (NMHC) may also be problematic for lean-burn gas engines operating at moderate-high GER
- Type approval of engines in these categories fuelled using natural gas/bio-methane effectively prevented unless principle of HC measurement is adapted

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BASIS OF HC MEASUREMENT
All engines other than SI engines < 56 kW
Proposed approach

- The hydrocarbon (HC) value shall be taken from the applicable CI core limit value
- The basis of the HC measurement shall be determined according to the following criteria:
  - For engines operated solely on liquid fuel (liquid mode) or on LPG the basis of the HC measurement shall be total hydrocarbons (THC) taken from the applicable CI core HC limit value. In this case no CH_4 limit shall apply
  - For engines operated on natural gas/bio-methane the CI core HC limit value shall be taken as NMHC and a separate CH_4 value shall additionally apply. The applicable HC limit shall be a composite total hydrocarbon (THC) limit determined from a formula that combines the NMHC & CH_4 values as a function of the proportion of energy on the regulatory cycle that is provided by the gaseous fuel (gas energy ratio)

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BASIS OF HC MEASUREMENT

All engines other than SI engines < 56 kW

Proposed formula

- Determine the average proportion of energy derived from the gaseous fuel over the regulatory cycle (gas energy ratio, GER)
  - Hot transient cycle for engines subject to a transient cycle
  - Hot steady cycle for all other engines
- For all GER apply a composite THC limit value ($THC_{composite}$) as a function of GER using the following criteria:

1. Calculate THC_{GER} using following equation:

   $THC_{GER} = NMHC + (1.5 \times CH_4 \times GER)$

   (THC, NMHC & CH_4 in units of g/kWh, GER as decimal fraction)

2. If $THC_{GER} \leq (CH_4 + NMHC)$ then $THC_{composite} = THC_{GER}$
3. If $THC_{GER} > (CH_4 + NMHC)$ then $THC_{composite} = CH_4 + NMHC$*

   * Separate CH_4 and NMHC results to be reported but without individual limits

- See slides 13, 16 & 17 for graphical examples

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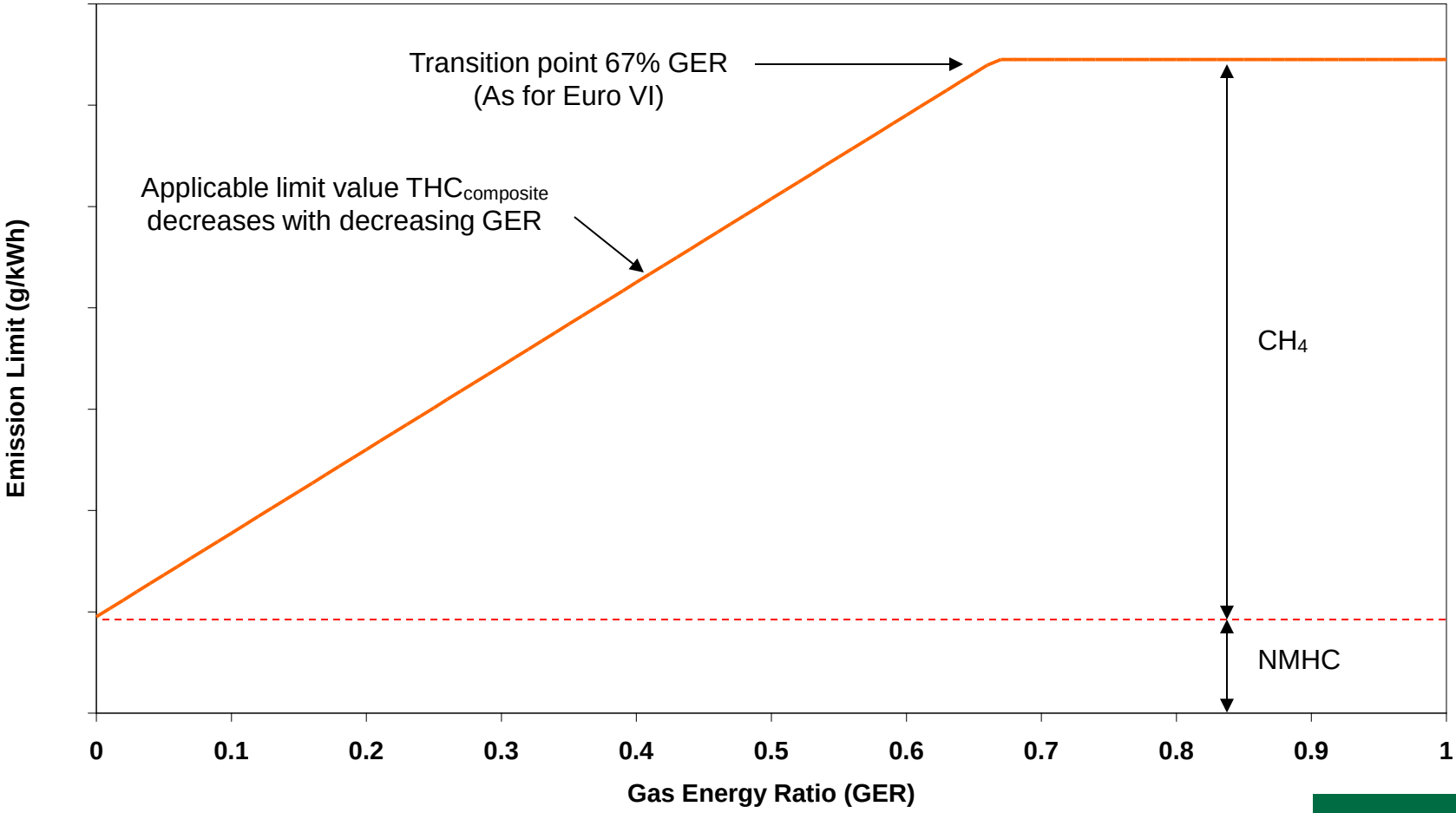
BASIS OF HC MEASUREMENT

All engines other than SI engines < 56 kW

Illustration of proposed formula



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BASIS OF HC MEASUREMENT

All engines other than SI engines < 56 kW
Characteristics of proposed approach

- Builds upon Euro VI approach with following differences
  - Modified equation to replicate Euro VI transition point at 67% GER independent of chosen CH_4 limit value
  - Uses $THC_{composite}$ limit throughout entire range of GER instead of just over GER range 10 – 67%
  - Maximum $THC_{composite}$ limit = CH_4 + NMHC
- Benefits of proposed approach
  - Enables effective limitation of methane, ethane and other hydrocarbons whilst permitting sufficient trade-off between these hydrocarbons to enable foreseen engine technologies and fuels
  - Recognises need for highest methane limit for engines using highest proportion of gas* and lowest methane limit for engines using lowest proportion of gas

    * Opportunity for reduction of direct CO_2 emission from carbon in the fuel is greatest for engines using highest proportion of gas

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PROPOSED CH_4 VALUES
All engines other than SI engines < 56 kW

CH_4 value for engines operated on natural gas/bio-methane (g/kWh)	
Inland waterway, locomotive & railcar engines (SI & CI)	6.0
All non-road engines (SI & CI) > 560 kW	6.0
All non-road engines (SI & CI) 56 - 560 kW	1.1
Non-road CI engines < 56 kW	1.1

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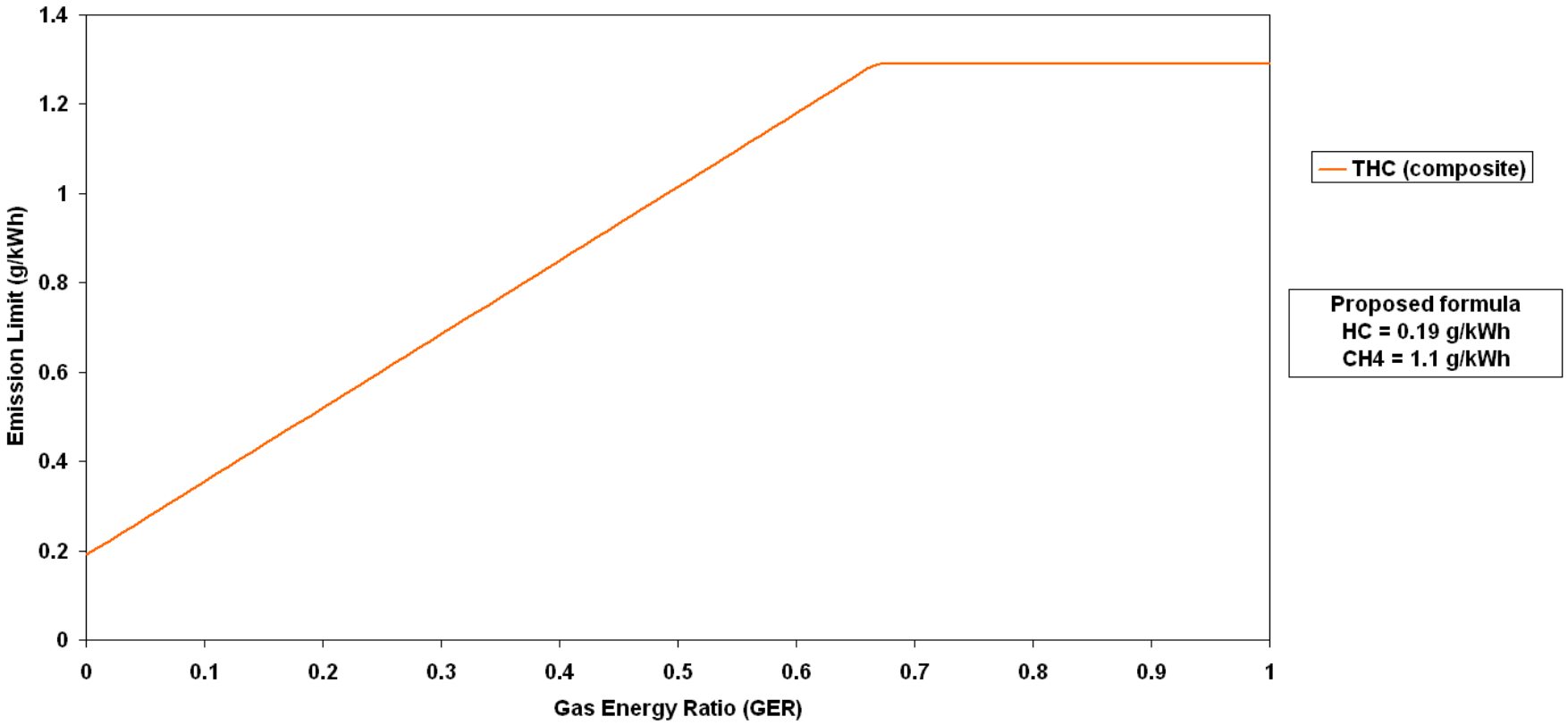
EXAMPLE $THC_{composite}$ versus GER



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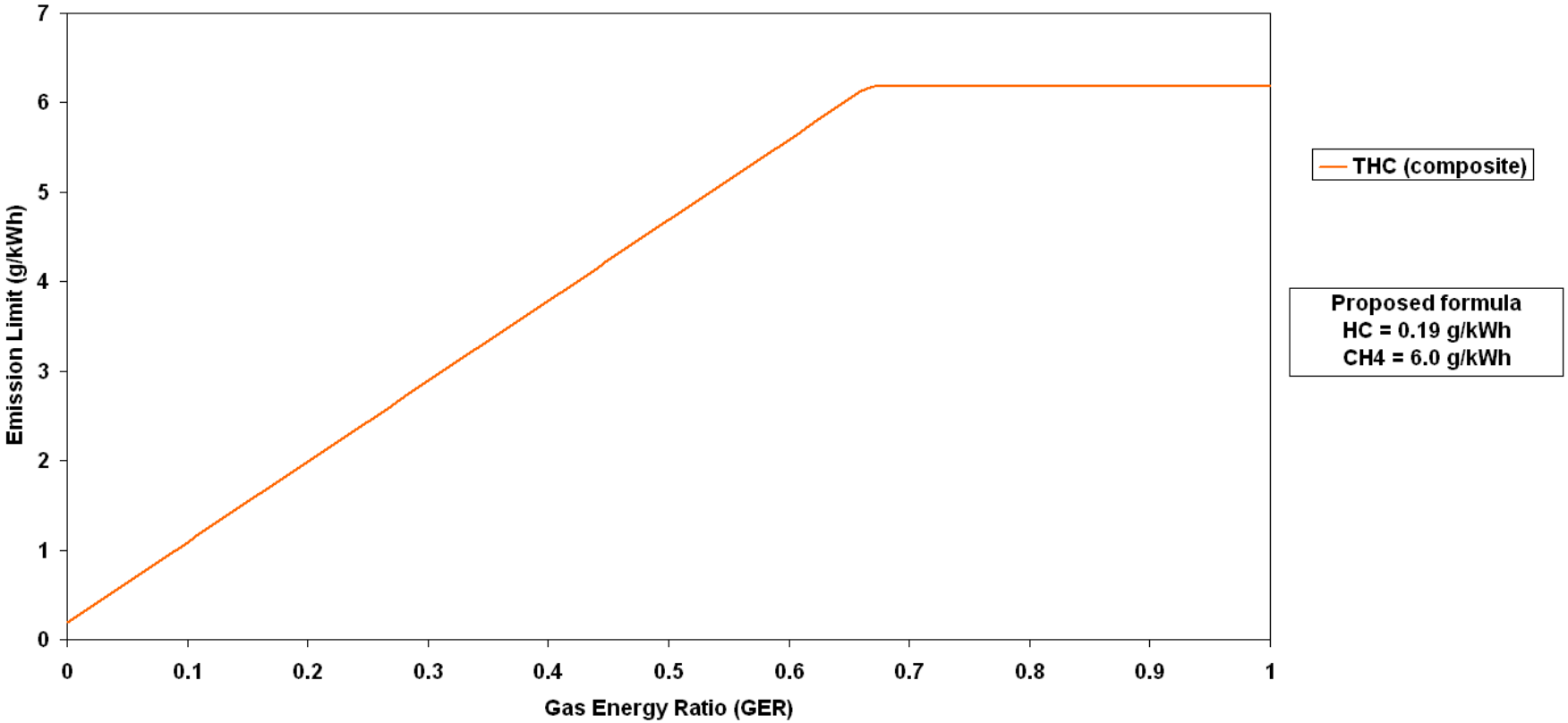
EXAMPLE $THC_{composite}$ versus GER



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ADAPTATION OF TEST PROCEDURES

- The non-road type approval procedures shall be adapted taking into consideration the following:
  - The HD on-highway gas engine test requirements in UN ECE R49.06
  - US 40 CFR 1065 (where appropriate)
  - The specific requirements of the various applications in 97/68/EC (inland waterway, locomotive, railcar and non-road)

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Promoting Engine in Society

EUROMOT - Lyoner Str. 18, DE-60528 Frankfurt/M. / Rond Point Schuman 6/5, BE-1040 Brussels

Tel: (+49 69) 6603-1354 / (+32 2) 234-6315 – E-Mail: info@euromot.eu

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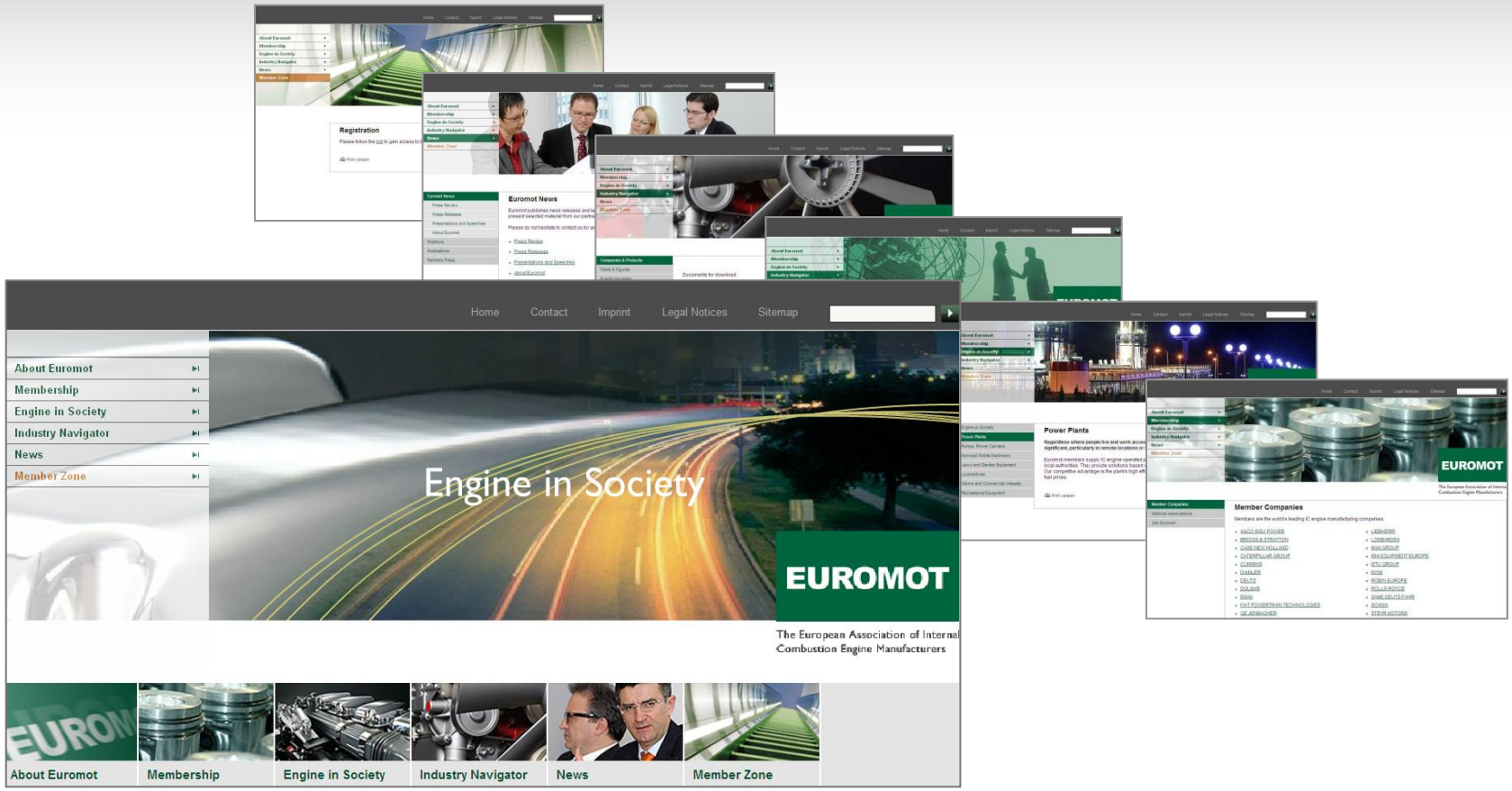

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