Shell Global Solutions

P-26

Assessment of Environmental Impacts of Shell GTL Fuel

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Environmental Impacts and Benefits

Are presented here for Shell GTL Fuel (SMDS) and conventional European ULSD, which have been investigated in terms of:

- Sustainability
- Aquatic Biodegradability
- Aquatic Ecotoxicity
- Soil Persistence and Toxicity

- Atmospheric emissions have been reported previously at numerous fora including DEER, Esslingen and SAE conferences
- Note that in this presentation, Shell GTL Fuel is also referred to as SMDS, since this describes the Shell Middle Distillate Synthesis process by which it is manufactured.

Sustainability

Typically assessed against three criteria :

- Economic, Social, and Environmental
  - should include entire life cycle of process: feedstock production, conversion, transportation and product usage

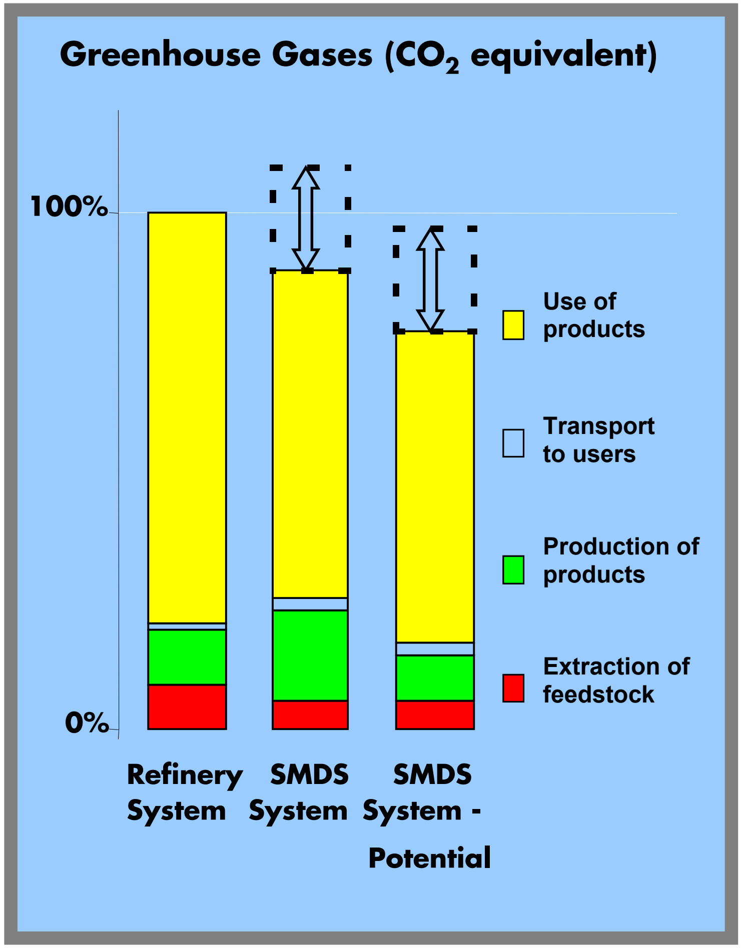
- Considering production route of transportation fuels & chemical feedstocks, SMDS likely to score well on all three sustainability criteria
  - e.g. should offer clear lifecycle benefits for NOx and SO_2 emissions

Sustainability

- Specific issue of GHG emissions comparison more complex:
  - Carbon efficiency of SMDS process currently lower than than typical leading refinery
  - Benefits upstream & product usage will (more than) offset this
  - Vehicle fuel usage gives CO_2 benefits of up to 5%
    - Higher caloric value and higher H/C ratio

- Full "SMDS and the environment" study, covering greenhouse gas emissions is available
  - Study by PwC

Sustainability – GHG Emissions



- External study* concluded that GHG emissions from a 'GTL system' are comparable to a 'crude oil refinery system', and has:
  - significant lower impact on air acidification and smog formation
  - lower emissions of particulate matter
  - less hazardous waste production and
  - no greater impact on global warming
- In order to reduce emissions from GTL, Shell is working on:
  - Focused R&D to improve GTL plant efficiency and reduce plant GHG emissions
  - Drive-train efficiency improvements - where additional 5-10% benefits are possible - through extensive collaboration with OEMs.

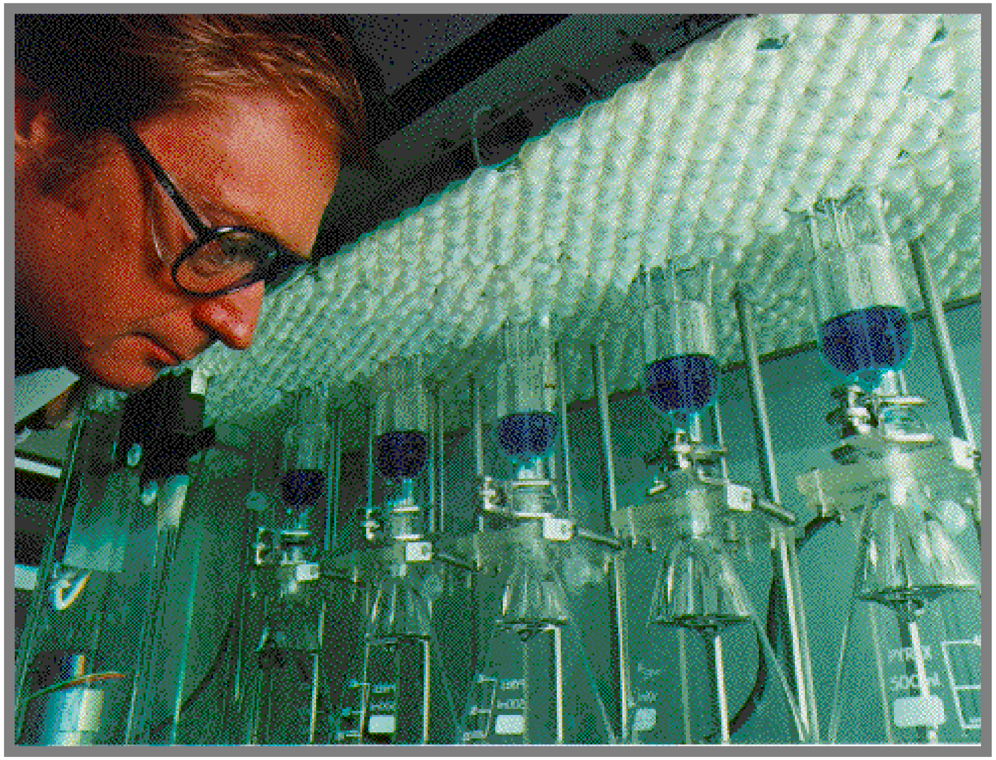
* Shell sponsored life-cycle assessment by PricewaterhouseCoopers LLP in accordance with ISO14040 standards.

Aqueous Biodegradability

- Matrix Design - comparison against European Ultra Low Sulphur Diesel (ULSD) which is a recognised clean diesel
  - ULSD (ex UK with sulfur ≤ 50 ppm)
  - SMDS-1 (original Bintulu production)
  - SMDS-2 (Bintulu production with 2nd generation catalyst)
  - Mixture of 24% SMDS-1 / 76% ULSD
  - Mixture of 24% SMDS-2 / 76% ULSD
  - Mixture of 76% SMDS-2 / 24% ULSD

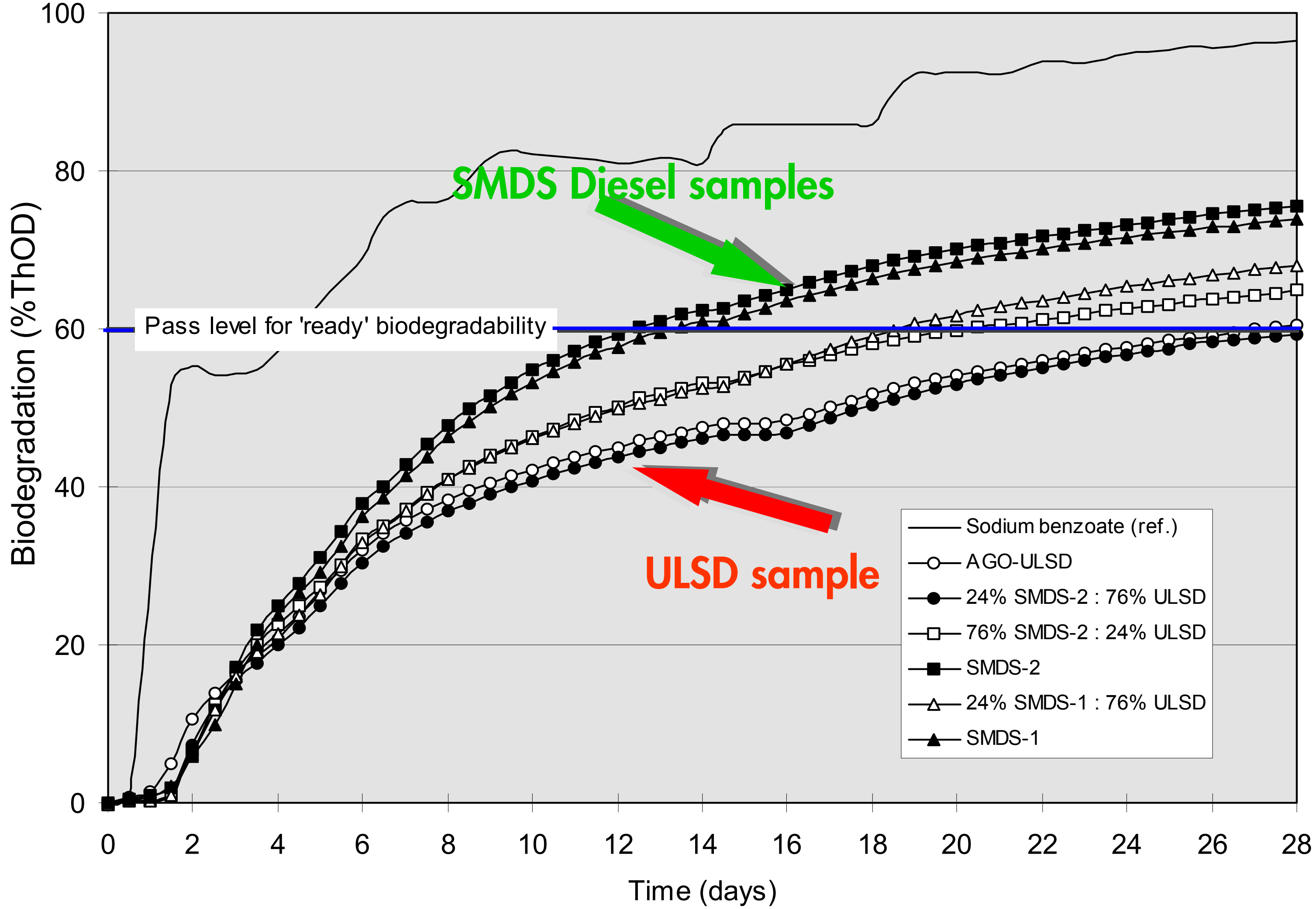
  Lowest proportion of 24%, chosen to be below EU limit of 25% when assessing substance preparations
- Methodology
  - Biodegradation accessed through oxygen demand
    - OECD Test Guideline 301 F: manometric respirometry

Aqueous Biodegradation Studies



- Theoretical Oxygen Demand (ThOD) for complete biochemical oxidation of fuels was calculated
- Biodegradation continuously measured as biochemical oxygen demand (BOD)
- Biodegradation expressed as a percentage of ThOD

Aqueous Biodegradability - Results



Aqueous Biodegradability Conclusions

- SMDS-2 'readily' biodegradable according to EU legislation
  - ≥ 60% ThOD in "10 day window"
- SMDS-1 was extensively biodegraded
  - ≥ 60% ThOD at end of test, but just failed "10 day" criterion for being classified as 'readily' biodegradable
- Biodegradabilities of SMDS-1 & SMDS-2 were significantly higher than ULSD (a clean diesel reference < 50ppm S)

- Difference expected to be greater with other diesels (>50 ppm S), since their aromatics contents are usually higher than this ULSD reference

- ULSD and blends with SMDS were also extensively biodegraded (≥ 60% ThOD) in OECD 301 F.

Aquatic Ecotoxicity

- Acute ecotoxicity of Water Accommodated Fractions (WAFs) assessed per OECD Test Guidelines 201-203:
  - *Raphidocelis subcapitata* (algae) (201)
  - *Daphnia magna* (water flea) (202)
  - *Pimephales promelas* (fathead minnow) (203)
- Ecotoxicity results expressed as loading rates (mg/L) for 50% effect (EL_{50}) and no observed effect level (NOEL)
- Fuels and Blends tested
  - 100% SMDS-2
  - Blend of 24% SMDS-2 / 76% ULSD
  - Blend of 50% SMDS-2 / 50% ULSD
  - Blend of 76% SMDS-2 / 24% ULSD
  - 100% ULSD (nominally < 50ppm S)

Aquatic Ecotoxicity – Results and Conclusions

- **Definitions – toxicity to aquatic organisms**
  - "toxic" when 1mg/L < EL50 < 10mg/L
  - "harmful" when 10mg/L < EL50 < 100mg/L
  - "not harmful" when 100mg/L < EL50

Results

- SMDS is non-toxic to *D. Magna, R. subcapita and P. promelas* under current EU criterion
  - Tested at 1000mg/L cf. 100mg/L criterion

- Blends tested for two species, *D. Magna, R. subcapita,*
  - 76% and 50% blends would also be classified as "not harmful" to aquatic organisms

Soil Persistence and Toxicity

- Designed to provide information for risk assessment and a better understanding of potential environmental impacts in the event of a terrestrial spill or leakage

Investigations on soil persistence include:

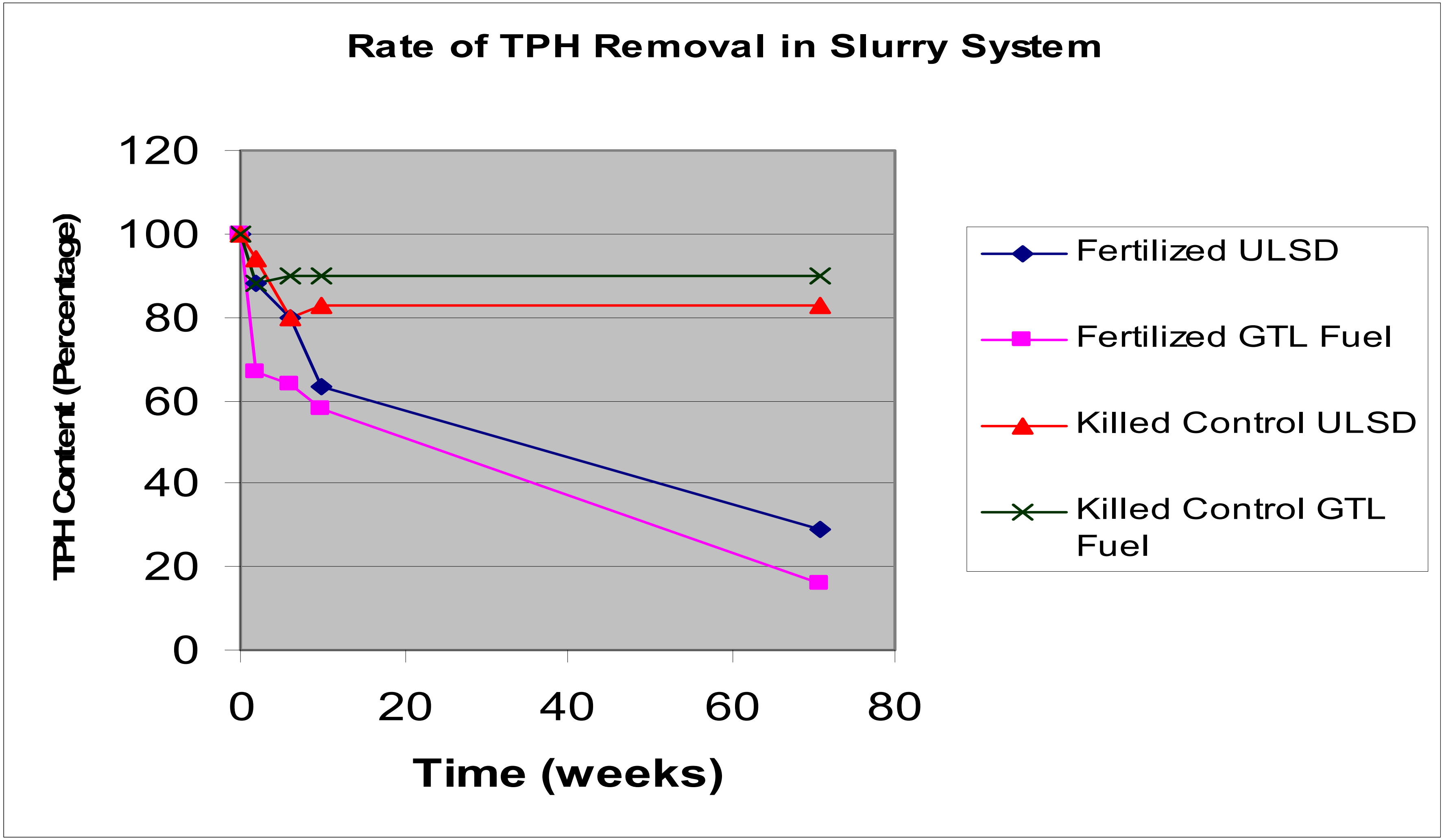
- Neat Shell GTL Fuel and neat EU ULSD ($\leq$ 50 ppm S)
- Static System - (dry soil)
  - live in presence of N and P fertilizers
  - killed control – biologically inactive
- Slurry System - (well mixed wet soil)
  - live in presence of mineral salt media
  - killed control – biologically inactive
- Measurement of Total Petroleum Hydrocarbon (TPH)

Soil Persistence – Static System - (Dry Soil)

Fuel	Time	Degradation Loss	Volatility Loss	Total TPH Loss
GTL Fuel	10 weeks	33%	10%	43%
ULSD	10 weeks	21%	16%	37%
GTL Fuel	71 weeks	74%	10%	84%
ULSD	71 weeks	57%	16%	73%

Note: significant non-biological losses of both fuels is largely due to volatilization

Soil Persistence – Slurry System



Soil Persistence – Slurry System

- More rapid removal of TPH in slurry than in static system
  - At 2 wks, 83% Shell GTL Fuel and 78% ULSD were removed
- Higher biological degradation observed versus static systems
  - At two weeks, 68% Shell GTL Fuel and 60% ULSD were removed
- Higher non-biological losses observed versus static systems – ULSD exhibited a volatility advantage
  - At 2 wks, 15% Shell GTL Fuel and 18% ULSD were removed

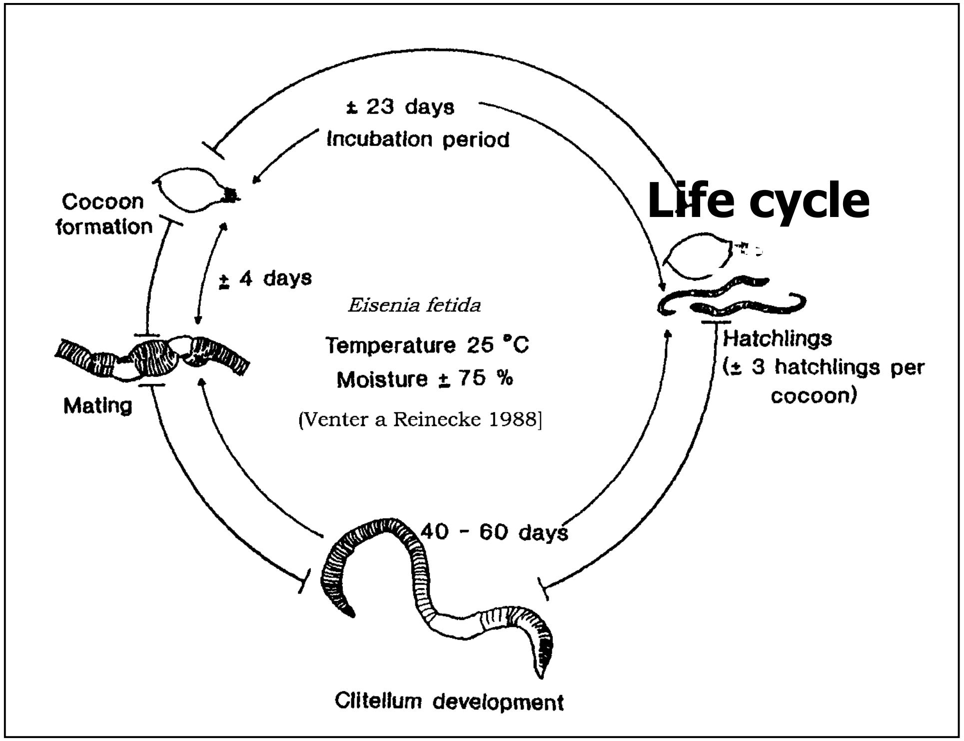
Soil Persistence – Conclusions

- Loss by evaporation is an important mechanism for removal in both static and slurry systems with ULSD evaporative losses greater than for GTL Fuel
- Ideally volatility of both fuels should have been better matched to make biodegradation comparisons easier
- Despite limitations results show that the major removal mechanism in both systems is biodegradation with GTL Fuel losses being statistically greater than those of ULSD
- Results indicate that overall removal of GTL Fuel from soil is greater than the more volatile ULSD

Soil Ecotoxicity

- An earthworm reproduction test following OECD guideline No. 222 was undertaken
- Earthworms are standard test organisms in terrestrial ecotoxicology as they represent primary decomposers which are key to soil function
- Earthworms (*Eisenia fetida*) were exposed to artificial soil that had been treated with either GTL Fuel or ULSD at concentrations that ranged from 0.01 – 3 g/Kg
- Adult survival and weight change was assessed after 28 days, and reproduction was assessed after 56 days

Earthworm *Eisenia fetida*



Soil Ecotoxicity – Results and Conclusions

- At the highest dose tested (3g/Kg) adult earthworms exposed to GTL Fuel were able to survive and produce young, whereas 85% of adult worms exposed to ULSD died, and no reproduction took place.
- Results from the earthworm test indicate that, as was found in the aquatic studies, GTL fuel is less toxic to soil organisms than ULSD.

Conclusions

- It has been previously shown that GTL Fuels exhibit improved engine emissions and that GTL Fuel Sustainability (based on an assessment of the entire production, processing and usage phases) is comparable to refinery fuels
- The unique properties of GTL Fuel offer environmental benefits in comparison to ULSD which include:
  - Enhanced aquatic and soil biodegradability
  - Lower aquatic and soil ecotoxicity
- The combination of these features indicate that GTL Fuel is less likely to cause adverse environmental impacts than clean conventional fuels such as ULSD