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EUROPEAN COMMISSION DIRECTORATE-GENERAL Joint Research Centre

Biofuel Generations: Learnings from the JEC Biofuels Programme and the NREAPs

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Fuels & Emissions, Refinery Technology

15th March, 2011

JEC Biofuels Programme

- EU Regulatory Environment
- Biofuel Generations
- The JEC Biofuels Programme
  - Background to the JRC/EUCAR/CONCAWE Consortium
  - 'Fleet & Fuels' Model
  - Biofuel Implementation Scenarios
  - Results and Conclusions
- CONCAWE research to support future biofuel specifications

EU Regulatory Environment

- **Renewable Energy Directive (RED)**
  - Requires Member States to meet 10% renewable energy share in the transport sector by 2020 (detailed in National Renewable Energy Action Plans)
  - Requires sustainable cultivation and production of Biofuels as well as minimum greenhouse gas (GHG) savings per energy unit
- **Fuels Quality Directive (FQD)**
  - Requires fuel suppliers to achieve at least 6% GHG saving from fuels supplied in 2020 with indicative targets (versus a 2010 baseline)
  - Specifies an E10 main grade with E5 'protection grade' for older vehicles
- **Vehicle Regulated Emissions**
  - Light-duty (LD) passenger cars: Euro 5/5b to 2014, Euro 6 from 2015 onwards
  - Heavy-duty (HD) vehicles: Euro V to 2013; Euro VI from 2014 onwards
- **Vehicle CO_2 Emissions**
  - LD passenger cars: new vehicle fleet average 130g/km by 2015 and review of 2020 targets
  - Light Commercial Vehicle (LCV) fleet: new fleet average 175g/km by 2015 and review of 2020 targets

Coming Decade for European Road Transport

- **Vehicles:**
  - More advanced engines & aftertreatment, diversification in engines and fleet
  - Fuel consumption of LD vehicles falling, HD diesel demand slightly increasing
  - Increasing pressure on CO_2 emissions with associated higher cost
  - Customer preferences potentially in conflict with mobility policies
- **Refineries:**
  - Increasing imbalance in diesel/gasoline demand ratio
  - Higher CO_2 emissions due to diesel demand and product specifications
  - Increasing pressure on CO_2 emissions with associated higher cost
- **Biofuels and other Renewables:**
  - Renewables in transport fuels mandated to 10% (energy basis) by 2020
  - Conventional biofuels widely available but with sustainability concerns
  - Slower than expected pace of development for advanced biofuels
  - National Renewable Energy Action Plans (NREAPs) show that pace/priorities differ across Member States, potentially leading to fuel diversification
  - CEN specifications are struggling to keep pace with legislative mandates

Biofuel Generations

	Defined By Feedstock Utilised		Defined By Technology Maturity
"1st Generation"	■ Ethanol from sugar cane, grains, sugar beets, etc.	■ FAME from: ■ vegetable oils ■ animal, waste oils	Widely available <u>commercial technology:</u> ■ Fermentation ■ Etherification ■ Esterification
"2nd Generation"	■ Ethanol from biomass ■ DME from black liquor	■ Hydrogenated oils ■ FAME from: ■ non-edible seeds (jatropha, karanja) ■ new seed oils (cuphea, crambe, cotton seed) ■ Biomass to Liquids	Being implemented or <u>at pilot plant stage:</u> ■ Hydrogenation ■ Hydrotreating ■ Gasification/synthesis ■ Lignocellulose process
"3rd Generation"	■ Biogas from waste ■ Biohydrogen	■ Biodiesel from algae	<u>At research stage:</u> ■ Pyrolysis ■ Hydrothermal upgrade

Winning technologies must:

- ➢ Reduce GHG emissions on a Well-to-Wheels basis
- ➢ Be energy efficient, sustainably produced, and cost-competitive
- ➢ And perform well in customer's vehicles!

The JEC Consortium: A Short History

The JEC Research Consortium was initiated in 2000 by:

- JRC: Joint Research Centre of the European Commission
- EUCAR: European Council for Automotive R&D
- CONCAWE: Research Association of the European Oil Refining Industry

JEC Consortium Activities:

- **2000-2011: Projects Completed**
  - Well-to-Wheels (WTW) Study Versions 1, 2b, and 2c
  - WTW Study Version 3: Tank-to-Wheels (TTW) (http://ies.jrc.ec.europa.eu/about-jec)
  - WTW Study Version 3: Well-to-Tank (WTT) and Well-to-Wheels (WTW)
  - Impact of ethanol on vehicle evaporative emissions (SAE 2007-01-1928)
  - Impact of ethanol in petrol on fuel consumption and emissions
  - JEC Biofuels Programme for a 2020 time horizon ← This presentation
- **2011+: Projects under discussion**
  - 2011+: Revision of WTW Study (Version 4)

JEC Biofuels Programme: Objectives

- **Objectives of the JEC Biofuels Programme:**
  - Clarify the opportunities and barriers to achieve 10% renewable energy (on an energy basis) in the transport sector by 2020
  - Focus on road transport with the development of an EU27+2 "Fleet & Fuels" Model as the main supporting tool
  - Focus on conventional and alternative fuels and biofuel blends while accounting for growth in alternative powertrains over decade
  - Develop biofuel implementation scenarios in which the introduction of biofuel blends to meet the 2020 target is seamless to consumers and results in no detrimental impact on vehicle performance and emissions
- **Three-year JEC Program initiated in February, 2008 (2008-2010)**

'Fleet & Fuels' Model

- **Spreadsheet-based 'Fleet & Fuels' model developed to simulate the EU27+2 vehicle fleet development and demand for fossil fuels and biofuels (2020 outlook):**
  - Focus on technical feasibility of achieving the 10% energy RED target with an associated calculation of FQD Article 7a GHG savings
  - Realistic assumptions regarding vehicles, fuels and renewable types
  - Based on historical vehicle fleet accepted by European Commission (TREMOVE)
  - Study did not assess viability, costs, logistics, or commercial readiness of analyzed scenarios
  - "Integrated Approach", i.e. all transport modes and actors were considered but with a clear focus on road transport

'Fleet & Fuels' Model: Vehicle (and Fuel) Options

Seven LD passenger car types (and fuel type options)

- Gasoline, Diesel, Flex-Fuel Vehicle (FFV)
- Compressed Natural Gas (CNG), Liquefied Propane Gas (LPG)
- Plug-in Hybrid Electric Vehicle (PHEV), Battery Electric Vehicle (BEV)

Three Van classes (and fuel type options)

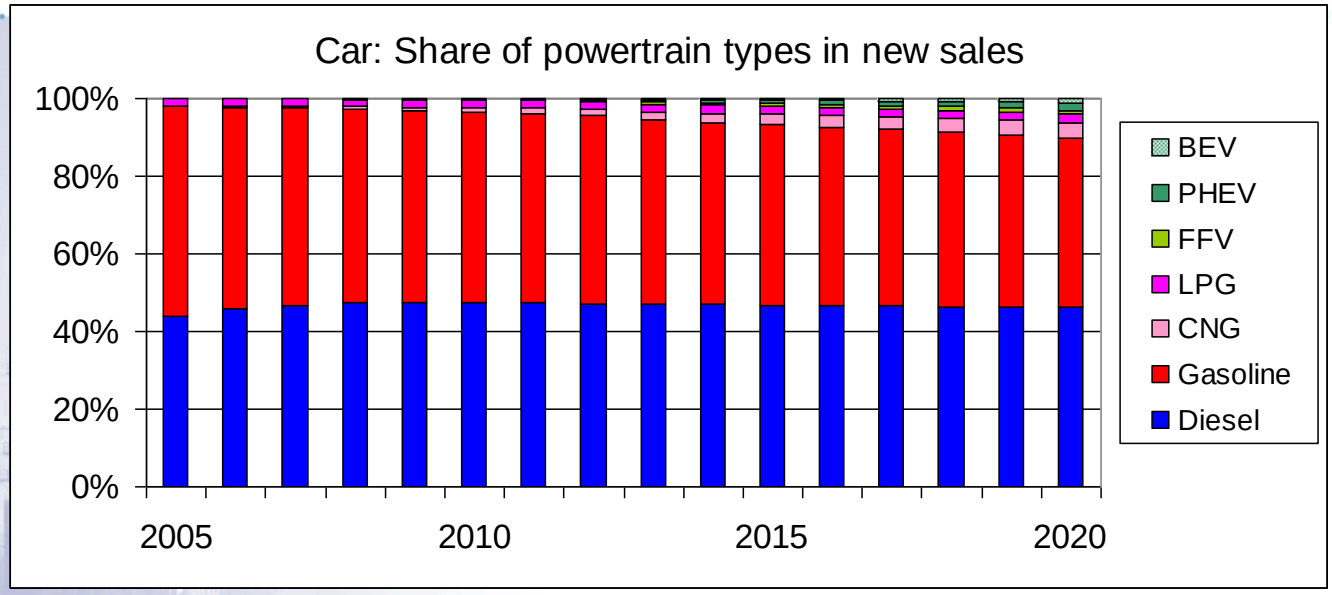
- Gasoline (Gasoline, CNG, LPG, xEV)
- Small Diesel <2.5 tonnes (Diesel, CNG, LPG, xEV)
- Large Diesel >2.5 tonnes (Diesel, CNG, LPG, xEV)

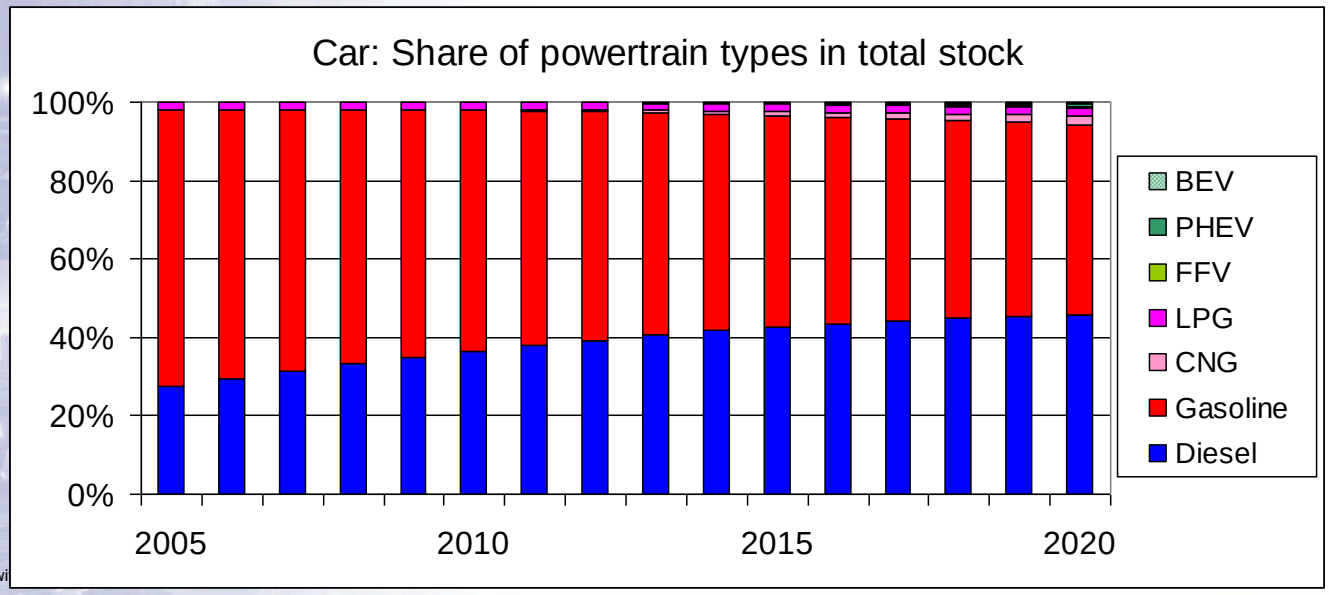
Five Heavy-duty vehicle classes (and fuel type options)

- 3.5 to 7.5 tonnes (Diesel, CNG)
- 7.5 to 16 tonnes (Diesel, CNG)
- 16 to 32 tonnes (Diesel, CNG, E95, DME)
- > 32 tonnes (Diesel)
- Buses and coaches (Diesel, CNG, E95)

xEV: represents the various electrified vehicles as BEV, PHEV, FCEV

'Fleet & Fuels' Model: Fleet Development





Vehicle fleet development in the Reference Scenario

- LD new car sales showing the growth of alternative vehicles over the decade
- LD vehicle fleet showing the impact of new car sales on the overall fleet
- Note the growth in the LD diesel fraction over the decade

'Fleet & Fuels' Model: Fuel Assumptions

- **Fuel assumptions:**
  - Optimistic assumptions for biofuel blending at max allowed specification (that is, E10 means E10 for all compatible vehicles)
  - Up to 3 different gasoline grades: 'protection grade', main grade, and E85
  - Up to 2 different diesel grades: 'protection grade' and main grade
  - Vehicle 'vintage' (Model Year) specified to be compatible with each fuel grade
  - HVO and some BTL included in diesel pool assuming full backward compatibility
  - Lignocellulose ethanol will be limited but sugarcane ethanol will not
  - Other oxygenates (e.g. ETBE, butanol): not specifically modeled but would be allowed up to the maximum oxygen specification
- **RED calculation included "extra credits" for advanced biofuels and renewable electricity**

Renewable Energy and GHG Calculations

Focus of the JEC Biofuel Programme:

- Model renewable energy in road transport.
- Use RED methodology to calculate **ROAD-%** contributions.
- Combine **ROAD-%** with reasonable assumptions for other transport sectors to calculate the **RED-%**

Calculation of the contribution of road transport to the RED 10% target:

$$\text{ROAD-\%} = \frac{\text{All types of energy from renewable sources consumed in road transport}}{\text{Petrol, diesel, biofuels consumed in road, inland navigation and rail transport, and electricity (in transport) but excluding off-road } ^{2)}}$$

Calculation of the overall RED-% of renewable energy in transport (Art. 3(4) of the RED):

$$\text{RED-\%} = \frac{\text{All types of energy from renewable sources consumed in all forms of transport}^{1)}}{\text{Petrol, diesel, biofuels consumed in road, inland navigation and rail transport, and electricity (in transport) but excluding off-road } ^{2)}}$$

1) Renewable energy in Road, Rail, Aviation, Inland Navigation and Pipeline Transport

2a) Off-road means mobile machinery (forestry, agriculture, and construction) ~20Mtoe

2b) CNG & LPG in road transport are not included, BUT: Biogas (= biofuel) is included

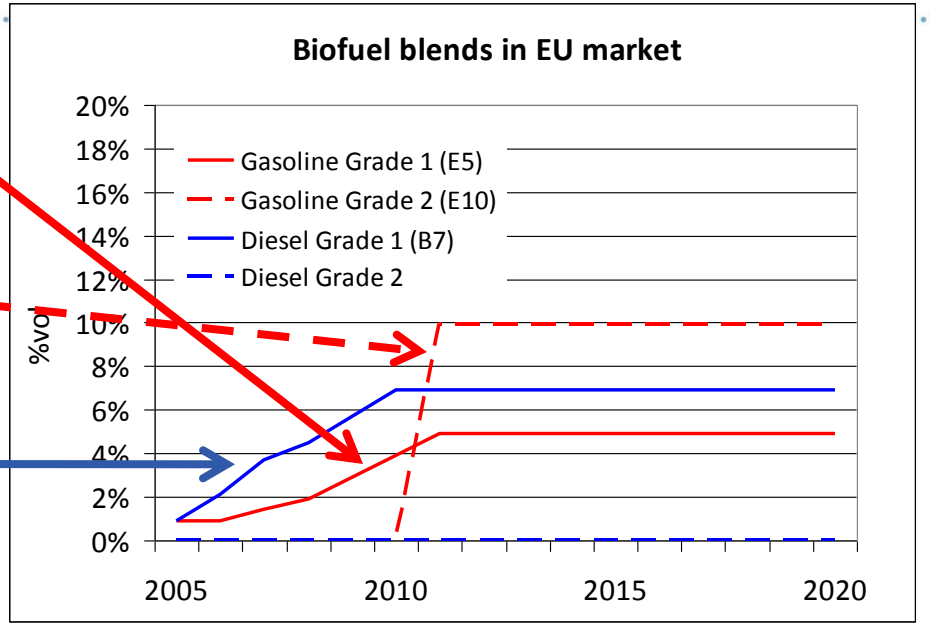
Application of factors:

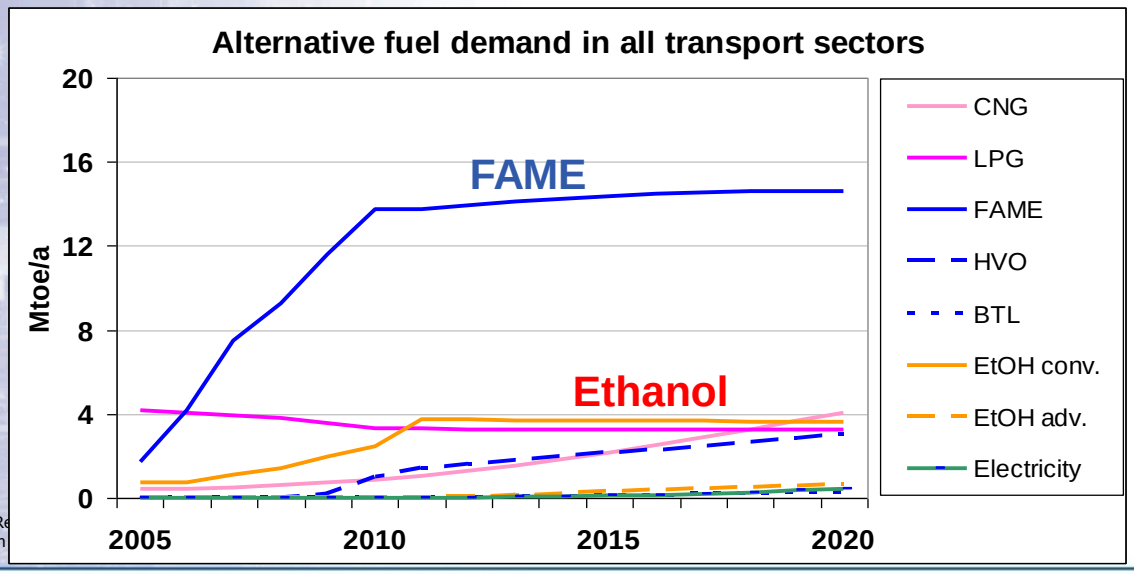
- "*Advanced Biofuels*" count 2 times in numerator (support)
  - Definition: biofuel from waste, residue and non-food cellulosic material, Article 21(2)
- *"Green Electricity"* for road transport counts 2.5 times in numerator & denominator (efficiency factor)
  - Definition: electricity from renewable sources, Article 3(4)

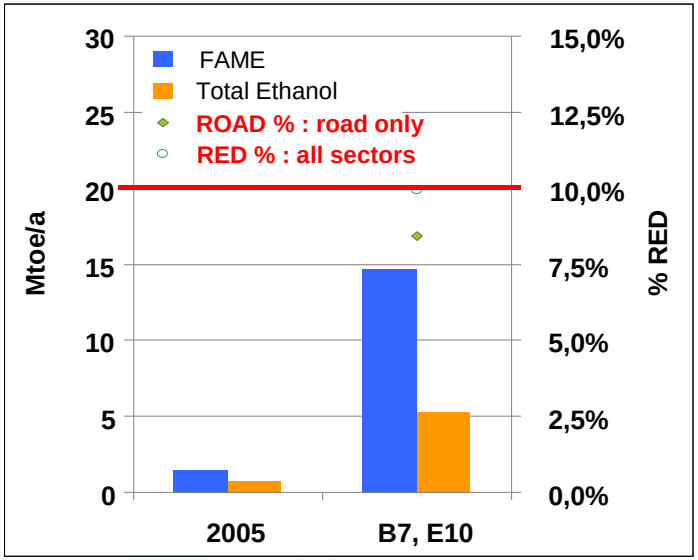
Reference Scenario 1: Parameters and Results

Biofuel grades in **Reference Scenario 1**

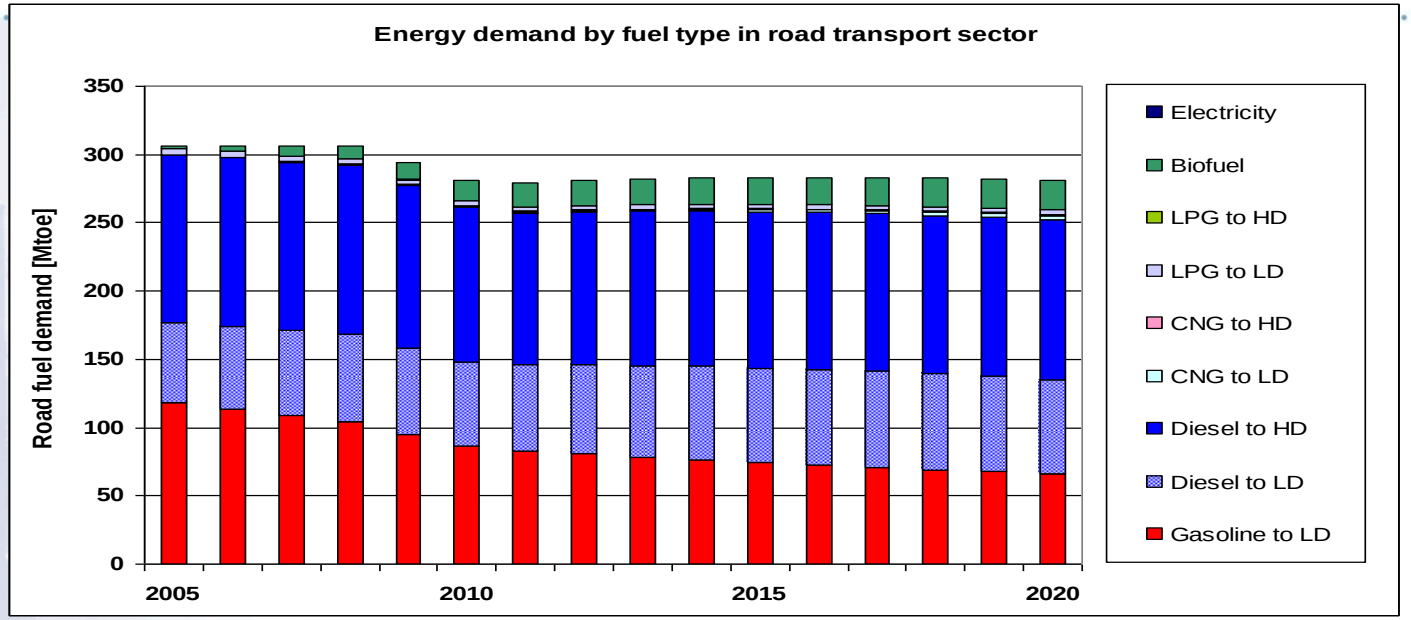
- Increasing ethanol in petrol up to **E5** by 2011
  - No vehicle compatibility restriction ('protection grade')
- New **E10** (main) grade introduced in 2011
  - Vehicles compatible with E10 assumed to be MY2005+
- Increasing FAME in diesel up to **B7** by 2010
  - No vehicle compatibility restriction







Reference Scenario 1: Results



Results comparing 2010 and 2020 (road fuel demand projection includes the impact of the 2008-2010 economic recession):

- Fossil demand changes:
  - Gasoline demand decreases by 24%
  - Diesel demand increases by 6%
  - Diesel demand increases 13% for LD, 3% for HD
  - Diesel/gasoline ratio increases from 2.0 to 2.8
- Large biofuel volumes will be needed
- Increasing demand for CNG & Compressed BioGas
- Renewable energy use in road transport ~8.6%

Biofuel Implementation Scenarios

Scenario 1	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline Grade 1						E5						
Gasoline Grade 2			E10									
Gasoline Grade 3												
Diesel Grade 1						B7						
Diesel Grade 2												

Scenario 2	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline Grade 1				E5					E10			
Gasoline Grade 2			E10						E20			
Gasoline Grade 3												
Diesel Grade 1						B7						
Diesel Grade 2												

Scenario 3	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline Grade 1						E5						
Gasoline Grade 2			E10									
Gasoline Grade 3												
Diesel Grade 1						B7						
Diesel Grade 2									B10 (all)			

Scenario 4	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline Grade 1				E5					E10			
Gasoline Grade 2			E10						E20			
Gasoline Grade 3												
Diesel Grade 1						B7						
Diesel Grade 2									B10 (all)			

Scenario 5	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline Grade 1						E5						
Gasoline Grade 2			E10									
Gasoline Grade 3												
Diesel Grade 1						B7						
Diesel Grade 2									B15 (HD)			

Scenario 6	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline Grade 1						E5			E10			
Gasoline Grade 2				E10					E20			
Gasoline Grade 3												
Diesel Grade 1						B7						
Diesel Grade 2									B10 (HD)			

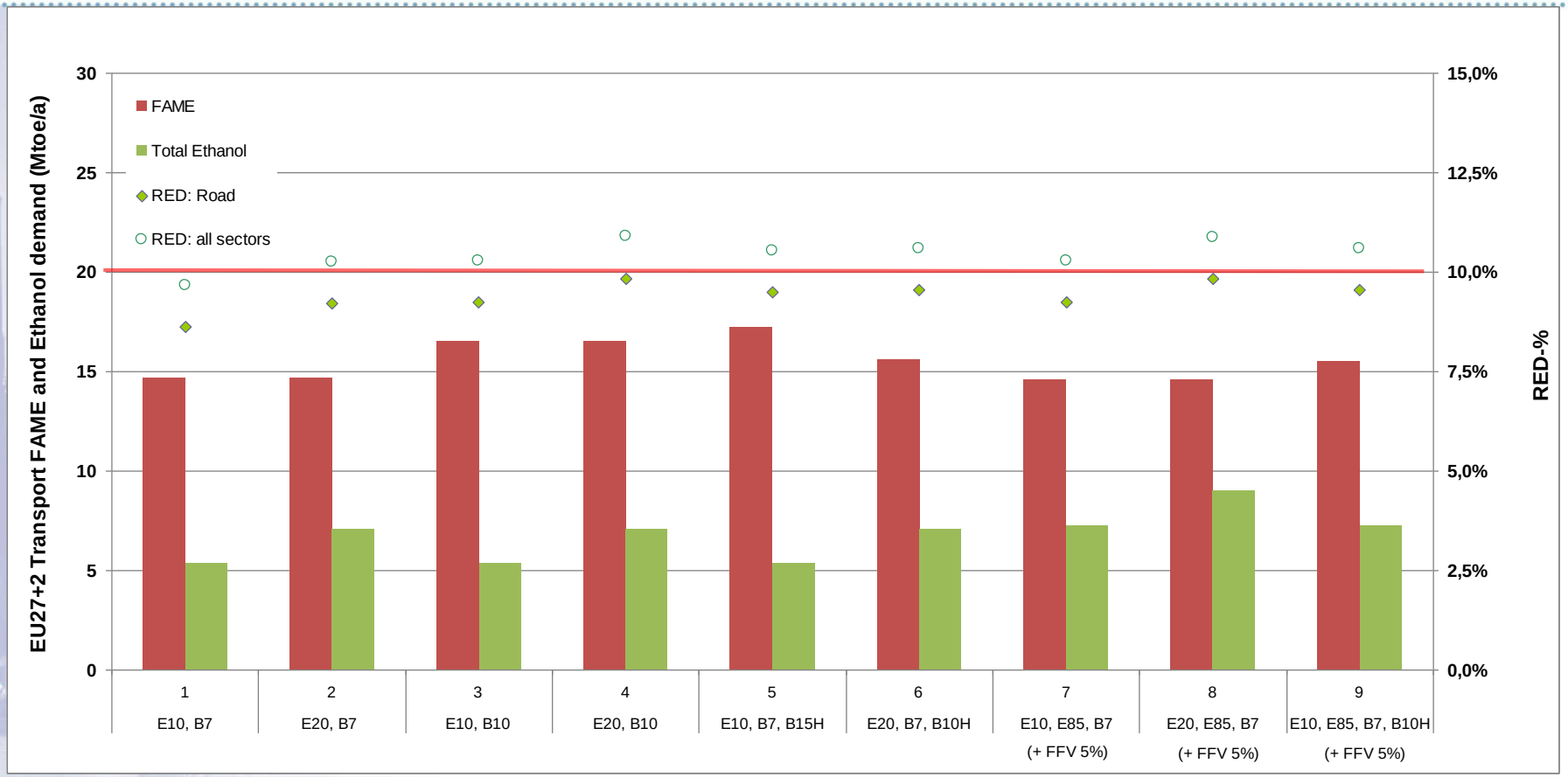
Scenario 7	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline Grade 1						E5						
Gasoline Grade 2				E10								
Gasoline Grade 3				E85								
Diesel Grade 1						B7						
Diesel Grade 2												

Scenario 8	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline Grade 1						E5			E10			
Gasoline Grade 2				E10					E20			
Gasoline Grade 3				E85								
Diesel Grade 1						B7						
Diesel Grade 2												

Scenario 9	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Gasoline Grade 1						E5						
Gasoline Grade 2				E10								
Gasoline Grade 3				E85								
Diesel Grade 1						B7						
Diesel Grade 2									B10 (HD)			

- **Scenario 1: Reference Case**
- **Scenario 2-4: High Biofuel Grades**
- **Scenarios 5-6: High Biodiesel Grades (HD)**
- **Scenarios 7-9: Plus Flex-Fuel Vehicles**

Biofuel Implementation: Scenario Summary



- FAME demand: 14.6 to 17.2 Mtoe (compare to 5.7 Mtoe in 2007, biofuels barometer)
- Ethanol demand: 5.3 to 9.0 Mtoe (compare to 1.2 Mtoe in 2007, biofuels barometer)

- **ROAD-%** (road contribution): 8.6% to 9.8%
- **RED-%** (all sectors contribution): 9.7% to 10.9%

Biofuel Scenarios: RED vs. FQD

Scenario		1	2	3	4	5	6	7	8	9
Biofuel Blends In 2020	Gasoline 1	E5	E10	E5	E10	E5	E10	E5	E10	E5
	Gasoline 2	E10	E20	E10	E20	E10	E20	E10	E20	E10
	Gasoline 3							E85	E85	E85
	Diesel 1	B7	B7	B7	B7	B7	B7	B7	B7	B7
	Diesel 2			B10 (ALL)	B10 (ALL)	B15 (HD)	B10 (HD)			B10 (HD)
ROAD-%	Road only	**8.6%**	**9.2%**	**9.2%**	**9.8%**	**9.5%**	**9.5%**	**9.2%**	**9.8%**	**9.6%**
RED-%	All modes	**9.7%**	**10.3%**	**10.3%**	**10.9%**	**10.5%**	**10.6%**	**10.3%**	**10.9%**	**10.6%**
GHG Savings FQD Art 7a		**-4.4%**	**-4.7%**	**-4.7%**	**-5.1%**	**-4.9%**	**-4.9%**	**-4.7%**	**-5.0%**	**-4.9%**

- Contribution of renewable fuels is sufficient to achieve the RED target but not sufficient to meet the FQD Article 7a target for the scenarios and assumptions evaluated in this study
- To achieve the 6% GHG saving target (FQD Art.7a), **average** GHG savings for **all** biofuels assumed in these scenarios would need to be in the range of 63-73%

JEC Biofuels Programme: Key Conclusions

- **Scenarios exist that can achieve the RED 10% energy target for renewable energy in the transport sector with the given assumptions**
- **None of these scenarios achieves the minimum 6% GHG target (FQD Art. 7a) with the given scenarios and assumptions**

- **Realization of the scenarios will depend on:**
  - Biofuel supply, especially the availability of sustainable biofuels in Europe
  - Vehicle compatibility, their pace of introduction, and CEN specifications
  - Compatibility of the supply and distribution system for all fuel products
  - Non-road contributions to RED-%, especially HVO/BTL use by the aviation sector
  - Each scenario would need policy measures (including incentives) to enable a smooth transition from today to the **"theoretically achievable"** projections

- **Much more technical work is needed to ensure feasibility of these scenarios and compatibility with upcoming Euro 6 emissions limits**
  - Compatible vehicles, fuels, & biofuels will take time, testing, and investments
  - Multi-stakeholder coordination and timely decisions will be essential
  - Seamless transition is important to ensure continued customer confidence

CONCAWE Research Related to Biofuels

- **Research related to Ethanol/Petrol Blends**
  - Literature review on volatility and vehicle driveability performance of ethanol/petrol blends (CONCAWE 8/09)
  - Analytical blending study on bioethanol/petrol blends from 5 to 25% vol (http://ec.europa.eu/energy/renewables/studies/biofuels_en.htm)
  - Impact of ethanol/oxygenates on fuel consumption and emissions (JEC Study)
  - Impact of volatility and oxygenates on vehicle emissions and driveability (2011 study)
  - Importance of Research and Motor Octane in modern vehicles (2011 study)

- **Research related to FAME/Diesel Blends**
  - Impact of FAME up to 50% v/v on vehicle fuel consumption and emissions (SAE 2010-01-1484 plus two CONCAWE reports in preparation)
  - Oxidation stability of FAME/diesel blends during prolonged vehicle storage (2010 ACEA/CONCAWE/Industry Study)
  - Laboratory oxidation study on FAME/diesel blends (2011 study)
  - Impact of biodiesel specifications on vehicle emissions and performance (2011 study)

JEC Biofuels Programme

The study report will be available soon on the JRC website:

http://ies.jrc.ec.europa.eu/about-jec

For questions / inquiries / requests / notes

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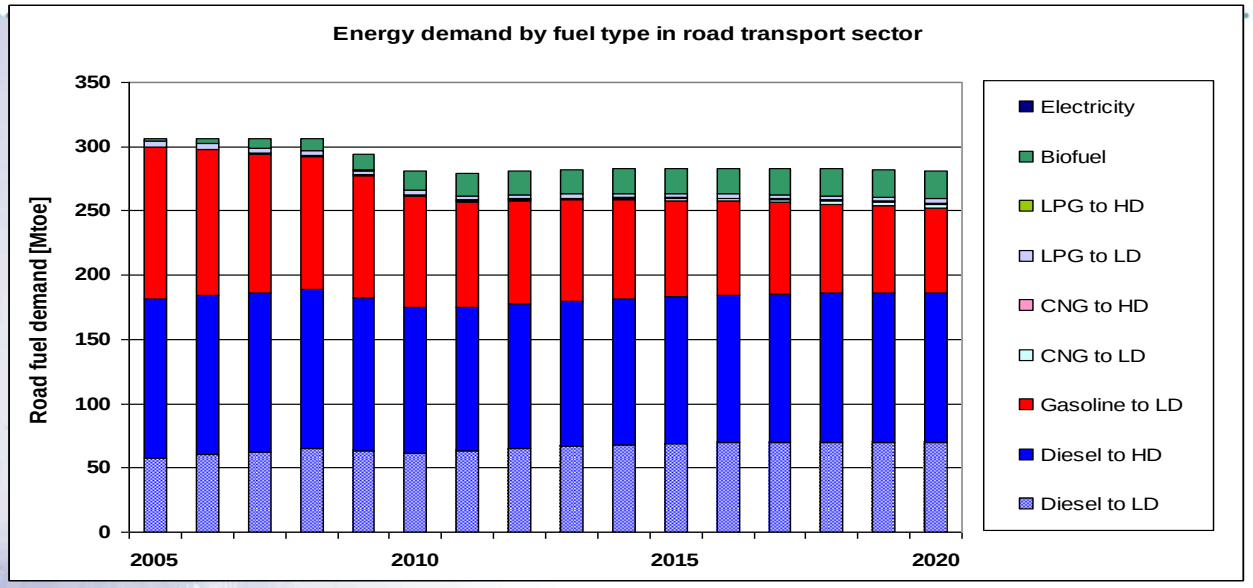
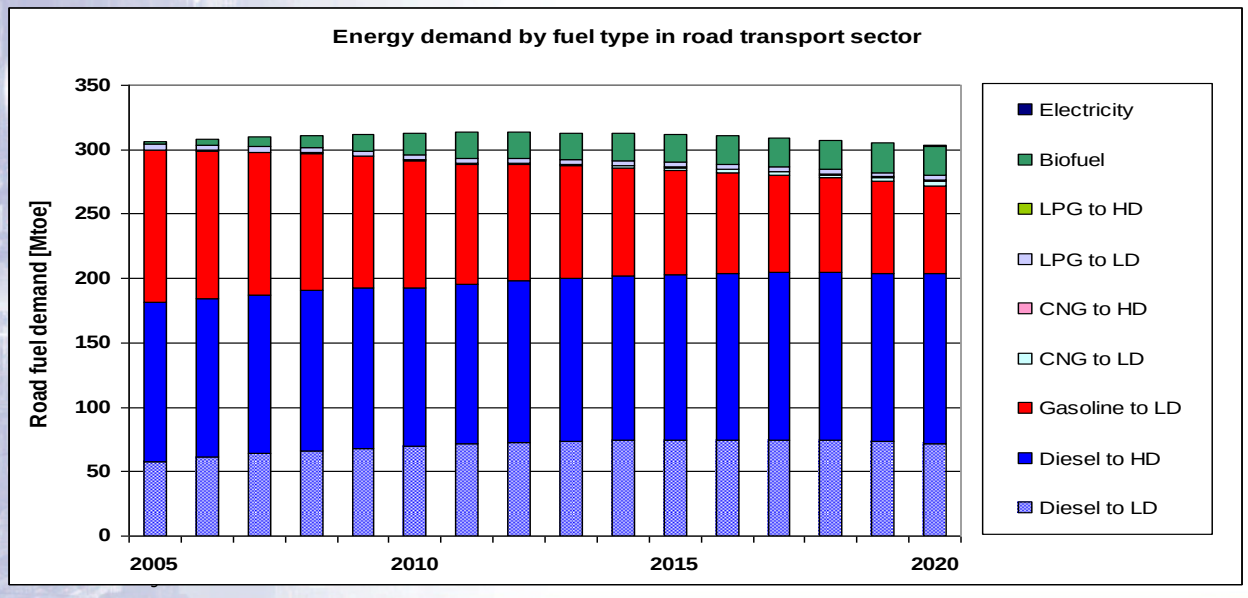
Back-up Charts

'Fleet & Fuels' Model: Fuel Demand



Road transport fuel demands

- Reference Scenario including the impact of the economic recession



- Reference Scenario excluding the impact of the economic recession

Reference Scenario 1: Alternative Fleet

Alternative Fuel Passenger Cars	In 2020 New Sales	In 2020 Vehicle Fleet[1]
Flex-Fuel Vehicles (FFV)	1%	0.5%
Compressed Natural Gas Vehicles (CNGV)	4% 0.8 Million	2% ~5 Million
Liquefied Propane Gas Vehicles (LPGV)	2% 0.4 Million	2% ~5 Million
Electric Vehicles Battery Electric (BEV) & Plug-in Hybrid (PHEV)	3% 0.6 Million	1% 2.7 Million

Alternative Fuel Vans	In 2020 New Sales	In 2020 Vehicle Fleet[1]
Compressed Natural Gas Vehicles (CNGV)	4%	1.7%
Liquefied Propane Gas Vehicles (LPGV)	1%	0.4%
Flex Fuel Vehicles (FFV)	1%	0.3%
Electric Vehicles Battery Electric (BEV) & Plug-in Hybrid (PHEV)	2% 24 Thousand	0.4% 90 Thousand

	In 2020 New Sales			
Alternative Fuel Heavy Duty Vehicles	3.5t to 7.5t	7.5t to 16t	16t to 32t	Bus-Coach
Compressed Natural Gas Vehicles (CNGV)	2%	1%	1%	5%
Di-Methyl Ether Vehicles (DMEV)	==	==	0.5%	==
95% Ethanol (E95) Vehicles	==	==	1%	2%

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Biofuel Scenarios: Summary of Results

Scenario		1 (Ref)	2	3	4	5	6	7	8	9
	Blends in 2020	E5, E10, B7	E10, **E20**, B7	E5, E10, B7, **B10**	E10, **E20**, B7, **B10**	E5, E10, B7, **B15 (HD)**	E10, **E20**, B7, **B10 (HD)**	E5, E10, **E85,** B7	E10, **E20, E85,** B7	E5, E10, **E85,** B7, **B10 (HD)**
ROAD-% Contributions:	**1st Gen Biofuels**	6.4%	7.0%	7.0%	7.6%	7.2%	7.3%	6.4%	7.0%	6.7%
	HVO, BTL, Adv. Ethanol	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%	1.4%
	Alt. vehicles LD: CNGV, EV, FFV HD: CNGV, E95V, DMEV	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%	1.4%	1.4%	1.4%
ROAD-%		**8.6%**	**9.2%**	**9.2%**	**9.8%**	**9.5%**	**9.5%**	**9.2%**	**9.8%**	**9.6%**
Other RED-% Contributions	Rail	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%
	Water	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
	Aviation	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Other off-road	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RED-%		**9.7%**	**10.3%**	**10.3%**	**10.9%**	**10.5%**	**10.6%**	**10.3%**	**10.9%**	**10.6%**

Biofuel Scenarios: FQD Article 7a

Impact of Renewable Fuels on Fuel Quality Directive Article 7a (2009/30/EC):

- GHG savings includes fuels used in on-road vehicles, non-road mobile machinery (including rail and inland marine), agricultural and forestry tractors and recreational craft

- GHG savings assumptions for biofuels and alternative fuels (vs. 2010 fossil fuel baseline):
  - 2010 fossil fuel baseline emissions per unit energy = **86.7**g CO_2/MJ [1)]
  - GHG savings do not assume potential improvements in biofuel production higher than 60% GHG reduction
    - 50% GHG reduction for existing biofuel plants up to 1/1/2017
    - 60% GHG reduction for new biofuel plants from 1/1/2017
  - Reductions apply uniformly to all ethanol, FAME, HVO, BTL, DME, road electricity, and biogas component in CNG
  - CNG is assumed to contain 20% biogas in 2020
  - Road electricity receives a 2.5 times credit; Rail electricity is excluded

1) Source: JEC WTW Version 2c fossil fuel default values and 2010 fossil fuel demand