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Market and Economic Feasibility Analysis for the Implementation of 2nd Generation Biofuels in Greece

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Abstract:
Increasing demand for fossil fuels worldwide coupled with environmental concerns has intensified the focus on Renewable Energy Sources. So-called ‘2nd generation’ biofuels, produced from residues, waste or cellulosic material, present distinct advantages over fossil fuels and can contribute to energy security and sustainable development of society.

This paper aims to demonstrate that Greece holds sufficient resources to support indigenous and possibly economic production of 2nd generation biofuels in order to meet the European Union ‘Renewable Energy Directive’ targets. These mandate 10% share of biofuels in the transport sector for member states by 2020 with continuous penetration of advanced biofuels towards the 2030 horizon (RED II). A market analysis has been performed to review the biofuels market in Greece and investigate the availability of 2nd generation resources, followed by economic feasibility assessment of their production routes.

Individual results identify substantial market gap, with potential to be filled through indigenous production of 2nd generation biofuels. This presents significant short to medium term growth opportunity as well as an attractive investment, provided appropriate technological pathways and feedstocks are selected that minimize overall supply-chain and productions costs, further supported by robust policies. In order to pursue this growth potential, careful central planning, de-risking and policy support from the government is required, followed by a radical reformation of the biofuels industry.

Keywords: *2nd generation biofuels, biomass, renewable energy, market analysis, feasibility analysis*

JEL Classification: Q41, Q42, Q16

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1. INTRODUCTION

Increasing demand for fossil fuels worldwide coupled with environmental concerns has intensified the focus on Renewable Energy Sources (RES). Biofuels play an increasing role in meeting global energy demand and can contribute significantly to sustainable development of the society. So-called '2nd generation' biofuels, produced from residues, waste or cellulosic material, present a recent trend, as they are considerably advantaged in terms of GHG emissions, cost and social acceptability compared to 1st generation biofuels.

Implementation of biofuels in the global energy mix is determined by national and international policies, key drivers for which include energy and environmental security, as well as economic development. At European Union (EU) level, targets for RES implementation are enforced through the 'Renewable Energy Directive' (RED), which mandates a minimum 10% share of biofuels in the transport sector for all member states by 2020, while the recently released RED-II addresses the sustainability issue of biofuels and mandates the reduction of their Greenhouse Gas (GHG) emissions by phasing out gradually food crop-based biofuels. The commitment of the Greek government to meet the RED targets by 2020 translates into measurable opportunities.

In principle, the market evolution towards 2nd generation biofuels is not only mandated by sustainability and quality issues of 1st generation biofuels that do not allow the extent of biofuels penetration according to the European regulatory framework, but also corresponds to a unique opportunity for Greece to fully exploit the indigenous RES potential and attract significant investments. The attractiveness of the investment environment is driven by the competitive advantage of Greece in terms of raw materials availability, infrastructure and labour, which create the conditions for profitable investments, provided that some degree of support by the government will incentivize the investors. The benefits of such investments can be at multiple fronts, as the industry development will amplify RES penetration, enhance compliance with the EU directives, support the Greek economy and stimulate job creation.

The objectives of the current study are to demonstrate that Greece holds sufficient indigenous resources to support economic production of 2nd generation biofuels; show the growth potential of the sector in Greece; and articulate how this can be achieved.

Similar studies have been conducted by Boukis et al (2009), describing the methodology to estimate biofuels demand in conjunction with demand for transportation fuels, and also outlining a detailed methodology for developing a national policy plan for biomass exploitation in Greece. The analysis describes the current situation with respect to the market of biomass and biofuels in Greece, the potential biomass availability, sourcing and production, the production cost, the supply chain and finally an economic evaluation. Tsita and Pilavachi (2013), also using the Analytic Hierarchy Process, provide a rather complete set of evaluation criteria for all potential pathways of 2nd generation biofuels in terms of economic, technical, social and policy criteria.

A similar approach is followed in this study, the aim of which is to elaborate further on these ideas and show the potential for Greece to produce biofuels by focusing solely on abundant 2nd generation resources.

The structure of the current paper is as follows: The biofuels market penetration required to meet RED targets is estimated in section 2 based on the forecasted demand. Subsequently in section 3, the current market environment in Greece with respect to biofuels supply is investigated, followed in section 4 by the availability of 2nd generation resources to meet RED targets and close the market gap. In section 5, the production economics of 2nd generation biofuels are investigated and an economic evaluation of the most promising route is provided. The constraints of the current business environment (policy, supply-chain, market, technology) are analysed in section 6 and a suitable strategy mix defined in section 7, based on which a conceptual industry model for Greece is proposed. Finally, section 8 presents the conclusions of the study.

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2. ANALYSIS OF DEMAND IN GREECE

Market trends with respect to biofuels demand towards the 2030 horizon are investigated on the basis of demand for transportation fuels, into which they are blended. The projected demand for transportation gasoline and diesel is estimated based on linear regression of historic data from 1990 to 2015 as provided by the Ministry of Environment Energy & Climate Change in Greece (MEECC, 2009a; MEECC, 2015).

After estimating the transport fuels demand, the amount of biofuels blended into the existing transport fuels pool is determined through a national policy plan implemented by MEECC and which is derived from the EU directive that mandates a RES percentage of 10% in the transport sector by 2020.

The 2030 RES scenarios are determined according to the EU commission (European Commission, 2013), energy and climate goals for 2030. These have converged towards a binding EU target of at least 40% reduction of Green House Gas (GHG), corresponding to a 40% RES penetration to the energy mix with the share of biofuels reaching 17.4% in the transport sector (Table 1) according to a scenario by Resch et al (2014).

Table 1: EU RES scenarios by 2030 (Resch et al, 2014)

Overall RES by 2030	30% RES	35% RES	40% RES	45% RES
Transport RES by 2030	9.9%	13.7%	17.4%	20.3%

The forecasted biofuels demand is estimated based on a linear regression model as presented in Figure 1. Since biofuels demand is based on transport fuels demand, naturally a dispersion of the estimates is observed based on the various sources depicted in Figure 1. 2020 predictions are provided in all cases by the given source while 2030 predictions are forecasted via each individual demand model slope. The changing slope of the model estimate is due to the rapid increase of RES share in the transport sector after 2010 based on the national plan (Resch et al, 2014). Nevertheless, the forecast model is found to be in very good agreement with the average biofuels demand data from various sources and reported in Table 2 (model deviation from estimated average equals 2% for 2020 and 0% for 2030 forecasts). The model demand forecast predicts an estimate of 655 ktoe RES consumption in 2020 (literature range 606 – 766 ktoe) and 1234 ktoe RES consumption in 2030 (literature range 907 – 1462 ktoe) to comply with the EU RED. Based on these values the model prediction is closely matching the trends of the literature data.

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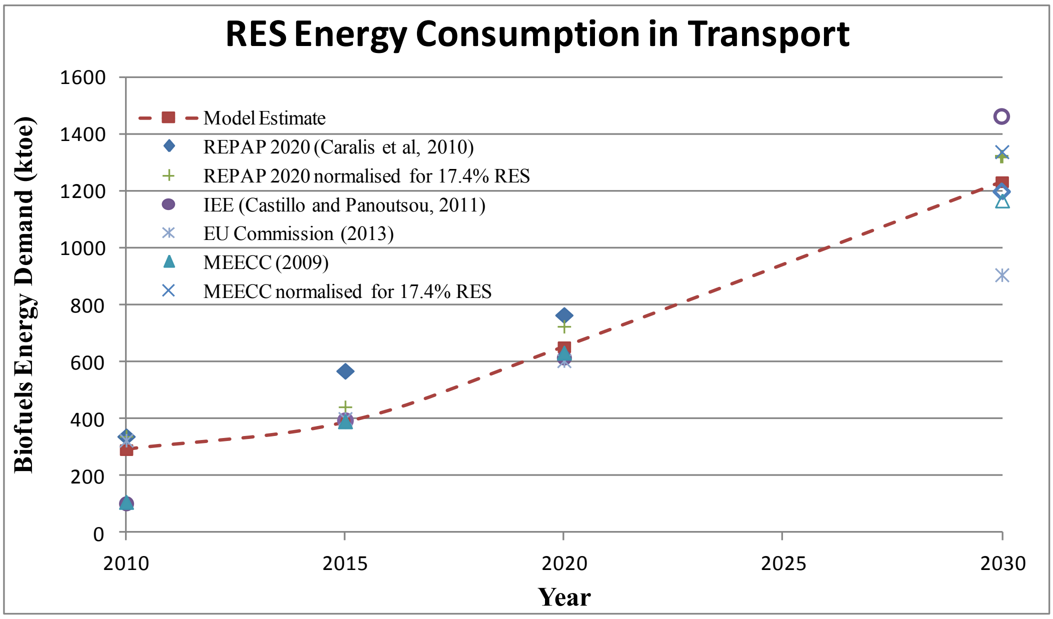

Figure 1: Biofuels demand estimation for transport in Greece

Table 2: Literature total energy consumption and RES contribution in transport

	2010	2015	2020	2030
REPAP 2020 (Caralis et al, 2010)				
Estimated Total Energy Transport (ktoe)	6800	7046	7192	7597
Final RES-T consumption (ktoe)	340	570	766	1198 (1)
Normalized RES (ktoe) (2)	340	444	726	1322 (2)
IEE (Castillo and Panoutsou, 2011)				
Estimated Total Energy Transport (ktoe)	6800	6900	7200	8400 (1)
Final RES-T consumption (ktoe)	105	390	617	1462 (2)
European Commission (2013)				
Estimated Total Energy Transport (ktoe)	6529	6386	5999	5215
Final RES-T consumption (ktoe)	326	402	606	907
MEECC (2009)				
Estimated TOTAL Energy Transport (ktoe)	6774	6864	7257	7699 (1)
Final RES-T consumption (ktoe)	110	393	634	1165
Normalized RES (ktoe) (2)				1340
AVERAGE RES-T DEMAND (ktoe)		**440**	**670**	**1232**
Min		390	606	907
Max		570	766	1462
MODEL RES-T DEMAND (ktoe)	293	**389**	**655**	**1234**
Model deviation (%)		-12%	-2%	0%

Note 1: Values for 2030 not reported in the study, thus estimated from the slope
Note 2: Normalised for 2030 RES% according to Resch et al (2014)

3. CURRENT MARKET AND SUPPLY IN GREECE

Following European Directive 2003/30/EC, the Greek Government introduced a quota mechanism under law L3851/2010 (and OG A/85/2010) aiming to accelerate the implementation of RED targets and fulfil the country's 2020 obligations (Castillo and Panoutsou, 2011).

The quota scheme allows the Government to decide the amount of biofuels (biodiesel) to be supplied to the market each year and allocates an annual, predetermined quantity to

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biodiesel producers based on their ability to meet several criteria. The produced volume is then tax exempt when sold to oil refineries or sellers for blending with regular automotive diesel (Iliopoulos and Rozakis, 2010).

According to the Greek Government Newspaper, the 2015 biofuels supply quota was distributed among 18 companies (down from 20 in 2014). Of these, 12 were production facilities in Greece and 6 were importers from associated EU producers. As shown in Table 3, the biggest share (93%) is for the producers. Industry sources indicate 85% of the produced capacity in the market is distributed via the quota mechanism, while 15% is supplied to the free market. The total nominal installed capacity of the 12 Greek biodiesel plants is 901,290 klitre/yr (718 ktoe), from which only 16% (130,017 klitre/yr) was utilized under the quota mechanism in 2015. The installed capacity corresponds to 58% of 2030 forecasted demand (1232 ktoe), whereas it already exceeds by 7% the 2020 national goals (670 ktoe) if there were no blending limitations. Current utilization however, covers only 17% of 2020 goals and 9% of forecased demand due to blending limitations to the diesel pool, while these targets correspond to both diesel and gasoline pools, causing many assets to be considered stranded.

The allocated quota represents only 35% of the total biofuels demand to meet the RES penetration plans, due to blending limitations of 1st generation biofuels in the diesel pool. Overall biofuels penetration to the transport fuels market is 2.2% (2.6% including the quantity sourced to free market), well below the 2015 target of 6.3% RES. One factor for this is that there is no current indigenous bioethanol production nor any foreseen to cover the additional demand unit the 2020 horizon (Castillo and Panoutsou, 2011).

Feedstock used for indigenous production originates mainly from 1st generation sources such as sunflower, rapeseed and soy, as well as 2nd generation sources such as residual cotton seeds, used vegetable oils (UVOs), used cooking oils (UCOs) and animal fats. According to the raw material supply in 2015, approximately 2/3 of biofuels are produced from 1st generation sources and only 1/3 from 2nd generation sources (corresponding to 0.7% demand coverage of transport fuels).

Based on market data and estimated demand for the biofuels sector, either imports and/or radical reformation of the biofuels industry will be required in order to meet RES energy targets by 2020(Caralis et al, 2010).

Table 3: Biofuels production, imports and quota for 2015 in Greece

(Newspaper of government of republic of Greece, 2015)

Company Name	Nominal Annual Capacity (klitre/yr)	Quota 2015 (klitre/yr)	Quota 2015 (%)
Producers			
BIOENERGIA S.A.	40,000	3,714	2.65%
STAFF COLOUR ENERGY S.A.	13,000	4,254	3.04%
MIL OIL HELLAS S.A.	11,363	7,144	5.10%
AGROINVEST S.A.	286,364	32,636	23.31%
BIODIESEL LTD	23,958	5,238	3.74%
NEW ENERGY S.A.	39,273	13,306	9.50%
COTTON GINNING & SPINNING FRAME S.A.	23,760	788	0.56%
PETSAS S.A.	39,600	756	0.54%
PAVLOS N. PETTAS S.A.	112,500	23,496	16.78%
ELIN VIOKAFSIMA S.A.	90,909	14,095	10.07%
ΜΑΝΟΣ S.A.	93,563	7,356	5.25%
GF ENERGY S.A.	127,000	17,234	12.31%

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Sub-total	***901,290***	***130,017***	***92.9%***
Importers			
HELLENIC PETROLEUM S.A.		1,228	0.88%
REVOIL BIOFUELS S.A.		932	0.67%
AVIN		1,440	1.03%
MOTOROIL HELLAS		2,746	1.96%
TAYLORS ENERGY S.A.		1,818	1.30%
TAYLORS CONSULTING AND COLOURS LTD		1,818	1.30%
SELECTED ENERGY S.A.			0.00%
BIODIESEL S.A.			0.00%
Sub-total		***9,983***	***7.1%***
TOTAL (klitre/yr)		***140,000***	***100%***

4. 2^{ND} GENERATION RESOURCE AVAILABILITY IN GREECE

Based on analysis of supply and demand in Greece, there is ample opportunity for penetration of 2^{nd} generation biofuels in the Greek market, since the established industry seems to be struggling to secure 1^{st} generation feedstock.

In order to generate a nation-wide master plan for penetration of 2^{nd} generation biofuels, it is of paramount importance to identify availability of resources that can be converted to biofuels.

Availability of resources is a necessary pre-condition regarding feasibility of investments in the field of biomass exploitation. Areas in Greece with rich biomass potential and relevant infrastructure (agricultural production) are at the forefront of such investments. According to the national industry roadmap for the penetration of renewable energy sources in Greece by 2020 (Caralis et al, 2010), forestry and agriculture present by far the greatest potential as shown in Table 4. Other potential sources for production of 2^{nd} generation biofuels are by-products from the food industry (e.g. molasses and bagasse from sugar industry), waste oils and animal fats. Collection of reliable and systematic data for biomass potential is, however, not actively carried out in Greece and existing estimates show great variability.

There is huge potential for further growth of the biofuels sector in the years to come, as market penetration needs to increase eight-fold by 2030 (from 2.1% to 17.4%) to meet mandates of the European directive. The forecasted demand for 2030 can be fully met or even exceeded by 2^{nd} generation resources, thus contributing significantly to economic and sustainable development of the country.

The abundance and accessibility of biomass feedstock together with the availability of agriculture infrastructure and agriculture labour are competitive advantage indicators for the Greek biofuels industry. Eventually, these indicators can translate to competitive advantage provided that biofuels cost remains lower than elsewhere in Europe, through supply chain optimization and continuous access to cheap abundant feedstock.

An additional advantage is protection from external sources, shown from the very low imports presented in Table 3, due to the regional nature of the market with low competition from neighbouring countries according to the European Commission statistics and forecasts.

Furthermore, assuming government intervention becomes limited in the future, penetration of low cost producers of 2^{nd} generation biofuels should retain a competitive advantage, while incentives to enter the market will shrink and hence imports will be further limited.

Finally, since future demand and availability of most 2^{nd} generation resources is not compatible with the current supply and existing installations, new conversion technologies should come into play. The production cost of these will play a major role in exploitation of

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2nd generation feedstocks and the installation of new plants. Most importantly, technologies that use cellulosic biomass are needed to meet the full biofuels demand with domestic resources.

Table 4: Energy supply potential of 2nd generation sources by 2030
(Boukis et al, 2009a; Caralis et al, 2010; Castillo and Panoutsou, 2011)

Biomass from Forestry (ktoe) [(1)]	1,361
Biomass from Agriculture (ktoe)	1,500
Olive Husks (ktoe)	89
Waste Oils & Animal Fats (ktoe)	85
Sugarcane by-products (ktoe)	24
Municipal Solid Waste (ktoe)	23
Cotton Ginning Residues (ktoe)	19
Fishery by-products (ktoe)	13
Sewage sludge (ktoe)	10
TOTAL (ktoe)	**3,124**

Note 1: Availability and recoverability of forestry resources is uncertain

5. ECONOMIC ANALYSIS AND EVALUATION

The previous section on market analysis clearly demonstrated that 2nd generation biofuels have the potential to significantly contribute to the transport sector and the country's energy mix. Whether this potential will be realized depends to a large extent on their production economics. Cost and large capital investments are considered to be major barriers to the commercial production of 2nd generation biofuels in the near to medium term. On the other hand, the contribution of feedstock to the total costs is significantly lower in compared to 1st generation biofuels.

Biofuels conversion routes and products are extensively covered in the literature by various authors, for example in the papers of Sims et al (2010), who provide an overview of 2nd generation technologies, or Naik et al (2010) who study the production of 1st and 2nd generation biofuels. In this section, the economic outlook of the various 2nd generation production routes is provided and a selection of the preferred 2nd generation feedstock mix in combination with the most promising technologies is suggested.

Production efficiency is a key performance metric for the various 2nd generation routes since different production methods have different biofuel yields, as shown in related studies (Brown et al, 2013; Carriquiry et al, 2011; Festel et al, 2014; Foust et al, 2009; Naik et al, 2010; Phillips et al, 2011; Tan et al, 2014; Thilakaratne et al, 2014; Trippe et al, 2013; Wright et al, 2010; Zhang et al, 2013a&b; Zhu et al, 2012).

Of the biomass conversion routes, pyrolysis results in the highest product yield, however, the pyrolysis product (also known as bio-oil) cannot be used as a drop-in fuel, but needs additional processing step as shown in **Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**.

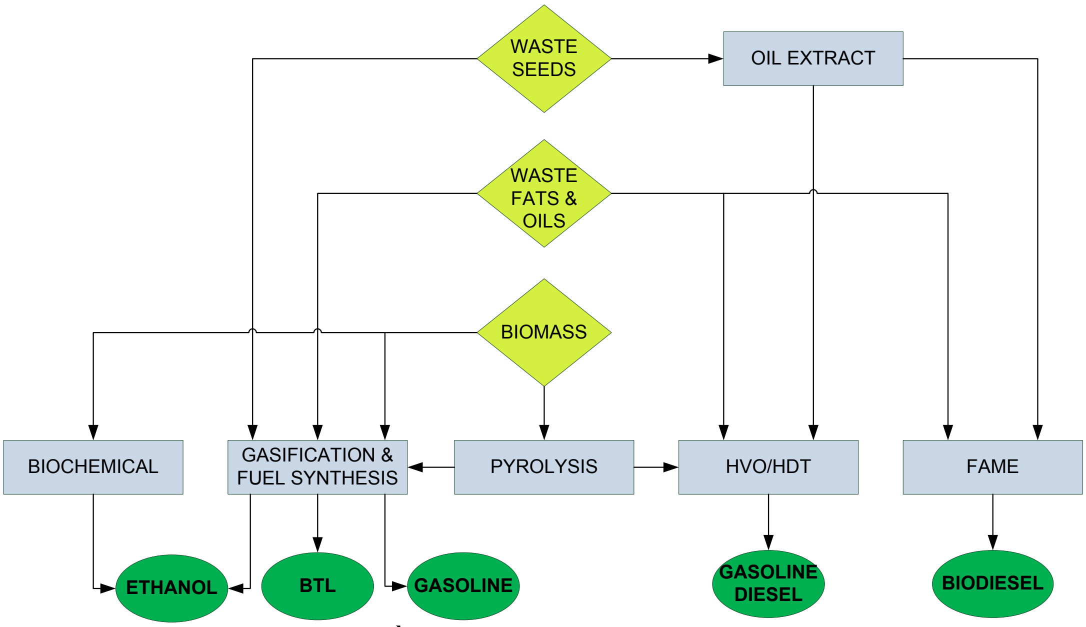

Figure 2: Viable 2nd generation biofuel conversion routes

The above technologies are evaluated and their production costs compared against each other. Production costs include various elements, which are broadly broken down into 3 major categories as part of the current analysis, as shown in Table 5.

Table 5: Production costs breakdown

Production Costs		
Feedstock Cost: Lignocellulosic Biomass Used Cooking Oils Animal fats	Operating Cost: - Personnel & maintenance - Consumables & utilities - Taxes & insurances - By-product credits	Capital Cost: Capital recovery ratio/ Return on investment & interest (annuity factor)

The feedstock cost depends most importantly on the feedstock price and the product yield of each technology. A technology with lower biofuels yield requires larger consumption of raw materials, hence will have increased feedstock cost.

With respect to the feedstock price this is more difficult to assess since biomass is not traded globally. Biomass cost depends on the quality, origin and transport of the resources (Haarlemmer et al, 2014); hence it is connected to a local market rather than to international prices. As part of this study, data from a wide variety of resources have been used to derive the feedstock price for lignocellulosic biomass (Apostolakou et al, 2009; Boukis et al, 2009; Brown, 2015; Festel et al, 2014; Haarlemmer et al, 2014; Haas et al, 2006; Iliopoulos and Rozakis, 2010; Zhang, 2011; Zhang et al, 2013;). Although this approach may not be optimal, the small dispersion of costs, the global price of oil (as biomass transportation is a major cost element) and the large amount of data, mean that the estimated price is expected to be a reasonable representation of the Greek local market price. A better understanding of the locally available biomass feedstock, its geographic distribution and production, transport, storage and processing costs is required to arrive at more accurate figures that reflect the local market (Sims, 2010).

All prices for the biofuels feedstock and products used in the current study are reported in Table 6. The reference year for this price set is 2015, escalated from the various sources (for biomass figures) with an average yearly inflation of 3% as per Haarlemmer et al (2014).

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Table 6: Biofuels feedstock and products prices for 2015

Category	Description	Price
Feedstock	Waste Seed Oils	900 €/ton
	UCOs	660 €/ton
	Animal Fats	588 €/ton
	Lignocellulosic Biomass (1)	87 €/ton
	Biodiesel (FAME) – Regulated	1.20 €/litre
Products	Biodiesel (FAME) – Free Market	0.90 €/ litre
	Ethanol	0.55 €/ litre
	Gasoline (2)	0.74 €/ litre
	Diesel	0.90 €/ litre

Note 1: Average price from various sources (Zhang, 2011 - Manzone, 2009 – Haarlemmer et al, 2014 – Brown et al, 2013) escalated by inflation to 2015
Note 2: Estimate from diesel price at refinery gate based on market data

The major factor in the production of 2nd generation biofuels is the conversion cost in comparison to the relatively cheap raw materials, which is the opposite situation compared to 1st generation biodiesel. These costs as well as investment costs are expected to reduce in time due to the learning effect. Scale effects are expected to remain important; for larger facilities the fixed cost per unit of product will be lower than for smaller facilities. Operating costs for the various 2nd generation biofuel technologies are summarized in Table 7 below according to the various sources (Boukis et al, 2009; Brown et al, 2013; Dutta et al, 2010; Dutta et al, 2012; Rozakis et al, 2013; Festel et al, 2014; Jones et al, 2009; Miller and Kumar, 2014; Phillips et al, 2011; Tan et al, 2014; Thilakaratne et al, 2014; Tripper et al, 2011; Tripper et al, 2013; Wright et al, 2010; Zhang et al, 2013; Zhu et al; 2012). The reference year for these costs is 2015, escalated with an average yearly inflation of 3%.

Table 7: 2nd Generation biofuel technologies operating costs

Conversion technology	Product	Operating Cost (€/litre product)
FAME	Bio-diesel	0.194
HVO / HDT	Renewable Diesel	0.089
Hydrolysis & Fermentation	Bio-ethanol	0.241
Gasification & FT Synthesis & HDT	BTL	0.819
Gasification & MTG Synthesis	Renewable Gasoline	0.248
Gasification & DME Synthesis	Renewable Gasoline	0.597
Gasification & FT & Alcohol Synthesis	Ethanol & Higher Alcohols	0.219
Pyrolysis	Bio-oil	0.112
Pyrolysis & Gasification & FT Synthesis & HDT	BTL	0.931
Pyrolysis & Gasification & DME Synthesis	Renewable Gasoline	0.709
Pyrolysis & Gasification & FT & Alcohol Synthesis	Ethanol & Higher Alcohols	0.331
Pyrolysis & HDT	Renewable Gasoline & Diesel	0.201

The feedstock cost together with the operating cost correspond to the cash cost of production. Adding the capital cost to the cash cost, the overall production cost is derived. In the current

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paper a capital recovery charge is utilized to estimate the total production costs using an annuity factor or a capital recovery ratio as provided by Trippe et al (2011):

$$P_a = \frac{(1+i)^n \times i}{(1+i)^n - 1}$$

i Interest rate

n Expected life time

The investment costs for the various 2nd generation conversion technologies in this study is derived from literature data, scaled for capacity to the year 2015. The escalation of investment costs is done via a cost index such as the Chemical Engineering Index, the Marshal & Swift index or the Process Engineering Programme (PEP) index. Herewith, the PEP index (IHS International) is used, according to the following equation:

$$P_{2015} = P_{Ref} \times \frac{PEP_{2015}}{PEP_{Ref}}$$

Scaling for capacity according to Haarlemmer et al (2014) is done via the following equation:

$$P^{unit} = P^{unit}_{Ref} \times \left(\frac{C^{unit}}{C^{Ref}}\right)^{0.7}$$

C^{unit} Capacity of current plant

C^{Ref} Capacity of reference plant

For plants processing biomass, the scaling factor may vary according to Swanson et al (2010) between 0.6-0.8. This formula proves the economies of scale; for larger capacity the marginal investment decreases and fixed costs are distributed across more product volume. The upper capacity limit is the equipment size for so-called “world-scale” units, beyond which the number of equipment needs to increase, eroding the economy of scale.

Typical scale for biomass gasification plants considered in this study is 400 MWth as per Brown (2015), which corresponds to approximately 2000 t/d biomass intake. This scale matches a typical FT synthesis unit of 150 MWth, producing approximately 280 t/d BTL product. For a HVO/HDT plant, sizes beyond 290 MMlitre/yr (230 kton/yr) increase the feedstock transportation costs such that they balance out any incremental capital benefits from economies of scale according to Miller and Kumar (2014). Based on the same source, however, there are currently two world-scale operating plants by Neste-Oil with capacity of 929 MMlitre/yr each, while the optimum capacity is estimated by the authors to be 812 MMlitre/yr.

Capital costs for the various 2nd generation biofuel technologies are summarized in Table 8 (Brown, 2015; Haarlemmer, 2014).

Table 8: 2nd Generation biofuel technologies specific investment cost

Conversion technology	Product	Specific Investment (€/litre product)
FAME	Bio-diesel	0.18
HVO / HDT	Renewable Diesel	0.59
Hydrolysis & Fermentation	Bio-ethanol	0.82
Gasification & FT Synthesis & HDT	BTL	5.43
Gasification & MTG Synthesis	Renewable Gasoline	1.65
Gasification & DME Synthesis	Renewable Gasoline	1.62
Gasification & FT & Alcohol Synthesis	Ethanol & Higher Alcohols	1.27
Pyrolysis	Bio-oil	1.09

Pyrolysis & Gasification & FT Synthesis & HDT	BTL	6.52
Pyrolysis & Gasification & DME Synthesis	Renewable Gasoline	2.71
Pyrolysis & Gasification & FT & Alcohol Synthesis	Ethanol & Higher Alcohols	2.36
Pyrolysis & HDT	Renewable Gasoline & Diesel	1.71

Economic evaluation and comparison of the various routes is done by estimating the production costs as presented in Table 9, from the addition of the operating costs in Table 7 and the annuity of the specific investment in Table 8. This method is widely used for techno-economic evaluation of biofuels technologies in the literature and is based on breaking down the overall production cost into feedstock, operating & maintenance (O&M) and capital costs as demonstrated by Tijmensen et al (2002). In this way, the different options can be compared on the same basis and the resulting production cost represents the minimum biofuels price to recover the investment and the operating expenditure. By comparing this cost with the market fuel price it can be concluded whether the technology has the potential to generate margin. This is demonstrated in Figure 3**Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.** & Figure 4, where the costs of different technologies are compared against the relevant product price.

Table 9: 2nd Generation biofuel technologies production cost

Feedstock	**Conversion technology**	**Product**	**Production Cost**	
			(€/litre)	**(€/MWh)**
Waste Seeds	FAME	Biodiesel	1.11	116
	HVO / HDT	Renewable Diesel	0.96	95
Waste Fats & Oils	FAME	Biodiesel	0.83	87
	HVO / HDT	Renewable Diesel	0.71	70
	Gasification & FT Synthesis	BTL	3.02	324
	Gasification & MTG Synthesis	Renewable Gasoline	3.02	326
	Gasification & DME Synthesis	Renewable Gasoline	3.00	559
	Gasification & FT & MAS	Ethanol & Alcohols	2.71	461
Lignocellulosic Biomass	Hydrolysis & Fermentation	Bioethanol	0.57	97
	Gasification & FT Synthesis	BTL	1.57	168
	Gasification & MTG Synthesis	Renewable Gasoline	0.77	83
	Gasification & DME Synthesis	Renewable Gasoline	1.06	198
	Gasification & FT & MAS	Ethanol & Alcohols	0.59	100
	Pyrolysis & Gasification & FT	BTL	2.17	233
	Pyrolysis & Gasification & DME	Renewable Gasoline	1.57	293
	Pyrolysis & Gasification & FT & MAS	Ethanol & Alcohols	1.21	206
	Pyrolysis & HDT	Renewable Gasoline & Diesel	0.69	68

Based on these results the following findings are established:

- Waste seed oils are very expensive feedstock for all technologies and unless product is sold at the regulated market price (1.2 €/litre), do not make economic sense based on the current feedstock prices and production methods.

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- UCOs and animal fats make good economic sense for converting to biofuels either in conventional FAME plants (with minor modifications) or in advanced HVO/HDT plants. HVO/HDT plants are more competitive than FAME plants even for zero capital cost of FAME plants (although requiring minor modifications). In the long run and at free market conditions HDT is therefore the preferred technology to convert waste oils and it is expected to displace the old technology.
- Gasification technology followed by FT synthesis to produce BTL, although being the most extensively studied in the literature, is by far the most expensive technology and certainly not viable.
- Biochemical conversion of biomass to bioethanol is the most cost competitive technology for gasoline replacing biofuels, followed by gasification with mixed alcohol synthesis (similar conclusion reported by Foust et al (2009)). For both technologies, however, economics are unfavourable as the ethanol price is marginally lower than the production cost.
- Overall the best technology that produces economically viable biofuels with positive margins is the pyrolysis plus HDT technology, both for diesel as well as for gasoline blended biofuels. In addition, the quality of the drop-in biofuels produced via this route alleviates the blending constraints as opposed to 1st generation biofuels, while reducing considerably the overall GHG emissions in line with the Fuel Quality Directive (FQD) and RED II.
- This technology offers maximum flexibility by co-processing UCOs and animal fats with pyrolysis bio-oil in the HDT unit, while it produces both renewable gasoline and diesel, making a very good business case from all perspectives.

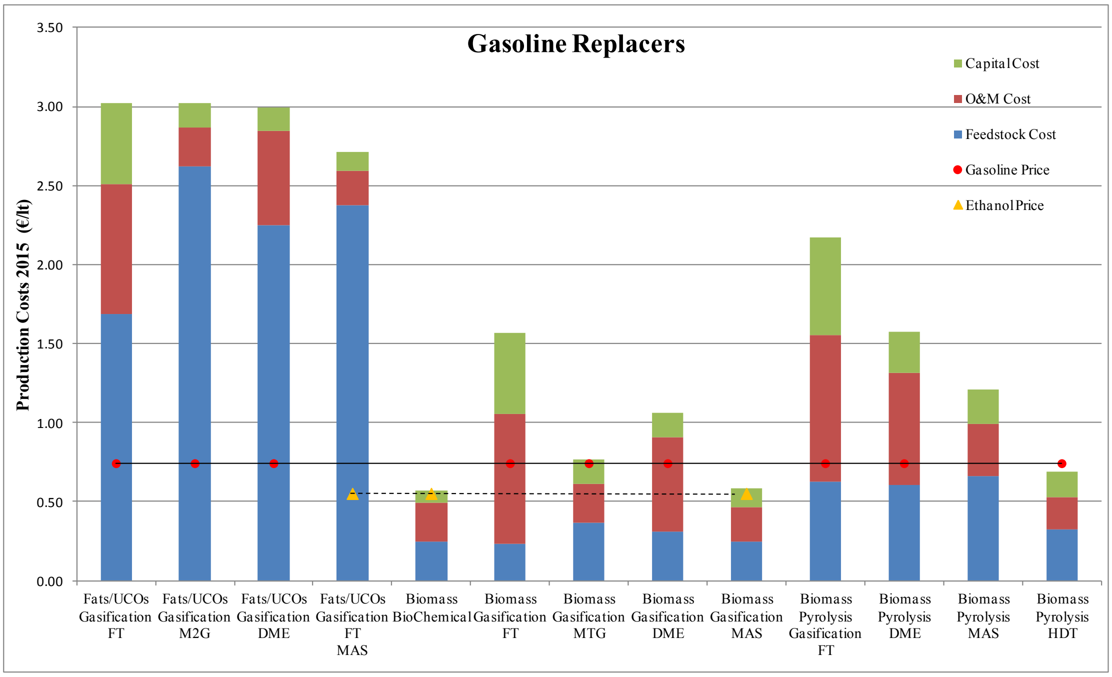

Figure 3: Production cost of 2G biofuels for gasoline blend

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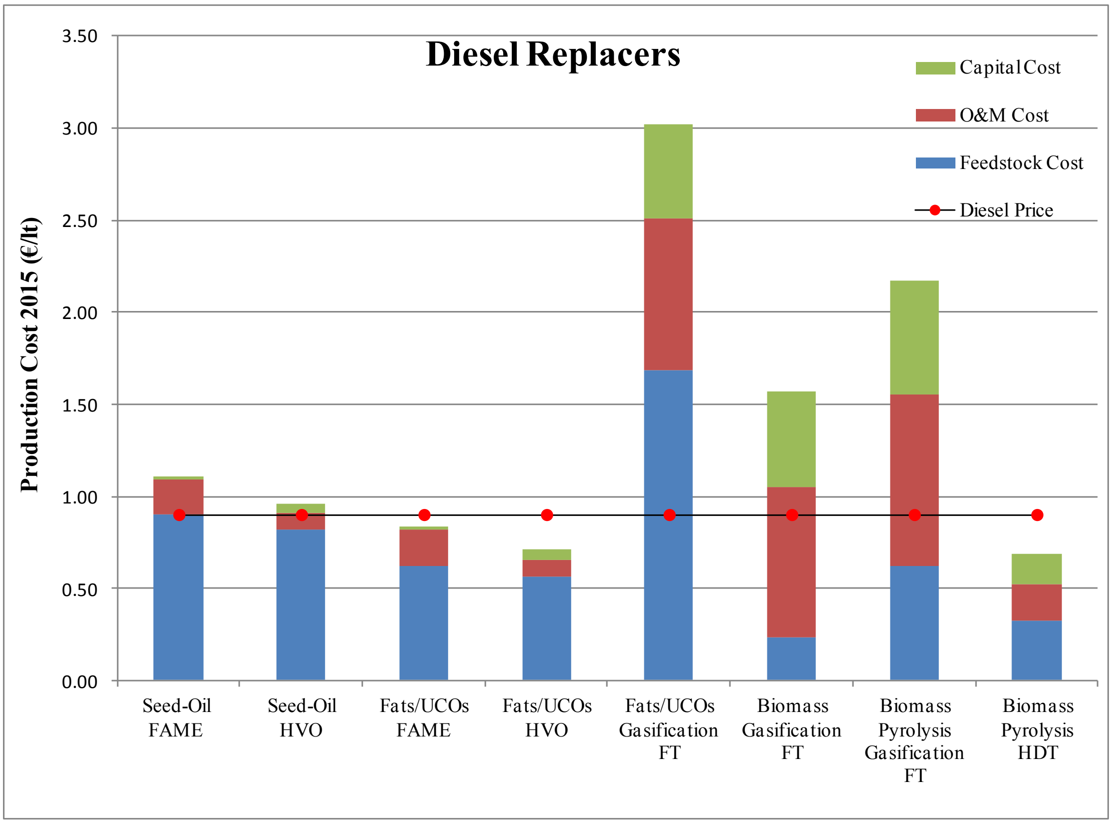

Figure 4: Production cost of 2G biofuels for diesel blend

Pyrolysis technology followed by Hydro-processing (HVO/HDT) is found to be the most advantaged technology to produce both renewable diesel and gasoline products from lignocellulosic biomass. A high level investment analysis is performed via the Discounted Cash Flow (DCF) technique to identify the key economic metrics of this process and make a sensitivity analysis. The most common economic criteria used for this analysis are the Net Present Value (NPV), the Pay-Out Time (POT), the Internal Rate of Return (IRR) and the Return on Investment (ROI). The following main assumptions are used for the analysis in this study:

- Currency and Exchange rate: 1€ = 1.3 US$
- Investment year: 2015
- Plant life time: 20 years
- Discount rate (interest rate and cost of equity): 7%
- Taxation rate: 25% of gross profits (Apostolakou et al, 2009)
- Linear depreciation method
- Zero salvage or terminal value of the plant
- On stream hours: 7884 hrs (90% plant availability)
- Plant capacity: 230 kton/yr (290 MMlitre/yr) renewable gasoline and diesel
- Plant capacity achieved 100% in the first year
- Feedstock price: lignocellulosic biomass at 87 €/ton
- Selling price of renewable diesel biofuel: 0.9 €/litre

As part of the DCF analysis the following steps are followed:

The plant total capital investment (TCI) is firstly estimated from Table 7 as follows:

$$TCI = SpecificInvestment\left(\frac{\text{Eur}}{\text{lt}}\right) \times Capacity(lt) = 495MEUR$$

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The Net Income Before Tax (NIBT) is calculated as follows:

$$\mathrm{NIBT} = \mathrm{Product\ Revenues} - \mathrm{Feedstock\ Cost} - \mathrm{Operating\ Cost} =$$

$$= \mathrm{Capacity} \times \mathrm{Product\ Price} - \frac{\mathrm{Capacity}}{\mathrm{Product\ Yield}} \times \mathrm{Feedstok\ Price} - \mathrm{Capacity} \times \mathrm{SOP} =$$

$$85\ \mathrm{M€/a}$$

The depreciation is estimated based on the linear method as follows:

$$\mathrm{Depreciation} = \mathrm{TCI/n} = 25\ \mathrm{M€/a}$$

The annual Cash Flow (CF) is calculated as follows:

$$CF = NIBT - (NIBT - Depreciation) \times TaxRate = 70 MEUR/a$$

Finally the Net Present Value (NPV) of the investment is calculated:

$$\mathbf{NPV} = -\mathrm{TCI} + \sum_{1}^{n} \frac{\mathrm{CF}}{(1+\mathrm{i})^{n}} = \mathbf{247\ M€}$$

A positive NPV in this case means that the present value of future cash flows is greater than the initial investment of capital; therefore the investment is assessed as profitable. Based on the DCF analysis the resulting POT of the investment is 10 years, which is the point in the project life-time that the NPV reaches zero before becoming positive.

Another important criterion is the Internal Rate of Return (IRR), which represents the discount rate at which the NPV becomes zero and results in IRR = 13%. Essentially for a project investment to be successful the IRR needs to be higher than the weighted average cost of capital (WACC), which involves the cost of debt (say interest rate of 7%) and the cost of equity. Since the IRR of 13% is higher than the WACC of 7% the project is creating value.

Finally the Return on Investment (ROI) or Return on Capital Employed (ROCE) is estimated by the following formula and is a metric for quick investment screening.

$$ROCE = \frac{NBIT}{TCI} = 17\%$$

Overall the investment metrics look quite positive for producing 2[nd] generation biofuels from biomass via Pyrolysis & HDT technology. It is important, however, to investigate sensitivity of the investment to various parameters such as feedstock or product prices, which may vary quite significantly based on volatile oil prices . The impact of varying feedstock and product prices is graphically shown in Figure 5.

Various scenarios based on correlation of historic fuel products price with Brent crude oil prices are provided. The evaluated base case scenario corresponds to a 75-80 \$/bbl crude price and the sensitivity scenarios capture two price ranges; 55-100\$/bbl (-20%, +20%) and 45-110\$/bbl (-30%, +30%) respectively.

In addition, the impact of technology specific parameters such as yields, operating and investment costs are shown via sensitivity analysis. Product yields impact both biomass feedstock cost (more raw materials required per unit product) as well as capital investment (plant capital investment escalated with 0.7 factor).

According to this graph the project profitability is most sensitive to changes in product price followed by changes in product yields. Standard deviation on the average literature technology yields used for this study is similar for pyrolysis & HDT compared to other competing technologies (i.e. biochemical conversion and gasification followed by alcohol synthesis), showing relative robustness of the technology, which would not impact its relative ranking. The project stops being profitable if product price declines by 13% (diesel price 0.78 €/litre equivalent to approximately 60-65\$/bbl Brent crude oil price scenario) or if feedstock price increases by 33% (biomass price 115 €/ton). Low product prices, as a consequence of low oil prices, certainly being a reality since late 2014, make the investment to any biofuels technology quite vulnerable if not supported by policy. Low oil price, on the other hand, will also counterbalance this effect to some extent, since the transportation cost of feedstock also reduces (not taken into account in this analysis). Similarly at high oil prices, both high product and feedstock prices are expected.

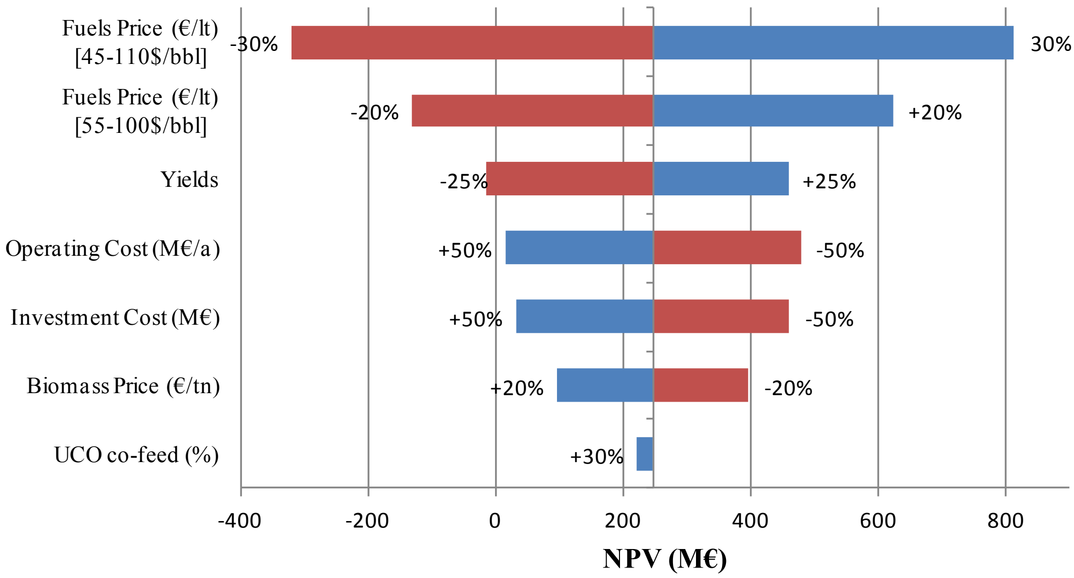

Figure 5 Sensitivity analysis of Pyrolysis & HDT biomass conversion

6. BUSINESS ENVIRONMENT CONSTRAINTS

Thus far it has been demonstrated that 2nd generation biofuels have the potential to close the market gap with respect to the penetration of biofuels into the transport sector, although there remains uncertainty about the amounts/conditions under which feedstock can be sustainably obtained. It is also shown they can be affordable compared to 1st generation biofuels, due to the utilization of cheap waste feedstock, but their profitability can be sensitive to several key parameters.

The current section outlines the risks, constraints and uncertainties regarding the implementation of 2nd generation biofuels and proposes ideas for addressing them in order to realize the opportunities that arise from climate change policy.

The industry framework is drawn within the constraints of technology, supply chain, policy framework and the external market environment, as depicted in relevant studies. More specifically, Papapostolou et al (2011) discuss the strategic decision-making for identification of the optimal supply chain configuration and conclude that an integrated supply chain model, taking into account both technical and economic parameters, is very critical. Iliopoulos and Rozakis (2010) present the main factors in the biodiesel supply chain in Greece, the most important of which is found to be the policy framework. Kampman et al (2013) discuss the implementation issues and limitations for bringing biofuels into the market and recommend designing a robust biofuels marketing strategy for EU members in the next 10-20 years, to ensure timely implementation of key policies and increasing biofuels R&D and production of sustainable (2nd generation) biofuels. The recently released RED II proposal by the EU commission supports this direction, since it differentiates advanced biofuels and proposes phasing out food crop based biofuels. These are all influential factors for the industry that are studied here to identify the limitations of the proposed industry model.

The macro-environment of the energy system comprises a variety of factors that can impact the industry. The analysis here covers global trends and external factors that affect the industry sector in Greece. Overall, these factors and trends create a turbulent macro-environment around the energy industry, which besides the risks and uncertainties entailed in the transition to biofuels, also present certain opportunities.

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Global and regional shifts in demand, market fluctuations with associated financial speculations, impact of the debt crisis and political instability create an environment of uncertainty which poses risks to companies active in the field as well as to potential investors. Furthermore, lag on deregulation creates barriers to competition, while at the same time international competition is becoming relentless. New legislation to promote energy efficiency and the transition to new car technologies creates pressure on the biofuels industry from competitive technological routes. Eventually, all the above in combination with increasing project costs and the human capital deficit makes the entrance of new players and the overall investment environment extremely difficult.

There are, however, strong business opportunities due to the climate change concerns and the gradual shortage of traditional energy sources that have incentivized the global community to implement green strategies. As a result of this, the industry has established new energy policies with priority on energy security, RES implementation targets and market liberalization. At the same time, technological advancements contribute towards making biofuels viable and approach price parity with fossil fuels. Finally, initiatives such as the carbon emission trading scheme (ETS) are certainly endorsed by the biofuels sector providing additional investment incentives. Adhering to the EU ETS scheme at country level will further allow biofuels players to secure and trade carbon credits, since 2nd generation biofuels reduce dramatically the oil products life-cycle GHG emissions. Finally, international competition (i.e. by free movement of goods in EU) provides product export possibilities.

In order to expand the biofuels industry in the most optimal way it is critical to design a strategy mix, taking into consideration the industry threats and their potential mitigations. A risk analysis is presented, taking into account technological, market environment, supply chain, and policy factors as summarized below:

1) Market risks:

- Turbulent oil prices and, more specifically, cheap oil, which makes biofuels less competitive with petroleum based fuels. To mitigate this, continued support and policy measures by the government are of paramount importance to ensure long-term viability of biofuels and allow deployment of these technologies.
- Energy efficient car engines, cheap electricity, electrification of cars and alternative renewable fuels (i.e. hydrogen) can have a serious impact on the demand of liquid transportation fuels (i.e. diesel and gasoline) and consequently biofuels. Although this is a long-term risk, cost leadership by production cost minimization through technology improvements and supply-chain optimization is needed for biofuels to remain competitive and continue to be part of the transport energy mix. Moreover, there is a longer term 'niche' for biofuels in the heavy-duty and aviation sector.
- Potential biofuels import from neighbouring countries can be overcome by ensuring that advanced biofuels are produced at low cost, below the international biofuels price, driven by the opportunities of abundant low cost feedstock and agriculture labour availability

2) Technical/technological:

- Failure to demonstrate technology development for further production cost reduction (capital and operational) to achieve price parity with petroleum based fuels.
- Scale incompatibility between pyrolysis and hydrotreating plants poses several scheduling, supply chain and operability challenges. In case of under-utilization, alternative feedstocks can be processed, such as 1st generation feedstocks, other residue oils or even refinery side-streams. In case of excess supply, alternative outlets can be investigated such as electricity production, exporting etc.
- Hydrogen shortage in refineries to supply hydrotreating plants. In this case additional steam reforming capacity needs to be installed for producing additional hydrogen either from bio-oil or natural gas feedstock, as demonstrated by Zhang et al (2013). Alternatively, green hydrogen production opportunities based on renewable solar or

wind electricity (via electrolysis) may play an important role in the coming decades to decarbonise fuels, especially in more challenging sectors (i.e. aviation and heavy duty)

3) Supply chain risks:

- Wide distribution of resources, highly localized biomass sources, transport costs, seasonality, disruption of supplies, availability of raw materials, supply variation and spatial distribution of customer demand zones are some of the risk factors. Also, low carbon intensity and life-cycle GHG of feedstock sourcing can be challenging to verify. These should be mitigated by careful supply-chain optimization and by selecting storage capacities, location and capacity of decentralized pyrolysis plants, close to where raw materials are produced.
- Competition with 1st generation biofuels can be a risk especially in the early phases of 2nd generation biofuels development. The supply-chain infrastructure of existing 1st generation biofuels can, however, be used for integrating 2nd generation biofuels and enabling transition to the new era. Utilization of the existing network should be maximized before extending with completely new infrastructure.
- The existence of multiple stakeholders scattered along the supply chain is the biggest risk towards developing and optimizing the network. This complexity can be partially mitigated by government regulations to allow sustainable growth of the sector, but in the long run should be settled by free market competition.

4) Policy risks:

- There are no government policies to differentiate between 1st and 2nd generation biofuels as per EU directive. This will impact the penetration of 2nd generation biofuels in the short-term and the potential biofuels exports in the long run. Reduction of production cost and free market competition should allow penetration of 2nd generation biofuels in the short to medium term. The recently released RED II proposal by EU commission differentiates advanced biofuels.
- Quotas set by the government were originally intended to support domestic industry and accelerate harmonization with the EU RED. Domestic 1st generation biofuels capacity, however, exceeds currently the volumes set by quotas and the capability of the industry to absorb this capacity. Retention of quotas creates insecure investment conditions and possibly acts as blockers for the development of 2nd generation biofuels. Quotas would in principle harm internal competition emerging from free market conditions. Reduction of production cost and supply-chain optimization in the long run should eventually enable penetration of 2nd generation biofuels, due to advantaged feedstock and affordable advanced technology.
- Similarly, retention of a regulated market with pre-defined biodiesel prices would in principle advantage 1st generation biofuels, but, as discussed above, cost leadership and focus on international competition should enable 2nd generation biofuels penetration in the short to medium term, especially since market penetration of biofuels remains far below targets.
- Failure to adapt energy policies and the RED national plan beyond 2020. Failing to support biofuels with subsidies, tax relief or other policy mechanisms will increase pressure on the biofuels industry and national targets will become impossible to meet. It is expected, therefore, that the situation will eventually be settled by the EU-wide regulators or via imports.

Along with the aforementioned risks the following uncertainties should be addressed and which can have a major impact on the implementation of 2nd generation biofuels:

- Availability and accessibility of biomass resources and in particular forestry residues. Great variability appears across literature references. Boukis et al (2009) claim very low availability of agriculture and forestry residues (10%), although other sources

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(Caralis et al, 2010 – Castillo and Panoutsou, 2011 – Zabaniotou et al, 2010) provide more optimistic view regarding agriculture residues.

- The price of biomass resources can present great variability depending on the various sources and types of biomass: 4 – 180 €/t (MEECC, 2014). Also biomass waste price can vary significantly among various references: 67 – 105 €/t (Brown et al, 2013 – Haarlemmer et al, 2014). This impact is addressed via the sensitivity analysis provided in Section 5.
- Sustainability issues with respect to feedstock supply and logistics can impact both feedstock prices and life-cycle GHG emissions. Therefore, an optimum supply chain network that takes into account geographical placement of feedstock sources and location of biofuels plants is essential.
- The demand range for biofuels can also vary significantly towards the 2030 horizon (900-1500 ktoe). This is critical for optimised central planning, although the available 2nd generation resources appear to be sufficient to cover demand (Table 5), even for low availability feedstock scenarios.
- The product price in a free market environment, bound to oil market prices, can potentially fluctuate significantly and impact seriously the project profitability as shown by the sensitivity analysis.
- Finally, technology maturation and how quickly aspired performance of 2nd generation biofuels facilities can be met is crucial for their implementation and success of the industry. Not many 2nd generation facilities currently operate globally, but recent investment projects using renewable proprietary technology (e.g. by Neste-Oil and ENI) can accelerate their evolution.

7. PROPOSED INDUSTRY MODEL

Based on current market supply data and estimated demand for the biofuels sector, it becomes clear that in order to meet the RES energy targets in the transport sector by 2020, either imports and/or radical reformation of the biofuels industry will be required (Caralis et al, 2010). In the current section an industry model for the development of 2nd generation biofuels is proposed, by matching the market demand, with the supply of 2nd generation resources, taking into account the feedstock availability and their economics of production.

An array of strategies is of paramount importance to formulate a robust industry model and enable growth of the sector, with focus on capitalizing the opportunities, within the aforementioned industry constraints. An optimum strategy mix shall therefore involve:

- Implementing a best cost strategy by pursuing cost leadership and delivering superior quality products.
- Maximizing the scale of production plants to minimize costs by capturing economies of scale where possible. Smaller scale decentralized units, however, could make sense when overall supply chain costs are minimized by utilizing for example synergies with existing infrastructure, addressing this way the risk of scale by optimized supply chains. Optimal scale is eventually defined by minimizing overall costs including supply-chain costs along with production costs.
- Optimizing capacities by matching supply with rigorous forecasted demand, hence optimizing utilization of facilities and avoiding over-capacity as it is the case currently for 1st generation biofuels facilities. Also consider phased investment to mitigate uncertainties from varied demand forecast, tapping first into high availability and low cost resources. As better information and infrastructure become available consider expanding further investments to meet increasing demand.
- Opting for the most advanced technology that minimizes overall production and supply-chain costs, enabling feedstock and product output flexibility with superior product quality. Feedstock flexibility for example can shield the investment against the risk of low resource availability of certain quality and thus ensure supply at minimum cost through life-cycle.

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- Expanding to abundantly available 2nd generation biomass resources and waste oils, utilizing the potential competitive advantage of feedstock and infrastructure.
- Ensuring low production cost through life cycle of the facilities at international levels therefore striving to continuously optimize supply chains and address supply-chain risks.
- Selecting technologies and feedstocks that minimize not only the raw material cost, but also the overall supply chain costs and the life-cycle GHG emissions. Optimize the supply chain network by considering upstream feedstock availability, transport cost minimization, storage capacity, plant capacity, plant location and distribution cost minimization.
- Extending the biofuels market, currently limited to 1st generation biodiesel only, to 2nd generation renewable gasoline and diesel which provides immense opportunities due to non-existent competition, possible first mover advantage (as there is no domestic renewable substitute products that can be blended in the gasoline pool) and potentially exports position.
- Integrating 2nd generation biofuels to existing 1st generation and fossil fuels supply-chain infrastructure to minimize both cost as well as risks.
- Capturing economies of scope through technology that allows multiple product output, addresses market risks related to changing vehicle fleet i.e. though electrification. Should production exceeds the domestic market capacity, exporting products and intermediates (bio-oil) to international market or alternative markets such as aviation, electricity production and domestic heating should be exploited.
- Competing internationally by minimizing production and supply chain costs to produce biofuels below the international prices.
- Playing an active role in lobbying with authorities to implement the most up-to-date EU regulations that reflect market needs and evolution of technology. Also adhering to the carbon emission trading scheme (ETS).
- Actively investing and pursuing R&D to improve production technology and costs.
- Finally, investing in better information on feedstock availability and conditions for the sustainable use of resources under various conditions.

Sensitivity analysis has shown that under certain circumstances investment to biofuels can be vulnerable, especially with respect to low oil prices. An array of well structured strategies together with robust policies can potentially form a safety net against the weaknesses of such investment, which is frequently common in all biofuels technologies. Opting for a superior technology that provides feedstock and product flexibility, in addition to superior product quality that utilizes existing infrastructure and supply chains mitigates further the technological risks of the investment.

The key strategic decisions for developing the biofuels industry include selection of raw materials, technology, location, number and capacity of production plants to satisfy the forecasted future market demand. Consequently the supply of raw materials matching this capacity will drive setup of the storage and distribution network. The optimum scheme is a complex mathematical optimization problem.

Based on this approach a simplified industry-wide supply-chain conceptual scheme is proposed on the basis of biomass pyrolysis followed by bio-oil upgrading in hydrotreating facilities.

The main driver for defining the biofuels network capacity is based on the forecasted market demand for the period 2015-2030. The overall strategy is to minimize production costs. The best way to minimize production costs is by opting for economy of scale and thus maximizing plant capacities. HVO/HDT technology is commercially proven in world-scale capacities (maximum HVO plant capacity 929 MMlitre/yr by Neste-Oil; Miller and Kumar, 2014), while pyrolysis technology is available in large-scale capacities (maximum pyrolysis plant capacity ~140 kton/yr - 2000 ton/day biomass feed; Brown, 2015). The number of plants is defined based on the market demand scenarios versus the maximum plant capacities.

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Based on the forecasted average biofuels demand for 2030 (~1230 ktoe), 8 large-scale pyrolysis plants of approximately 2000 ton/day biomass intake (~140 kton/yr bio-oil) and 2 optimally sized world scale hydro-treating plants (~600 kton/yr biofuels) can cover the domestic average demand of 2030, while additional pyrolysis plants and larger hydro-treating plants could cover for higher demand scenarios.

As shown above the biofuels plant production capacity is determined by domestic market demand, whereas the intake capacity defines the feedstock requirements. Meeting the forecasted demand for 2030 requires utilization of approximately 40% (range 29-47%) of the total 2nd generation resources, proving the sufficiency of resources in Greece.

Biomass feedstock is mainly available in the periphery of the country where agriculture and forestry is developed. Transport can be very expensive due to low biomass energy density, representing major supply chain limitations. This means that from a feedstock supply perspective, conversion to biofuels in the periphery of the country is favoured. On the other hand, biofuels consumption is in the three refineries, located centrally near major fuel demand centres of Athens and Thessaloniki. To satisfy these limitations an optimal supply-chain network concept needs to meet the following principles:

- Biomass transport to central markets is prohibitive, hence it needs to be converted regionally in large-scale distributed pyrolysis plants close to where the primary resources are located as proposed by Trippe et al (2011, 2013).
- The intermediate pyrolysis bio-oil product can be regionally collected and transported for a final conversion step in world-scale HVO/HDT plants.
- The HVO/HDT plants shall be located centrally so that the final products can be directly sourced for blending to refineries. Hydrogen, being an important raw material for the HVO/HDT plants, can be directly supplied from the refineries. Ideally these units are located within (or next to) the refineries.
- Biofuels blended into transport fuels in the refineries are sent directly to the local market or exported in bulk quantities from the refineries to neighbouring markets.

To optimize logistics, biomass shall be supplied to the pyrolysis units in the periphery of the country, whereas waste oils shall be collected in the big population centres, where their availability is larger with lower collection costs and can be directly fed to the HVO/HDT plants.

Based on the steps proposed above, the configuration of the optimal supply-chain scheme to cover domestic demand shall consist of 8 large-scale decentralized pyrolysis plants, as proposed by Trippe et al (2011, 2013), of average capacity ~140 kton/yr (or more with lower average capacity). These shall be distributed in various regional centres in the periphery of the country close to where the bulk of the primary sources are located, in order to ensure sufficient feedstock availability and continuous supply.

Consequently the bio-oil from the pyrolysis plants shall be imported in 2 world-scale HVO/HDT plants of average capacity 600 kton/yr located in the two main centres (Athens, Thessaloniki), next to the existing oil refineries. The renewable gasoline and diesel biofuel products shall be blended into the refinery fuel pools in order to satisfy the domestic market demand (min-max: 907 – 1462 ktoe; average: 1232 ktoe).

Detailed supply-chain optimization needs to be carried out as follow-up of this work to place the peripheral pyrolysis plants. These plants should be placed strategically to minimize overall logistic costs.

When installed plant capacity exceeds domestic demand, biofuels export to the neighbouring markets can be considered as long as marginal production costs are lower than the production costs in those markets. This can be a promising option as there is sufficient 2nd generation feedstock availability and the renewable biofuels can be produced at a lower cost than the current European biodiesel price.

The proposed conceptual supply-chain configuration, inspired by Trippe et al (2011, 2013), is presented in Figure 6 below:

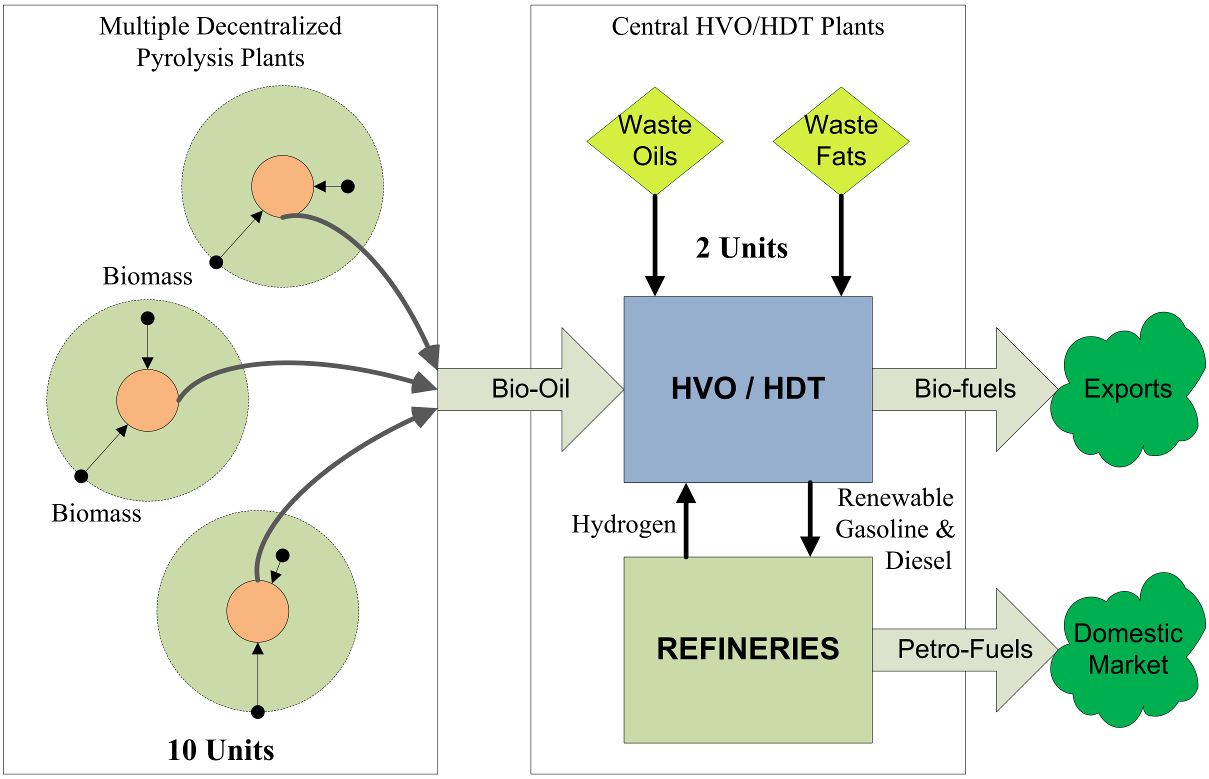

Figure 6: Proposed supply-chain configuration for 2G biofuels in Greece

Implementation of this industry model is favoured by investments in HVO/HDT plants within the refineries. It is in the best interest of the refiners to increase their market share (by capturing the increased demand), reduce costs (prevent importing 1st or 2nd generation biofuels for mandatory blending at high market prices), reduce their products life cycle GHG emissions and increase their overall profitability by investing in a profitable technology. Furthermore, biofuels are not competing against fossil fuels within the refinery battery limits, as their penetration to the market is mandated by European and national regulations. Hence, they can contribute to their feedstock and product diversification.

This framework shall be co-developed with private investors for building the peripheral biomass upgrading units. A price arrangement, e.g. in the form of an offtake contract, between the peripheral players and the central refineries for the bio-oil supply will therefore be necessary. This also enables sharing the regulatory award e.g. in an emission trading scheme.

Finally, the regulatory framework can support the proposed model by providing investment incentives such as subsidies and tax incentives, rather than setting quotas. In this way, the conditions for market competitiveness can be established with proper regulatory control for such an emerging market. The recent development law that came into force in July 2016 certainly contributes in this direction, as it involves both a tax regulation mechanism and subsidies in addition to the existing quotas mechanism (Maroulis, 2017). If the technologies perform as analysed, the industry should be able to develop in the long run without heavy government intervention, but solely based on robust green national and EU policies.

Gradual evolution towards robust policies that stimulate investment to 2nd generation biofuels would not necessarily impact directly existing capital stock, as they need to bridge a considerable market gap towards 2030 horizon targets, which cannot be served by current 1st generation facilities due to blending limitations. It is of government's best interest to create competitive market conditions and attract investments, otherwise the long term goals could only be met by imports. Longer term competition by 2nd generation biofuels, however, could alter the market dynamics and impact sustainability of current 1st generation facilities. Utilizing existing facilities to support 2nd generation biofuels production (e.g. FAME conversion to HVO) or enable alternative/2nd generation feedstock intake through technology modifications, in order to make use of infrastructure synergies and existing supply chains, could also potentially present attractive opportunities.

8. CONCLUSIONS

Market analysis has clearly demonstrated that 2nd generation biofuels can have a major impact on the transport sector in Greece and contribute significantly towards meeting national RES targets. Also their implementation are in line with the RED II proposal recently released by EU commission that supports advanced biofuels and drives reduction of food crop based biofuels. Current biofuels penetration, solely based on 1st generation biodiesel (FAME), corresponds to only 2.2% of the transport fuels market. This is based on the distributed quota for 2015, which is well below the targeted 6.3% RES by the Greek government for 2015 and the mandates of the EU directive.

It has been shown that Greece holds sufficient resources to support indigenous production of 2nd generation biofuels. The available lignocellulosic biomass resources exceed the 2030 demand and could potentially support export of biofuels based on surplus feedstock supply. Approximately 40% (range 29-47%) of the total 2nd generation resources are required to meet forecasted average biofuels demand for 2030, although recoverability of certain resources remains uncertain. The abundance and accessibility of biomass feedstock together with the availability of agriculture infrastructure and labour are important competitive advantage indicators of the Greek biofuels industry.

Current supply from existing installations is insufficient to meet future demand, due to incompatibility of 2nd generation resources. New conversion technologies should be introduced, the production cost of which will play a major role in the exploitation of 2nd generation feedstocks and the installation of new biofuel units. Most importantly, technologies that use cellulosic biomass are needed to meet the full demand of biofuels from domestic resources.

Economic evaluation of the various 2nd generation biofuel production routes concluded that fast pyrolysis of biomass combined with hydrotreating (HDT) is the most advantaged technology to produce biofuels from lignocellulosic biomass. The quality of the drop-in biofuels produced by this technology (renewable gasoline and diesel) alleviates the blending constraints compared to 1st generation biofuels, while reducing the overall GHG emissions in line with the FQD and RED II. Additionally, it provides positive investment criteria based on a high level economic evaluation that was carried out using a discounted cash flow analysis. On the other hand, sensitivity analysis showed the investment to be somewhat vulnerable, especially with respect to low oil prices (<60-65 $/bbl), making policy support and green credits via an Emission Trading Scheme imperative to minimize investment risk and incentivize investors to take advantage of opportunities driven by climate change policy.

Implementation of a strategy mix is key to enable an optimal supply-chain network for deployment of 2nd generation biofuels. The proposed strategy mix consists of multiple large-scale decentralized pyrolysis plants located close to the 2nd generation biomass sources. The produced pyrolysis bio-oil shall be transported to world-scale HDT plants centrally located in the two main supply centres (Athens, Thessaloniki), within or next to the existing oil refineries. The HDT plants can be optionally fed with waste oils from the two main centres. The biofuel products are then directly blended to the refinery fuel pools and sent to the domestic market. When installed plant capacity exceeds domestic demand, the biofuel products can be potentially exported to neighbouring international markets.

2nd generation biofuels certainly have the potential to close the biofuels market penetration gap and they can possibly be produced economically, presenting significant growth and investment opportunity. To pursue this growth potential, careful central planning and policy support from the government is required as well as a radical reformation of the biofuels industry as a whole.

Implementation of competitive advantaged 2nd generation biofuels presents an opportunity to meet the EU RED directives, support the Greek economy and stimulate job creation.

Hence, support by the Greek government should aim to incentivize investments and expansion of the 2nd generation biofuels industry.

The role of government through the implementation of robust policies is important to accelerate penetration of 2nd generation biofuels to the market. The policy goals shall focus on stimulating investments rather than protectionism that minimizes competition. This could be potentially achieved by gradually transforming the current quota system and increasing investment incentives i.e. via national or EU subsidies and tax reliefs. Provided robust and competitive technology performance, the industry should be able to develop in the long run solely based on green policies without heavy government intervention.

Finally, based on the limitations of the current study, future research to enable better understanding of various factors that impact the industry development is required. These include a better understanding of the locally available biomass feedstock, its geographic distribution, recoverability and production. It is also important to understand its transport, storage and processing costs, to arrive to more accurate pricing figures that reflect the local market as recommended by Sims, 2010. To determine the optimum 2nd generation biofuels production network and geographical location of facilities in Greece, detailed techno-economic analysis and supply-chain modelling are recommended.

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