2017

Supplying bio-compressed natural gas to the transport industry in Ireland: is the current regulatory framework facilitating or hindering development?

Niamh Power

Civil, Structural, Env. Engineering, Munster Technological University, Cork, Ireland, niamh.power@cit.ie

Daniel Goulding

Department of Civil, Structural and Environmental Engineering, Cork Institute of Technology, Cork, Ireland

Bord Gáis Networks, Gasworks Road, Cork, Ireland, daniel.goulding@cit.ie

Dan Fitzpatrick

Gas Networks Ireland, Gasworks Road, Cork, Ireland

Rodger O'Connor

Gas Networks Ireland, Gasworks Road, Cork, Ireland

James D. Browne

Gas Networks Ireland, Gasworks Road, Cork, Ireland

Recommended Citation

Goulding D., Fitzpatrick D., O'Connor R., Browne J.D., Power N., 'Supplying bio-compressed natural gas to the transport industry in Ireland: is the current regulatory framework facilitating or hindering development?', Energy, 136 (2017) pp.80-89.

Manuscript Details

Manuscript number ENVSCI_2017_956

Title Introducing gaseous transport fuel to Ireland: A strategic infrastructure framework

Article type Research Paper

Abstract

European Union (EU) legislation in the form of the Renewable Energy Directive 2009/28/EC and the Deployment of the Alternative Fuels Infrastructure Directive 2014/94/EC have placed mandatory requirements on Member States to deliver sustainable forms of alternative transport infrastructure in order to reduce greenhouse gas emissions in the transport sector. However, there is currently little or no refuelling infrastructure to support the development of an alternative transport fuel market for compressed natural gas and its renewable form biomethane in a number of EU Member States. Primarily focussing on a combination of biomethane and compressed natural gas (bio-CNG), this paper analyses the key considerations to develop a strategic infrastructure framework for bio-CNG and defines the criteria for the placement of public access refuelling stations in order to satisfy legislative requirements, commercial considerations, strategic placement and natural gas network infrastructure utilisation. This paper maps a strategic infrastructure framework on which a national public access refuelling network for bio-CNG could be provided for Ireland as a template and for other Member States with similar infrastructure and requirements to follow. The framework includes the provision of 22 bio-CNG installations in strategic locations across the country.

Keywords compressed natural gas, biomethane, strategic development, transport policy

Taxonomy Environmental Technology, European Energy Policy, National Energy Policy, Renewable Energy Policy, Natural Gas Vehicles, Transport

Manuscript region of origin Europe

Corresponding Author Daniel Goulding

Order of Authors Daniel Goulding, Dan Fitzpatrick, Rodger O'Connor, James Browne, Niamh Power

Suggested reviewers Richard Dinsdale

Submission Files Included in this PDF

File Name [File Type]

D Goulding - Bio-CNG Infrastructure Framework_Cover Letter.docx [Cover Letter]

D Goulding - Bio-CNG Infrastructure Framework_Manuscript.docx [Manuscript File]

To view all the submission files, including those not included in the PDF, click on the manuscript title on your EVISE Homepage, then click 'Download zip file'.

Research Data Related to this Submission

There are no linked research data sets for this submission. The following reason is given:
Data will be made available on request

Cork Institute of Technology
Rossa Avenue
Bishopstown
Cork
09th November, 2017

Re: Article submission to the Environmental Science & Policy journal

Dear Editor,

Please find attached my Full Length Article for review titled 'Introducing gaseous transport fuel to Ireland: A strategic infrastructure framework'.

This paper investigates the infrastructure framework required to develop a gaseous transport industry (through compressed natural gas and biomethane – bio-CNG) in Ireland. The Article focuses on current European/Irish transport and renewable policy, the natural gas industry and determines the associated policy requirements to develop such an infrastructure framework for supplying bio-CNG including: transport legislation, natural gas infrastructure, bio-CNG technology, vehicle refuelling requirements and renewable biomethane interaction. The paper then devises an infrastructure framework for gaseous transport fuel utilisation for Ireland that can be used as a template for other European countries.

With environmental protection, rising fuel prices, energy efficiency and sustainable development becoming increasing important issues in Europe, this paper offers a relevant solution to address the key concerns facing the transport industry, policy makers and investors through strategic policy recommendations. This topic is of significant relevance to Ireland and other European countries in order to achieve the significant environmental, renewable source and alternative fuel infrastructure targets in transport.

I hope you enjoy this paper and feel that it is at an acceptable standard for your esteemed journal.

Best regards,

Daniel Goulding

Title of paper: Introducing gaseous transport fuel to Ireland: A strategic infrastructure framework

Authors: D Goulding [(1) (2), (*)], D Fitzpatrick [(2)], R O'Connor [(2)], JD Browne [(2)], NM Power [(1)]

Keywords: compressed natural gas, biomethane, strategic development, transport policy

Abstract: European Union (EU) legislation in the form of the Renewable Energy Directive 2009/28/EC and the Deployment of the Alternative Fuels Infrastructure Directive 2014/94/EC have placed mandatory requirements on Member States to deliver sustainable forms of alternative transport infrastructure in order to reduce greenhouse gas emissions in the transport sector. However, there is currently little or no refuelling infrastructure to support the development of an alternative transport fuel market for compressed natural gas and its renewable form biomethane in a number of EU Member States. Primarily focussing on a combination of biomethane and compressed natural gas (bio-CNG), this paper analyses the key considerations to develop a strategic infrastructure framework for bio-CNG and defines the criteria for the placement of public access refuelling stations in order to satisfy legislative requirements, commercial considerations, strategic placement and natural gas network infrastructure utilisation. This paper maps a strategic infrastructure framework on which a national public access refuelling network for bio-CNG could be provided for Ireland as a template and for other Member States with similar infrastructure and requirements to follow. The framework includes the provision of 22 bio-CNG installations in strategic locations across the country.

Note: (1) Department of Civil, Structural and Environmental Engineering, Cork Institute of Technology, Cork, Ireland;

(2) Gas Networks Ireland, Gasworks Road, Cork, Ireland;

(*) Corresponding author - Tel: +353857065051; Fax: +353214544460; E-mail: daniel.goulding@gasnetworks.ie

Introduction

1.1 Focus of paper

This paper aims to determine the infrastructure requirements for the public supply of gaseous transport fuel in Ireland. Previous work published by the authors (which focussed on the potential penetration of Compressed Natural Gas (CNG) blended with biomethane (bio-CNG[1]) as a gaseous transport fuel sector in Ireland) proposed a bio-CNG production roadmap in which 11 anaerobic digestion (AD) facilities are developed to inject biomethane into the natural gas network, thus meeting 1% of Ireland's renewables share in final transport energy demand (RES-T) target by fuelling 14,000 commercial (buses, light goods vehicles and taxies) gaseous vehicles (Goulding, et al, 2014). Other works by the authors derived a regulatory framework to introduce the associated bio-CNG production roadmap into Ireland's transport sector (Goulding et al, 2016).

However in Ireland, bio-CNG refuelling infrastructure is a key element of the industry which is currently absent with no public bio-CNG refuelling stations in operation at present. The establishment of bio-CNG refuelling infrastructure is an expensive investment when demand is not yet strong enough (Kirk et al, 2014). This paper will complement the author's bio-CNG production roadmap and regulatory framework by focussing on the infrastructure requirements for the supply of bio-CNG to public customers in Ireland and can act as a template for Member States (MS) with similar infrastructure and bio-CNG requirements. Accordingly, the key objectives of this paper are as follows:

- Examine the key infrastructural requirements of European Union (EU) and national legislation in order for a bio-CNG transport market to succeed.

[1] Bio-CNG will be considered the same term as CNG for the entirety of the paper.

- Identify the criteria for the placement of public access refuelling stations through the review of successful bio-CNG transport industries in the EU while also considering legislative requirements, commercial considerations, strategic placement and natural gas network infrastructure utilisation.
- Present a strategic bio-CNG infrastructure framework for Ireland by identifying suitable public access refuelling station locations as per the author's defined criteria.

1.2 Natural gas vehicles

Natural gas vehicles (NGVs) operate on CNG, its renewable form biomethane and blended bio-CNG. From a global perspective, Pakistan is a country which has placed significant emphasis on introducing CNG into its transport sector, experiencing the fastest growth in both NGV utilisation and CNG station development for 2005 to 2014 (Khan and Yasmin, 2014). *Khan and Yasmin* attributed the emergence of the CNG industry in Pakistan to friendly government policies including; loans on soft terms to setup a CNG station, gas network connection priority to CNG stations, liberal procedures for the granting of licenses to setup a CNG stations and exemptions on import duty for CNG station equipment and vehicle conversion equipment (Khan and Yasmin, 2014). The Government of China has also introduced aggressive policies to develop a CNG industry with over 3M NGVs currently in operation by providing supports such as subsidies for NGVs, investment grants for CNG infrastructure and research and development funding for NGV technology development (Li, 2015).

Biomethane has a comparable calorific value and similar chemical composition to natural gas (> 98% methane) and is produced in a process which converts organic matter into biogas in an oxygen free environment known as AD. Raw biogas must be upgraded to biomethane (> 98% methane) by removing carbon dioxide and other impurities in order to meet the minimum gross calorific value required by the natural gas network operator for injection. Although injection of biomethane into the natural gas network is common in many EU countries, there's a relatively wide range in gas quality specification between network operators. Sweden is currently the only EU country with a national standard for biomethane as a transport fuel (Svensson, 2014).

The ability of biomethane as a transport fuel is being overlooked by Ireland and other EU countries as a renewable fuel which can help to achieve environmental targets for 2020 and beyond. Well to wheel analysis conducted by *Bordelanne, et al* of biomethane produced from organic waste (90%) and CNG (10%) as a blended transport fuel in a passenger NGV generates greenhouse gas emissions that are twice as low as an equivalent vehicle utilising gasoline over its operational life (Bordelanne, et al, 2011). The same analysis found that dedicated biomethane as a transport fuel from energy crops reduces emissions by 76% while CNG on its own as a transport fuel reduces emissions by 17% in comparison to gasoline (Bordelanne, et al, 2011). Another study from *Shahraeeni et al* found that a 34% reduction of greenhouse gas emissions may be achieved by replacing a diesel light goods vehicle fleets with an NGV equivalent fleet over its operational life, saving $30,000 per NGV in the process (Shahraeeni et al, 2015). A comparative analysis of operational bus fleets in Dublin, Ireland found that CO_2 emissions were reduced 7% for CNG and a further 63% for bio-CNG in comparison to diesel (Ryan & Caulfield, 2010). Furthermore, a minimum decrease of 70% in all air pollutants was observed (Ryan & Caulfield, 2010).

1.3 Current legislation

The EU Renewable Energy Directive 2009/28/EC (RED) has been the main policy mechanism for MSs to develop renewable transport infrastructure to achieve a binding 10% RES-T by 2020 (EC, 2009a). However, the RED did not instruct MSs on how to achieve their RES-T target. Ireland has chosen to achieve the mandatory RED target in the form of biofuels (blending with petrol and diesel) and electric vehicles (EVs), with blended biofuels contributing to the vast entirety of the 10% (DTTS, 2017). Although bio-CNG is not on the radar for some MSs as a transport fuel to satisfy the RED, another EU Directive has been introduced which places emphasis on bio-CNG as a transport fuel for the future in Europe.

The EU Directive for the Deployment of the Alternative Fuels Infrastructure 2014/94/EC (AFID) sets out requirements on establishing National Policy Frameworks (NPFs) for the market and infrastructural development of alternative fuels (including bio-CNG), including the implementation of common technical specifications (EC, 2014a). (EC, 2014b). Each MS will need to provide adequate recharging points for alternative fuels such as CNG, LNG, hydrogen and electricity in order to allow full circulation of alternative vehicles across the EU.

1.4 Progress versus targets

The progress of delivering a 10% renewable transport energy share in the EU has been slower than anticipated to date. In a 2014 report from the EU assessing the MS current RES-T progress and along the trajectory towards the 2020 target suggests that after a solid initial start the ability to achieve the RES-T 2020 target will require the removal of key regulatory barriers and additional efforts from the EU and MSs (EC, 2014c). In 2014, the combined EU RES-T stood at 5.9% (EC, 2014c). Furthermore, only 6 of the 28 MSs managed to achieve over 5.75%, while in 2012 Sweden was the only MS to pass the 2020 RES-T of 10% (EC, 2013; Eurostat, 2012). In Ireland, the RES-T reached 3.3% in 2015 which is elevated to 5.7 % when weightings are applied to biofuels from waste and second generation biofuels under the RED (SEAI, 2016). Biomethane did not account for any of Ireland’s RES-T share in 2015.

In terms of NGV utilisation, the EU had 1.316M NGVs in operation utilising 3,408 refuelling stations in 2016 (NGVAE, 2017). However, 92% of these NGVs are operating in only four MSs; Italy (76%), Germany (7%), Bulgaria (5%) and Sweden (4%) (NGVAE, 2017). It is evident from Figure 1, that a significant number of MSs have little or no bio-CNG supply infrastructure in operation and require drastic action in order to achieve the AFID mandate.

NATURAL GAS VEHICLES & STATIONS IN EUROPE (EU+EFTA) 2016

Country	NGV Stations	NGV Vehicles	Country	NGV Stations	NGV Vehicles
Austria	172	7.084	Lithuania	3	343
Belgium	78	5.365	Luxembourg	7	306
Bulgaria	125	69.820	Malta	-	-
Croatia	2	318	Netherlands	183	11.020
Cyprus	-	-	Poland	28	3.600
Czech Republic	143	15.500	Portugal	19	570
Denmark	15	327	Romania	1	1.390
Estonia	6	1.504	Slovakia	11	1.893
Finland	29	2.375	Slovenia	4	335
France	60	14.548	Spain	66	5.797
Germany	885	93.964	Sweden	173	54.379
Greece	10	2.210	UK	38	310
Hungary	10	6.314	EFTA Iceland	5	1.236
Ireland	1	8	EFTA Norway	7	745
Italy	1.186	1.001.614	EFTA Switzerland	141	12.912
Latvia	-	-			
			Total EU + EFTA	3.408	1.315.787

Figure 1: EU NGV statistics for 2016 (NGVAE, 2017)

2.0 Material and methods

2.1 Legislative requirements

The AFID mandates each MS to adopt a NPF for the development of the market as regards alternative fuels in the transport sector and the deployment of the relevant infrastructure (EC, 2014a). In terms of bio-CNG infrastructure, Article 6 of the AFID places mandatory criteria on each MS:

- The commissioning of an appropriate number of bio-CNG refuelling points accessible to the public in order to ensure that NGVs can circulate in urban/suburban agglomerations and other densely populated areas as determined by the MS's NPF. This must be completed by 31 December 2020.
- The commissioning of an appropriate number of bio-CNG refuelling points accessible to the public in order to ensure that NGVs can circulate at least along the existing TEN-T Core Network, to ensure that NGVs can circulate throughout the EU. This must be completed by 31 December 2025.
- The necessary average distance between refuelling points along the TEN-T Core Network should be approximately 150 km. This must be completed by 31 December 2025.

TEN-T Guidelines:

The EU Transport Policy Regulation (EU) No 1315/2013 aims to develop the Core Network Corridors of the TEN-T and was adopted by the EU in 2013 (EC, 2014b). The TEN-T Guidelines define a dual layer approach to how each MS is to implement the Core Network Corridors by the end of 2030. The basic layer, known as the 'Comprehensive Network', should ensure accessibility of all regions of the EU while the second layer, known as the 'Core Network', should efficiently facilitate trans-national traffic and long-distance flows for both freight and passengers (EC, 2013). In Ireland, the TEN-T Core Network currently consists of the route from Northern Ireland via Dublin and connects all the core sea ports from Dublin Port (east) to Cork/Ringaskiddy (south) and Limerick/Foynes (west) (NRA, 2014).

National Service Area Policy:

The Transport Infrastructure Ireland (TII) is the statutory body charged with providing a safe and efficient network of national roads in Ireland under the current TEN-T policy. In August 2014, the TII introduced their Service Area Policy which sets out the policy basis on which transport service areas will be provided to meet the requirements of road users on the national road network in Ireland (NRA, 2014). In terms of service areas on all motorways of the Irish Core Network, the TII outlined the need for Type 1 Service Stations that are designed under the following criteria:

- A Type 1 Service Area (full service area) will be a large scale service area providing an amenity building (including a convenience shop, restaurant, washrooms and tourist information), fuel facilities, parking and picnic area.
- Type 1 Service Areas are to be provided approximately every 100 km.

2.1.1 NPF of Ireland

In May 2017, the Irish Government issued its NPF as its strategy in order to satisfy the mandate of the AFID. Bio-CNG is addressed in the NPF; proposing the development of 13 Core and 10 Comprehensive CNG refuelling stations by 2025, rising to 24 Core and 18 Comprehensive by 2030 (DTTS, 2017). Such an ambitious strategy is welcoming, however, the NPF does not go far enough as to explain how this strategy will be achieved, what are the criteria for determining bio-CNG refuelling station locations and how the production of biomethane will be aligned with this infrastructural framework. Therefore, the criteria proposed by the authors in this paper will assist in enhancing the requirements of the AFID and strategy of Ireland's NPF to develop a strategic infrastructure framework for bio-CNG deployment in Ireland.

2.1.2 The Core Network

The AFID requires that bio-CNG fuelling facilities be made available every 150km along the TEN-T Core Networks. However, from an Irish perspective, Type 1 service stations are required every 100km along the Core Network.

Criteria 1: *In order to avail of existing refuelling infrastructure for traditional transport fossil fuels, this paper recommends that bio-CNG refuelling installations be commissioning in the existing and proposed Type 1 stations (as identified by the TII) to be located every 100km along the Core Network where possible.*

This will allow bio-CNG technology to leverage off current multi-fuel service station facilities and therefore will not be required to develop standalone bio-CNG service stations. Co-locating bio-CNG installations with multi-fuel Type 1 service stations every 100km allows; further flexibility for customers, avoids duplication of service stations for different fuel types and ensures compliance with the AFID.

The proximity of the Type 1 service stations to the natural gas network is also a key consideration for the locating of bio-CNG installations and is dependent on a number of factors. Firstly, the closer a Type 1 service station is to the natural gas grid, then less capital investment is required to connect to the network. The cost per kilometre of constructing gas pipelines is significant. Furthermore, there are significant differences in the costs of connecting to the transmission network and connecting to the distribution network for a bio-CNG installation as highlighted as follows (Browne et al, 2011; Urban, 2013; GNI, 2017):

- Cost of connection to the natural gas network (excluding biomethane upgrading and injection):
  - Transmission connection: €300,000

- Distribution connection: €150,000

▪ Cost of pipeline to facilitate the connection to the natural gas network:
  - Transmission pipeline: €1,000,000/km
  - Distribution pipeline: €100,000/km

It should be noted that natural gas proximity and system pressure may not be considered as limiting factors if the bio-CNG developers feel that the service station location is of enough strategic importance once the additional costs do not jeopardise the bio-CNG installation's business case. Each bio-CNG installation project will have particular constraints and costs will vary depending on the developer requirements and location characteristics.

2.1.3 The Comprehensive Network

The locations of bio-CNG service stations should be identified in areas where population density is high and the opportunity to attract demand is greater. The AFID mandates the commissioning of an appropriate number of bio-CNG refuelling points accessible to the public in order to ensure that NGVs can circulate in urban/suburban agglomerations and other densely populated areas as determined by the MS's NPF. However, the terms 'urban', 'suburban' and 'densely populated areas' are not defined in the AFID. Ireland's NFP only lists the main cities where bio-CNG refuelling stations should be located; namely, Dublin, Cork, Limerick, Galway and Waterford (DTTS, 2017). It does not consider suburban areas in its strategy document.

Therefore, this paper produces a matrix comparing a number of MSs in Table 2 which defines densely populated areas into urban and suburban categories based on the population density of the MS (EC, 2014a). For example, Ireland has a population density of 67 persons/km^2 and lies in the 0-75 persons/km^2 range. From population analysis of the cities and towns in Ireland, the authors propose that urban areas be defined as areas with populations greater than 50,000 persons (Galway, Limerick, etc.). Furthermore any urban area of greater than 100,000 persons (Cork, Dublin) should be considered for significant bio-CNG development utilising multiple locations if the other criteria highlighted in this paper is satisfied. Smaller suburban areas such as large towns with a population of greater than 20,000 persons should be considered for pilot bio-CNG utilising one location as a starting point for further development.

Population density (persons/km^2)	Country	Population density (persons/km^2)	Population	No. of Vehicles	Vehicles per 1000PE	Area to be defined	Defined Urban Area (persons)
0 –75	Ireland	67	4,605,501	2,208,056	479	Urban	>50,000
						Suburban	>20,000
75 – 150	Portugal	103	10,427,301	5,757,400	552	Urban	>200,000
						Suburban	>40,000
>150	United Kingdom	263	64,308,261	34,457,011	536	Urban	>400,000
						Suburban	>60,000

Table 2: Population matrix for determining bio-CNG station locations

The United Kingdom lies in the greater than 150 persons/km^2 range and as a starting point should focus on multi-location development in urban areas of greater than 400,000 persons (London, Manchester, etc.) and one-off pilot locations in suburban areas of greater than 60,000 persons (Cambridge, Wigan, etc.) once the other criteria highlighted in this paper is satisfied. Once a MS has developed the urban and suburban areas in its population density range it can then focus on the next lower range to develop bio-CNG in smaller areas relative to the degree of success achieved from its initial development.

Criteria 2: *In relation to the Comprehensive Network, the placement of multiple bio-CNG service stations should occur in urban areas, while pilot projects should be located in suburban areas with 1 station required per 20,000 PE (population equivalent).*

Criteria 3: *In order to allow full circulation of NGVs, bio-CNG stations should also be located within 150km along the Comprehensive Network.*

Although it is not a requirement of the AFID, placement of stations at 150km along the Comprehensive network ensures that urban/suburban bio-CNG stations do not become isolated and restrict NGVs from undertaking long transit journeys.

2.2 Natural gas infrastructure requirements

In Europe, the European Network of Transmission System Operators for Gas (ENTSOG) is mandated by European Gas Regulation (EC 715/2009) to ensure the efficient management, development and coordinated operation of the European gas network (EC, 2009b). The role of ENTSOG is to facilitate and enhance cooperation between 44 national gas transmission system operators (TSOs) across Europe to ensure the development of a pan-European transmission system in line with EU energy goals (ENTSOG, 2015). ENTSOG's work is monitored by ACER (Agency for the Cooperation of Energy Regulators) whose mission is to complement and coordinate the work of national energy regulators at EU level and work towards the completion of the single EU energy market for electricity and natural gas (ACER, 2015a).

In January 2015, ACER published its updated Gas Target Model, presenting its vision for a competitive and secure European gas market that benefits all consumers (ACER, 2015b). There are two distinct options available in terms of harnessing natural gas infrastructure to introduce bio-CNG into each MS. The first option is the use of the existing natural gas network as a palpable solution in which a bio-CNG refuelling installation connects to the network to offtake bio-CNG for supply. The second option is the utilisation of virtual pipeline in which bio-CNG is delivered via a supply chain to final consumers using road or sea transportation (ACER, 2015b). In the absence of a natural gas network, virtual pipelines can be utilised as an intermediate step for the supply of regions prior to the development of a gas network or in cases where the construction of pipeline infrastructure is not cost effective or technically not possible. However, such a solution is considerable more expensive than the utilisation of existing gas networks and is dependent on customer demand, location, distance from the loading terminal and availability of road network (ACER, 2015b).

Criteria 4: *Ireland (and similar MSs) should focus on the utilisation of the existing natural gas network as the primary tool for introducing bio-CNG. In the absence of adequate natural gas infrastructure, MSs should explore the option of virtual pipeline solutions in order to allow full bio-CNG utilisation to be achieved throughout the regions and to facilitate full competition if demanded by the market.*

Gas Networks Ireland (GNI) is the owner and operator of the natural gas network in Ireland which is targeted for bio-CNG utilisation (GNI, 2013). Gas Networks Ireland develops, operates and maintains the gas infrastructure in Ireland consisting of over 13,000km of gas pipelines which is regulated by the Commission for Energy Regulation (CER). The Irish gas network serves over 160 population centres, providing significant coverage across the majority of urban and suburban areas in Ireland.

2.3 CNG installation requirements

Equipment: In 2016, the International Standards Organisation (ISO) released the standard for natural gas fuelling stations – bio-CNG stations (ISO 16923:2016) which "covers the design, construction, operation, inspection and maintenance of stations for fuelling bio-CNG to vehicles, including equipment, safety and control devices" (ISO, 2016). The key equipment required for a bio-CNG refuelling installation includes a compressor (which increases the pressure from 1 bar to 250 bar), high pressure multistage storage (where the bio-CNG that has been compressed is stored), inter facility piping (that connect the compressor and storage to the dispenser) and the dispensers (where the customer or end user dispenses gas to the NGV). A cash point system is also required to record the volume of bio-CNG purchased while refuelling.

<u>*Equipment sizing and costs:*</u> As this paper is proposing criteria for locating public service stations for all vehicle markets, ranging from the heavy goods commercial market to the private car market, the size of the bio-CNG refuelling installation should be equipped to meet the needs of all customers. The cost of the bio-CNG refuelling installation is dependent on a number of factors: the number of NGVs to refuel, the quantity of bio-CNG the NGVs use, the speed at which the NGV is filled and the NGVs refuelling patterns (EERE, 2014). For example, a public bio-CNG refuelling installation (as proposed in this roadmap) is assumed to serve large numbers of NGVs with short refuelling windows and unpredictable refuelling patterns and thus may require large compressors, larger storage capacity, and/or a large number of dispensers (EERE, 2014).

$$273{,}648\ln(x) + 491{,}859 \qquad \textbf{(Eq. 1)}$$

Where x = the quantity of trucks to be fuelled in a day.

Through the utilisation of Equation 1, the full capital cost of installing a bio-CNG refuelling installation into an existing service station can be determined based on NGV consumption; as developed in Figure 2 through a review of the industry focussing on public bio-CNG refuelling installations (GNI, 2017). For example, a public bio-CNG refuelling stations which forecasts the filling capacity of 40 trucks a day will cost approximately €1.5m to develop.

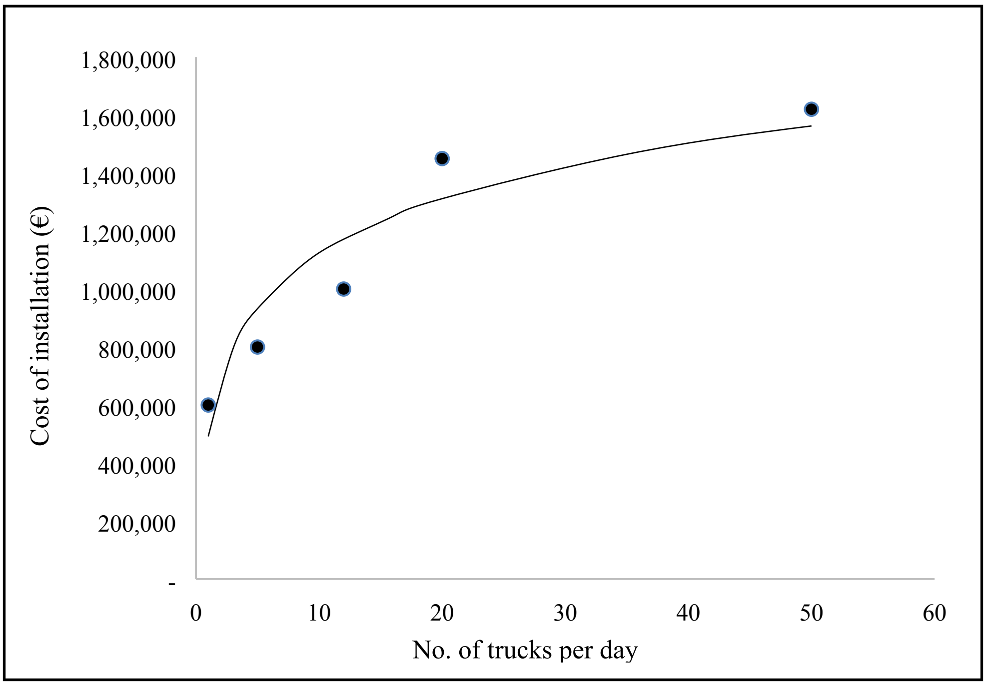

Figure 2: Capital costs of bio-CNG installations (GNI, 2017)

2.4 NGV requirements

Vehicle ranges:

NGV typically have a lower range in terms of distance travelled per fuel tank in comparison to traditional fossil fuel vehicles (Engerer & Horn, 2010). To combat the lower distance range that dedicated NGVs can travel, manufacturers reacted by developing bi-fuel and dual-fuel vehicles which run on a mixture of bio-CNG and diesel, thus increasing the potential distance travelled significantly and also providing the ability to refuel in traditional fossil fuel service stations when required. Bi-fuel NGVs have two separate fuelling systems that allow them to operate on either bio-CNG or petrol while dual-fuel NGVs have fuel systems that operates on a mixture of natural gas and diesel fuel, usually starting on diesel then switch to a quantified mixture of bio-CNG and diesel (PSE, 2015). The typical fuel ranges of industry available NGVs while operating on bio-CNG is 200 – 400km for HGVs while smaller LGVs have a range of up to 600kms on natural gas alone (NGVAE, 2015; Cenex, 2012). When considering the locations of facilities not on the Core or Compressive TEN-T Networks in a MS, the placement of bio-CNG installations should not be greater distance than the lower range of industry available NGVs.

2.5 Biomethane requirements

AD infrastructure:

In Ireland, as is the case with many MSs, there is currently no anaerobic digesters injecting biomethane into their respective natural gas networks. However, countries such as the United Kingdom, Germany and Sweden have an array of AD facilities injecting biomethane into their networks. *Goulding & Power* found that Ireland has the potential to develop 29 AD facilities, fuelling over 43,000 NGVs, when utilising 1% of the grassland area in Ireland and animal slurry as feedstock (Goulding & Power, 2013). Figure 3 highlights the potential for each county in Ireland to develop AD facilities from grass and animal slurries.

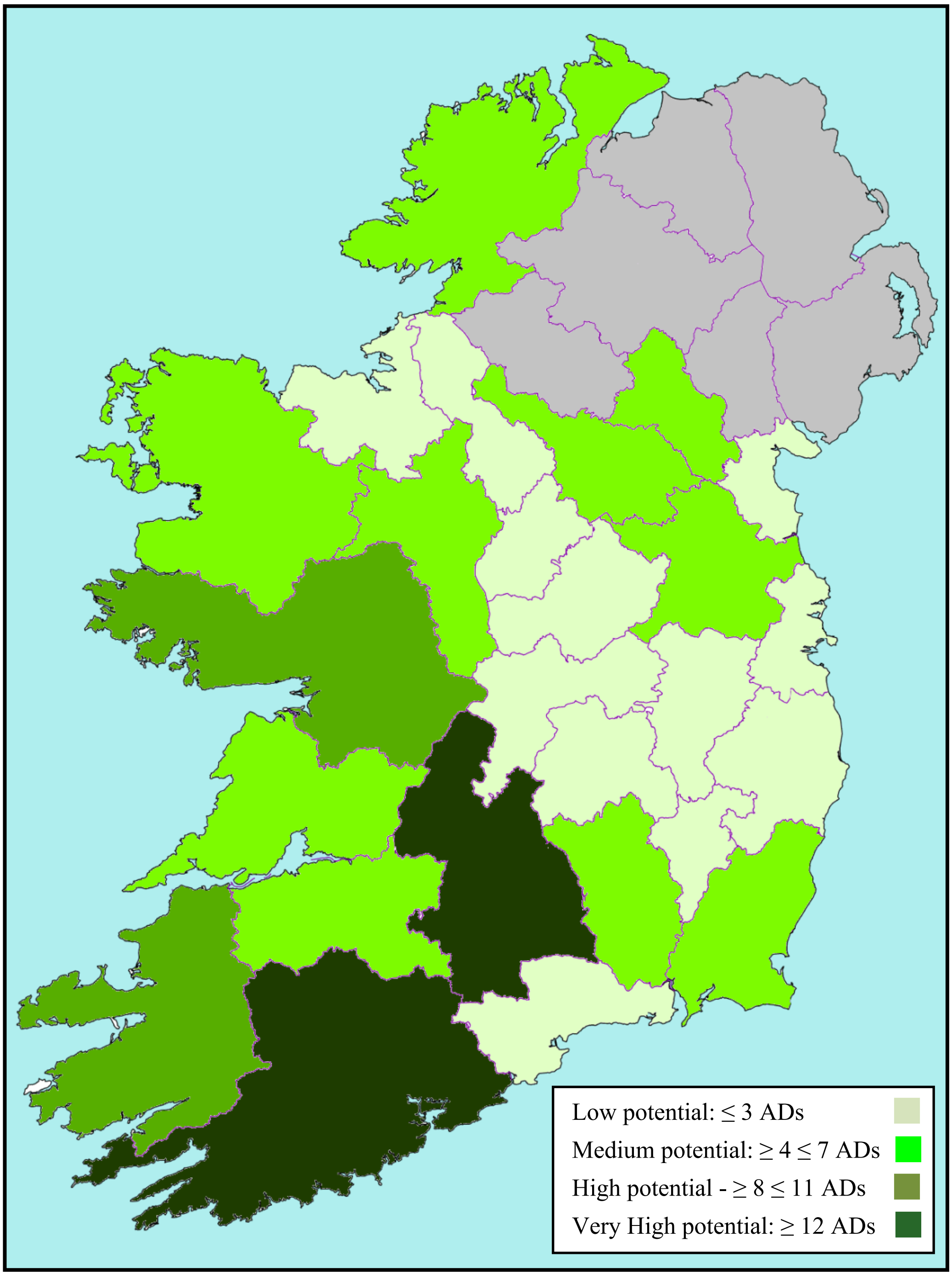

Figure 3: Suitable locations for AD from grass and slurry in Ireland based on area under grassland (Goulding & Power, 2013)

<u>Injection to the network:</u>

In Ireland, all natural gas currently entering the network must adhere to the relevant gas quality specifications laid down in Part G of the Transporter's Code of Operations (GNI, 2013). Currently in Ireland, for the connection of a natural gas undertaking who wishes to provide natural gas for the network; the GNI Code of Operations requires that any Entry Point must hold a Connected System Agreement (CSA) to govern how the delivery of natural gas is effectively achieved (GNI, 2013). The function of a CSA is to ensure that the Entry Point is technically and operationally compatible at the point of connection such that the natural gas network and associated natural gas production facility may safely be connected to deliver natural gas to the network. At present, the GNI Code of Operations does not consider the injection of an unconventional form of natural gas production such as biomethane from AD.

Criteria 5: *The criteria for biomethane injection should be managed through a specific CSA which is individual for each biomethane injection facility.*

In order to deliver efficiencies and to avail of an already successfully developed natural gas specification, a CSA for biomethane should utilise the same technical specifications for natural gas in line with the Part G of the current GNI Code of Operations. The key elements of the biomethane injection technical criteria are as follows (Goulding, 2011; GNI, 2013):

- Biomethane injection requires a compressor unit to compress the natural gas to the operating pressure of the network at the point of entry. Specific technical requirements to be mandated through the CSA.
  - Distribution pressure: 25 mbarg - 4 barg
  - Transmission pressure: 9 barg - 85 barg
- As per the GNI Code of Operations, biomethane injection is required to meet natural gas quality specification of the network to ensure it is of the same quality as the natural gas in the network. This may be dependent on the specification defined by network TSOs in each individual MS.
- There is no smell from natural gas, therefore under the GNI Code of Operations, odourisation of biomethane is mandated before injection to ensure that the biomethane

can be identified by humans if a leak were to occur. This is dependent on the specification defined by network TSOs in individual MS as some networks do not transport odoured gas.

Proximity of network:

As is the case with determining bio-CNG installation locations, the proximity of the anaerobic digester to the natural gas network and the type of network to connect to (transmission or distribution) are key considerations in terms of additional capital costs to the development as highlighted in Section 2.1.2. These costs do not include the cleaning and injection equipment. Again, it should be noted that all such connections for biomethane injection have specific costs depending on the characteristics of the individual biomethane injection facility to be connected. However, it is clear that the closer the location of the anaerobic digester to the network the less expensive the pipeline will cost to connect to the network.

Criteria 6*: Biomethane injection facilities should be located preferably near the distribution network to ensure that connection costs are economically viable.*

Connecting to the distribution network will result in lower operational costs as the biomethane will not need to be compressed as much as if it was being injected in the transmission network at a significantly higher pressure. However, when injecting into the distribution network, sufficient network capacity must be available. Preferably, a biomethane facility should be located near a point on the distribution network where a significant consistent demand is required even through low demand seasons (Goulding, 2011). If injection into a distribution network is not viable, then a connection to the transmission network may be utilised, albeit at significantly higher cost.

4.0 Results

4.1 A strategic infrastructure framework

The criteria determined in this paper to develop a strategic infrastructure framework for EU MSs has been applied to Ireland in which the following proposals are suggested for implementation:

- The construction of 22 bio-CNG refuelling stations in existing Type 1 Service stations as illustrated in Figure 4.
- 11 of the 22 bio-CNG refuelling stations should be located on the Core Network within 100km of each other and fully service the Irish TEN-T Core Network from Northern Ireland via Dublin to both major sea ports in Cork/Ringaskiddy and Limerick/Foynes.
- The Comprehensive Network is serviced by strategically placing the other 11 bio-CNG service stations in urban/suburban cities and towns located on the Comprehensive Network based on their population profile as determined in Section 2.1.3.
- In terms of the natural gas infrastructure, 17 of the 22 bio-CNG stations are located in areas where the natural gas network is present. Two further bio-CNG stations are proposed for towns where the natural gas network is currently being extended to; namely Wexford Town and Nenagh.
- Three virtual pipeline bio-CNG stations are included in order to service areas of the country where there is no natural gas network available but are of strategic importance. These three stations will allow counties in the south-west as far as Kerry and counties in the north-west such as Sligo and Donegal to utilise bio-CNG and travel in NGVs from one end of Ireland to the other.

The bio-CNG refuelling stations locations meet all the criteria determined in this paper as highlighted in Table 2. The locations of the Core and Comprehensive bio-CNG refuelling stations in Ireland allows NGV customers to travel along the Ten-T network of the entire State on bio-CNG with no station greater than 150km from the next bio-CNG station.

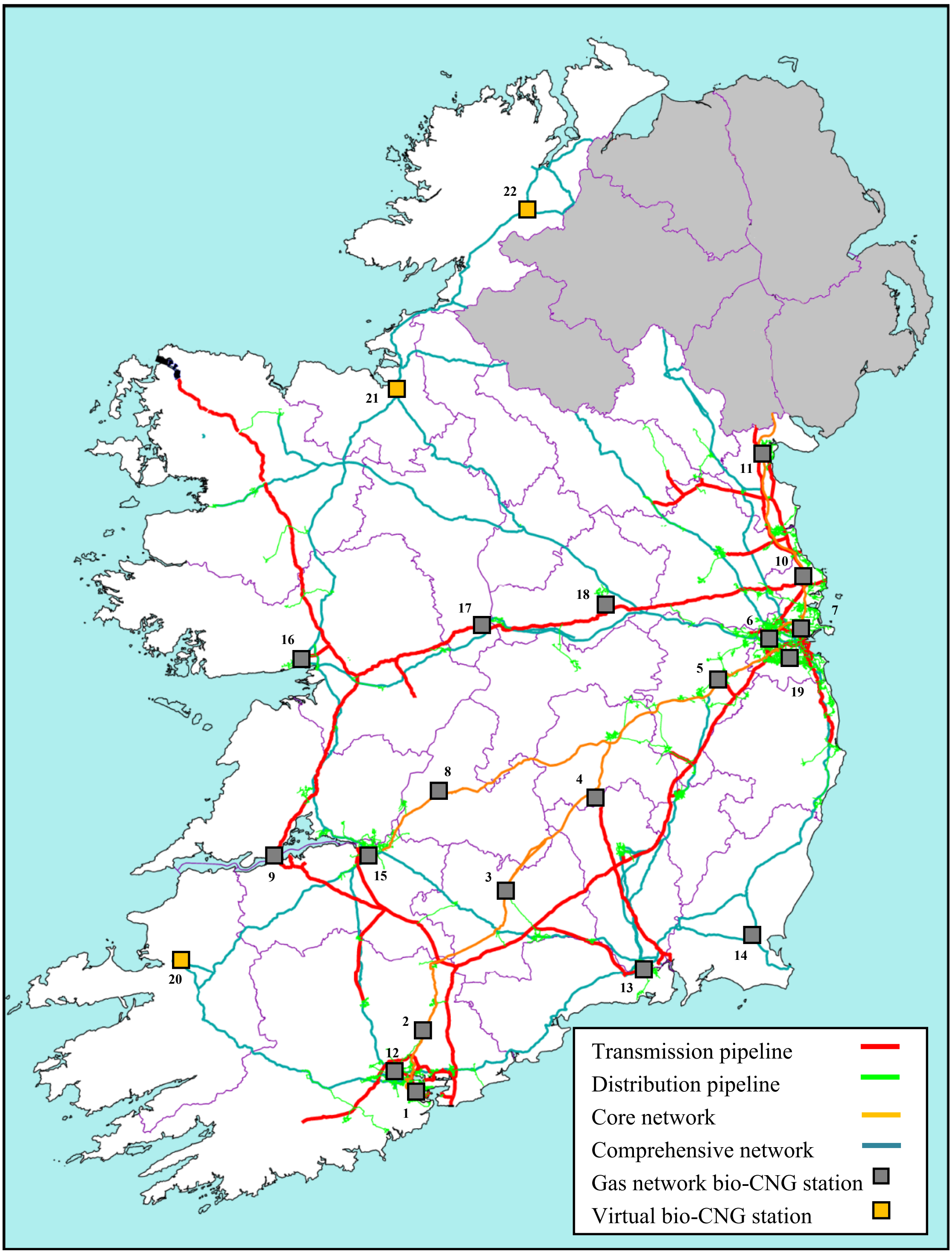

Figure 4: A bio-CNG public access refuelling network for Ireland

	Station Location	County	TEN-T Network *(Criteria 1)*	Core Network Linkage *(Criteria 1)*	Distance to Nearest Station (km) *(Criteria 1, 3)*	Population *(Criteria 2)*	Gas Network Available *(Criteria 4)*	Biomethane Injection Potential *(Criteria 5, 6)*
1	Cork Harbour - Ringaskiddy	Cork	Core	Cork/Dublin	45km to Fermoy		Yes	Very-High
2	Fermoy	Cork	Core	Cork/Dublin	56km to Cashel	6,489	Yes	Very-High
3	Cashel	Tipperary	Core	Cork/Dublin	75km to Portlaoise	4,051	Yes	Very-High
4	Portlaoise	Laois	Core	Cork/Dublin Limerick/Dublin Dublin/Dundalk	56km to Naas	20,713	Yes	Medium
5	Naas	Kildare	Core	Cork/Dublin Limerick/Dublin	40km to Ballymun	20,145	Yes	Low
6	Ballymun	Dublin	Core	Cork/Dublin Limerick/Dublin	25km to Lusk	22,109	Yes	Low
7	Dublin Port	Dublin	Core	Cork/Dublin Limerick/Dublin	10km to Ballymun		Yes	Low
8	Nenagh	Tipperary	Core	Limerick/Dublin	72km to Portlaoise	8,439	Planned	Very High
9	Foynes Port	Limerick	Core	Limerick/Dublin	78km to Nenagh		Yes	High
10	Dundalk	Louth	Core	Dublin/Dundalk	73km to Lusk	37,816	Yes	Low
11	Lusk	Dublin	Core	Dublin/Dundalk	30km to Dublin Port	7,022	Yes	Low
12	Cork City	Cork	Comprehensive		40km to Fermoy	198,582	Yes	Very High
13	Waterford City	Waterford	Comprehensive		120km to Cork City	51,519	Yes	Medium
14	Wexford Town	Wexford	Comprehensive		60km to Waterford City	20,072	Planned	Medium
15	Limerick City	Limerick	Comprehensive		40km to Nenagh	91,454	Yes	High
16	Galway City	Galway	Comprehensive		85km to Athlone	76,778	Yes	High
17	Athlone	Westmeath	Comprehensive		125km to Ballymun	20,153	Yes	Medium
18	Mullingar	Westmeath	Comprehensive		82km to Ballymun	20,103	Yes	Medium
19	Tallaght	Dublin	Comprehensive		20km to Ballymun	71,504	Yes	Low
20	Tralee	Kerry	Comprehensive		75km to Limerick City	23,693	Virtual pipeline	High
21	Sligo	Sligo	Comprehensive		130km to Mullingar	19,452	Virtual pipeline	Medium
22	Letterkenny	Donegal	Comprehensive		112km to Letterkenny	19,588	Virtual pipeline	Medium

Table 2: A Bio-CNG public access refuelling network for Ireland

5.0 Discussion

5.1 Definitive Criteria

This paper proposes a number of criteria which will assist countries such as Ireland to develop bio-CNG supply infrastructure, and comply with the requirements of the AFID. However in a number of instances, this paper highlights that the AFID and NPF of Ireland does not go far enough and this paper recommends strengthening in a number of areas including:

- A requirement that bio-CNG fuelling facilities be made available every 100km along the TEN-T Core Networks, instead of the current 150km, this would align EU policy to Irish National Policy and best practice for the provision of service stations. This will reduce the need to develop standalone bio-CNG service stations and will avoid the duplication of service stations for various fuel types.
- A definition to adequately define the terms ‘urban’ and ‘sub-urban’ is required. This paper proposes a definition of urban and sub-urban areas based on the population density of a country. Using Ireland as a test case; an urban area is defined as >50,000PE and a sub-urban area is >20,000PE.
- The installation of bio-CNG units every 150km along the Comprehensive Network in existing or proposed service stations. This would ensure that vehicles travelling throughout Europe could avail of bio-CNG throughout the Comprehensive Network and are not confined to the just the Core network.

In order to compliment the enhancements to current EU infrastructure policy conceived by the authors in this paper and to fully realise the potential for bio-CNG deployment, additional technical infrastructural requirements must also be taken into consideration including:

- The utilisation of the existing natural gas network as the primary tool for bio-CNG deployment, as this is more cost effective than using a virtual pipeline. This will help to ensure that bio-CNG is economically competitive.
- To ensure that biomethane injection into the natural gas network complies with the technical specification of the associated network in each MS.
- Development of biomethane injection facilities into the distribution network preferably to ensure connection and operational costs are economically competitive. The injection facilities should be located in counties with high agricultural AD potential as determined by the authors.

6.0 Conclusions

Using Ireland as a test case, if the proposed criteria was implemented then Ireland could deploy 22 bio-CNG service stations to initiate an alternative bio-CNG transport fuel market as mandated by the AFID; 19 of which are located on the existing (and proposed) natural gas network with a further three virtual pipeline stations. 9 of these stations could be located in areas where there is a high or very-high biomethane potential. This infrastructural framework would enable Ireland to comply with the AFID, enhance and provide a more defined bio-CNG strategy for Ireland's NPF, and will also help Ireland achieve its RES-T by 2020. However, more importantly the proposed service stations are close to large population centres in Ireland thus further strengthening the potential for bio-CNG as a sustainable transport fuel into the future.

This paper proposes six criteria to abide by in order to develop a successful infrastructure framework for bio-CNG deployment in Ireland. The criteria range from strengthening current EU policy and the NPF of Ireland, to essential technical infrastructural requirements to be taken into consideration. Furthermore, the proposed criteria can be utilised as a template to follow for other MSs with similar infrastructure and bio-CNG requirements.

Acknowledgements

The authors wish to acknowledge the part funding (grant number: 2008-S-ET-8) received from the Environmental Protection Agency under the Science, Technology, Research and Innovation for the Environment (STRIVE) Programme 2007-2013. The authors also wish to acknowledge the support provided by Gas Networks Ireland, the owner of the natural gas network in Ireland.

References

(ACER, 2015a) "Mission and Objectives webpage", Agency for the Cooperation of the Energy Regulators, Trg republike 3, 1000 Ljubljana, Slovenia. Accessed in 2015. http://www.acer.europa.eu/The_agency/Mission_and_Objectives/Pages/default.aspx

(ACER, 2015b) "ACER Gas Target Model 2015", Agency for the Cooperation of the Energy Regulators, Trg republike 3, 1000 Ljubljana, Slovenia. 2015. http://www.acer.europa.eu/Events/Presentation-of-ACER-Gas-Target-Model-/default.aspx

(Bordelanne et al, 2011) Bordelanne O, Montero M, Bravin F, Prieur-Vernat A, Oliveti-Selmi O, Pierre H, Papadopoulo M, Muller T, "Biomethane CNG hybrid: A reduction by more than 80% of the greenhouse gases emissions compared to gasoline", Journal of Natural Gas Science and Engineering 3 (2011) 617e624, doi:10.1016/j.jngse.2011.07.007

(Browne et al, 2011) Browne J, Nizamia A-S, Thamsiriroja T, Murphy JD, "Assessing the cost of biofuel production with increasing penetration of the transport fuel market: A case study of gaseous biomethane in Ireland", Renewable and Sustainable Energy Reviews, Volume 15, Issue 9, December 2011, Pages 4537–4547. doi:10.1016/j.rser.2011.07.098

(Cenex, 2012) Carroll S, Walsh C, "The Coca-Cola Enterprises Biomethane Trial Report", Cenex Head Office, Innovation Centre, Holywell Park, Loughborough University, Ashby Road, Loughborough, Leicestershire, LE11 3TU. 2012.

(DTTS, 2017) "National Policy Framework – Alternative Fuels Infrastructure for Transport in Ireland 2017 – 2030", Department of Transport, Tourism and Sport, Leeson Lane, Dublin 2, Ireland D02TR60. 2017.
http://www.dttas.ie/sites/default/files/publications/public-transport/english/alternative-fuels-framework/6186npfalternative-fuels300517.pdf

(EC, 2014a) Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure, presented by Commission of the European Communities. Official Journal of the European Communities, 2014, L307/1.

(EC, 2014b) "Transport Progress Report of the European Coordinators Corridors", European Commission – Directorate General for Mobility and Transport, Directorate B – European Mobility Network, Unit B1 – Trans European Network, 2014.

(EC, 2014c) "Renewable Energy Progress Report", presented by the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Brussels, 15.6.2015. COM (2015) 293 final.

(EC, 2013) "The Core Network Corridors - Trans European Transport Network 2013", European Commission – Directorate General for Mobility and Transport, Directorate B – European Mobility Network, Unit B1 – Trans European Network, 2013.

(EC, 2009a) Directive 2009/28/EC of the European Parliament and of the Council on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, Brussels 29th April 2009, presented by Commission of the European Communities. Official Journal of the European Communities, Strasbourg, 2009, L140/16.

(EC, 2009b) Regulation (EC) No 715/2009 of the European Parliament and of the Council of 13 July 2009 on conditions for access to the natural gas transmission networks and repealing Regulation (EC) No 1775/2005, presented by Commission of the European Communities. Official Journal of the European Communities, Strasbourg, 2009, L211/36.

(EERE, 2014) Smith M & Gonzales J, "Costs Associated With Compressed Natural Gas Vehicle Fuelling Infrastructure", U.S. Department of Energy – Energy Efficiency & Renewable Energy, September 2014. Accessed in 2017.
https://www.nrel.gov/docs/fy14osti/62421.pdf

(Engerer & Horn, 2010) Engerer H, Horn M, 'Natural gas vehicles: An option for Europe', Energy Policy 38 (2010) 1017–1029, doi:10.1016/j.enpol.2009.10.054. 2010.

(ENTSOG, 2015) "Mission webpage", European Network of Transmission System Operators for Gas, Avenue de Cortenbergh 100 / second floor, 1000 Brussels, Belgium. Accessed in 2015.

http://www.entsog.eu/mission

(Eurostat, 2012) "Energy from Renewable Sources", Article from Eurostat data: Further Eurostat information, Main tables and Database. May 2014. http://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_from_renewable_sources#Share_of_energy_from_renewable_sources:_transport

(GNI, 2017) Consultation with the Gas Networks Ireland CNG Commercial Department. 2017.

(GNI, 2013) "Code of Operations – Version 4.0", Gas Networks Ireland, Gasworks Road, Cork, Ireland. 2013.

(Goulding et al, 2016) Goulding D, Fitzpatrick D, O'Connor R, Browne JD, Power NM, "Supplying bio-compressed natural gas to the transport industry in Ireland: Is the current regulatory framework facilitating or hindering development?", Energy, http://dx.doi.org/10.1016/j.energy.2016.08.037.

(Goulding et al, 2014), Goulding D, Gallagher C, Power NM, "What policies should be implemented to develop a gaseous transport industry in Ireland?" Environmental Science & Policy (2014) 215 – 225, http://dx.doi.org/10.1016/j.envsci.2014.08.004. 2014.

(Goulding & Power, 2013) Goulding D, Power NM, "Which is the preferable biogas utilisation technology for anaerobic digestion of agricultural crops in Ireland: Biogas to CHP or biomethane as a transport fuel?", Renewable Energy, Volume 53, May 2013, Pages 121-131. http://dx.doi.org/10.1016/j.renene.2012.11.001 2013.

(Goulding, 2011) Goulding D, “What are the technical requirements for improving the sustainability of the natural gas network through the injection of renewable gas?”, 1st Prize Award Winner at the Pipeline Industries Guild Graduate Competition 2011.

(ISO, 2016) “Standard for Natural Gas Fuelling Stations – CNG Stations (ISO 16923:2016)”, International Organisation for Standardisation, ISO Central Secretariat, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland. 2016.

(Khan and Yasmin, 2014) Khan MI, Yasmin T “Development of natural gas as a vehicular fuel in Pakistan: Issues and prospects”, Journal of Natural Gas Science and Engineering 17 (2014) 99e109. http://dx.doi.org/10.1016/j.jngse.2014.01.006. 2014.

(Kirk et al, 2014) Kirk JL, Bristow AL, Zanni AM, “Exploring the market for Compressed Natural Gas light commercial vehicles in the United Kingdom”, Transportation Research Part D 29 (2014) 22–31. http://dx.doi.org/10.1016/j.trd.2014.03.004

(Li, 2015) Li X, “Natural gas in China: a regional analysis”, OIES PAPER: NG 103, Oxford Institute for Energy Studies, 57 Woodstock, Road Oxford, OX2 6FA, United Kingdom, 2015.

(NGVAE, 2017) “Statistical Report 2017”, Natural and Bio Gas Vehicle Association Europe, Avenue de Cortenbergh 172/6, 1000 Brussels, Belgium. 2017.
https://www.ngva.eu/downloads/NGVA_Europe_Statistical_Report-2017.pdf

(NGVAE, 2015) “Natural Gas Vehicle Catalogue”, Natural and Bio Gas Vehicle Association Europe, Avenue de Cortenbergh 172/6, 1000 Brussels, Belgium. Accessed in 2015.

http://www.ngvaeurope.eu/cars

(NRA, 2014) National Roads Authority, "Service Area Policy", St. Martin's House, Waterloo Road, Dublin 4. 2014.

(PSE, 2015) Messersmith DT, "Natural Gas Vehicle Basics", Penn State Extension, College of Agricultural Sciences. 2015.

(Ryan & Caulfield, 2010) Ryan F & Caulfield B, "Examining the benefits of using bio-CNG in urban bus operations", Transportation Research Part D 15 (2010) 362–365. Doi: 10.1016/j.trd.2010.04.002. 2010.

(SEAI, 2016) Howley M & Holland M, "Energy in Ireland 1990 – 2015 – 2016 Report", Energy Policy Statistical Support Unit, Sustainable Energy Authority of Ireland, Wilton Park House, Wilton Place, Dublin 2. 2016.
http://www.seai.ie/Publications/Statistics_Publications/Energy_in_Ireland/Energy-in-Ireland-1990-2015.pdf

(Shahraeeni et al, 2015) Shahraeeni M, Ahmed S, Malek K, Van Drimmelen B, Kjeang E, "Life cycle emissions and cost of transportation systems: Case study on diesel and natural gas for light duty trucks in municipal fleet operations", Journal of Natural Gas Science and Engineering 24 (2015) 26e34. 2015.
http://dx.doi.org/10.1016/j.jngse.2015.03.009

(Svensson, 2014) Svensson M, "Biomethane standards Gas quality standardisation of biomethane, going from national to international level", Swedish Gas Technology Centre, European workshop Biomethane, Brussels, (IEE/10/235 GreenGasGrids). 2014. http://european-biogas.eu/wp-content/uploads/2014/03/8_Mattias Svensson_standards.pdf

(Urban, 2013) Urban, W, "Biomethane injection into natural gas networks", the biogas handbook. Science, production and applications. Woodhead Publishing Series in Energy. Oxford, Cambridge, Philadelphia, New Delhi: Woodhead Publishing, 378-403. 2013. doi: 10.1533/9780857097415.3.378