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Environmental and Economic factors necessary to stimulate growth of CNG vehicles in NAFTA vs EMEA model

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Environmental and Economic factors necessary to stimulate growth of CNG vehicles in NAFTA vs EMEA model

By
Giuseppe Lovero

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Environmental and Economic factors necessary to stimulate growth of CNG vehicles in NAFTA vs EMEA model

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ABSTRACT

The drive towards greater sustainability in the automotive industry and the continuing and rapid evolution of international emission standards have prompted nearly all automotive manufacturers to develop vehicles using alternative fuels compared to conventional gasoline. Natural gas is one promising fuel and could serve as a bridge fuel towards greener transportation. In particular, the renewed interest in natural gas as a vehicle fuel in the U.S has grown due to recent shale gas development which could ensure a long-term, low-cost and domestic source of natural gas. Unlike North America, however, natural gas vehicles are more widely used elsewhere in the world, and particularly in Europe. This thesis investigates the main issues and challenges associated with the growth of compressed natural gas light duty vehicles in the United States. To assess the feasibility of such strategy, a comparison analysis with the implementation of natural gas vehicles and infrastructure support in Italy was undertaken. Furthermore, the broad economic and environmental tradeoffs have been assessed using the Economic Input-Output Life Cycle Assessment model.

DEDICATION

To my family,

for having given me the chance to be here at this point

ACKNOWLEDGEMENTS

This thesis is the result of a Double Degree Master program that was possible only with the cooperation and guidance of people from two universities, the Politecnico di Torino and the University of Windsor, and two leading automotive companies Fiat Group Automobile and Chrysler LLC.

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LIST OF ABBREVIATIONS/SYMBOLS

ACEA	European Automobile Manufactures' Association
AEO	Annual energy outlook
AGA	American Gas Association
ANGA	America's Natural Gas Alliance
ASTM	American society for testing and materials
Bcf	Billion cubic feet
Bcm	Billion cubic meter
BEA	Bureau of Economic Analysis
BP	British Petroleum
BTU	British thermal unit
CAFE	Corporate Average Fuel Economy
CARB	California Air Resources Board
CEN	European Committee for Standardization
cm	Centimeter
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_{2eq}	Carbon dioxide equivalent
DNGI	Drive Natural Gas Initiative
DOE	Department of Energy
DOT	Department of Transportation
EIA	U.S. Energy Information Administration
EIO-LCA	Economic Input-Output life cycle analysis
EMEA	Europe Middle East and Asia
ENI	Ente Nazionale Idrocarburi
EPA	Environmental Protection Agency
FERC	Federal Energy Regulatory Commission
FFV	Flexible Fuel Vehicle
FTP-75	Federal Test Procedure -75

g	Gram
GDP	Gross Domestic Product
GGE	Gasoline Gallon Equivalent
GHG	Greenhouse Gas
Gm^3	Cubic Gigameter
GOM	Gulf of Mexico
GWI	Global warming potential index
HC	Unburned hydrocarbon
HCHO	Formaldehyde
HEV	Hybrid electric vehicle
HOV	High occupants vehicle
HRA	Home refueling appliance
in	Inch
INGAA	Interstate Natural Gas Association of America
I-O	Input-Output
J	Joule
KGal	Kilo Gallon
Km	Kilometer
LCA	Life cycle analysis
LDV	Light duty vehicle
LEV II	Low emission vehicle II
LNG	Liquefied natural gas
m^3	Cubic meter
Mcf	Thousands of cubic feet
MMcf	Million cubic feet
MMcm	Million cubic meter
MMcm\d	Million cubic meter per day
MOU	Memorandum of Understanding
Mt	Metric tons
N_2O	Nitrous Oxide
NAFTA	North American Free Trade Agreement

NAICS	North American Industry Classification System
NEI	National Emission Inventory
NG	Natural gas
NGV	Natural gas vehicle
NGVA	Natural Gas Vehicle Association
NH_3	Ammonia
NMOG	Non methane Organic gases
NO_x	Nitrogen oxide
OEM	Original Equipment Manufacturer
OPS	Office of pipeline safety
Pb	Lead
PM	Particulate matter
PPI	Producer Price Index
PTW	Pump to Wheel
Quad	Quadrillion
R&D	Research & Development
RNG	Renewable natural gas
ROI	Return of Investment
RON	Octane rating number
SAIC	Scientific Application International Corporation
SCADA	Supervisory control and data acquisition
SDWA	Safe drinking water act
SETAC	Society of Environmental Technology and Chemistry
SO_2	Sulfur dioxide
SULEV	Super ultra-low emission vehicle
TAC	Trans Adriatic Pipeline
TAG	Trans Austria Gasleitung
Tcf	Trillion cubic feet
Tcm	Trillion cubic meter
TCO	Total cost of ownership
TENP	Trans Europa Naturgas Pipeline

TJ	Tera Joule
Tm^3	Cubic Terameter
TRR	Technically recoverable resources
TTPC	Trans Tunisian Pipeline Company
TTW	Tank to Wheel
U.S.	United States
ULEV	Ultra low emission vehicle
USGS	United States Geological Survey
VA	Value Added
VOC	Volatile organic compounds
VRI	Vehicle to refueling station index
WEO	World Energy Outlook
WTP	Well to Pump
WTT	Well to Tank
WTW	Well to Wheel

NOMENCLATURE

O_i	Intermediate Output
Y_i	Final demand
X_i	Total Output
I_i	Intermediate Input
V_i	Value Added
X_{ij}	Input to column sector $_j$ from row sector $_i$
A	Direct requirement matrix
I	Identity matrix
E	Vector of environmental impacts
R	Diagonal matrix representing the impact per dollar of output

1. INTRODUCTION

The societal drive for sustainable but affordable solutions and the corresponding evolution of international standards regarding the reduction of fuel consumption and pollutants emissions have prompted many automotive original equipment manufacturers (OEMs) to consider the development of vehicles based on alternative fuels compared to traditional petroleum. However, vehicles powered by alternative fuels must not only be provide favorable environmental performance, but also remain attractive to consumer needs in terms of performance and price.

Recently, in part due to the discovery of shale gas deposits in the United States and the technological advances to extract them, ***natural gas*** has emerged as a potential main fuel source in vehicle fuels and can reduce carbon dioxide (CO_2) emissions while maintaining a reasonable total cost of vehicle ownership (TCO). Natural gas has the potential to significantly shape the transportation sector, particularly for fleets, providing a bridge to a greener, low carbon future because of its abundance, and lower and less volatile price compared to traditional fuels. Furthermore, the recent emergence of new sources of natural gas in the U.S., mainly as a result on large scale of shale plays developments, has increased the awareness of natural gas as a strategic alternative to reduce the $330 billion of annual imports of oil.

In the United States, the estimates of technically recoverable natural gas may stimulate producers to seek new markets for natural gas, such as an increasing use for transportation. According to the Energy Information Administration (EIA) there are in United States 72,039 Cubic Gigameter (Gm^3) including proven, unproven, undiscovered and unconventional natural gas, which could ensure gas self-sufficiency for about 120 years. For transportation then, compressed natural gas (CNG) represents for the United States a means to reduce the dependency on oil consumption and improve air quality. Despite this fact, the abundance of methane in the U.S. has had only a small contribution to stimulating growth of both commercial and retail light duty vehicles because of a lack of infrastructure to deliver CNG and other key uncertainties. This contrasts with the greater success and adoption of natural gas powered vehicles in Europe, and particularly Italy.

1.1. Problem statement

Natural gas (NG) has long been considered an alternative fuel for transportation. As reported by the Natural Gas Vehicle Association, there are currently more than 130,000 Natural gas vehicles (NGVs) on the road in the United States, but about 1 million in Europe and more than 17 million NGVs worldwide [1]. In recent years, technology has improved to accomplish the rapid development of natural gas vehicles, especially for high-mileage fleets. Despite these advances, if compared with the total number of vehicles (gasoline or diesel) on the road worldwide, these values represent a very low percentage. The main reasons lie in the higher initial cost of NGVs and lack of refueling infrastructure which limit the widespread adoption of natural gas vehicles. In North America, NGVs for passenger vehicles are affected by a very limited infrastructure fueling system for distributing natural gas, characterized by 0.2% of natural gas public stations compared to gasoline ones. In addition, one of the main problems connected to natural gas filling stations are their locations: most natural gas filling stations are far away from the city center, and a very low number of stations are available on motorways compared to the number of gas vehicles.

Consequently, natural gas might be competitive with gasoline only where transmission and distribution networks are present. However, while investments in vehicles, pipelines as well as in storage infrastructure can generate positive returns, state and federal policies, including subsidies, tax incentives, procurement policies, and emission standard may be required to establish a NGV market. What is required then is an analysis into the circumstances that would encourage greater natural gas adoption for vehicles in the U.S. and a preliminary assessment of the economic and environmental impacts that would result under different levels of NGV proliferation. Automotive OEMs could then recognize how they may or may not be able capitalize on these circumstances.

It will be critical to understand the differences between the U.S. and European markets and conditions for NGVs to determine if there are any “lessons learned”. Europe has significant greater natural gas implementation for transportation. Currently, only Honda and Chevrolet offer a CNG option in the U.S, but in Europe, many automakers, including FIAT, GM, Mercedes, Peugeot, Toyota, Ford, Volkswagen, offer CNG options.

1.2. **Objectives and hypothesis**

1.2.1. General target

This project will assess the potential of using compressed natural gas as a fuel source for passenger vehicle transportation in the United States, and focus on the economic and environmental tradeoffs of developing the infrastructure and related systems to permit natural gas adoption. Automotive OEMs can then use this assessment to position themselves within the developing U.S. market. The first stage of this research is to define the state of the natural gas infrastructure and supporting systems in both Europe and North America. This analysis includes assessing, by region, issues such as: proven and estimated resources, transmission pipelines, and the number of refilling stations, as well as government actions like subsidies, tax incentives and loan programs that encourage or discourage natural gas usage. As a whole the conceptual framework of this analysis is based on the following assumptions:

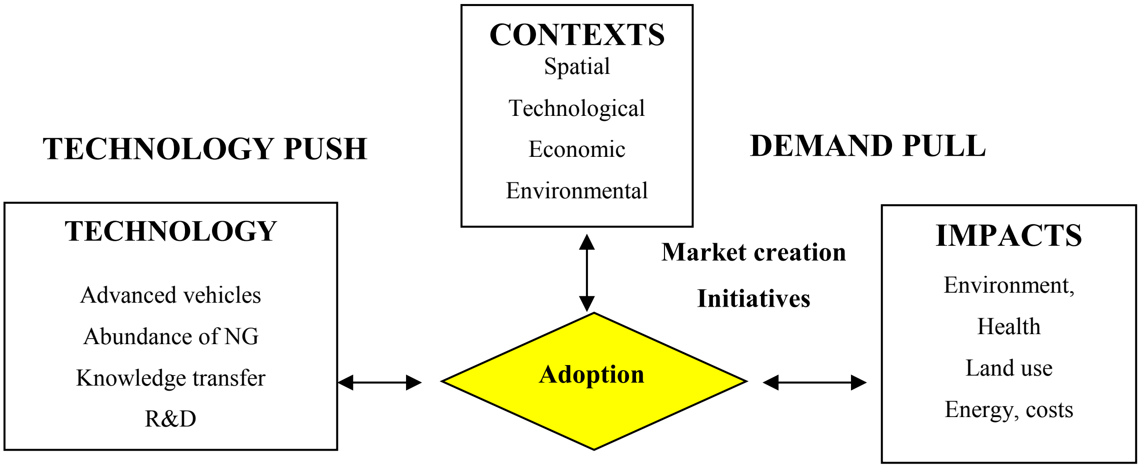


Figure 1.2-1 Conceptual framework of the analysis

1.2.2. Major steps and issues

The block diagram reported above shows that a number of parameters are significant in this research, and there are also a number of discrepancies between Europe and the United States. To improve the manageability of this research, the core research will focus on developing selected case studies to best illustrate the issues and how different levels of natural gas infrastructure development to support NGV adoption in the U.S. result in economic and environmental tradeoffs. Defining these case studies requires first developing and evaluating a reference model to assume as a target or goal to compare the natural gas situations between the United States and Europe. Then, a multiple scenario matrix will be developed to assess more specific input/factor combinations.

Within Europe, Italy has the greatest adoption of NGVs and natural gas infrastructure to support them. The primary scenario assessment will use Italy as the “reference model” to analyze the environmental and economic effects associated with the expansion of NGVs in the United States to the same degree as found in Italy. Then, a series of integrated, multiple scenario analyses will be undertaken to segregate the analysis based on regional differences within the U.S., and to compare the potential of different regions (i.e., states) to move either to the levels of NGVs and natural gas distribution exhibited in Italy, or to some other level. Although this research is aimed ultimately at the U.S. as a whole, there are important regional differences in terms of natural gas availability, the likelihood of associated infrastructure development, and government or societal initiatives towards natural gas implementation: some states already show a “high potential” of natural gas implementation, while others lag severely. As a result, some states may more realistically be modeled to achieve an intermediate level of natural gas adoption, while others may approach that of the reference model, Italy. There may be a stepped approach for encouraging, adopting and implementing NGVs throughout the U.S. over time.

Finally, a life cycle analysis combined with a cost analysis provides a decision frame helpful to understand the environmental and economic impacts from moving from one natural gas level of implementation to another. The LCA results should help illustrate why natural gas adoption for NGVs would be favored in some areas compared to others, but will also reveal if alternative fuel proposals using natural gas create other environmental impacts that are not immediately apparent.

2. LITERATURE REVIEW

2.1. Alternative fuels

The need to reduce the dependence on oil together with the rapid evolution of the international emission standards regarding the reduction of fuel consumption and pollutants emissions have pushed technological research to develop alternative fuels to the traditional petroleum products.

Based on data reported by Eni's annual review "World Oil and Gas Review", the global reserve of oil may be completely used up in the next fifty years. This value can be shown considering the ratio between the Word Oil Reserves and Annual World Oil consumption (around 32,008 million barrels per year) [2] in Figure 2.1-1 below.

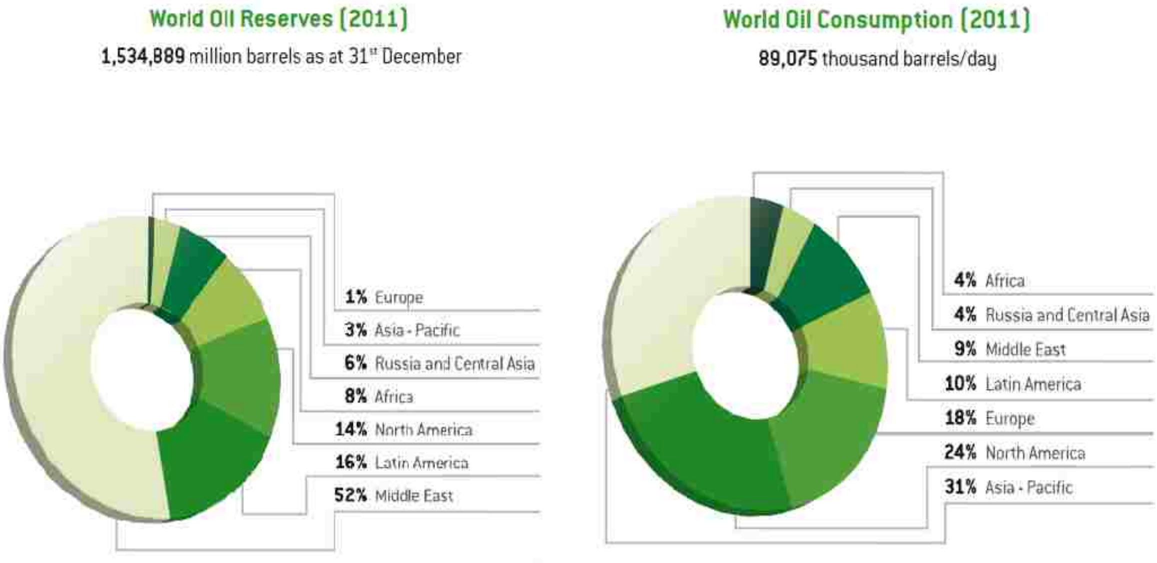


Figure 2.1-1 World Oil Reserve and Consumption [2]

The other important driver that pushes alternative fuels is the possibility to exploit a more stable supply source. Indeed, the major reserves of oil are often located in regions characterized by socio-political instability, including the Middle East, Latin America and Russia. Political instability in the Middle East has been cause of price volatility and supply interruption [3].

Over the years, different kinds of alternative fuels to gasoline and diesel have been studied and implemented as fuel for transportation.

These include:

- natural gas (compressed natural gas CNG and liquefied natural gas LNG),
- hydrogen
- ethanol
- biodiesel

Electricity is reported as an alternative fuel even if it is not properly a fuel. In the following section, a general overview of alternative fuels is presented before focusing on natural gas and the related impacts that could stimulate the growth of CNG vehicles.

Figure 2.1-2 Alternative fuel. Adapted from [4]

2.1.1. Biodiesel

Biodiesel represents one of the main candidate fuels to penetrate the European and American transportation sector since it can be easily implemented in current vehicles and does not require significant changes in the actual infrastructures. Unlike oil, biodiesel is a domestically produced and renewable fuel that can be produced from animal fats or vegetable oils, like rape seed sunflower crops. Biodiesel is similar to petroleum diesel but is a cleaner-burning alternative and so it offers significant reductions in GHG emissions. Biodiesel can be blended with petroleum diesel and used in different concentrations: fuel composition is indicated with a letter B followed by the percentage of biodiesel in the mix. B20 is a common biodiesel blend in the United States. Among European automakers, the Volkswagen Group has released a statement indicating that several of its vehicles are compatible with B5 and B100 made from rape-seed oil and compatible with the EN 14214 standard. The use of the specified biodiesel in its cars will not void any warranty [5]. On the contrary, Mercedes Benz does not allow diesel fuels containing greater than 5% biodiesel (B5) due to concerns about "production shortcomings" [6]. In 2007, McDonalds of UK announced it would start producing biodiesel to fuel its fleet, from the waste oil by product of its restaurants [7]. The 2014 Chevy Cruze Clean Turbo Diesel will be rated for up to B20 biodiesel compatibility [8].

Engines operating on B20 exhibit similar power, torque and fuel consumption of a conventional diesel engine due to a higher cetane number. The use of biodiesel combined with petroleum diesel allows significant pollutants emissions reduction, including reduced carbon monoxide (CO), unburned hydrocarbons (HC) and particulate matter (PM). The greatest benefit is provided by using pure biodiesel B100, but lower level blends also provide notable emissions reductions, as shown in Figure 2.1-3 [9]

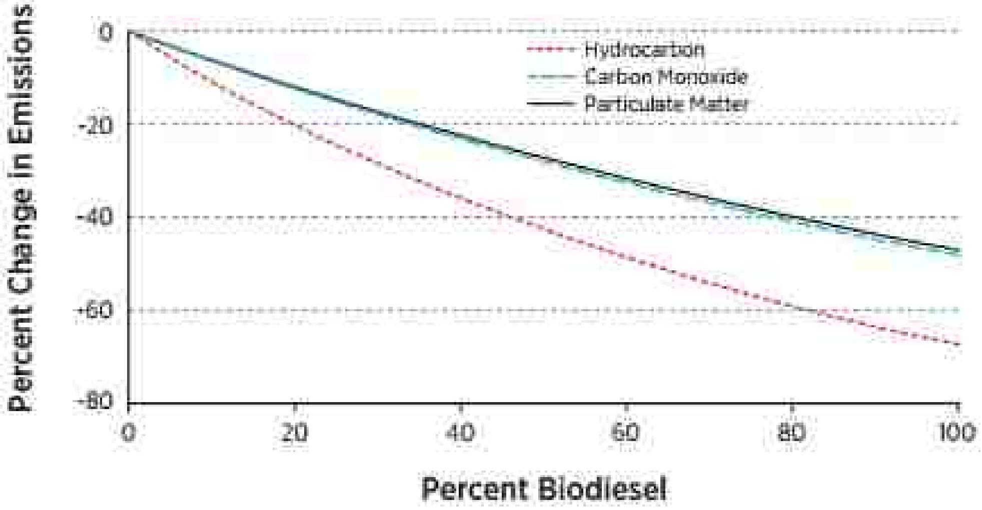


Figure 2.1-3 Average emission impact of biodiesel [10]

Biodiesel used in blends has to meet specification D6751, a quality standard from ASTM. If it meets this standard, it is legally registered as a fuel blend stock or additive with US EPA. The European Standard for biodiesel to be used as fuel for transportation is reported with the standard number EN 14214. This standard sets the limits and measurement procedures for biodiesel used as fuel alone or blended with diesel. The current limit considers at most 5% of volume of biodiesel in conventional biodiesel while CEN is currently studying a revised EN590 that will enlarge the limit up to 7% by volume [11].

2.1.2. Hydrogen

Hydrogen is another alternative fuel for reducing pollution, GHG emissions and oil dependence. Different programs have been initiated aimed to promote hydrogen as an alternative fuel for the transport sector. As reported in the Communication from the Commision on alternative fuels, hydrogen use as a fuel is projected to reach a 5% replacement of conventional fuels by 2020 [12]. However, the growth of hydrogen as alternative fuel is slowed down by a series of technological factors concerning its production, storage, distribution and usage. In addition, the deployment of hydrogen in the transportation sector will depend on technical innovations as well as on economic and political issues.

There are different methods for hydrogen production, but currently, hydrogen is obtained mostly from natural gas through a process called reforming in which steam reacts at high temperature with the fossil fuel in a device called reformer. This method can be exploited to provide fuel for fuel cells. Fuel cell vehicles with on board reforming are based on the concept that a methanol tank and a steam reforming unit would replace pressurized hydrogen tanks that would otherwise be necessary [13]. As for CO_2 emissions, fossil fuel reforming reduces the issue of releasing carbon dioxide in the atmosphere but does not eliminate the problem. The environmental and health benefits are more evident when hydrogen is made from cleaner sources such as wind, sun, or nuclear energy.

Unfortunately, there are different challenges when growing the hydrogen market share. Some of them are due to technological gaps in production, storage and delivery as well as low durability, relatively low performance, and high manufacturing cost. Economic and institutional components also play a fundamental role. There are economic and decisional risks in developing new manufacturing capacity for hydrogen and fuel cell, or in developing new infrastructure, due to an almost inexistent demand for hydrogen in transportation sector. For these reason, as occur for any new technology, programs are needed in order to reduce the lack of understanding and increase the awareness of hydrogen and fuel cell [14].

2.1.3. Ethanol

Ethanol is a renewable, domestically produced transportation fuel that contributes to reduced dependence on oil consumption and reduced GHG emissions. To date, several methods have been developed to produce ethanol, such as through chemical synthesis (hydrolysis of ethylene), but the most used is the fermentation of glucose content in grains or in the sugar beet. This fuel is used in flexible fuel vehicles, which can run on high level blends of E85 (85% of ethanol by volume), gasoline or any combination of these [15]. Ethanol is intended to fuel a large share of the market mainly in blends with gasoline. In the United States, low levels of ethanol (E10) are present in more than 95% of gasoline sold [16]. Pure ethanol, E100, is less suitable as a fuel for transportation due to its low volatility and problems during cold starting.

In the European market, the requirement of using ethanol in blends with gasoline has been introduced recently and in some countries, such as Sweden and Germany, initiatives have been taken to develop locally a market for alcohol-gasoline mixture (mostly E85) to be used in flexible fuel vehicles (FFV).

The strategy adopted by Fiat to reduce the social and environmental impact of the vehicle along the whole lifecycle is notable. All Fiat engines sold in Europe can run with bioethanol E10 (10% bioethanol). In addition, considering the Fiat overseas market, it is important to underline the specific investment made by Fiat in Brazil in order to make bioethanol a viable solution across the entire fleet of vehicles. This solution has made FIAT the sales leader on the Brazilian market [17].

2.2. **Emission Control Legislation**

To better understand the impacts of mandatory CO_2 and fuel economy requirements, it is instructive to examine past, current and anticipated future emission regulations in Europe and North America. Since 1963, the year the first emission regulation was introduced in California, increasingly stringent regulations have been introduced every 4 to 5 years, frequently halving the emissions limits. The legislation with the most influence are:

- CARB (California Air Resources Board) regulations
- EPA (U.S Environmental Protection Agency) regulations
- EU regulations

- Japanese regulations

These regulations have been adopted either “as-is” or in modified form by a number of other countries [18].

Figure 2.2-1 Application areas for individual emissions regulations [18]

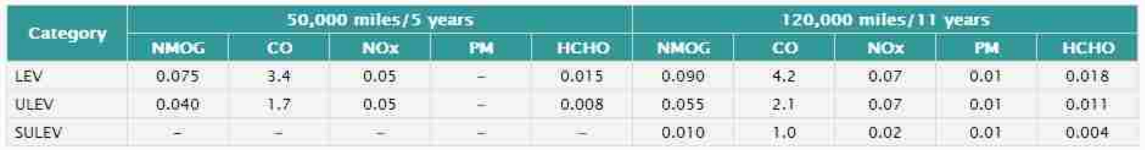
2.2.1. CARB regulations

The CARB regulations define limits on:

- Carbon monoxide (CO),
- Nitrous oxides (NO$_{x}$)
- NMOG (non-methane organic gases)
- Formaldehyde
- Particulate matter

The actual standards are indicated as LEVII standards where the acronym LEV stands for low emission vehicle II. Those standards were phased-in from 2004 through 2010 but car manufacturers may homologate vehicles to LEV II emission standards until model year 2019 [19].

Table 2.2-1LEV II Emission Standards for Passenger Cars and LDVs < 8500 lbs (LDT1 & LDT2), FTP-75, g/mi [19]



Category	50,000 miles/5 years					120,000 miles/11 years				
	NMOG	CO	NOx	PM	HCHO	NMOG	CO	NOx	PM	HCHO
LEV	0.075	3.4	0.05	-	0.015	0.090	4.2	0.07	0.01	0.018
ULEV	0.040	1.7	0.05	-	0.008	0.055	2.1	0.07	0.01	0.011
SULEV	-	-	-	-	-	0.010	1.0	0.02	0.01	0.004

As shown in the Table 2.2-1, the limits, applied to gasoline and diesel vehicle, are expressed through the following emission categories:

- Low Emission Vehicles (LEV)
- Ultra Low Emission Vehicles (ULEV)
- Super Ultra Low Emission Vehicles (SULEV)

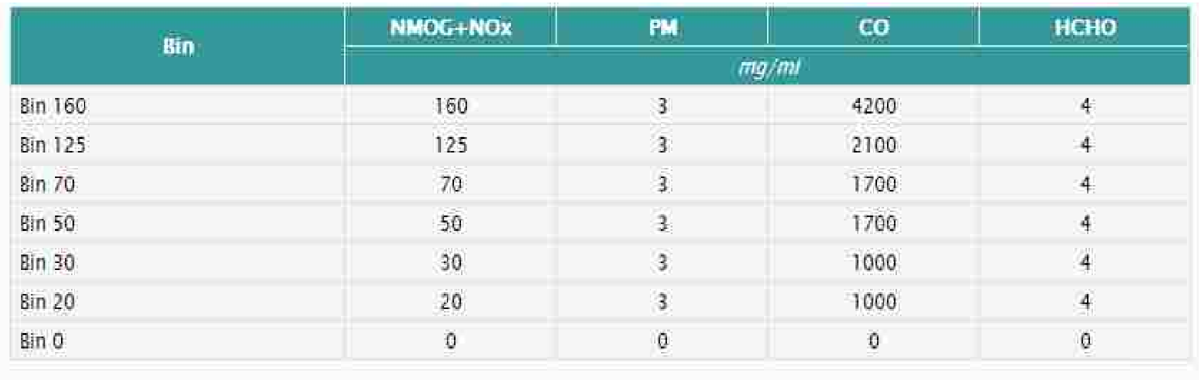
2.2.2. *EPA regulations*

The EPA regulations apply to 49 states outside California and set standards that are less stringent than CARB requirements. Each state has then the option to adopt also the CARB emission regulations. The EPA authority is based on the *Clean Air Act*, which specifies measures to protect the environment but does not specify limits.

The current rule introduced on March 29, 2013, by US EPA defines the Tier 3 emission standard for light-duty vehicles. Those standards, applicable to all vehicles regardless of the fuel type, are almost similar to the California LEV III standards starting from 2017, and are to be phased-in through 2025 [20].

The structure is similar to Tier 2 standards with seven available certification bins. As for Tier 2 vehicles, manufacturers must meet an average emission standards for their vehicle fleet in a given model year.

Table 2.2-2Proposed Tier 3 Certification Bin Standards (FTP; 150,000 miles) [20]

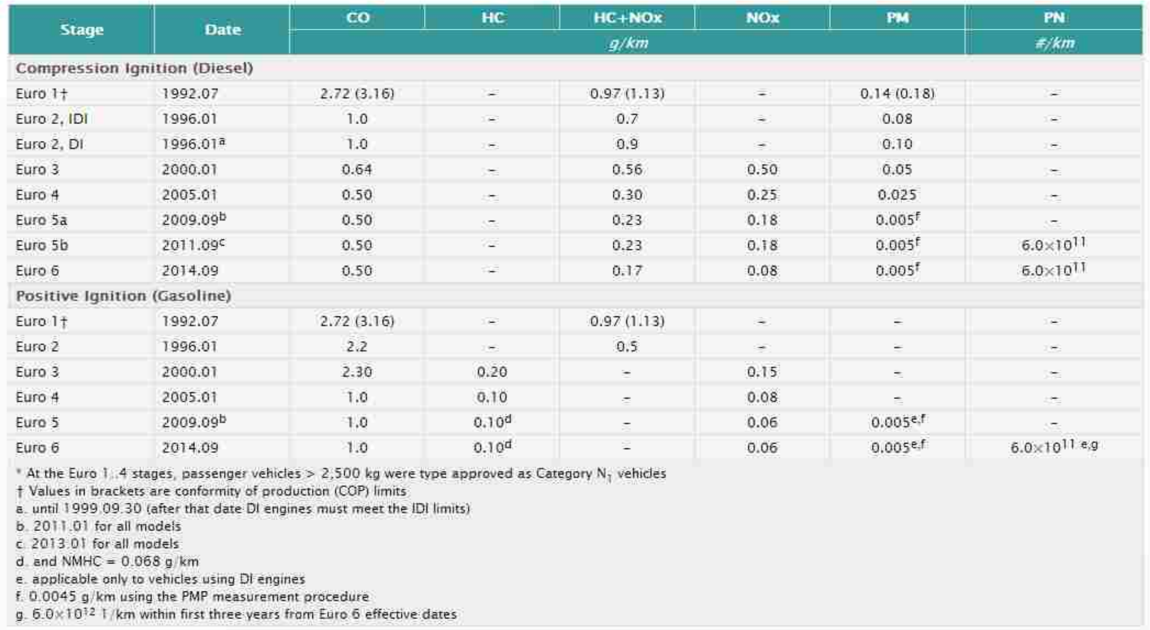


Bin	NMOG+NOx	PM	CO	HCHO
	mg/mi			
Bin 160	160	3	4200	4
Bin 125	125	3	2100	4
Bin 70	70	3	1700	4
Bin 50	50	3	1700	4
Bin 30	30	3	1000	4
Bin 20	20	3	1000	4
Bin 0	0	0	0	0

2.2.3. *EU regulations*

The regulations contained in the European Union directives are defined by the European Commission: these are shown in Table 2.2-3. The EU standards are different for gasoline and diesel engine while the limits are based on mileage and indicated in grams per kilometer (g/km).

Table 2.2-3EU emission standard for passenger car (category M1) [21]



Stage	Date	CO	HC	HC+NOx	NOx	PM	PN
		g/km					#/km
Compression Ignition (Diesel)							
Euro 1†	1992.07	2.72 (3.16)	–	0.97 (1.13)	–	0.14 (0.18)	–
Euro 2, IDI	1996.01	1.0	–	0.7	–	0.08	–
Euro 2, DI	1996.01^{a}	1.0	–	0.9	–	0.10	–
Euro 3	2000.01	0.64	–	0.56	0.50	0.05	–
Euro 4	2005.01	0.50	–	0.30	0.25	0.025	–
Euro 5a	2009.09^{b}	0.50	–	0.23	0.18	0.005^{f}	–
Euro 5b	2011.09^{c}	0.50	–	0.23	0.18	0.005^{f}	6.0×10^{11}
Euro 6	2014.09	0.50	–	0.17	0.08	0.005^{f}	6.0×10^{11}
Positive Ignition (Gasoline)							
Euro 1†	1992.07	2.72 (3.16)	–	0.97 (1.13)	–	–	–
Euro 2	1996.01	2.2	–	0.5	–	–	–
Euro 3	2000.01	2.30	0.20	–	0.15	–	–
Euro 4	2005.01	1.0	0.10	–	0.08	–	–
Euro 5	2009.09^{b}	1.0	0.10^{d}	–	0.06	$0.005^{e,f}$	–
Euro 6	2014.09	1.0	0.10^{d}	–	0.06	$0.005^{e,f}$	$6.0\times10^{11\ e,g}$

* At the Euro 1..4 stages, passenger vehicles > 2,500 kg were type approved as Category N_1 vehicles
† Values in brackets are conformity of production (COP) limits
a. until 1999.09.30 (after that date DI engines must meet the IDI limits)
b. 2011.01 for all models
c. 2013.01 for all models
d. and NMHC = 0.068 g/km
e. applicable only to vehicles using DI engines
f. 0.0045 g/km using the PMP measurement procedure
g. 6.0×10^{12} 1/km within first three years from Euro 6 effective dates

2.2.4. *Reducing CO_2 emissions*

The automotive sector is complying with CO_2 reduction by means of alternative fuels or technical innovations that allow reducing its emissions from products in use and at design stage. A significant step forward was in 1998 when the ACEA (European Automobile Manufactures' Association) signed a voluntary agreement to lower the CO_2 emission in 2008 up to 25% compared to 1995. As an example, over the same period, Fiat cars achieved a reduction of 32%, enforcing its position as the most ecological brand in Europe [17].

In December 2008, the European Parliament and Council approved new CO_2 emission rules for passenger cars, aimed to cut emissions to 130 g/km by 2015 and 95g/km in 2020 with a consequent improvement of fuel economy to 24.7 km/l. The legislation declares that manufacturers will be given interim targets of ensuring that average CO_2 emission of

80% of their fleet in January 2014 and 100% from 2015 comply with the specific CO_2 target.

With respect to the U.S. legislation, the Energy Policy and Conservation Act of 1975 required passenger car and LD manufacturers to meet CAFE standards. The Corporate Average Fuel Economy (CAFE) standards are not applied on a single vehicle but on a fleet-wide basis, reflecting the fact that most automakers offer vehicles in all market segments. The latest limits introduced in August 2012 by Obama administration require increasing the average vehicle fuel economy from the current 27.3 mpg (11.6 km/L) to 34.1 mpg (14.5km/L) by 2016, and reaching 54.5 mpg (23.1 km/L) by 2025 [22]. The standards include tax incentives for purchasing certain type of alternative fuel vehicles associated. There is also an incentive multiplier to encourage the adoption of certain fuels. For example, on NGVs and on hybrid vehicles, a multiplier of 1.6 is applied. However, based on what reported so far and considering Figure 2.2-2, European standards appear are more stringent with respect to the ones imposed by U.S. federal government

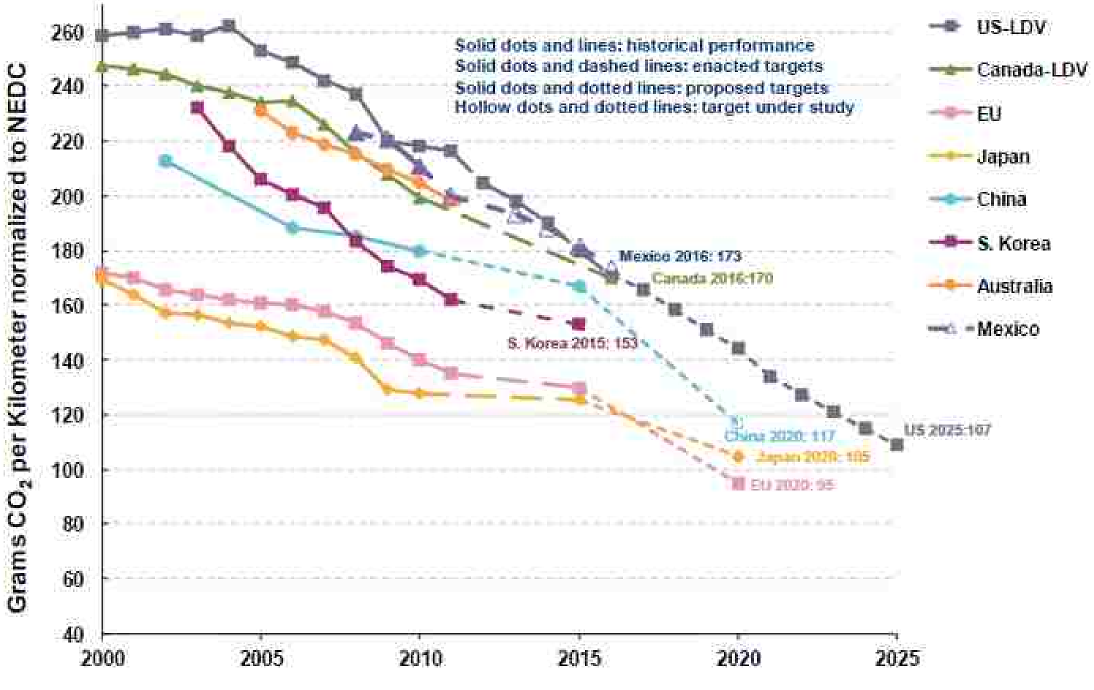


Figure 2.2-2 Convergence of global CO_2 regulations [22]

2.3. **Natural Gas**

The adoption of alternative fuels analyzed in the section 2.1 face many challenges. To date, the alternative energy source that has experienced the most significant adoption and global development is natural gas. Until the beginning of the last century, natural gas was released in the atmosphere or flared near oil wells due to the lack of knowledge and technology to harness its potential. In the 1970s, technologies for storing and transporting natural gas (e.g., pipelines and tankers) became more popular making the natural gas much more important. Since that time, because of technological progress, international market expansion, and significant proven resources, natural gas is a rising success. It represents the primary fuel in commercial and residential heating, electric power generation, and industrial processes [23]. Its use as a transportation fuel has increased on a global scale over the last decade, although initially it did not have much popularity in all countries. Interestingly, due to economic, technical and political issues, it occupies only a niche market as fuel for transportation in the United States. Interestingly, the development of unconventional North American natural gas resources like shale gas and the resulting possibility for long term and low cost domestic source of supply have re-kindled significant interest in using natural gas for transportation.

2.3.1. Chemistry of natural gas

Natural gas (Compressed Natural Gas, CNG, or Liquefied Natural Gas, LNG) is a mixture of hydrocarbon gases. It is colorless, shapeless, tasteless and odorless in its pure form. Due to this latter aspect, regulations require a substance, called Mercaptan, to be added in order to provide natural gas a typical rotten egg smell to render it detectable if there is a leakage. Typically the concentration of Mercaptan is 0.5 pound/million standard cubic feet of gas [24].

Since CNG and LNG are almost identical from a chemical point of view, in this section they are treated together and referred as natural gas. The primary element of natural gas is methane, even if there are other hydrocarbons in variable concentration depending on deposits. There is also “dry” or “wet” natural gas. The former refers to pure methane, after removing all the associated hydrocarbons while the latter indicates natural gas composed by methane and all the other hydrocarbons [25]. In addition, natural gas, before being sent to consumers, is purified in treatment facilities to remove carbon dioxide and nitrogen which lower its flammability. Hydrogen sulfide is removed because of its toxic and corrosive characteristics. Helium, being a noble gas, is retrieved whenever it is present in significant quantities.

Natural gas has with hydrogen to carbon ratio of 4:1, the lowest carbon content among the fossil fuels used for transportation, but methane, the primary component of natural gas, has a global warming potential index (GWI) over 23 times higher than carbon dioxide [26]. Overall however, natural gas has a lower impact on GHG profile compared to gasoline, diesel and other fossil fuel if there is a limited gas leakage over the full supply chain and if it is used in vehicles with high fuel efficiency. The main concern about methane leakages at production level is related to the fact that methane is 20 times more harmful than CO_2 and so the flaring or venting of methane at production site has significant impact on the environment. According to EPA, the estimation of the GWI (Global Warming Index) can be performed using the following equation [27]:

$$GWI = CO_2 + 23CH_4 + 296\,N_2O$$

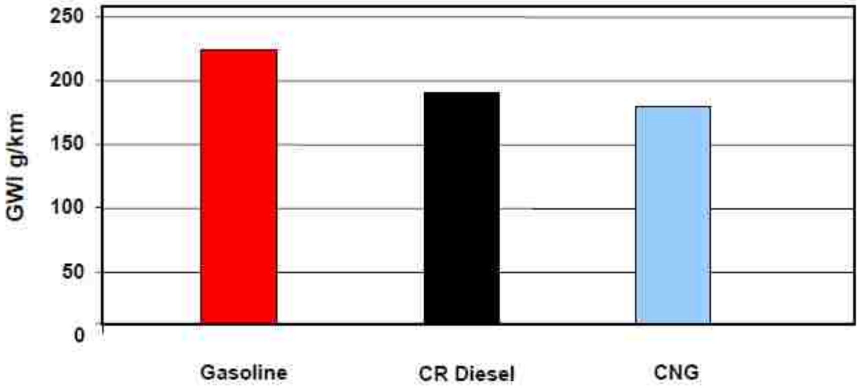


Figure 2.3-1 GWI comparison between Gasoline, Diesel, CNG [28]

2.3.1.1 ***Emission Characteristics & Performance of CNG vehicles***

Due to a higher octane rating for CNG with respect to gasoline (RON=130), acceleration and cruise speed, in a dedicated CNG vehicle, could be greater than that of a gasoline-fueled vehicle. Furthermore, CNG vehicles are characterized by higher efficiency than a gasoline powered engine thanks to a cleaner combustion of natural gas. Technology plays a critical role in how well CNG performs as an alternative fuel since the gains from the chemistry of this fuel may be offset by a poorly developed drive train. Assuming ideal

NG technologies are implemented, the potential reductions offered by a dedicated CNG engine with respect to a conventional gasoline engine include [29]:

- Reduction in Carbon dioxide emissions of 25% or more due to the higher H/C ratio;
- Reduction in Carbon monoxide emission of 90 to 97%;
- Reduction in NO_X of 35 to 60% due to a lower adiabatic flame temperature;
- Potential reduction of NMHC of 50 to 75%;
- No evaporative emissions in dedicated CNG engine since the fuel is used in gaseous state; and
- No PM produced.

However, since the majority of commercialized CNG vehicles are bifuel, the benefits are likely lower than the ones reported in the bulled list due to the emissions resulting from the gasoline operation.

The environmental impacts of natural gas throughout the full life cycle of a vehicle are generally assessed using a well-to-wheels (WTW) approach.

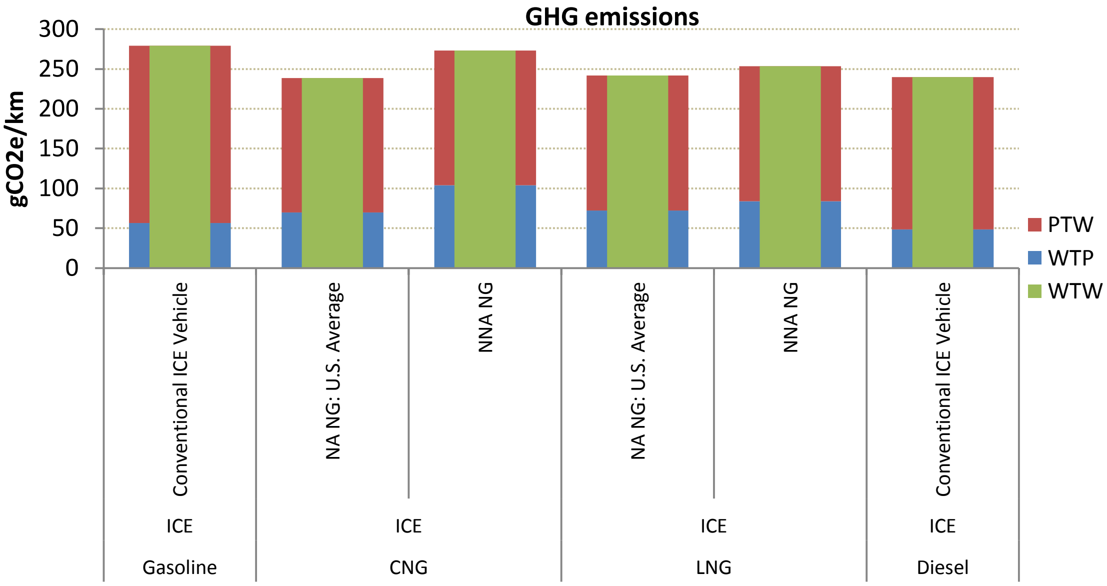


Figure 2.3-2 Full life cycle emissions for gasoline, diesel and natural gas (NA NG=North American natural gas; NNA NG= Non North American natural gas).Adapted from [30]

This analysis for NGVs depends on several parameters such as feedstock sources, the combustion cycle of the vehicle, the distribution method (CNG or LNG) and benchmarked fuels and engine technologies. A wells-to-wheels analysis assesses emissions across two consecutive stages: well-to-pump, and pump-to-wheels. The well-to-pump (WTP) stage includes the fuel feedstock recovery, the fuel production, and ends with assessing fuel emissions at the pump. The pump-to-wheels (PTW) stage simply refers to the fuel emissions associated to the vehicle's operation [31]. Argonne National Laboratory's GREET model reports that most GHG emissions along the CNG life cycle are due to gas leakages during the production phase [30]. In spite of this, on a WTW basis, CNG emits approximately 11% to 29 % lower levels of GHGs than gasoline depending on North American sources as shown in Figure 2.3-2.

2.3.1.2 *Safety & Maintenance*

Even though CNG is a flammable gas, it is a safer fuel since it presents a limited flammability range (it is only explosive in a range of 5% to 15% mixture by volume with air). CNG does not affect land or water in case of accidental spill. Natural gas is lighter than air and so it disperses rapidly, minimizing ignition risk relative to gasoline, unless there is excessive leakage in a closed environment, creating a risk of fire and explosion.

The NGV industry is regulated by a series of codes and standards concerning the fuel, vehicle and fueling infrastructure safety. These include FMVSS 303 Fuel System Integrity of Compressed Natural Gas Vehicles, FMVSS 304 Compressed Natural Gas Fuel Container Integrity in the U.S and CMVSS 301.1 in Canada. The European Commission is developing ISO standards to comply with those requirements [32].

Finally, with respect to maintenance, the oil in a CNG vehicle does not need as frequent changing compared to gasoline powered engines due to the cleaner burning of CNG which results in less deposit in the oil [29].

2.4. **Natural Gas Supply Chain: "from well to tank"**

The process for bringing natural gas to market through the three primary phases of production, transmission and distribution is complex. This section provides an overview of the processes from extraction to transformation into the natural gas used for transportation.

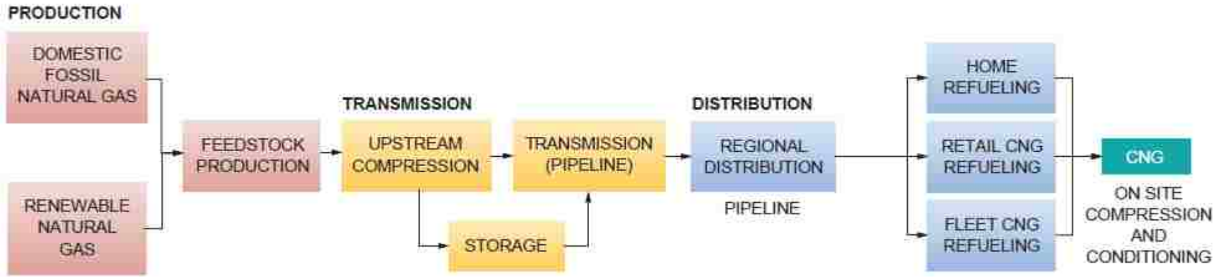


Figure 2.4-1 Natural Gas for Transportation Supply Chain [32]

Natural gas is located in underground reservoirs from which it emerges spontaneously or is extracted by drilling. The origin of natural gas is twofold: from decomposition of plankton and algae (organic) or from coal (vegetable source).

There is another type of natural gas that is called “biogas” or “renewable natural gas” (RNG) that is not from fossils. RNG is produced from a variety of biomass or biogas sources including landfill gas. It can also be produced from forestry and agriculture waste through the process of thermal gasification and methanation [33].

The majority of current natural gas is organic, and was formed along with oil and coal deposits from the decomposition of plankton and algae. These raw materials were deposited on the bottom of shallow seas and transformed then in a putrid sludge called sapropelite. Afterwards the organic material contained in the parent rock turned into a solid substance similar to oil named bitumen. The gradual lowering of the seabed and the accumulation of sedimentary layers increased temperatures and pressures that turned the bitumen into liquid and gaseous hydrocarbons: first heavy oil, light oil, and then finally natural gas [34].

Another source of natural gas is coal and the associated process of carbonization. The carbonization generates gaseous reaction products such as methane. The natural gas fields related to the formation of coal are found for example in the Netherlands and in the southern North Sea [34].

2.4.1. Deposits Generation and the Geology of natural gas resources

With the overlap of sedimentary layers, the rock is pushed deeper in the ground and then subjected to increasing pressures that bring out the oil and/or natural gas. Due to their low density, oil and natural gas rise through cracks and cavities in the upper layers of porous rock. The migration ends where the porous rock is covered by a more compact and waterproof layer, such as shale [34].

The most important natural gas fields, however, could have formed only in places where impermeable strata covered a considerable thickness of the reservoir rock (sandstone, dolomite, limestone cracked) forming a so-called trap accumulation [34].

Natural gas may be of varying geologic nature as depicted in Figure 2.4-2.

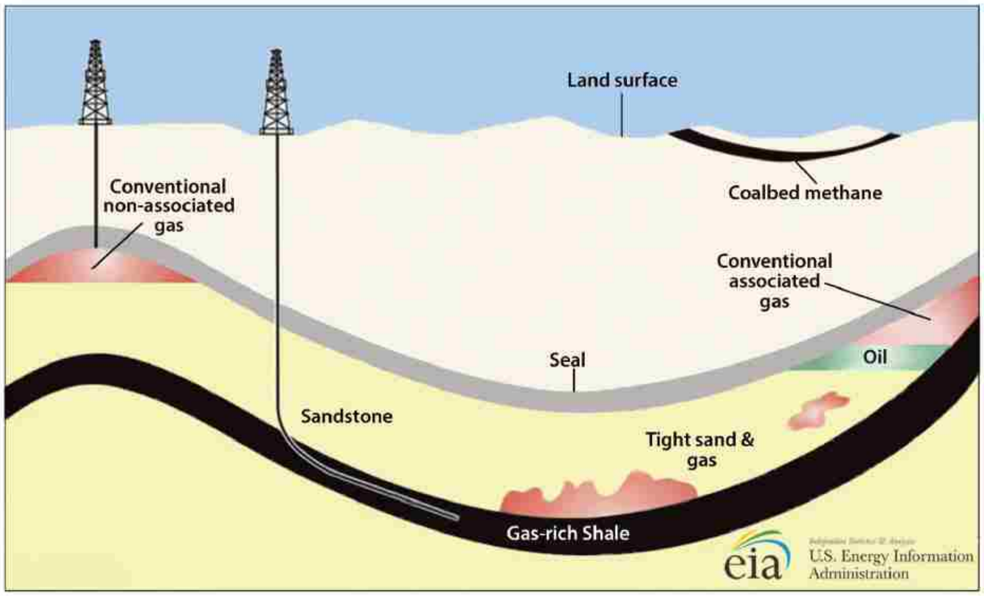


Figure 2.4-2 Geology of Natural Gas Resources [35]

In the recent past, conventional natural gas deposits were the most exploited. Currently because of increasing progresses in technology, unconventional natural gas deposits are becoming a fundamental part of the available resources. Conventional gas reserves form when gas migrates from gas-rich shale into various naturally occurring rock formations such as carbonates, sandstones, and siltstones and then remain trapped by a less porous overlaying layer. Conventional gas can be of two types: 1) associated gas accumulates in conjunction with oil; and 2) non-associated gas does not accumulate with oil reserve deposit [35].

In contrast, unconventional resources are in basins with low permeability. Unconventional gas reservoirs include tight sand gas, coal bed methane, gas hydrates and shale gas. Among those, tight sand gas accumulations present a lower permeability in the sandstone and so has a reduced tendency to migrate upward while coal bed methane does not migrate from shale, but is generated during the transformation of organic material to coal [36].

The last form of unconventional natural gas is referred to as shale gas. Due to some properties of shale, the extraction of natural gas from shale formations is more difficult and perhaps more expensive than that of conventional natural gas. Shale is a very fine-grained sedimentary rock that is impermeable to natural gas unless it is artificially fractured [36].

Figure 2.4-3 summarizes the "pyramid classification" of natural gas reserves according to volume and level of technology required for the extraction.

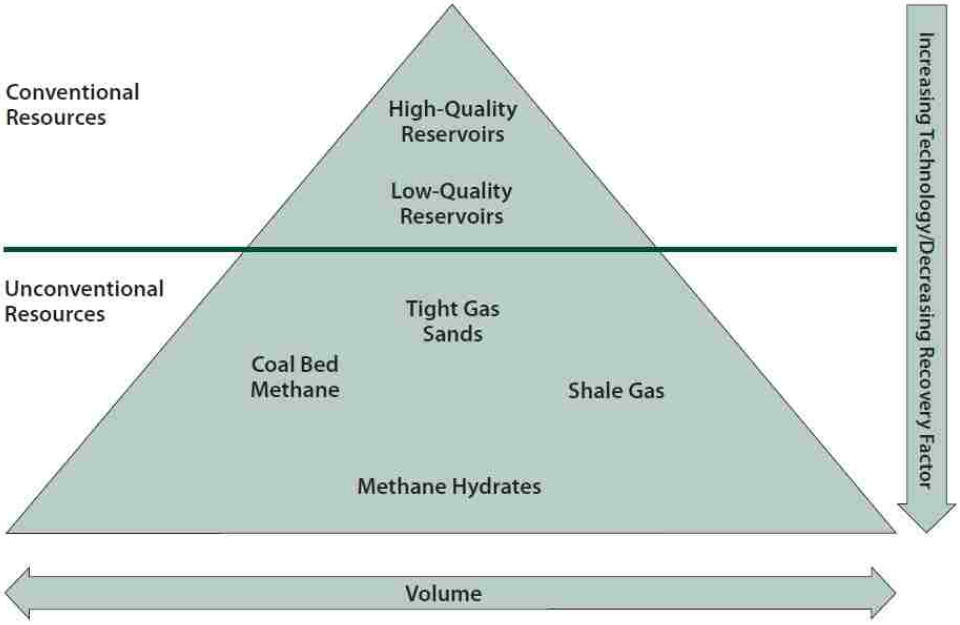


Figure 2.4-3 Natural gas reserve classification [3]

2.4.2. *Exploration*

The practice of locating natural gas deposits is continuously evolving. In the past, a technique widely used to locate underground natural gas deposits was to search for surface evidence of these underground formations. The low efficiency of this method together with a rising demand for natural gas has stimulated the developments of more accurate methods for locating natural gas deposits [37].

2.4.2.1 ***Onshore Seismology***

The current method of searching deposits is based on seismic principles. The method measures the propagation speed of artificially created seismic waves, which are reflected by different geological layers, and then are detected by geophones embedded in the ground or placed on the ground surface. The measured values provide information on the stratigraphy and structure of the subsoil to several kilometers deep. Once a reservoir is located, the needed extraction facilities are constructed as well as several wells are drilled. Afterwards the individual wells are connected to a main collector through a pipe network as shown in Figure 2.4-4 [37].

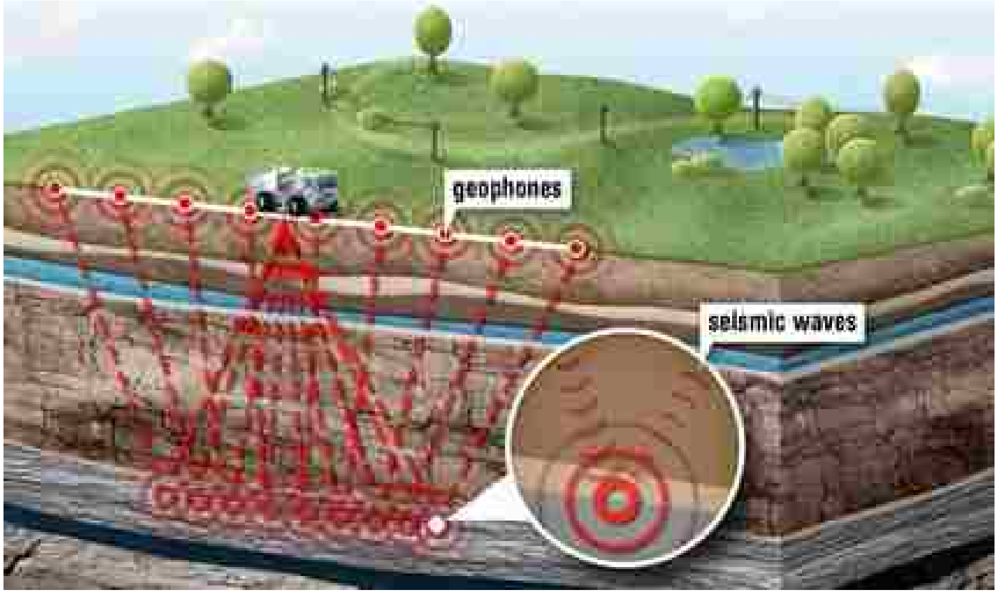


Figure 2.4-4 Onshore seismology [38]

2.4.2.2 ***Offshore Seismology***

The underlying idea in the offshore seismology process is similar to the previous one. The only difference lies in the needed instruments. In fact, natural gas may exist several kilometers below the seabed floor, which may itself be hundreds of kilometers below sea level.

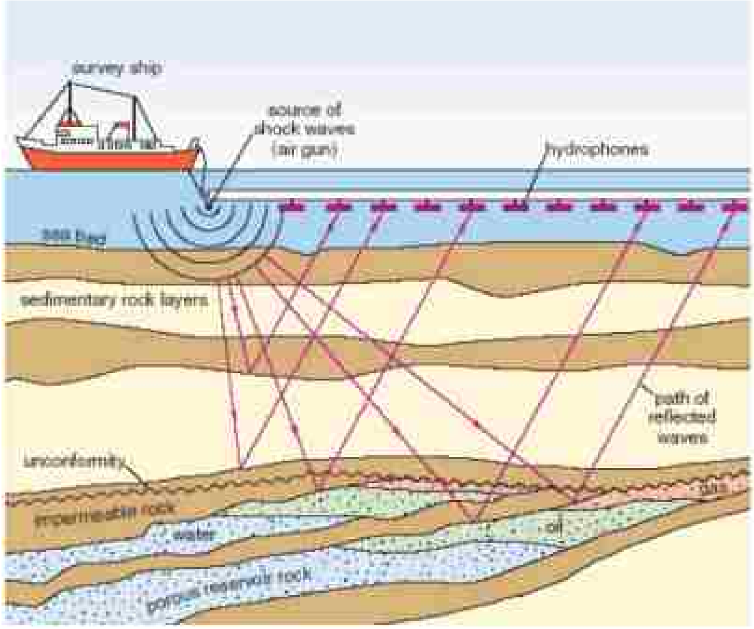


Figure 2.4-5 Offshore Seismology [39]

In this case a ship carries the equipment needed to generate seismic waves and store data while hydrophones collect seismic waves underwater.

Rather than using invasive method, the seismic ship uses a large air gun that releases bursts of compressed air under water to create seismic waves that travel through the earth's crust and generate the necessary seismic reflections [39].

2.4.3. Extraction

The process of drilling for natural gas takes place as soon as a potential natural gas deposit has been located. Different factors are related to this process such as the economic risk in the case that natural gas is not found. The environmental aspect is particularly relevant. The extraction of natural gas is governed by different regulations and associated permits, leases, and royalties. Afterwards, if the presence of natural gas is ascertained, the well is developed to allow for the extraction of natural gas and assumes the name of “development” or “productive” well. By contrast, if the estimation about natural gas presence is incorrect, the well is named “dry” well and the process stops.

At this point, the main differences in term of techniques, equipment and environmental requirements, and between onshore, offshore and shale drilling will be analyzed [40].

2.4.3.1 ***Onshore drilling***

Onshore drilling can be performed in two different ways. The former called “percussion” or “cable tool drilling” consists of drilling, by means of boreholes, the rock layer between the ground and the deposit. This method is more suitable for low pressure formations. The latter method, named “rotary drilling”, is based on the employment of the rotational force to penetrate the ground [40]. The basic concept is let natural gas, due to the high pressure gradient, release naturally.

Despite advances and new technologies, such as the use of steam power in cable tool drilling, there is greater usage of the rotary drilling method. It may be conducted in two different ways:

- *Dry Rotary Methods* are those in which the drilling process takes place without the need of a flushing medium to clear the spoil and spills from drilling. The primary advantage of dry drilling system is that it is safer than the wet one in case of contamination risk since there is no flush water [41].
- *Wet Rotary Methods* requires a flush medium to moderate heat and contain the fine spoils that are generated during the process due to the high speed of the cutting face. For this reason, the bit must be cooled, lubricated and the hole kept clear. The cooling medium can be water, air, or a mixture colloquially known as “air-mist” [41].

Afterwards, the extracted natural gas is forwarded by means of pipes towards the final destination or to storage centres. The latter are not tanks, but former natural deposits now exhausted where there was once natural gas, oil or water, and are now reused as a real storage spaces for gas.

2.4.3.2 ***Offshore drilling***

Offshore drilling is more complex and expensive than the onshore ones because, depending on the depth of the sea and the environmental conditions, different requirements are needed such as floating structure (floating platforms) or fixed structure (fixed platforms). The main challenges are related to the fact that the floor to drill can be hundreds of kilometres under the sea level and since there is not a stable platform an artificial one is required.

2.4.3.3 ***Hydraulic fracturing and horizontal drilling***

The extraction of large volumes of natural gas from unconventional accumulations such as shale gas requires adopting a new technology called horizontal drilling and hydraulic fracturing. Shale gas debates have arisen because of the environmental safety of the fracturing process and managing water disposal.

Hydraulic fracturing, commonly known as *fracking,* is the method used to create small cracks in the shale rock allowing natural gas to flow through the shale to the wellbore. Shale reservoirs are usually one mile or more below the surface, well below any underground sources of drinking water that are typically no more than 300 to 1000 feet below the surface. Additionally, steel pipes called casing cemented in place provide multilayers barriers to protect surrounding water. The initial step consists into drill the ground several thousand feet until the natural gas reservoir is reached. A hole is drilled straight down using a flush medium which cools the drill bit. After that the drill pipe is removed and replaced with steel pipe called surface casing [3]. This process is shown in Figure 2.4-6.

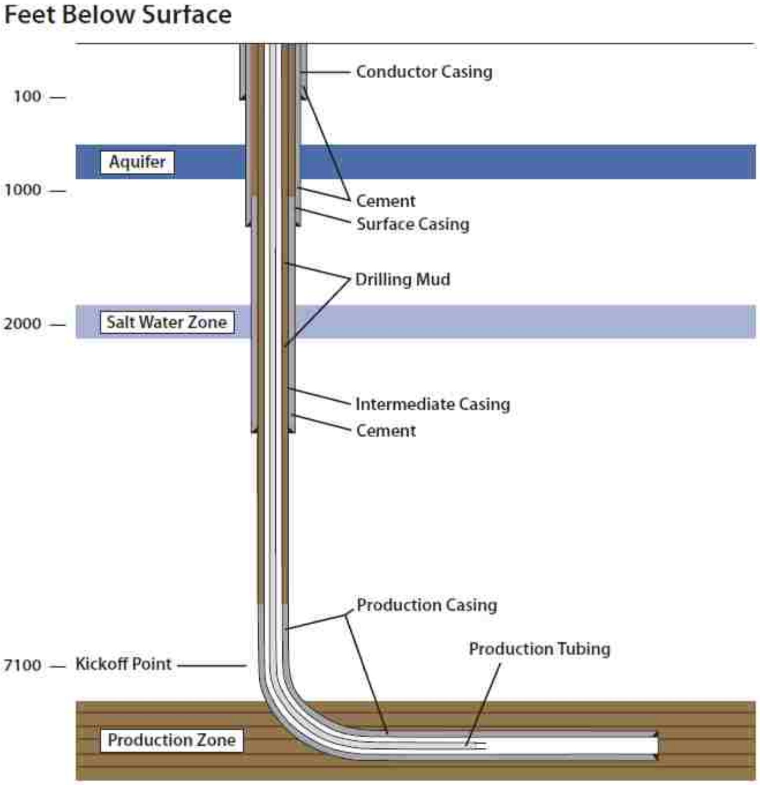


Figure 2.4-6 Typical shale well construction [3]

The space between the casing and the drilled hole is filled with cement which creates an impermeable additional protective barrier between the wellbore and any fresh water sources.

In some cases, depending on the geology of the area and the depth of the well, additional casing sections may be created and surface casing is cemented in place to ensure no movement of fluids or gas between those layers and ground water sources. What makes shale gas extraction unique is the necessity of drilling horizontally. Vertical drillings continue up to a depth called the “kickoff point”. This is the point where the wellbore begins curving to the horizontal plane. One of the advantages of horizontal drilling is that it is possible to drill several wells at the same time minimizing the impact on the environment [42]. When the targeted distance is reached, the drill pipe is removed and additional steel casings are inserted through the whole link of the drill bore and cemented in place. Once the drilling is finished and final casing has been installed, the drilling rig is removed and preparations are made for the next step. The first step in completing the well is to create a connection between the final casing and the reservoir rock. In this case a specialized tool called perforating gun and equipped with explosive charges is used. The gun is fired creating holes through casings, cements and target rock. These perforations create a connection between the reservoir and the wellbore. Since these perforations are few centimeters long and performed more than a mile in the ground, the entire process is imperceptible on the surface. The perforation gun is then removed and hydraulic fracturing takes place. The process consists of pumping a mixture of water and sands plus few chemicals in controlled concentration in the deep underground formation as shown in Figure 2.4-7. The chemicals are generally for lubrication and typically account for 0.1 to 0.5 by volume.

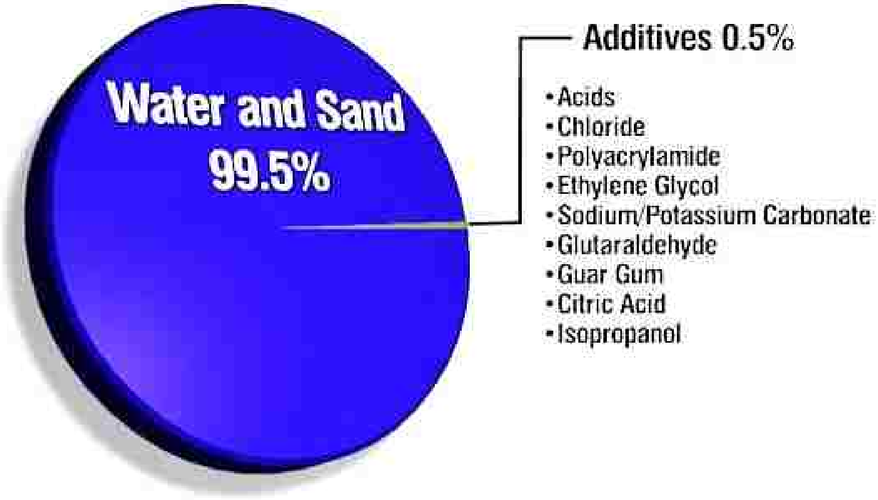


Figure 2.4-7 Mixture composition. Adapted from [42]

This process creates fractures in the reservoir rock. Sands remain in the fractures and keep them open when the pumping pressure is relieved. This process permits the previously trapped gas to flow to the wellbore more easily. Afterwards, in order to perforate the next stage, the previously fractured segment needs to be isolated by means of specially designed plugs. This process is then repeated for the entire horizontal segment of the well which can extend several miles. When the stimulation process is completed, isolation plugs are drilled out and production begins. Initially water and then natural gas flow in the horizontal casing and up to the wellbore. In the course of initial production of the well, approximately 15% to 50% of the fracturing fluid is recovered. This fluid is recycled to be used in new fracturing operations or disposed, presumably according to government regulations. The whole process of developing a well typically takes from 3 to 5 months but a well can produce natural gas for 20 to 40 years, or ven more. When all the natural gas that can be economically recovered from reservoir has been produced, the next step is to restore the land to its state before the drilling operation. The well will be filled with cement and pipes cut off 3 to 6 feet below the ground level. All surface equipment will be removed so the land can be reused by landowner for other activities [42].

The main concerns on hydraulic fracturing are related to the chemicals used during the fracking process which could be toxic to the surrounding ground water source. Environmentalists and other interest groups are actively lobbying for fracturing fluids to be federally regulated under the Safe Drinking Water Act (SDWA), requiring the disclosure of fracturing fluid formulas to the public.

2.4.4. Treatment

Natural gas that comes through the pipelines is not the same as the natural gas that exists underground. Natural gas extracted from the reservoir may contain liquid hydrocarbons and non-hydrocarbon gases such as carbon dioxide, helium nitrogen, hydrogen sulfide, water vapour, and other gases. This means that the newly withdrawn natural gas from a well must be treated before being transported to remove hydrogen sulfide, carbon dioxide, nitrogen and other impurities. Further processing involves separating the methane fraction (CH_4) in the raw gas from pollutants such as:

- dehydration (removal of water),
- the desulfurization (sulfur removal)
- Condensable hydrocarbons removal
- Ethane, propane, butane separation

Since the amount of impurities varies depending on the geographic location of the reservoir, such purification treatments are not standardized. For instance the recovery of helium is often carried out in the United States because this noble gas is present in the natural gas in levels up to 7%. Although rare, methane deposits need to be purged from the sulfur present in it, because during the combustion process sulfur gives rise to sulfur dioxide which is toxic. In addition, in the presence of moisture, it contributes to the formation of acid rain, responsible for lung disease, destruction of flora and deterioration of objects exposed to the open air.

In the case of associated gas, extra steps are required to separate the natural gas before processing because natural gas may be dissolved into oil (dissolved gas) or already separated from the oil (free gas) [43].

Another important aspect concerns the energy requirements during the treatment processes. In case of offshore production and treatment, the electricity is produced on site while in case of onshore production it may be taken from the grid. Besides the environmental impacts associated with natural gas production, the effect of the electricity generation should also be taken into account during the life cycle analysis [43].

2.4.5. Pipelines Transport

After being processed, natural gas needs to be transported over long distance by means of pipelines, which can connect two places in the same stater in different states (in this case the pipelines are referred as "crosspipes").

The total pipeline "system", designed to efficiently and safely transport natural gas from its origin to areas of high demand, in general covers all the following components [43]:

- Pipelines whose diameters range from 25 to 150 cm (20 to 42 inches).
- Compression stations
- Import/export stations
- Metering

Along the transportation chain it is possible to distinguish three types of pipelines: the gathering system, the interstate pipeline system and the distribution system. This can be seen in Figure 2.4-8.

The gathering system moves natural gas at low pressure raw from the wellhead to the processing plant.

The interstate pipelines transport natural gas across neighboring states differing from intrastate pipelines that convey natural gas within a particular state.

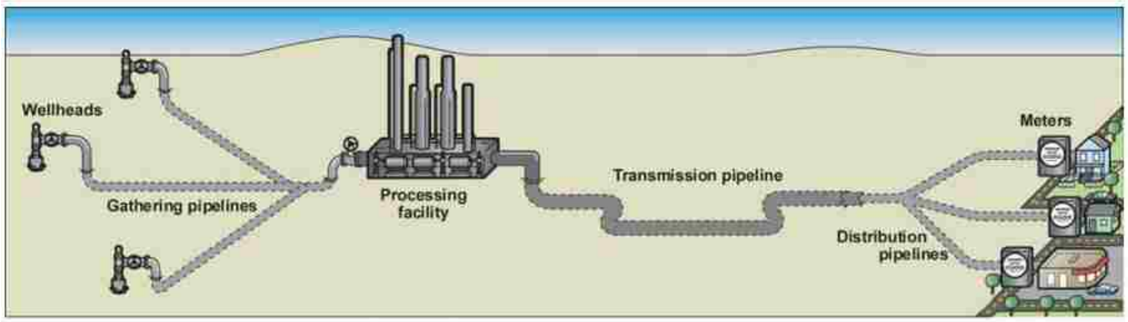


Figure 2.4-8 The natural gas transportation system [44]

Transmission pipelines are produced in steel mills, which are sometimes specialized to produce only pipeline. Small diameter pipes and large diameter pipes are produced using two different techniques. Large diameter pipes, from 50 to 150 centimeters in diameter, are produced from sheets of metal which are folded into a tube shape, with the ends welded together to form a pipe section. Small diameter pipe are produced first by heating a metal bar to very high temperatures and then punching a hole through the middle of the bar to produce a hollow tube. In either case, the pipe is tested before being shipped from the steel mill, to ensure that it can meet the pressure and strength standards for transporting natural gas.

To be transported over a large distance, indeed, natural gas is compressed up to approximately 70 bar in case of on land pipelines, or 200 bar for subsea pipelines reducing its volume up to 600 fold. Additionally, because pipelines cover large distances, to maintain a constant flow and compensate the pressure loss due to friction of gas along the pipeline wall, intermediate compressor stations is required. These intermediate stations are installed every 100-200 km in order to restore the pressure sufficient to move the methane at a speed of 20-30 km/h.

Quality control, pressure and temperature control and odorization are performed at the end of the transport chain where blending stations, metering and pressure regulation stations as well as export/import stations connect the long-distance transmission grid to the regional distribution grid.

Another important section associated to the pipeline system concerns inspection and safety. In order to ensure the efficient and safe operation of the extensive network of natural gas, pipelines corrosion and defects must be monitored. Intelligent robotic devices called “smart pigs” are inserted into the pipelines to evaluate the interior of the pipe. Different parameters can be tested simultaneously, like pipe thickness, and roundness, signs of corrosion, minute leaks, and any other defect along the interior of the pipeline that may either impede the flow of gas, or pose a potential safety risk to the operation of the pipeline. This operation is known as ‘pigging’ the pipeline [45].

The inspection with smart pigs is associated with a number of safety precautions and procedures in effort to minimize the risk of accidents. According to the Department of Transportation (DOT), pipelines are the safest methods of transporting petroleum and natural gas, mainly because the infrastructure is fixed and usually placed underground.

2.4.6. Storage

Storage facilities are necessary along the natural gas supply chain in order to handle the variable demand of natural gas and to prevent the risk of emergency situations. The main option for natural gas storage is to use geological structures. These include aquifers, salt cavities, depleted oil or gas reservoirs or empty mines.

As shown in the Figure 2.4-9, most natural gas is stored in depleted oil and gas reservoirs underground [43].

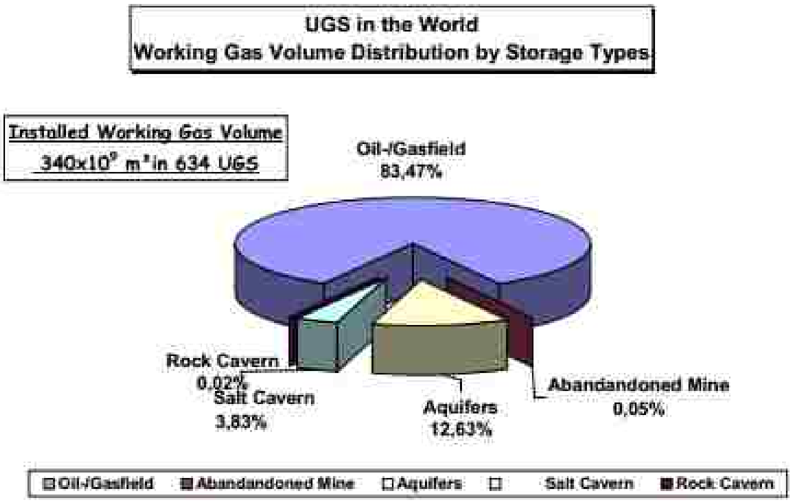


Figure 2.4-9 Underground storage of natural gas in the world [46]

All the natural storage facilities undergo reconditioning before natural gas is injected in order to create a safe storage vessel underground. Regarding underground storage facility, there may be physically unrecoverable gas. This occurs when the pressure in the container drops below that of the wellhead, removing the pressure differential that pushes natural gas out of the storage facility. This means that a small amount of gas may be never extracted. In addition, underground storage facilities include other two portion of gas:

- Cushion gas is the volume of gas that remains in the container to provide the pressurization required to extract the remaining gas (almost 50 % of the available volume).
- Working gas is the available volume of natural gas in the reservoir and represents the capacity of storage facilities.

As mentioned before, the most common form of underground storage consists into exploited depleted gas reservoirs. A typical storage well is shown in Figure 2.4-10.

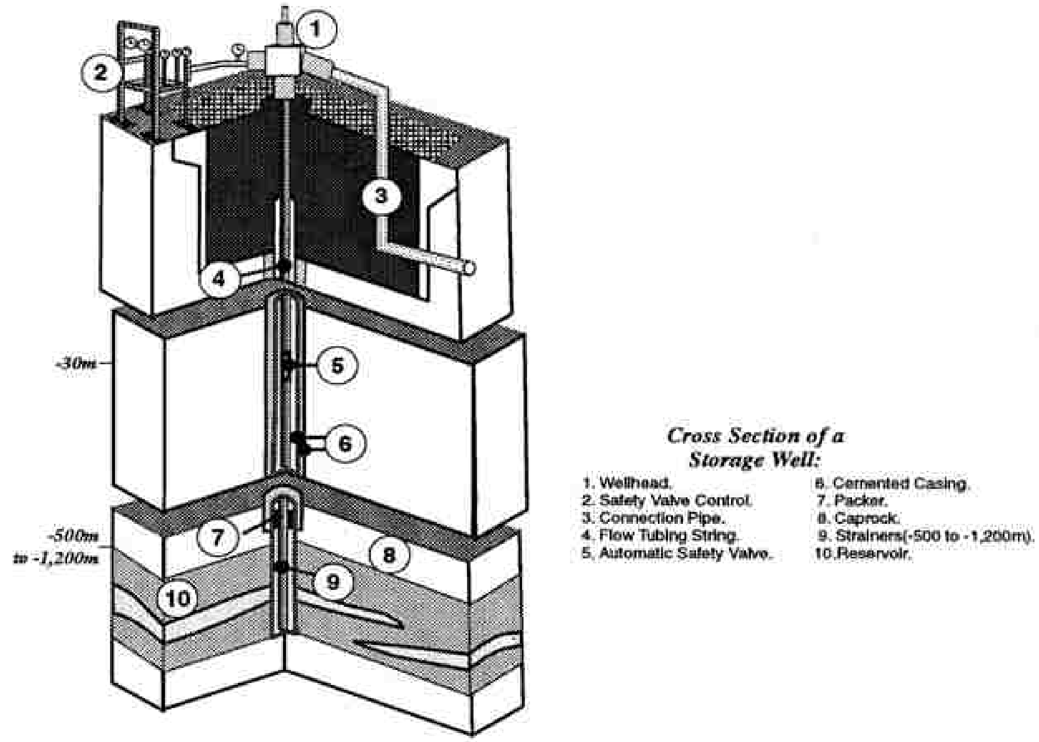


Figure 2.4-10 Depleted Production Reservoir Underground Natural Gas Storage Well Configuration [47]

Using an already developed reservoir for storage purposes allows the use of the extraction and distribution equipment left over from when the field was productive, reducing the cost of maintenance, operation and development. The main aspects that are considered to evaluate the possible development of a storage facility are both geographic and geologic. Depleted reservoirs must be relatively close to consuming regions, while having high permeability and porosity. Porosity determines the amount of natural gas that can be stored whereas permeability determines the rate of withdrawing of the working gas [48].

2.4.7. Distribution

The distribution phase conveys natural gas to end users. For large users like industrial operators or power generators, natural gas is provided directly from high capacity gas pipelines. Most other customers receive natural gas from a local distribution company. The distribution pipelines serve a large number of customers over a short distance. They also carry smaller volumes of gas at much lower pressures than the transmission pipelines. At a gate station, which separates the transmission segment from the distribution one, natural gas undergoes a depressurization process from a pressure of 150 bar to as low as 1 bar. At the same time, an odorant is added to natural gas for safety reasons.

Traditional distribution pipelines are made in rigid steel or cast iron but the use of plastics is gaining because of greater flexibility and lower cost. Other components of distribution network are the safety and operating valves as well as meters and customer lines. In addition, local distribution companies make use of a supervisory control and data acquisition system, or SCADA, to manage gas flow. The data is sent to a centralized control station where pipeline engineers have a real time control on the status of the pipelines. This enables quick reactions to monitor equipment malfunctions, leaks, or any other unusual activity along the pipeline. Some SCADA systems also incorporate the ability to remotely operate certain equipment along the pipeline, including compressor stations, allowing engineers in a centralized control center to immediately and easily adjust flow rates in the pipeline [43].

2.4.8. Utilization

The consumption phase represents the last step of the natural gas supply chain. Natural gas has always been used as source for a variety of applications including:

- Transport (LNG,CNG)
- Residential (heating, cooking)
- Electricity or Power generation
- Industrial
- Hydrogen production
- Material (non-energy use, chemical industry)

Based on data reported in “World Energy Outlook 2012”, some 38% of the worldwide demand comes from power generation and about 22% (800 Gm^3) goes toward residential and commercial heating and cooking. Transport applications currently account only for 3% of the gas supply but according to reports in WEO 2012 the application of natural gas for the transport seems to increasing due to proven reserves of natural gas worldwide and in particular in U.S. This has brought renewed interest in the use of CNG powered vehicles.

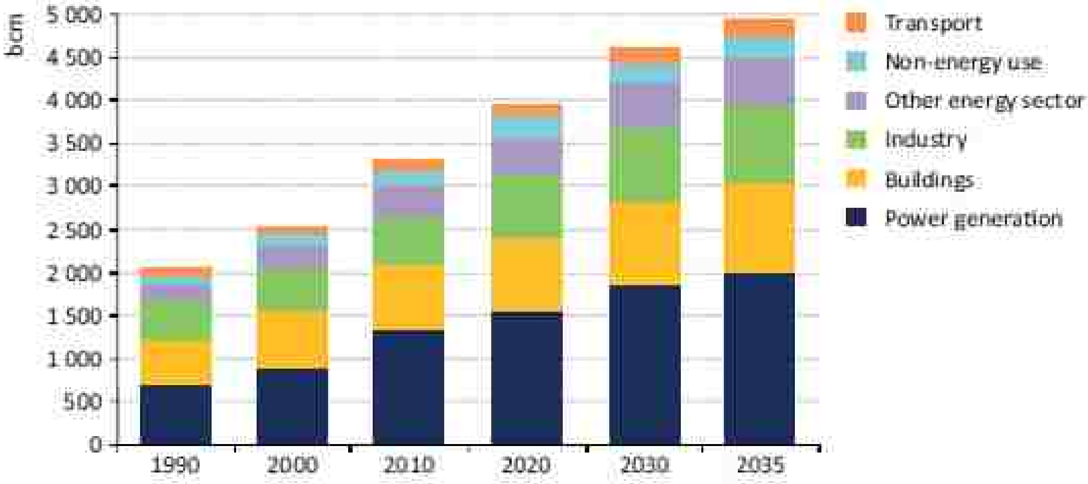


Figure 2.4-11 World natural gas demand in the current and future scenario [49]

2.5. **Actual Scenario of Natural Gas**

The development of unconventional natural gas resources, mainly in North America, has brought renewed interest in the potential use of CNG powered vehicles. To analyze the current barriers and challenges that affect the adoption of natural gas as a vehicle fuel, it is necessary to assess the current and future estimates of natural gas resources.

2.5.1. Reserves

New production technologies have fundamentally altered the profile of the world natural gas production. Based on update estimates of proven reserves and recoverable resources of both conventional and unconventional natural gas, the world's resources of natural gas seems to be able to satisfy the growing of demand for several years.

At the end of 2013, proven resources of natural gas accounted to 200.7 Tm^3, according to ENI "World oil and Natural Gas Review, 2013". Most of this is located in Russia, Iran and Qatar and their share is higher than 50 percent of the world's resources as shown in Figure 2.5-1.

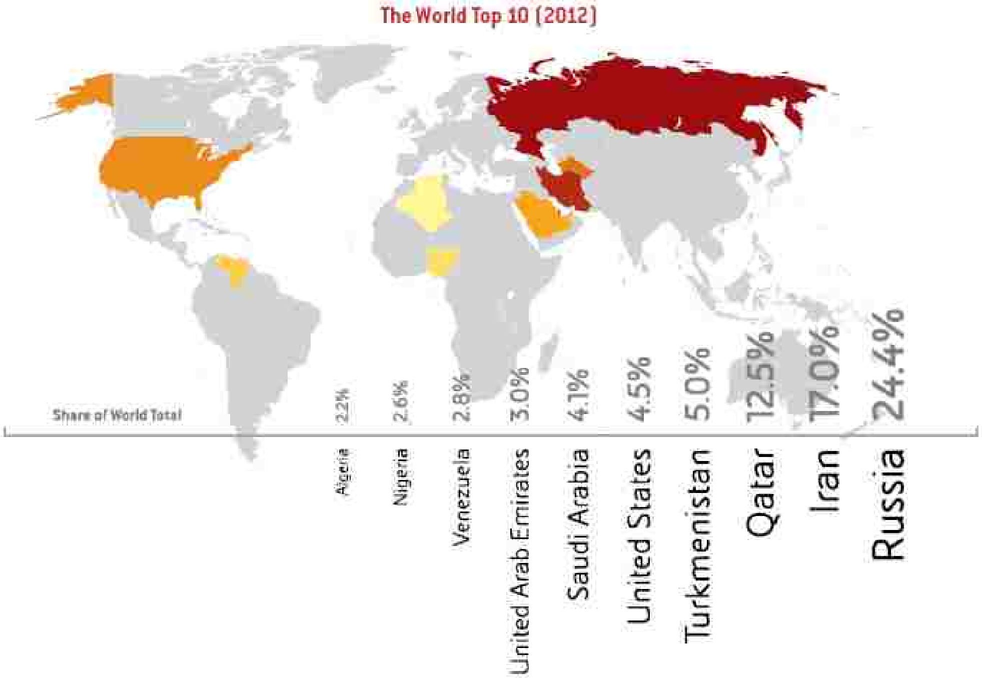


Figure 2.5-1 The world Top 10 share of natural gas, 2012 [2]

However, these percentages refer mostly to conventional reserves except for the United States and Canada where unconventional gas resources (shale, tight gas, and coalbed methane) are constantly growing.

Discoveries of gas fields have continued at a constant rate and according to the updated assessments reported on the "World Energy Outlook 2012", the remaining technically recoverable resources (TRR) of conventional natural gas worldwide, including proven reserves, reserve growth, and undiscovered resources are slightly over 460 Tm^3. Moreover, estimates of technically recoverable unconventional resources are now at 200 Tm^3 for shale gas, 81 Tm^3 for tight gas and 47 Tm^3 for coalbed methane, reaching a total amount of 790 Tm^3 as shown in Figure 2.5-2.

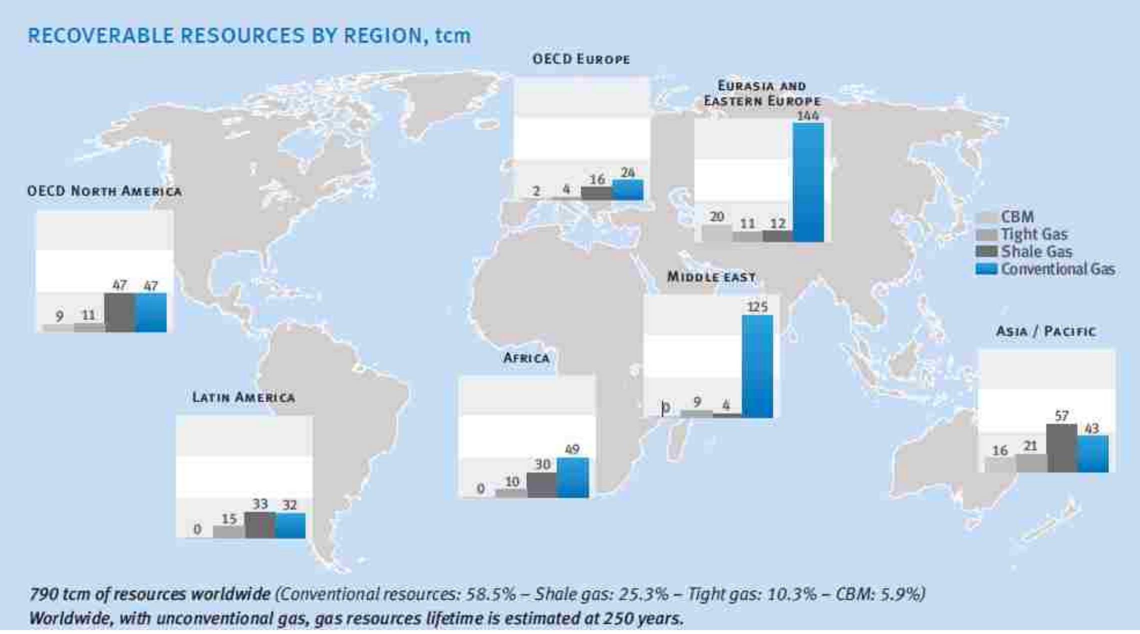


Figure 2.5-2 Recoverable resources by region [49]

2.5.1.1 *North American Scenario*

Recoverable shale gas resources offer a potential long term and low cost domestic natural gas source of supply in North America. In the last century, oil and natural gas consumption trends have been very similar. Since 2006, their paths diverged with natural gas pursuing an upward path while petroleum showing a downward trend. If this trend continues, it iw possible that natural gas will replace petroleum as main energy source in the United States in the next twenty years as illustrated in Figure 2.5-3.

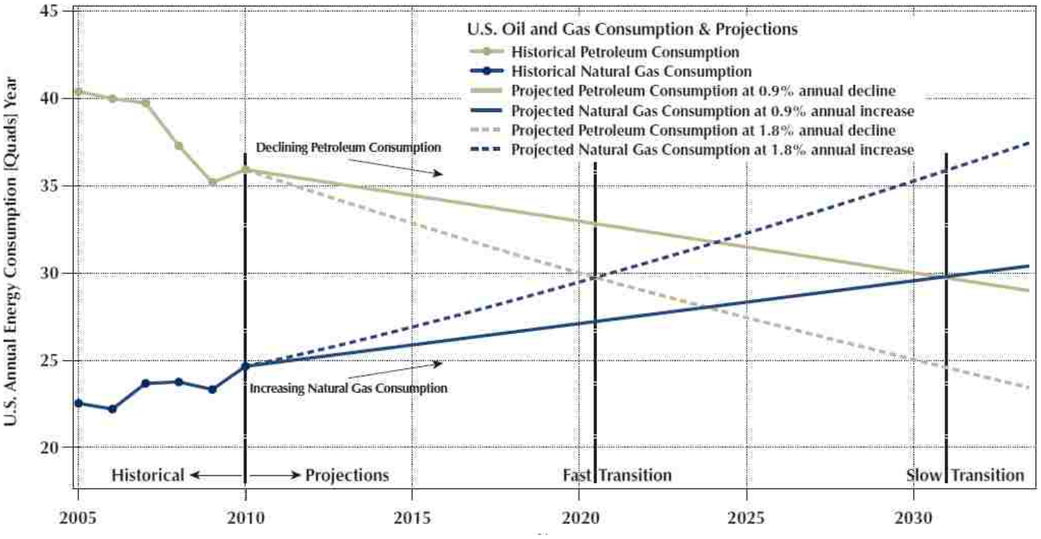


Figure 2.5-3 U.S. Oil and Natural Gas Consumption and Projections- 1 Quad = 970.434 bcf =27.48 Gm^3 [50]

The continuous reduction in petroleum consumption of 1.8% per year is assumed considering the introduction of severe emission standards and the unfavorable price differential compared to natural gas [50].

There is no absolute certainty about how much natural gas remains, and estimates made by different associations are based on various methodologies. The Energy Information Administration (EIA) Annual Energy Outlook (AEO) 2013 estimates proven reserves of dry natural gas in the lower 48 states equal to 8.72 Tm^3 (307.8 tcf) at the end of the 2013 with an annual growth rate from 2011 to 2040 equal to 0.6%. According to this analysis the projection of dry natural gas reserves at the end of 2040 will amount to 10.19 Tm^3 (359.97 tcf). Moreover, based on that data, at the end of the 2013, only 2.75 Tm^3 (97 tcf) of the 8.72 Tm^3 is from proven reserves of shale gas in the lower 48 states with only a small fraction of the total quantity located offshore [51]. Figure 2.5-4 shows the projections of dry natural gas located offshore and onshore in the lower 48 States:

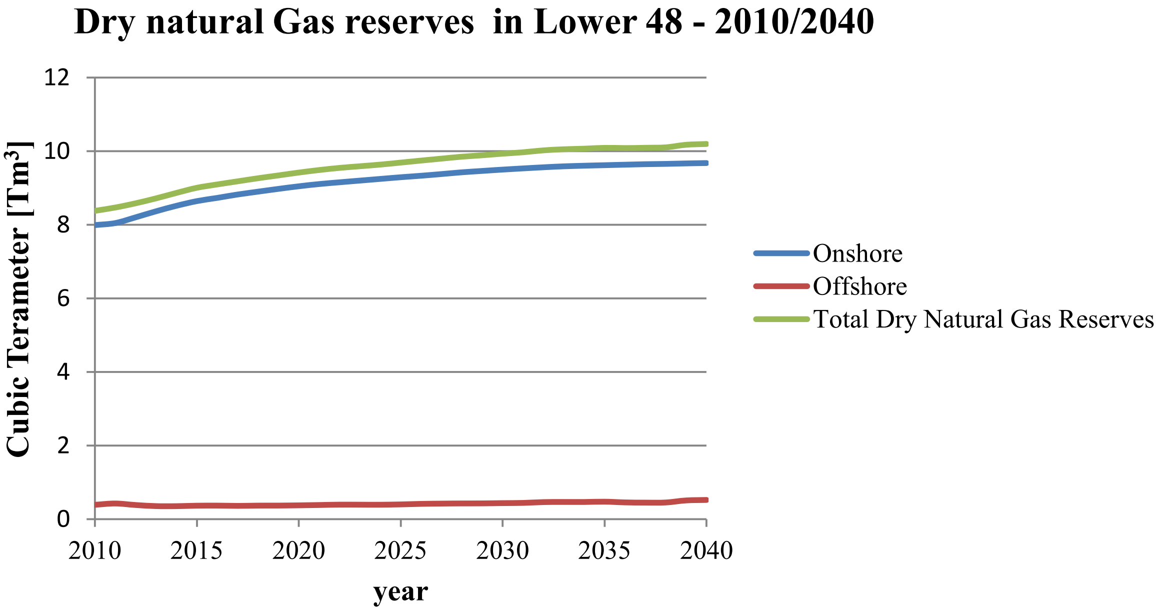


Figure 2.5-4 Dry Natural Gas Reserves in Lower 48. Adapted from [51]

More important is the distribution of these resources through the United States. Figure 2.5-5 shows the wet natural gas proved reserves by state/area in 2011. The value is slightly higher than what reported above because it refers to wet natural gas rather than dry natural gas. Wet natural gas is evaluated multiplying by 1.045 the value of dry natural gas.

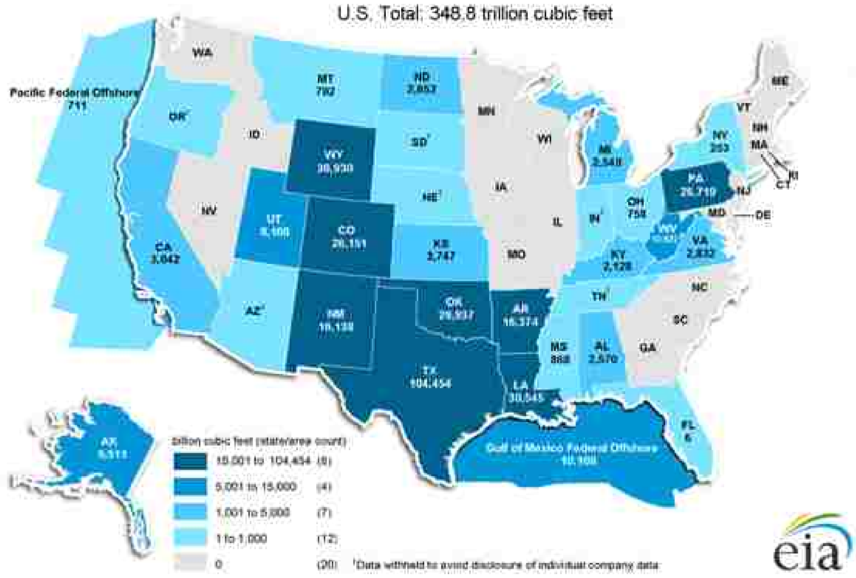
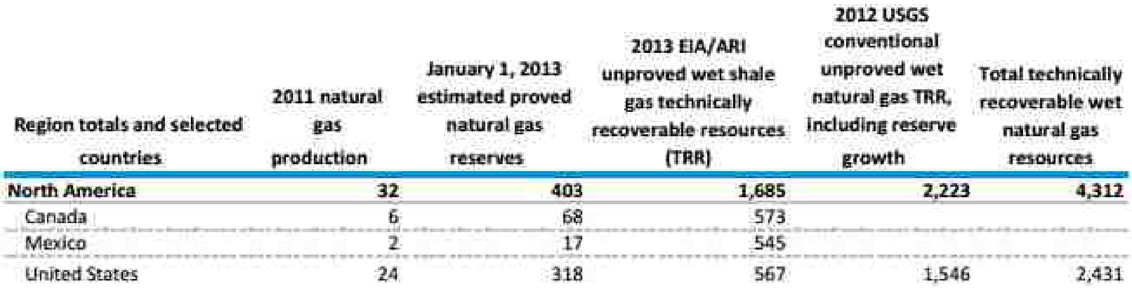


Figure 2.5-5 Wet Natural Gas proved reserve by state/area 2011 [52]

Natural gas reserves are not equally distributed in all the states. The highest concentration of proven reserves of natural gas are located in the southwest region including, from high to low, Texas, Louisiana, Oklahoma, Arkansas and New Mexico. An intermediate scenario is offered by the central region where the average concentration per state is less than 0.28 Tm^3 (10 tcf) except for Wyoming and Colorado that present more than 0.56 Tm^3 (20 tcf) each. Finally, the regions with the lowest concentration of reserves are in the Midwest with Minnesota, Wisconsin, Iowa, Illinois and Missouri, plus three states on the west coast such as Washington, Idaho and Nevada. In addition, Canada and Mexico have proven reserves of natural gas at the end of 2013 of respectively 1.93 Tm^3 (68 tcf) and 0.48 Tm^3 (17 tcf).

A common rule adopted to assess the long-term availability of domestic supply is the remaining technically recoverable resource (TRR). This includes proven reserve and unproven resources which become proven given increasing production experience and as new technologies are developed. The Energy Information Administration updates its estimates on TRR every year based on data provided by the U.S. Geological Survey (USGS). The most updated data are:



Region totals and selected countries	2011 natural gas production	January 1, 2013 estimated proved natural gas reserves	2013 EIA/ARI unproved wet shale gas technically recoverable resources (TRR)	2012 USGS conventional unproved wet natural gas TRR, including reserve growth	Total technically recoverable wet natural gas resources
North America	**32**	**403**	**1,685**	**2,223**	**4,312**
Canada	6	68	573		
Mexico	2	17	545		
United States	24	318	567	1,546	2,431

Figure 2.5-6 Technically Recoverable Resource of Natural Gas in North America measured in Tcf. Adapted from [53]

Based on these data there are 122.10 Tm^3 of TRR in North America, supporting what was reported in the World Energy Outlook 2012. However, the reduction of the U.S. import of natural gas from Canada is because of shale gas production. The adoption of horizontal drilling with hydraulic fracturing enables extracting natural gas from low permeability geologic formations, such as shale basins.

Shale gas production on large scale started in 2000 in the Barnett Shale located in the north-central Texas. The profitability of this formation represented the beginning for the drilling of new wells in other shale formations, including the Haynesville, Marcellus, Woodford, and Eagle Ford shales.

These drilling activities became popular in the Lower 48 shale formations, increasing dry shale gas production in the United States from 0.3 trillion cubic feet in 2000 to 9.6 trillion cubic feet (0.27 Tm^3) in 2012, or to 40 percent of the U.S. dry natural gas production. As mentioned before, there are 97 tcf (2.75 Tm^3) of proven shale gas reserves. EIA's current estimate of technically recoverable dry shale gas is 637 tcf (18.04 Tm^3), thus the 27% of the domestic natural gas resource represented in the AEO2013 projections (68.87 Tm^3) [53].

Source: U.S. Energy Information Administration based on data from various published studies. Canada and Mexico plays from ARI.
Updated: May 9, 2011

Figure 2.5-7 North America Shale Gas plays [54]

The Marcellus Shale is to date the largest shale basin in the world covering the states of New York, Ohio, Pennsylvania and West Virginia. These are states that are more densely populated but less familiar with natural gas production than Texas, Oklahoma, Arkansas and Louisiana, the locations of other major producing shale basins. Moreover, comparing this map with Figure 2.5-5, states such as Illinois, Iowa and Missouri that present zero wet proven natural gas resources offer on the contrary the potential for shale developments. Other favorable zones for shale extraction are the Southwest region and the central region that present at the same time prolific processing plants.

The developing the production in this formation requires significant investments in infrastructure. However, the location of Marcellus production in the Northeast presents an economic advantage because of the lower transportation costs to the densely populated

Northeastern US market, which has typically relied on LNG imports, and Canadian and Gulf of Mexico (GOM) gas via pipeline.

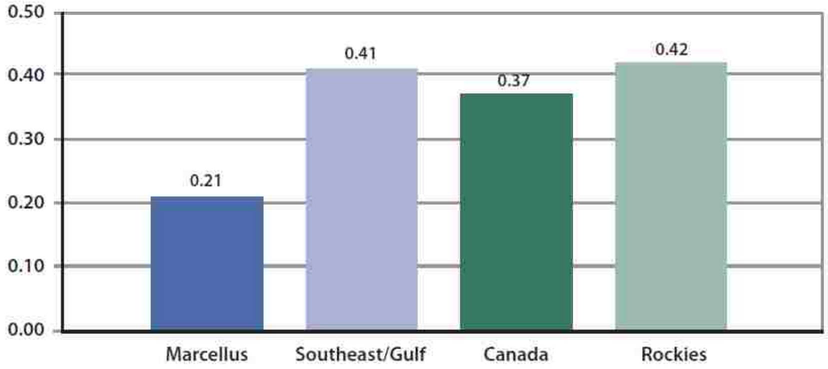


Figure 2.5-8 Average transportation cost to Northeast Market ($ per Mmcf) [2]

The United States currently produces less than it consumes. In the 2011 according to "National Gas Information 2012", the U.S. imported 97,791 MMcm and exported 42,678 MMcm, resulting in a net import of 55,113 MMcm (almost 2 trillion of cubic feet). As the domestic production increased, led by development of shale gas resources, imports have reduced and lower prices have led to increasing exports [51]. The AEO2013 Reference case projections position the U.S. as a net exporter of natural gas by 2020.

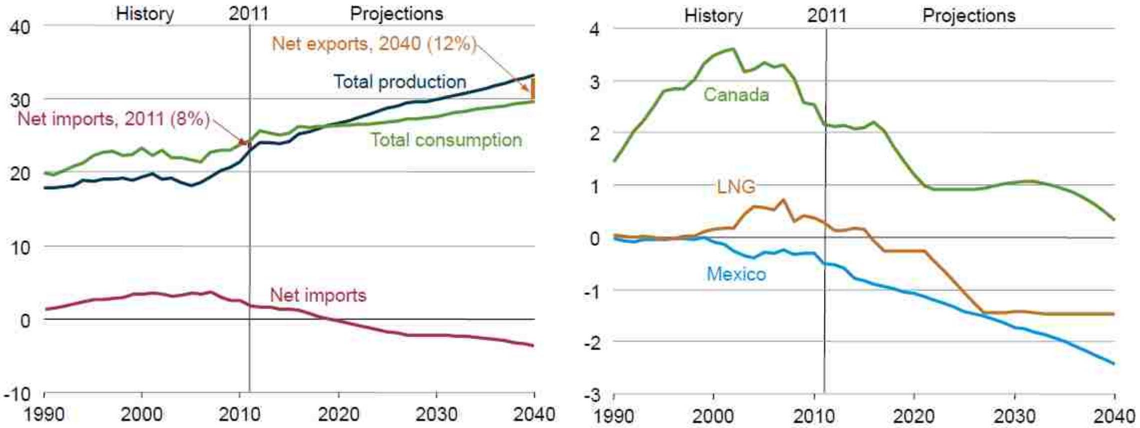


Figure 2.5-9 Total U.S. natural gas production and net imports [tcf] , 1990-2040 Adapted from [51]

Shale gas production which is expected to grow by 113 percent from 2011 to 2040 is the main driver of natural gas production growth. As the Figure 2.5-10 shows, shale gas production will represent the 50% of the total production in 2040 while the production in the lower 48 states' onshore conventional formation seems to decline to less than 2 trillion of cubic feet at the same time [51]. In the 2013, the U.S registered a production of 23.69 tcf (670.82 Gm^3) in the lower 48 states with onshore and offshore production of 21.77 tcf (616.7 Gm^3) and 1.92 tcf (54.4 Gm^3) respectively.

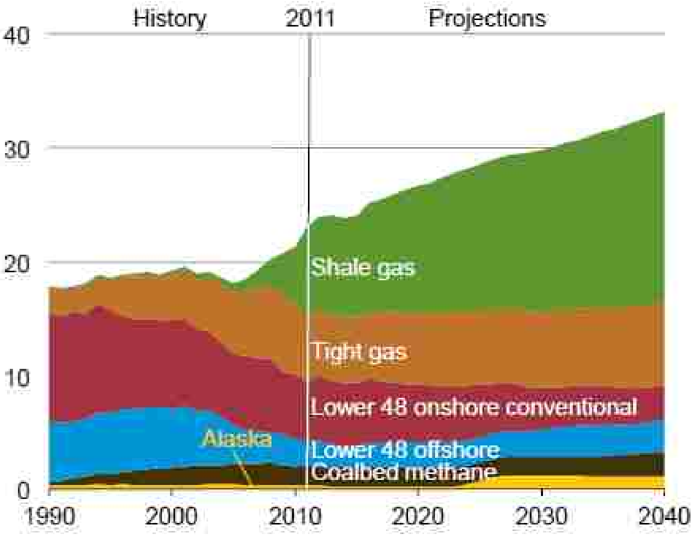


Figure 2.5-10 Natural gas production by source [tcf], 1990-2040 [55]

This favorable trend for natural gas does not occur without any impacts. With respect to water impacts, the two main problems are related to the risk of contamination and to the quantity used. Land risks include the effects on the land due to production activity and the predicted increasing seismic activity from wastewater reinjection. Air risks are primarily derived from leaks on site, leaks through the distribution system, and flaring at the point of production. Furthermore, there is also an economic challenge. The natural gas price should be a compromise between the price that promotes abundant supply and the price that guarantees abundant demand. In particular, a high price \$4 to \$8/MMBTU (1 MMBTU = 7.74 GGEs) allows broader investments in production but limits the demand for gas due to other cheaper alternatives to natural gas [56]. Below a certain price of \$1 to \$3/MMBTU the demand for natural gas increases in all the sectors but that price is not high enough to justify increases in supply. However, if economic and environmental risks are managed properly, then positive trends are entirely possible [56]. In 2010 only 3% of transportation sector was powered by natural gas against the 93% of vehicles fueled by petroleum. Thus, transportation using alternate fuels could see significant increases.

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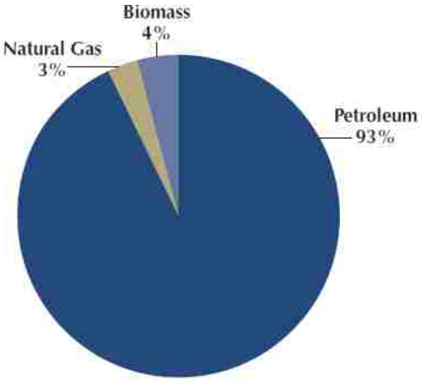
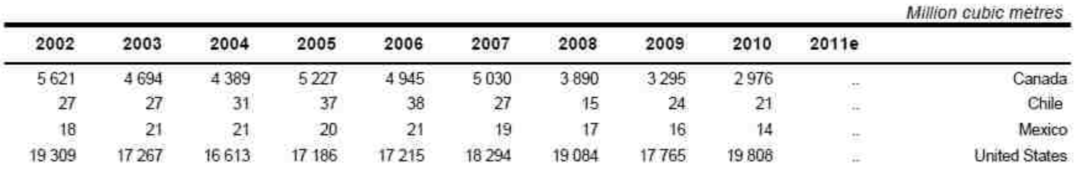


Figure 2.5-11 Energy sources in the U.S Transportation Sector, 2010 [57]



Million cubic metres

2002	2003	2004	2005	2006	2007	2008	2009	2010	2011e	
5 621	4 694	4 389	5 227	4 945	5 030	3 890	3 295	2 976	..	Canada
27	27	31	37	38	27	15	24	21	..	Chile
18	21	21	20	21	19	17	16	14	..	Mexico
19 309	17 267	16 613	17 186	17 215	18 294	19 084	17 765	19 808	..	United States

Figure 2.5-12 Natural Gas Used in Transportation [58]

2.5.1.2 *Italian Scenario*

The use of natural gas in Italy developed in the immediate postwar period, followed by a gradual growth of the gas pipeline network first in the north, and then in the central and southern Italian regions. This expansion of natural gas utilization occurred coincidentally with the discovery of methane in the Italian seabed. In Italy, important deposits have been located under the blanket flood of the Po Valley, in the area of Ravenna (northern Adriatic Sea) and in some areas of southern Italy and Sicily [59].

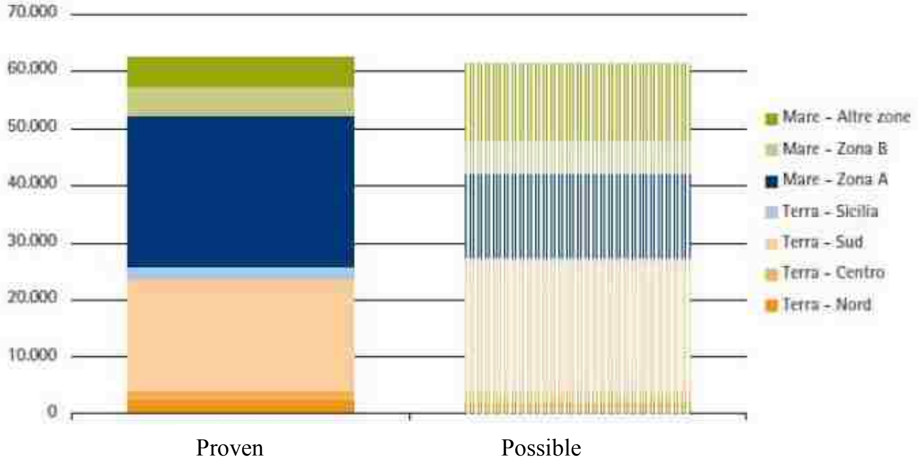


Figure 2.5-13 Natural Gas reserves and resources in 2011 (MMcm). Adapted from [59]

Proven reserves of natural gas amounted to 61.5 Gm^3 at the end of 2011. Recently, new natural gas basins were discovered in the northern, central and southern regions and offshore in the northern Adriatic Sea and in the Tyrrhenian Sea, west of Sicily. Hovewer, as Figure 2.5-13 shows, most of the Italian natural gas is concentrated in the Southern Italy for the terrestrial reservoirs, and in in the marine area A (northern Adriatic) for marine deposits.

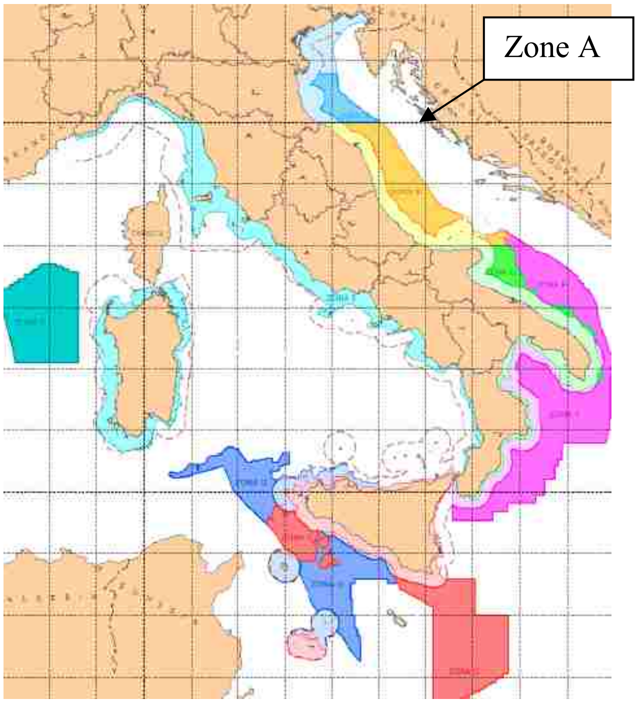
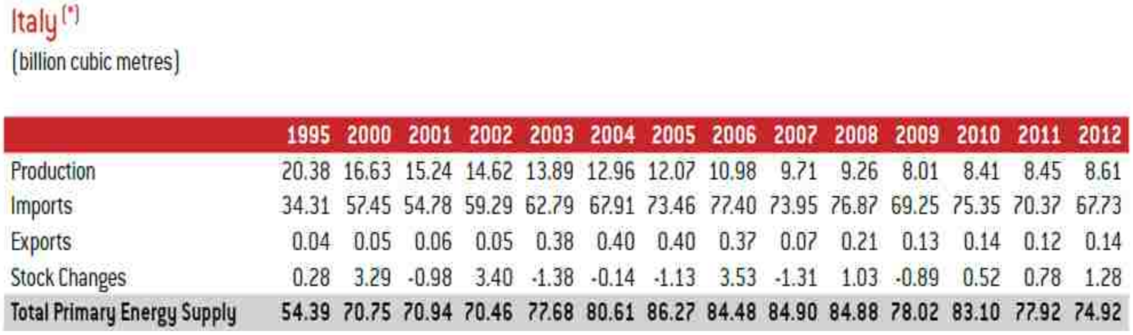


Figure 2.5-14 Marine areas for natural gas extraction. Adapted from [60]

According to data provided by “Ministero dello Sviluppo Economico, almost 60% of Italian natural gas reserves are located offshore. Indeed, more than 72% (6 Gm^3/y) of the total Italian natural gas production (8.61 Gm^3 in 2012) comes from offshore basins. Moreover, based on historical data, the national production of natural gas peaked at 20 Gm^3/y in the 1995 and began to decline of about 15% per year since then. However, after years of continuous decline, national production maintained steady at a level of 8 Gm^3 since 2008. Beyond poor resources, the limited production is due to difficulties in obtaining authorization and the severe government act introduced in 2010 as a consequence of the BP’s Gulf of Mexico oil spill, which banned offshore drilling and limited planned exploration and development project. In 2012 that code was revised, opening a small window of opportunity for the future. This new revision banned the drilling of wells and for all offshore operation to 12 miles (19 km) from the coast except for all concessions and applications for concession issued before June 2010 [61].



Italy (*)
(billion cubic metres)

	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Production	20.38	16.63	15.24	14.62	13.89	12.96	12.07	10.98	9.71	9.26	8.01	8.41	8.45	8.61
Imports	34.31	57.45	54.78	59.29	62.79	67.91	73.46	77.40	73.95	76.87	69.25	75.35	70.37	67.73
Exports	0.04	0.05	0.06	0.05	0.38	0.40	0.40	0.37	0.07	0.21	0.13	0.14	0.12	0.14
Stock Changes	0.28	3.29	-0.98	3.40	-1.38	-0.14	-1.13	3.53	-1.31	1.03	-0.89	0.52	0.78	1.28
Total Primary Energy Supply	**54.39**	**70.75**	**70.94**	**70.46**	**77.68**	**80.61**	**86.27**	**84.48**	**84.90**	**84.88**	**78.02**	**83.10**	**77.92**	**74.92**

Figure 2.5-15 Natural gas balance in Italy [2]

There are currently 107 offshore platforms dedicated to extracting natural gas which are located almost entirely in the Adriatic Sea. In particular, 68 are operating in the North Adriatic Sea (Zone A), 33 in Central Adriatic (Zone B) and 6 in the Ionian Sea off the coast of Crotone (Zones D and F). Interesting, the depth at which these platforms operate does not compare to the more than 1,500 metres of operating depth for the platforms located in the Gulf of Mexico or in other areas rich in natural gas and oil. The platforms of Adriatic operate at an average depth of about 37 meters, with a range that goes from 9 meters of the platform “Angela” in the North Adriatic to a maximum of 117 meters of the platform “Giovanna”, 40 km off the coast of Pescara.

However, Italy produces only 12% of its domestic demand of gas. The remaining demand is met by imports of natural gas from foreign countries and then transported through four pipelines, as shown in Figure 2.5-16, which convey natural gas from Algeria, Libya, the North Sea and Siberian Russia. 88% of imported natural gas represents the main difference compared to the American scenario where imports account for only to 8% of the total supply.

Figure 2.5-16 Gas import infrastructure 2011 [62]

Imports from Algeria, which supplies a third of the total natural gas in Italy, is through the pipeline gasline TTPC (Trans Tunisian Pipeline Company). It is 742 km long and crosses the Tunisian border at 370 km, reaching the shores of the Mediterranean Sea. In the region of Cap Bon, the gasline TTPC connects to the undersea gas pipeline Transmed which is 775 km long, resurfaces in Mazara del Vallo, Sicily, where the network held by SnamRete Gas starts. In total, Algeria provides Italy 26 Gm^3 of gas per year [63].

The pipeline GreenStream opened in October of 2004 and at 520 km long carries natural gas from Libya, passing to the west of the island of Malta and reaching Sicily after a route that reaches a maximum depth of 1127 m. The Trans Austria Gasleitung (TAG) carries the gas from Siberian Russia (24.8 Gm^3 of gas per year) into Italy using the access point located at border with Austria. This pipeline, which supplies Austria, Slovenia and Croatia, from the border between Austria and the Czech Republic to Tarvisio has a total length of 380 km [63].

The fourth is the Tenp pipeline (Trans Europa Naturgas Pipeline), which leads into the Italian network natural gas from Norway and the Netherlands. It has a total length of 968 kilometers and a transit capacity of 44 million cubic meters per day.

There are three additional pipelines under development. The first, called Galsi (Algeria Sardinia Italy pipeline) will connect Algeria to Piombino while passing through Sardinia. The second, called South Stream, will bring the gas from Russia at Otranto through the

Black Sea. The third, the Trans Adriatic Pipeline (TAP) is a 800 kilometer pipeline from Greece via Albania and the Adriatic Sea and brings gas from the fields in the Azeri Caspian Sea in Puglia [63].

What reported up to now was referred only to imports of compressed natural gas since the imports of LNG take place by special ships called tankers. The national "Natural Gas Balance" states that in the 2012 almost all the annual demand of natural gas has been satisfied using external supply (67.73 Gm^3) while the domestic production amounted to 8.61 Gm^3. Only a small amount of natural gas (140 MMcm) is exported to Switzerland, Croatia and Austria.

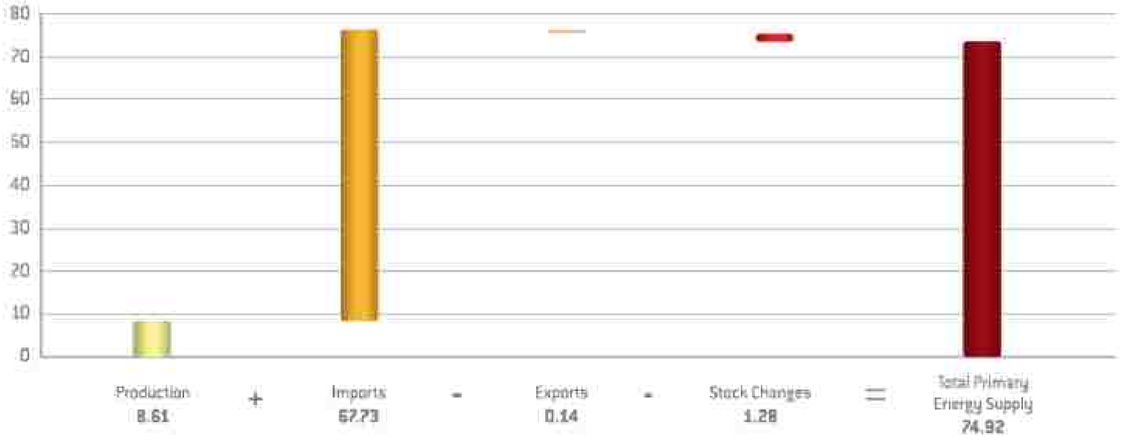


Figure 2.5-17 Italian National Balance [2]

2.5.2. *Infrastructure*

2.5.2.1 *North American Scenario*

The United States is characterized by an infrastructure system for transporting natural gas from production and importation sites to end users. The major components of the system, as shown in the Figure 2.5-18, are gathering pipelines, interstate and intrastate transmission pipelines, distribution pipelines, storage facilities, LNG regasification terminals and gas processing unit. This thesis focuses only on CNG transportation ignoring the transportation of natural gas in liquid form.

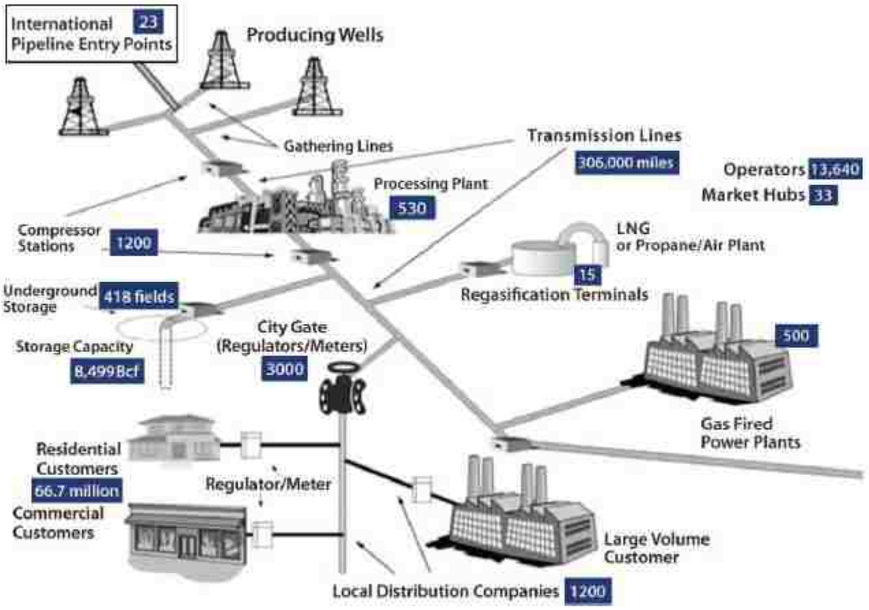


Figure 2.5-18 U.S Natural Gas Infrastructure [3] (The values reported in the figure are only indicative because they may change during time)

As mentioned in the section 2.4.5, the connection between the extraction points and the processing facilities is provided by gathering pipelines. At the end of 2013, there were more than 20,000 miles of gathering pipelines in the United States, which depart from 460,000 wellheads. After the treatment process, natural gas is sorted towards demand centres, often hundreds of miles away, through transmission pipelines called interstate pipelines or trunk lines.

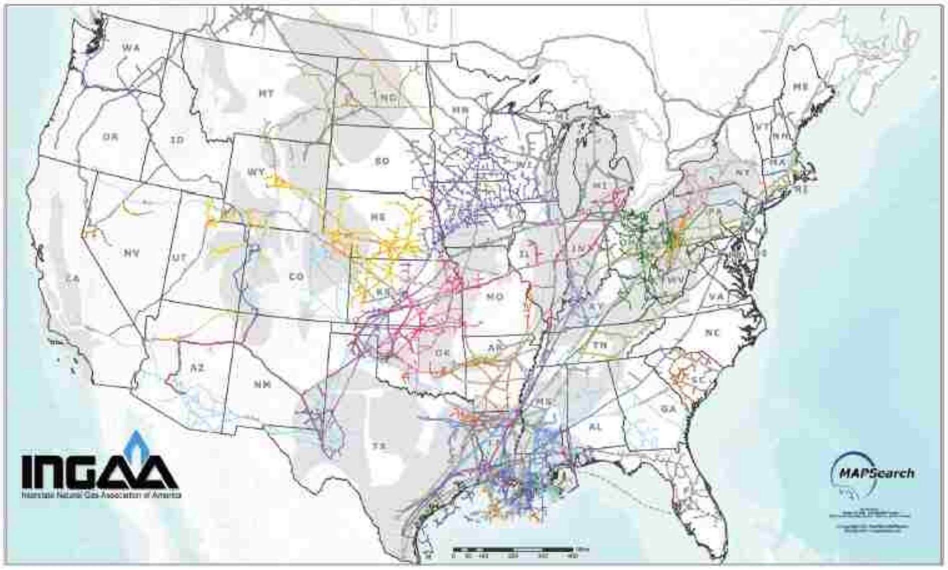


Figure 2.5-19 Interstate Pipelines 2013 [56]

Currently there are almost 306,000 miles (about 492,000 km) of transmission pipelines in the United States but their capacity and flow direction varies across the country. Interstate pipelines are not evenly distributed but are most extensive in the Southwest Region (Texas, Oklahoma, Louisiana, Arkansas) which contains the largest number of individual natural gas pipeline systems (more than 90) and the highest level of pipeline mileage (over 106,000). The distribution of resources is related to the development of transmission pipelines. Indeed the two maps (Figure 2.5-5 and Figure 2.5-19) are pretty comparable in the sense that the highest density of pipelines is located in the same states that present a long term potential of supply. In particular it is possible to notice how the eastern side is undeveloped with respect to the central and western side.

- Texas presents, to date, both the highest concentration of reserves with 2.9 Tm^3 (104 tcf) of natural gas and the most widely developed network with about 60 thousand miles of pipelines;
- States like Washington, Idaho, Nevada and all the states on the east coast that present few if any proven resources are in turn characterized by less than 2 thousand miles of pipelines per state;
- An intermediate scenario is represented by states such as California, Utah, Louisiana and Oklahoma [64].

The pipeline infrastructure as illustrated in Figure 2.5-19 has a daily delivery capacity of 119 billion cubic feet (3.37 Gm^3). The U.S. infrastructure system includes more than 1,400 compressor stations that maintain pressure on the natural gas pipeline network and assure continuous forward movement of supplies (Figure 2.5-20). As expected the compressor stations are more concentrated in the southwest region due to a higher density of interstate pipelines. Along transmission pipelines there are also meters to monitor the flow and valves located at regular intervals that can be used to stop the flow if needed.

There were 414 storage facilities across the United States in 2012. Of these more than 300 were depleted oil or natural gas reserves while the rest were salt caverns and aquifers. Working gas storage capacity in 2011 was around 127.88 Gm^3 in the U.S and about 19.69 Gm^3 in Canada [58].

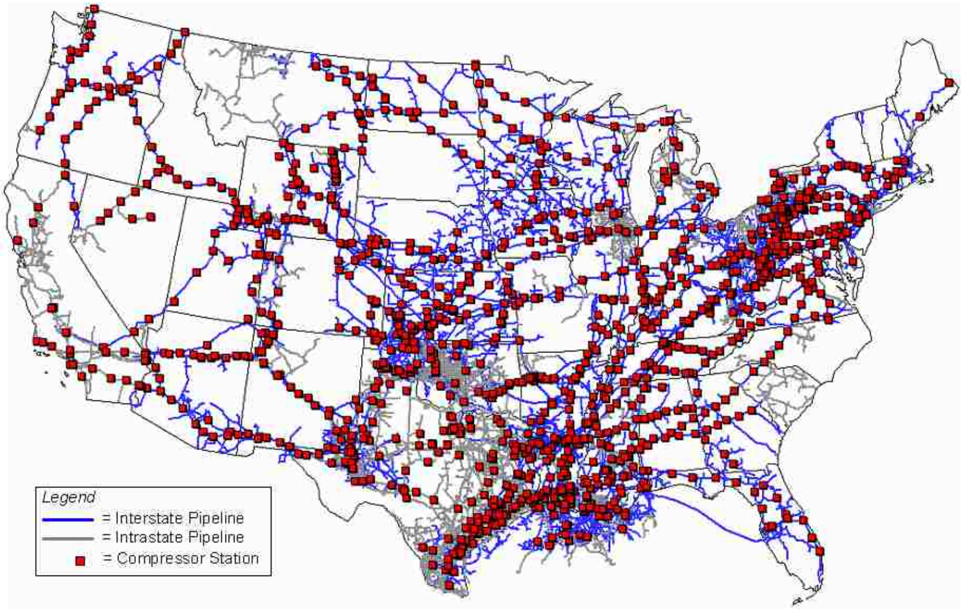


Figure 2.5-20 Compressor Station [65]

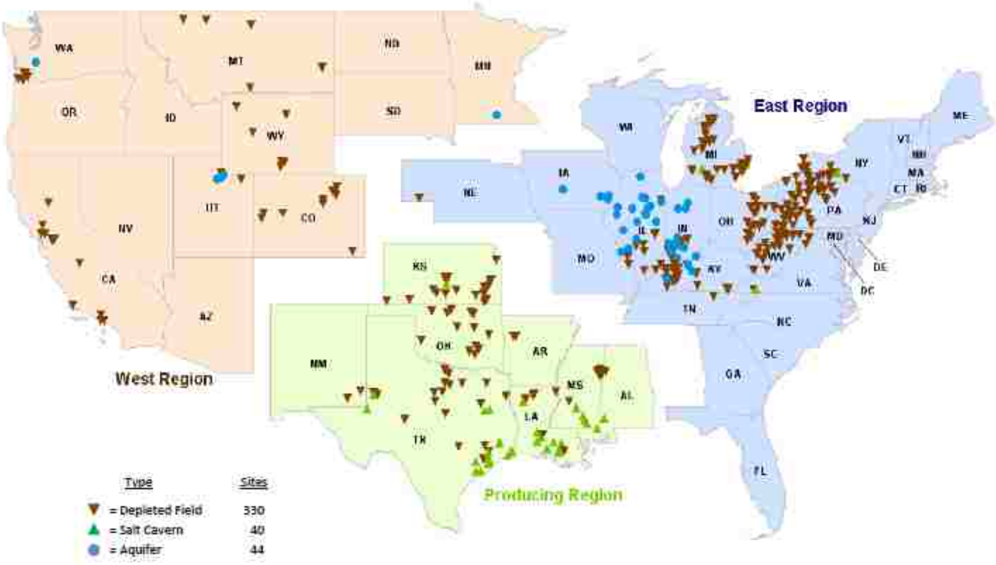


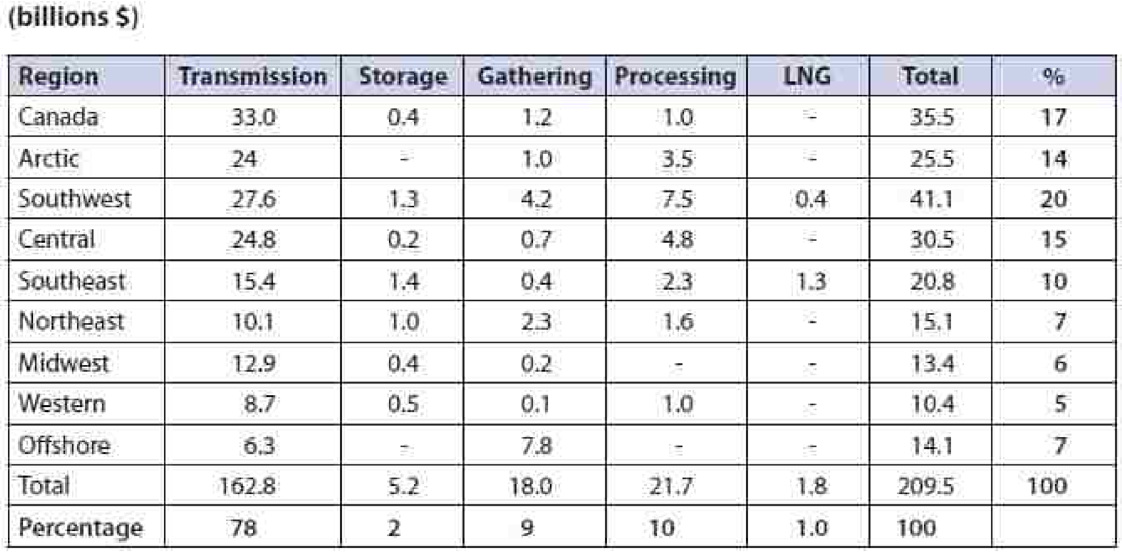
Figure 2.5-21 U.S. Natural Gas storage facilities [66]

These storage facilities are generally used also to store natural gas when purchased at low price and to withdraw it later when selling as the price rises.

Lastly, distribution pipelines are generally owned by local distribution companies (local gas utilities) which, after adding odorant and lowering the pressure, distribute it to residential and commercial customers. Distribution pipelines are much smaller pipelines, often only 0.5 to 2 inches in diameter, which move natural gas at very low pressure. They may be made of plastic, which is less likely to leak than metal. At present, distribution networks used by local distribution companies extend over 2 million miles thus more than 3.2 million of kilometers.

However, the potential of the adoption of natural gas on large scale in the U.S, driven by a low price and increases in supply and demand has led to a need for expanded infrastructure to easily distribute natural gas to the end user. The Interstate Natural Gas Association of American (INGAA) estimates that the U.S. and Canada will need approximately 28,900 to 61,900 miles of additional transmission and distribution pipelines for natural gas by 2030. Beyond the need for extended pipelines, INGAA also predicts a need for 371 to 598 billion cubic feet (Bcf) of additional storage capacity, a 15% to 20% increase over current levels. [3]. These future developments will occur with a certain cost. The following table shows expected costs by 2030 organized by region and phases.

Table 2.5-1 Total Expected Cost 2009-2030 [3]



(billions $)

Region	Transmission	Storage	Gathering	Processing	LNG	Total	%
Canada	33.0	0.4	1.2	1.0	-	35.5	17
Arctic	24	-	1.0	3.5	-	25.5	14
Southwest	27.6	1.3	4.2	7.5	0.4	41.1	20
Central	24.8	0.2	0.7	4.8	-	30.5	15
Southeast	15.4	1.4	0.4	2.3	1.3	20.8	10
Northeast	10.1	1.0	2.3	1.6	-	15.1	7
Midwest	12.9	0.4	0.2	-	-	13.4	6
Western	8.7	0.5	0.1	1.0	-	10.4	5
Offshore	6.3	-	7.8	-	-	14.1	7
Total	162.8	5.2	18.0	21.7	1.8	209.5	100
Percentage	78	2	9	10	1.0	100	

INGAA estimates reports that the highest expenditures are due to the construction of transmission pipelines while additional storage capacity will require only 2% of the total cost. While storage facilities and pipelines are important elements, the presence of underground resources represents the “push factor” for developing infrastructure elements.

2.5.2.2 ***Italian Scenario***

In Italy, the management of the entire supply chain of natural gas (imports, nationwide distribution and storage) is entrusted to Snam Rete Gas. SnamRete Gas, the market leader in the Italian natural gas sector, transports and dispatches natural gas using an integrated system of infrastructure directly connected to production fields, import lines and storage centres. The whole system is shown in Figure 2.5-22 and is composed of:

- the gas pipeline network
- 11 compression stations
- the Panigaglia LNG terminal
- 8 regional operating centres
- 55 maintenance centres

The connection between distribution points and commercial or domestic end users is provided by a group of local distribution companies.

Figure 2.5-22 Italian Gas Network 2011 [58]

At the end of 2011, the gas transmission network extended over 34,000 km across Italy where 32,010 km were owned and operated by Snam Rete Gas while the others belong to smaller operators such as Societa' Gasdotti Italia or Edison Stoccaggi [67]. Comparing pipeline lengths, Texas has a network three times longer than Italy while Oklahoma, Louisiana and Kansas are comparable to the Italian scenario. A more useful comparison is the density of pipelines the length of pipelines versus their area of coverage. In this context, Texas has a pipeline density of 0.139 km/km^2 compared to 0.105 km/km^2 of Italy. Oklahoma and Louisiana have transmission pipeline densities of 0.168 and 0.270 km/km^2 respectively.

In 2011, the distribution network in Italy was over 245,000 km. The network has 229 active operators, but Snam has the largest share since its Italgas subsidiary manages over 50,000 km of the distribution network and serves about 5.8 MM customers [67]. In Italy, the storage system consists of 10 onshore depleted fields mostly located in the north. Eight are owned and operated by Stoccaggi Gas Italia (Stogit) (a legally unbundled entity owned by Snam Rete Gas) and the remaining two by Edison Stoccaggio [58]. These storage facilities provide another way to prevent shortages in case of emergencies or an alternative supply to meet demand fluctuations. For example, almost 60% of natural gas sales occur during the winter months.

The Italian storage capacity account for 15.15 Gm^3 with a delivery capacity that varies from 292.2 MMcm/d at the beginning of the winter (maximum pressure) to a minimum level of 150 MMcm/d [58].

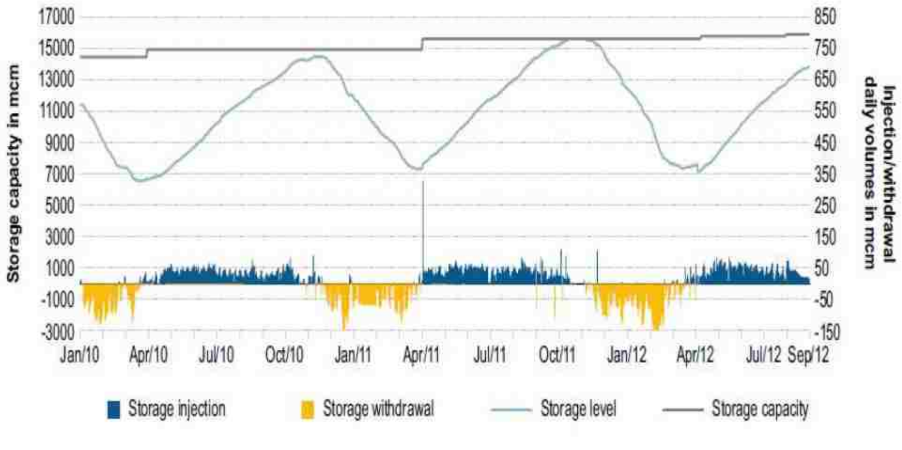


Figure 2.5-23 Underground Storage Utilisation levels (MMcm) [67]

Because of the extensive use of natural gas in Italy, the Italian industry is the leader in developing and producing natural gas technologies for transport.

In the transportation segment, the final step along the natural gas supply chain is occupied by the CNG filling stations which can differ in term of size of the plant and the type of customers to which it is designed. Generally, a filling station includes all the following components:

- compression units
- electric motor drive
- main cooling system
- extra cooling system for gas at distribution
- lubrication system
- gas storage
- power control/panel
- control/managing instrumentation
- operation and regulation devices, both manually and automatically operated
- mechanical and electronic safety devices
- gas measuring system
- air compression system
- articulate filtering, liquid separation and moisture drying systems
- auxiliary storage
- high pressure tubing
- CNG multilevel dispensers
- CNG high capacity dispensers
- sequential refilling systems [68].

The main components of a CNG filling station are the gas inlet, the dryer, the compressor, the storage and the dispenser, and these components can be arranged in different ways in order to satisfy various requirements.

In Italy, as well as in North America, there are three predominant configurations of CNG stations:

- **Cascade Fast Fill**

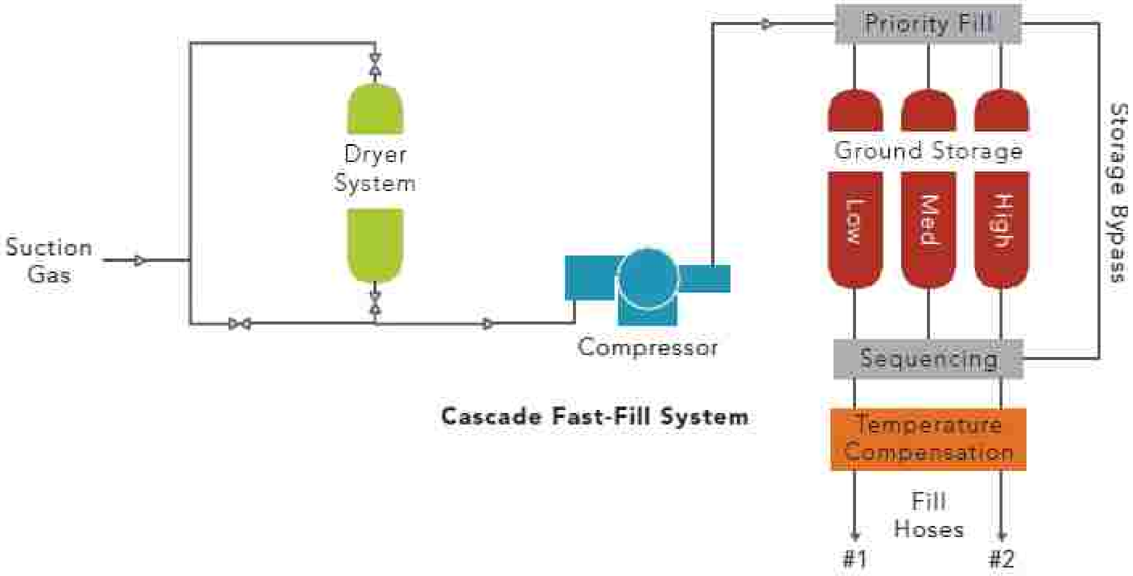


Figure 2.5-24 Cascade Fast-Fill System [69]

Cascade fast-fill refuelling stations (shown in Figure 2.5-24) provide fast and convenient fuelling similar to that provided by conventional liquid fuel stations. The first component, common to all typologies of filling stations, is the dryer which removes water or water vapour prior the compression. CNG storage vessels arranged in cascades, or banks, are used to quickly fill vehicles during peak fuelling times, when the compressors alone cannot meet demand. During off-peak times, the compressor refills the CNG storage cascades. These stations are suitable for fuelling light-duty vehicles at public access stations where use patterns are random. More than one compressor are installed in order to provide a continuous supply of fuel and avoid customer dissatisfaction [70].

- Buffered Fast Fill

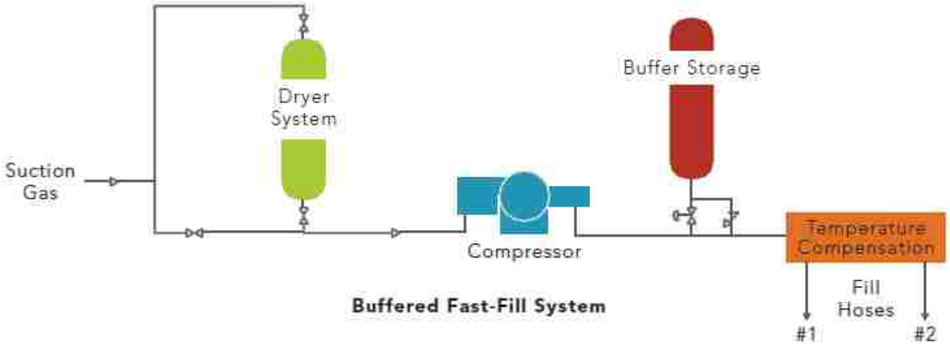


Figure 2.5-25 Buffer Fast Fill System [69]

Buffered fast-fill refilling is generally used to fill fleets. This provides relatively fast, continuous, high volume fuelling and is generally designed to fit the needs of that fleet. The main difference compared to the cascade fast-fill system is that in this case CNG is directly filled from the compressor into the vehicle. A small quantity of storage is filled during interval between vehicles [69].

- Time-Fill

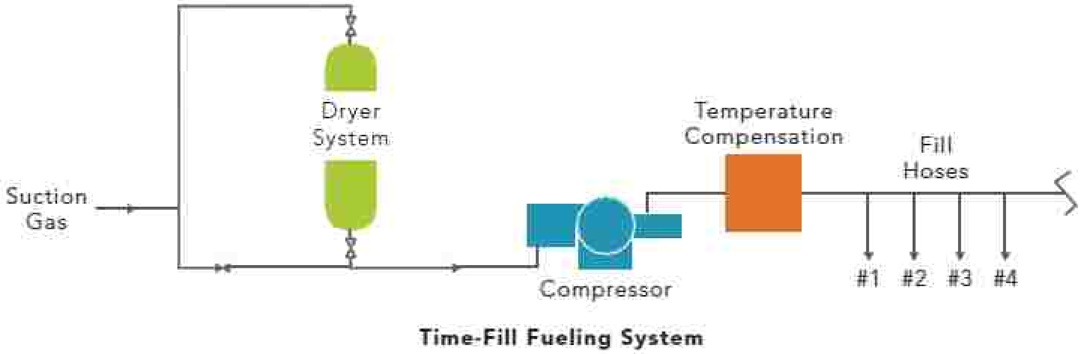


Figure 2.5-26 Time Fill Fueling System [69]

Time-fill stations fill vehicles over a six- to eight-hour period. Compressors compress natural gas from pipeline pressure (5–100 psi or 0.344-6.89 bar) to the required vehicle pressure (2400–3600 psi or up to 250 bar) and dispense it into multiple vehicles simultaneously. This kind of system is suitable for fleets whose vehicles return daily to central locations. The main advantage is a lower cost for the component acquisition and installation [69].

The cost of a filling station can vary from \$0.8M to \$1.5M according to the size, location and local taxes. Expanding the filling network requires significant investment that can be justified only by a positive ROI and margin for stakeholders [70]. Currently there are two methods to evaluate the profitability and worthiness of the investment. A rule of thumb is to consider that a filling station amortizes the cost of capital and variable cost if it dispenses 200,000 gasoline gallon equivalent (GGE) per year. The other method consists of evaluating the CNG vehicle-to-refuelling-station index (VRI). This index, calculated as the ratio between the numbers of CNG vehicles (in thousands) and the number of CNG refuelling stations, is a function of two main variables [71]:

- The spatial density of refuelling stations for CNG vehicle drivers
- The profitability of CNG refuelling facilities for the station operators.

A VRI value of approximately *1000 vehicles per 1 refuelling station* is considered the optimal balance between profitability for fuelling stations and convenience to NGV operators. It is important to note that within the industry, this ratio is often referred to as "1" as a convention (i.e., as a multiples of one thousand). This value comes from an analysis performed by Janssen et al. on NGV penetration worldwide between 2003 and 2004. They arrived to that conclusion based on a VRI close to "1" for countries with a well-established CNG market like Argentina, Brazil, Italy, and India. This reference VRI value of 1 is now commonly used through the industries [72].

2.5.3. National and regional laws, technical regulations

2.5.3.1 ***North American Scenario***

At both federal and state levels, various policies have been introduced to promote the growth of natural gas as a vehicle fuel, including subsidies, tax incentives and procurement policies. The main program is the Clean Cities Initiative enacted in 1993 by Department of Energy aimed at lowering the dependence on petroleum for transportation by promoting alternative fuels. This program consists of more than 100 Clean Cities coalitions among suppliers, OEMs, federal and state agencies which collaborate to develop new environmentally friendly technologies and cheaper alternatives.

The favorable price differential of NG compared to traditional fuels provides a stimulus first for fleets and then also to individuals to consider natural gas fueled vehicles. Indeed, CNG has a lower average price than gasoline for all regions of the country, with the largest difference (\$1.77 per GGE) being in the Midwest region and an average difference in all the other countries of 1.51 \$ per GGE [73].

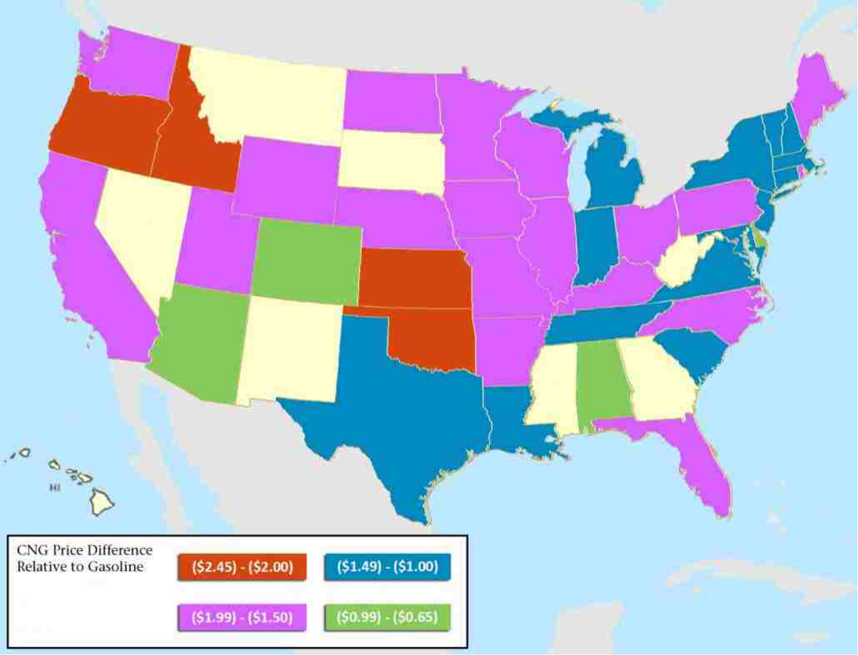


Figure 2.5-27 CNG price difference relative to gasoline [\$/GGE] [73]

However, the move to natural gas is challenged by the current higher cost of NGVs compared to current gasoline and diesel vehicles, and the limited presence of filling infrastructures. Thus, some public policies promote the adoption of NGV by reducing the upfront costs and providing incentives to build more infrastructures. These policies are intended to promote the growth of natural gas by: 1) reducing the upfront cost of natural gas adoption; 2) providing fuel incentives; and 3) providing privileges to NGV users.

Currently, at the federal level, 27 natural gas promotion policies are active including infrastructure and technological developments, High occupant vehicle (HOV) lane use and aftermarket conversions. At the state level, significant effort in supporting natural adoption is being undertaken by Colorado (with 11 natural gas policies in place), Oklahoma (14), Texas (15), Utah (10), West Virginia (16), Indiana (18) and California (27). This has been possible due to natural gas resources in the regions [74].

In particular, California has always been a leader in this field by providing alternative fuel promotion policies, including parking incentives, and the ability to use HOV lanes regardless of the number of passengers in a vehicle. Another step in this direction was achieved on September 28 when Governor Jerry Brown decided to extend various other clean vehicle incentive programs until 2023. He also signed legislation that will extend HOV lane access for certain alternative fuels vehicles until January 1, 2019 [74].

Utah provides an income tax credit of 35% of the vehicle purchase price, up to $2,500, for OEM compressed natural gas vehicles registered in Utah. It provides also incentives for conversion to alternative fuels.

As of September 2013, based on a report by VNG.CO, a company that offers a nationwide CNG retail-centric fuelling facility program to owners and operators of light-duty NGVs, twenty-seven states offer some form of incentives for converting fleets to light-duty NGVs as shown in Figure 2.5-28.

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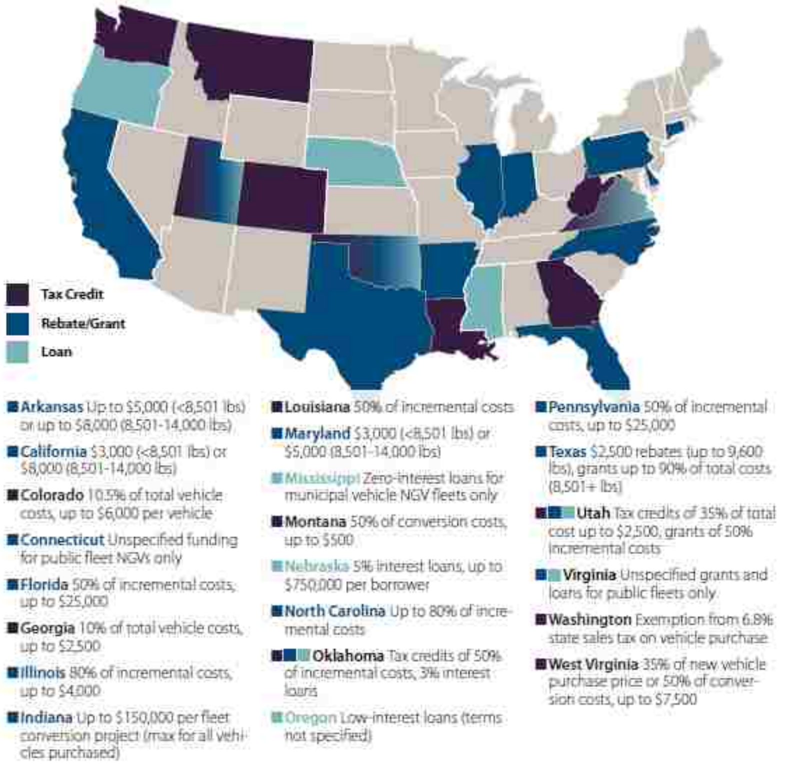

Arkansas Up to $5,000 (<8,501 lbs) or up to $8,000 (8,501-14,000 lbs)

California $3,000 (<8,501 lbs) or $8,000 (8,501-14,000 lbs)

Colorado 10.5% of total vehicle costs, up to $6,000 per vehicle

Connecticut Unspecified funding for public fleet NGVs only

Florida 50% of incremental costs, up to $25,000

Georgia 10% of total vehicle costs, up to $2,500

Illinois 80% of incremental costs, up to $4,000

Indiana Up to $150,000 per fleet conversion project (max for all vehicles purchased)

Louisiana 50% of incremental costs

Maryland $3,000 (<8,501 lbs) or $5,000 (8,501-14,000 lbs)

Mississippi Zero-interest loans for municipal vehicle NGV fleets only

Montana 50% of conversion costs, up to $500

Nebraska 5% interest loans, up to $750,000 per borrower

North Carolina Up to 80% of incremental costs

Oklahoma Tax credits of 50% of incremental costs, 3% interest loans

Oregon Low-interest loans (terms not specified)

Pennsylvania 50% of incremental costs, up to $25,000

Texas $2,500 rebates (up to 9,600 lbs), grants up to 90% of total costs (8,501+ lbs)

Utah Tax credits of 35% of total cost up to $2,500, grants of 50% incremental costs

Virginia Unspecified grants and loans for public fleets only

Washington Exemption from 6.8% state sales tax on vehicle purchase

West Virginia 35% of new vehicle purchase price or 50% of conversion costs, up to $7,500

Figure 2.5-28 Map of States offering various incentives for light-duty CNG vehicles [75]

As mentioned before, the U.S. Federal Government plays an important role in promoting NGVs. President Obama issued a Presidential Memorandum in May 2011 in which he commissioned all federal agencies to purchase or lease only alternative fuel passenger vehicles or light duty trucks by 2015. This action had two effects since on one hand it was expected to directly stimulate demand for such vehicles and, by creating economies of scale, reduce the upfront costs of such vehicles and thereby increase their market share. In addition, the indirect effect was to increase the utilization of existing natural gas infrastructure and promote demand for additional fuelling stations. The main goal at the end was to make people more aware of the benefits of this category of vehicle and of the lower cost of natural gas as a fuel.

Also 15 States, shown in Figure 2.5-29, decided to collaborate and announced a Memorandum of Understanding (MOU) in November 2011 in an effort to convert their state vehicle fleets to natural gas. In particular, the states are motivated by the low cost of the CNG and the high availability of the resource. The hope is to convince OEMs to widen their fleet offerings to include natural gas [74].

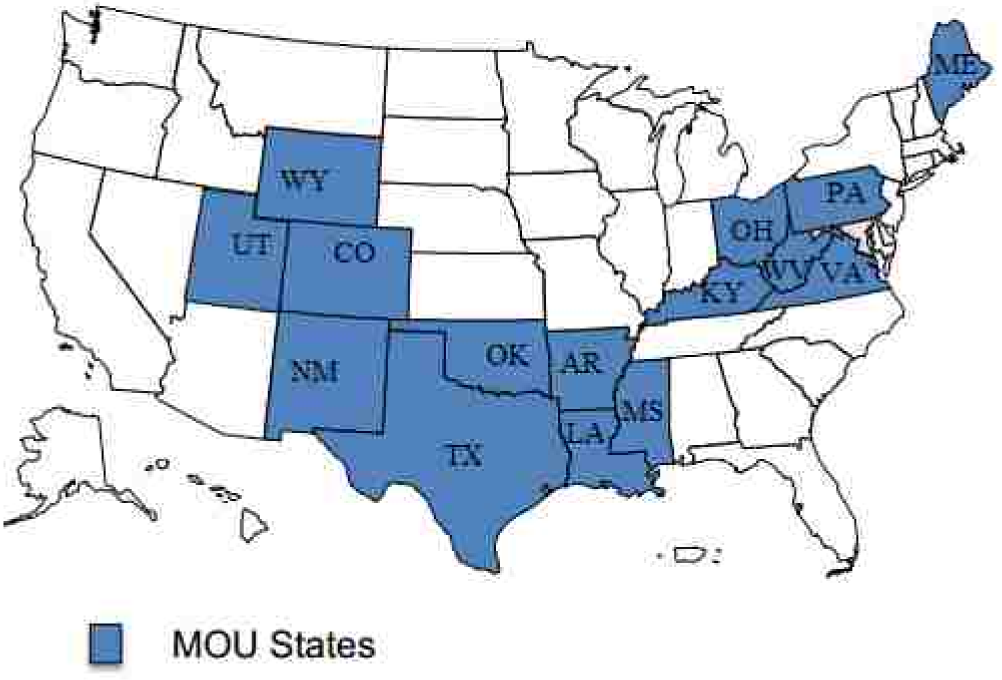

Figure 2.5-29 States that signed the MOU [76]

Environmentally, the main concern revolves around extracting natural gas in fracking operations. In 2012 the Environmental Protection Agency (EPA) set air quality standards for fracking operations imposing operators to capture released gasses. In addition, during this year it is supposed to set similar standards for water quality.

Pipelines are regulated by both the federal and state governments. The Federal Energy Regulatory Commission (FERC) regulates the operation and siting of interstate pipelines while intrastate pipelines are regulated by state regulatory commissions. State regulatory commissions regulate both transmission lines and local distribution companies for pipeline siting, construction, operation, and expansion, as well as consumer rate structure. The federal government is also responsible of pipeline safety through the Department of Transportation, which collaborates with state governments on pipeline providing periodic inspection and safety maintenance. Other federal agencies play significant roles in construction permitting, including [74]:

- The EPA ensures that a pipeline development project meets federal environmental guidelines.
- The Fish and Wildlife Service.
- The Office of Pipeline Safety (OPS) at the Department of Transportation (DOT) which regulates the safety of pipeline operations.

2.5.3.2 *Italian Scenario*

Over the years, different regulations have been applied to natural gas sector both at the national and community levels. On a wider prospective, considering the European segment, the regulations were set by the *Gas Directive* which defined specific laws for the transportation, distribution, supply and storage of natural gas. These rules defined the starting point for liberalizing the sector with the aim of creating a single European gas market, eliminating unequal treatment and discriminatory access for all users of the system.

This Gas Directive was implemented in Italy on 17 May 1999, n°144 (“Legge Delega”) and the Law Decree 23 May 2000, n° 164 (“Letta Decree”). The Law Decree introduced rules defining the timing and methods for the liberalisation of the Italian gas market in line with the Gas Directive, identifying and defining the roles of the different segments of the natural gas “chain” such as import, production, export, transportation and dispatching, storage, distribution and sale [77]. In the near future, further development of the Italian CNG distribution network are expected because of recent improvements of the legislation that allow the construction of multi-fuel stations with CNG or small CNG islands next to petrol ones, as well as the possibility to install self-service refuelling systems at the CNG filling stations. Current CNG stations do not offer 24h service but require the presence on site of a qualified attendant which can be inconvenient to consumers and even deter them from considering an NGV.

For these reasons, one of the main players in promoting the global use of natural gas as a fuel and its technological development is the Italian government. As a part of the initiative, the Italian Government has provided a number of incentives to switch to CNG or other low emission fuel. In particular, in the “Gazzetta Ufficiale” on February 12, 2013, the Italian Government has allocated the eco-incentives for consumers to purchase electric, hybrid, CNG or LPG vehicles with CO_2 emissions up to 120 g/km. These benefits, valid for contracts from 14 March 2013 until 31 December 2015, total to € 120 million: € 40 million in 2013, € 35 million in 2014 and € 45 million in 2015. These benefits were available from March 14, 2013 but will be granted only to new vehicle purchases not previously registered and only if an obsolete vehicle of the same class is scrapped at the same time. However, new vehicle purchases with CO_2 emissions of not more than 95 g/km do not require an older vehicle to be scrapped.

The €40 million allocated in the 2013 were divided into 4.5 million Euros allocated to all categories of buyers for purchasing of vehicles with CO_2 emissions lower than 95g/km, with a further share of the € 1.5 million allocated to the purchase of vehicles with emissions lower than 50g/km. The remaining € 35 million were allocated to the purchase of vehicles intended for use by business or organizations.

The framework of the Government Incentives valid for the three years is reported in the following table [78]:

Table 2.5-2 Italian Government incentives 2013-2015 [78]

	Government Incentives			
	2013-2014		**2015**	
	Private (NO scrapping)	**Commercial use** (with scrapping)	**Private** (NO scrapping)	**Commercial use** (with scrapping)
$CO_2 < 50$ g/km	20 % MAX 5,000 €	20 % MAX 5,000 €	20 % MAX 3,500 €	20 % MAX 3,500 €
$CO_2 < 95$ g/km	20 % MAX 4,000 €	20 % MAX 4,000 €	20 % MAX 3,000 €	20 % MAX 3,000 €
$CO_2<120$ g/km	NO	20 % MAX 2.000 €	NO	20 % MAX 1,800 €
$CO_2 >120$ g/km	NO	NO	NO	NO

The incentive is divided equally between a state contribution, within the resources allocated, and a discount charged by the OEM vehicle seller. In fact, the purchase contract must include by law both the discount applied and the state contribution. However the discount mentioned in the law is not intended to replace the normal discount that the OEM could offer. For these reasons, car manufacturers can decide to extend their program providing further incentives besides the government ones in order to promote the growth of their market share. For example, in March 2013, the Fiat Group extended the government incentives, applying them to all vehicles. The promotion was valid on all natural gas powered (CNG and LNG) cars, and commercial vehicles, without distinction between professional and private clients, with or without scrapping and without limit in terms of number of vehicles subject to incentives [79].

Beyond incentives for vehicles, same Italian regions have enacted special incentives to promote new CNG filling stations and to expand the network such as:

- Liguria Region, year 2010: Public bid (total budget 1,050,000€) for private or public entities interested in opening new CNG filling stations. Eligible costs can be reimbursed up to 70% of the total with a limit of 90.000€ per CNG filling station
- Lombardia Region, year 2010: Public bid (total budget 2,000,000€) for private or public entities interested in opening new CNG filling stations. Eligible costs can be reimbursed up to 50% of the total with a limit of 200,000€ per CNG filling station.

To date, Lombardia is still the most active region with 20 CNG stations opened in 2013 and 19 stations in 2012.

The process of opening a natural gas filling station can be challenging and requires assessing:

- Area location;
- Safety regulations;
- Feasibility project;
- Preliminary project of the installation;
- Estate costs, demolition and renovating costs;
- Filling station costs (fuel dispensers, pumps, compressors, point of services etc.);
- Possibility of connection to the gas grid;
- Possibility of power supply and connection to water;
- Electrical equipment;
- Environmental impact analysis (use of renewable energies for energy consumption reduction).

Beyond this analysis, it is important to outline that the construction of a gas filling station may take 12 months before all the required authorizations are obtained. The main issues are:

- Permission from the Fire department;
- License for fuel selling (both for public and private stations);
- Municipal permission to operate in the area, as well as the environmental impact;
- Sanitary authorization;

- Access and impact on already existing infrastructure [68].

The last aspect that should be taken into account for the realization of a CNG filling station is the total cost of investment. Table 2.5-3 summarizes the cost for a public or private gas filling station:

Table 2.5-3 Investment cost for CNG filling station [68]

	Public gas filling station		Private gas filling station		
	Mono fuel	Multi-fuel	Minimum	Medium	Large
Annual supply (m^3)	>1,000,000	>500,000	150,000-200,000	1,000,000-1,200,000	2,000,000
Number of vehicles	500-600	250-300	50 cars+ 2 bus	100 cars+20-30 bus	>100 cars + 50 bus
Technologies costs € (fuel supplying, compressors etc..)	350,000-450,000	250,000-350,000	80,000-120,000	350,000-450,000	500,000-800,000
Connection to electrical grid €	50,000-70,000		15,000	25,000-40,000	
Connection to gas grid €	200				

As the table 2.5-3, the cost of a gas filling station is determined mainly by technologies costs like fuel supplying, control instrumentation system and compressors. Based on the type and size of the plant, compressors of different volume may be required in order to compress natural gas from pipeline pressure up to 250 bar required in the vehicle. As a consequence, compression cost is influenced by the pressure of natural gas from the gas grid.

- low pressure (3-5 bar): 0.02-0.03 €/m^3
- medium pressure (20 bar): 0.02 €/m^3
- high pressure (40 bar): ≤ 0.015 €/m^3

Maintenance costs average from 3,000 €/year to 8,000 €/year according to the dimensions of the plant.

However, even if natural gas is a viable solution in Italy to address the high cost of gasoline and diesel, its adoption on large scale is affected by technical, economical and legislative obstacles.

The main barrier is the lack of CNG filling stations compared to the number of conventional fuel stations. Moreover, even where there is a consistent presence of CNG stations, their location is not easily accessible. In fact, a large number of methane service stations are far away from the city center while a very low number of stations are localized on Italian highways compared to the number of gas vehicles. A feasible solution, depending on the declaration of suitability of the area, may be to develop the network of CNG filling stations in densely populated areas or along high speed roads.

Another issue concerns the penalties that the filling station operators should pay to the grid operator if they exceed the daily allowed consumption rate. On the customer side, together with unfavorable location of CNG stations, a major cause of dissatisfaction is the time for refueling. Although, new technologies have reduced the refueling time to values comparable to those of traditional fuel stations, in certain cases the compressors often do not support the load for the supplying from gas grid. The time to refuel a car could be 10-15 min [68].

To the present, possible innovations in gas filling station technologies include:

- The trend to develop modular filling stations;
- Low energy consumption;
- Low noise in the supplying;
- Improved environmental measures in an urban environment; and
- The trend to develop self-service and multi dispenser CNG filling stations.

Another means to enlarge natural gas adoption is to promote alternative filling system like a home filling system. Currently, this technology under research by different companies in effort to reduce the difficulties associated to the compression phase. The pressure of natural gas delivered to a residential connection is very low (<0.5 psig or 0.03 bar), which increases the amount of compression required that must be performed to bring the natural gas to the 3600 psig (250 bar) needed to refill a vehicle CNG fuel tank.

2.5.4. *Comparing the Two Natural Gas Vehicle Markets*

Natural gas vehicles have continuously increased their market share over the last years becoming more and more competitive with gasoline and diesel fueled vehicles in a series of markets. However, until recently, their penetration in North America has always been limited. Despite this, prospects for change are expected for the U.S. in the near future supported by significant economically recoverable shale gas resources. Recent statistics report a worldwide distribution of NGVs that accounts more than 17 million units of all classes with the largest share in Latin America and Asia-Pacific. Almost 94% of the totals are Light Duty Vehicles (16,310,105 LDV) [1]. Surprisingly, more than 95% of the total number of NGV is found within just 15 countries.

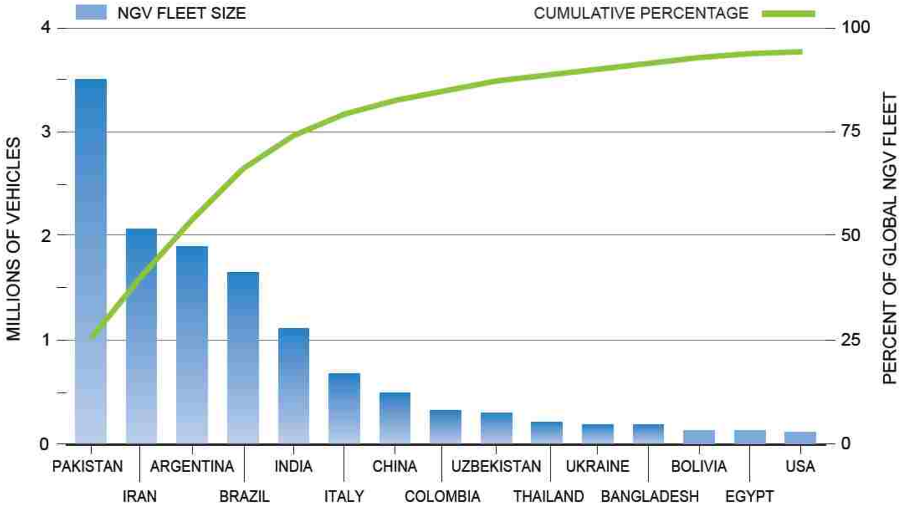

Figure 2.5-30 NGV population by country [32]

These countries are characterized by at least one of the following factors that are fundamental to promote and to trigger the shift to natural gas transportation:

- High dependence on oil which generally comes from unstable source of supply;
- Domestically available and economically recoverable natural gas resources;
- Advantageous price differentials compared to gasoline or diesel;
- Sufficiently developed gas transmission and distribution networks coincident with major transport routes
- Urban air quality concerns
- Stringent emissions standards

- Regulations and policies for either GHG mitigation or energy security purposes that either mandate alternative fuels or incentivize their use.

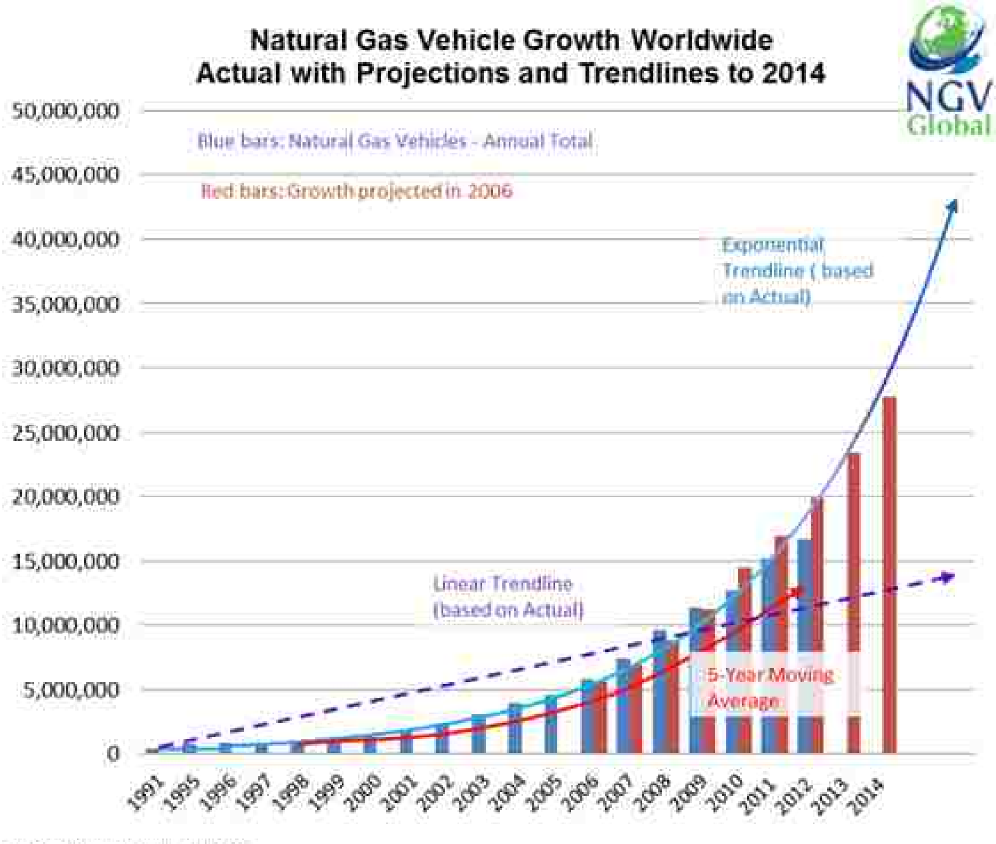

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Figure 2.5-31 NGV growth worldwide and projections [80]

The North American NGV market became a reality in the 1970s during the Middle East Oil Crisis especially for fleet customers, taxis and private retail customers. After that the adoption of NG as a fuel for transportation remained stationary and limited only to a niche market until the beginning of the 1990s when two remarkable coincidences for natural gas as a transportation fuel emerged. First, many local distribution companies (LDCs) started to apply significant pressure to original equipment manufacturers (OEMs) to offer NGVs. Second, as mentioned in the section 2.5.3.1, the introduced Energy Policy act of 1992 (EPAct92) required at all levels to replace their fleets with NG vehicles.

As a consequence, based on these two favorable events, a large number of CNG filling stations were built between the early 1990s and the mid-2000s to meet anticipated demand from such natural gas mandated fleets.

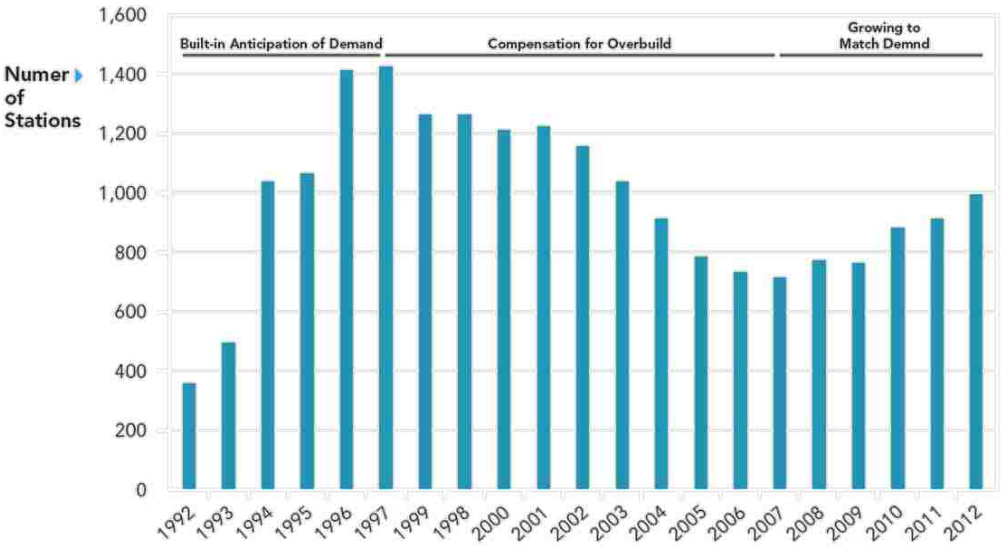


Figure 2.5-32 Number of U.S CNG stations 1992-2012 [69]

As depicted in the figure, the market for natural gas, expected to emerge due to EPAct92 mandates, did not materialize resulting in much lower natural gas consumption than originally estimated.

In addition by 2000, even if major component suppliers and upfitters continued to supply the market, the three American automakers Chrysler, Ford, and GM gradually abandoned the NG market declaring that there was limited demand for OEM NGVs.

This highlights the influence of OEM on CNG infrastructure developments. Chrysler departed the market in 2002, and a decline in CNG infrastructure was measured in 2003. Similarly, Ford and GM announced their departures in 2004 and 2006, respectively, followed by further decreases in the number of CNG stations. By contrast, while the number of CNG stations gradually declined, the NGV fuel consumption showed an opposite trend suggesting the consolidation of stations serviced high mileage fleets and high duty sector vehicles.

Figure 2.5-33 OEM influence on CNG infrastructure development [69]

The correlation between natural gas infrastructures and OEMs' activities in this sector could result in future developments in North America since possible OEM re-entries in the market have been recently announced. To date, the only NG fuelled vehicle offered nationwide is the Honda GX NG while Chevrolet intends to offer a bi-fuel version of the Impala by 2015.

However, if CNG is to become widely popular for all classes of vehicles and the market for fueling infrastructure is to expand not only the fleets, but retail infrastructure needs to grow to conveniently serve the general public.

At the end of 2013, there were 1,374 CNG stations operating in the United States. The highest stations population has been registered in California at 301, with New York, Oklahoma and Utah having the next highest populations at 111, 95, and 94, respectively [81]. The major critical aspect that limits the access to CNG to general customers is the fact that for the U.S. as a whole, 63 percent of stations are private access and only 37 percent are public access. In contrast, the large majority of the CNG fueling stations in Canada are public access. Canada reports 83 stations, 80 of which offer public access [1].

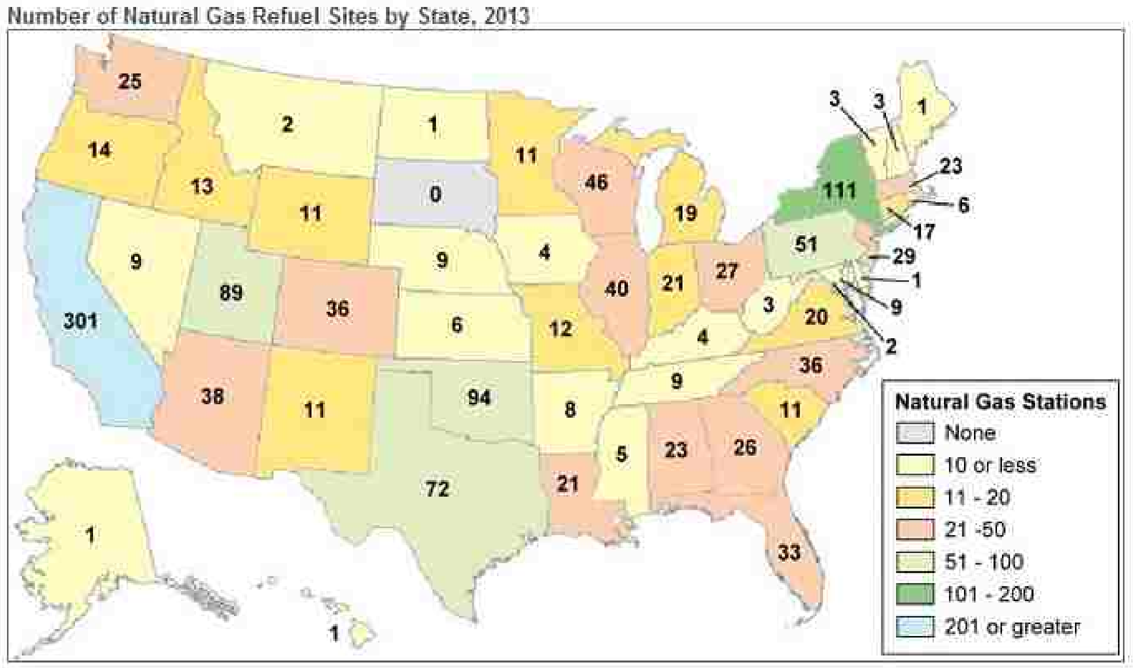


Figure 2.5-34 Number of U.S Natural Gas Refuel Sites by State, 2013 [81]

Currently, CNG stations in U.S. account only for 1.1% of the total number of gasoline retail outlets (121,446) while public fueling infrastructure for CNG in U.S is approximately 0.2 percent that of gasoline.

Tiax's report for Amerca's Natural Gas Alliance, ensures market penetration for NGVs if total number of current CNG stations is increased by at least twenty times [69].

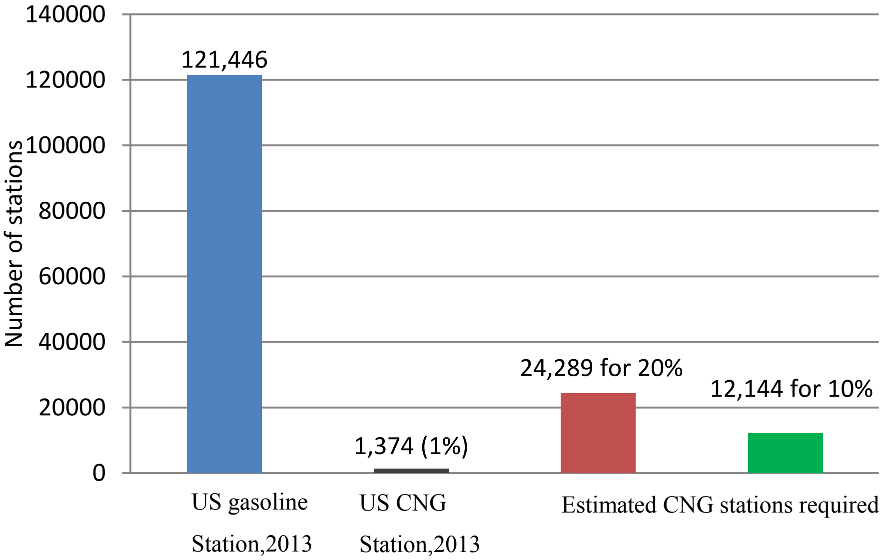


Figure 2.5-35 Comparison between gasoline and CNG stations in the U.S.

The OEM's influence in determining the development of CNG distribution network has been also observed in the Italian market. Figure 2.5-36 shows that the number of public filling station in Italy increased dramatically once FIAT started mass production in 1997 (refer to Appendix A for more details on the National gas plan 2001).

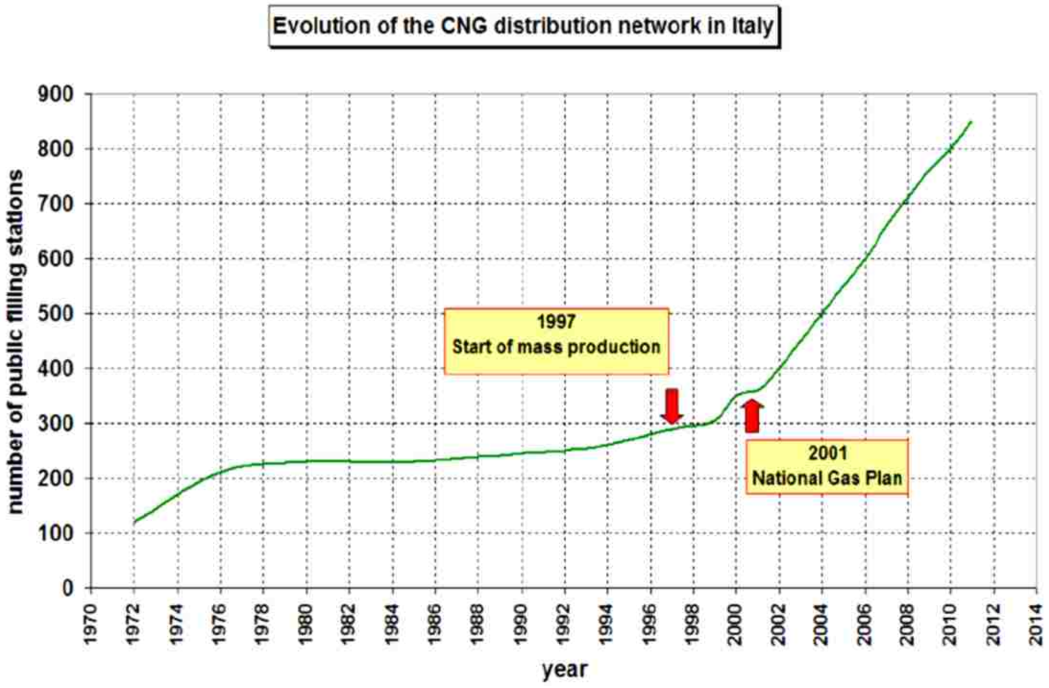


Figure 2.5-36 Evolution of the CNG distribution network in Italy [82]

Currently, there are 959 CNG stations operating in Italy with 95% of them providing public access. Considering only these numbers, the Italian and the North American Scenarios look very similar, but to reasonably compare them, it necessary to consider these values as a function of other parameters like national populations, total number of NGV on the road and number of vehicles per filling station.

Table 2.5-4 Comparison of the main domains

	Italy		**Europe**		**U.S.**		**Canada**	
Population	60.92 million		739.2 million		318.9 million		35.13 million	
Area	301,230 km^2		10.18 million km^2		9.827 million km^2		9.985 million km^2	
Number LD Vehicle on the road	39.79 million		343.22 million		234.47 million		21.172 million	
Number NGV LD Vehicle on the road	843,023		1,378,006		127,735		11,800	
NGVs shares	2.10%		0.40%		0.05%		0.0446%	
NGVs per 1,000 human population	**14**		**2**		**0.40**		**0.27**	
NG refilling station	private	47	private	731	private	866	private	3
	public	912	public	3.46	public	508	public	80
	Total	959	Total	4,191	Total	1,374	Total	83
	planned	~50	planned	285	planned	12,000/24,000	planned	NA
CNG vehicle to refueling station index (VRI) [CNG vehicles(1,000)/CNG stations]	**0.879**		**0.328**		**0.09**		**0.0142**	
Traditional fueling station	24,005				121,446		12,684	
Actual Percentage CNG stations	3.90%				0.80%		0.50%	

Analyzing these data, the actual scenario in the two different countries is very different. The most evident issues are the number of NGV per thousands of people and the vehicle to refilling station index (VRI).

As mentioned before, a VRI index close to 1 is a satisfactory compromise between convenience for CNG operators and profitability for NG stations. Based on this assumption, the NG network is much weaker in the U.S than in Italy.

However, Figure 2.5-37 shows that CNG stations are not equally distributed over the Italian country: the largest quantity is located in the Northern part while the Southern has noticeably less distribution. This is one of the reasons for the low uptake of the vehicles dedicated exclusively to using natural gas.

Figure 2.5-37 CNG stations distribution in Italy [83]

Another important comparison parameter is the number of NGV per thousands of people. In this case the gap between the two countries is more significant because, despite the Italian population being five times lower than that of the U.S., the number of natural gas vehicles is six times higher. In addition, Italy shares more than 60% of European NGV market. This market command supported by a wide range of vehicles offered by FIAT and other OEMs, and a government's active promoting incentives and subsidies to minimize the upfront cost of NGVs. By implication, jurisdictions in North America can explore the available resources and make NG a more attractive and interesting solution. For instance the high investment required to build a new dedicate CNG station could be amortized in a very short time assuming a positive price differential for natural gas and high utilization rate for the station.

Figure 2.5-38 summarizes all the reported parameters for each state for comparison.

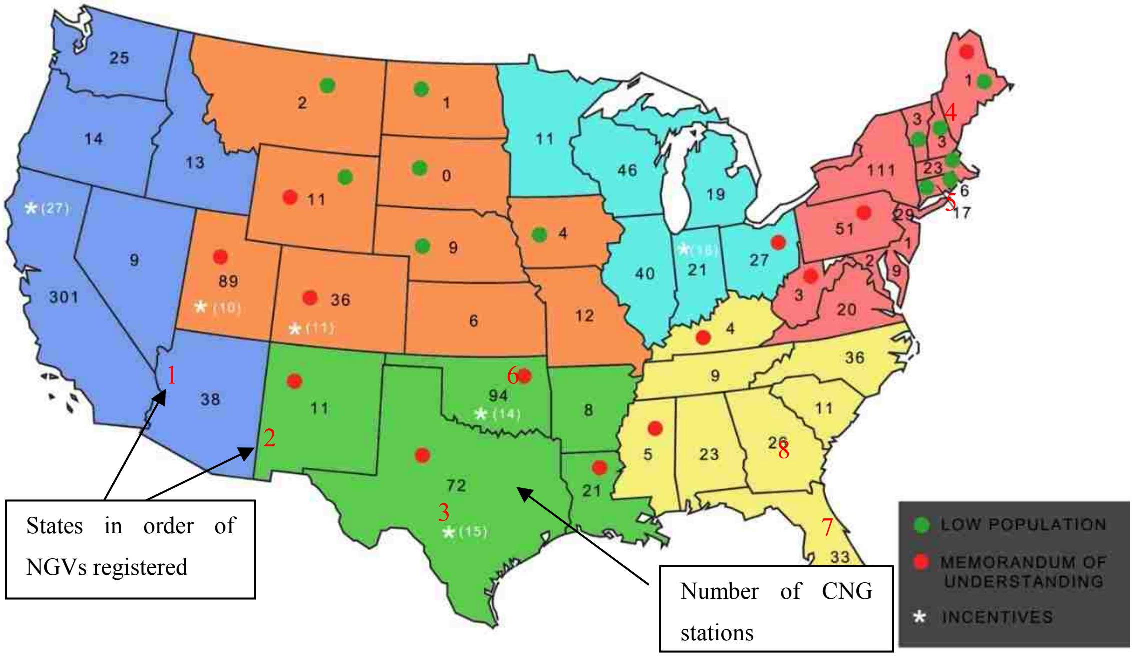


Figure 2.5-38 Analysis by state of the American scenario

The region that presents several favorable parameters to promote the adoption of NG as a vehicle fuel is the Southwest. Indeed, as mentioned in the previous sections, these states (Texas, Oklahoma, New Mexico and Louisiana) report significant amount of natural gas left in the ground, and the highest concentration of transmission pipelines. Consider also that these states have signed the Memorandum of Understanding and enacted policies that have lead in turn to the diffusion of NGVs and the development of CNG stations. However this analysis is far from simple: there are complicating circumstances. For instance, states such as Illinois and Wisconsin that apparently have no natural gas resources are characterized by a higher than average CNG stations if the NG market is almost non-existent. In central states, the low uptake towards adopting natural gas as a vehicle fuel may be because of the low population density and the cheap cost of gasoline. Finally, California represents the best developed scenario in the U.S., given its location within the US, number of NGVs, and infrastructure.

As with other topical issues, there is the “chicken versus egg” debate within the natural gas market on whether the main driver to increase natural gas usage as a fuel is the availability of a CNG vehicle (or vehicles) or the presence of sufficient infrastructure to support CNG vehicles. The main advantage for natural gas is its lower price compared to the cost of gasoline or diesel fuel. According to AGL Resources, a natural gas provider, the CNG cost is less affected by commodity price volatility. Indeed due to a different cost composition, CNG cost would be less than gasoline even if the raw cost of NG doubles [84].

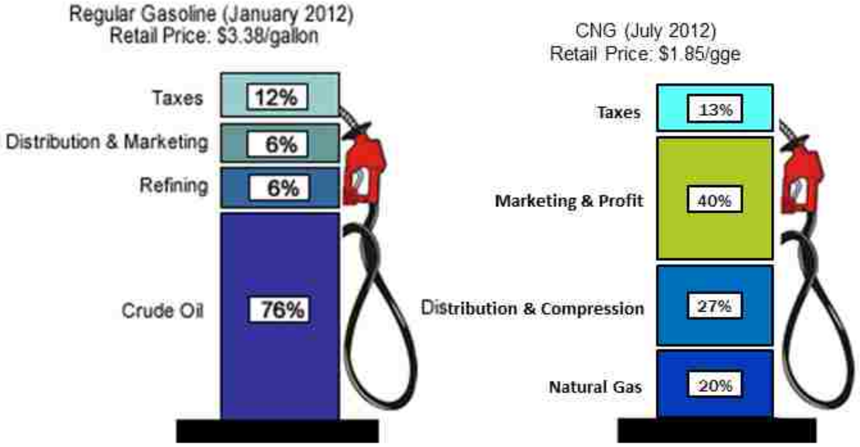


Figure 2.5-39 Comparison of price composition [84]

Table 2.5-5Price characteristics [84]

Natural Gas at $2.88/Mcf		**Natural Gas at $5.76/Mcf**	
Natural Gas (divide by 7.2) [GGE]	$0.40	Natural Gas (divide by 7.2) [GGE]	$0.80
Transport Costs & Fees	$0.20	Transport Costs & Fees	$0.20
Electricity Costs per GGE	$0.10	Electricity Costs per GGE	$0.10
Maintenance per GGE	$0.20	Maintenance per GGE	$0.20
Federal and State Taxes	$0.25	Federal and State Taxes	$0.25
Fuel Card Fees per GGE	$0.05	Fuel Card Fees per GGE	$0.05
Retailer Profit Margin	$0.70	Retailer Profit Margin	$0.70
CNG at the Pump [$/GGE]	**$1.90**	**CNG at the Pump [$/GGE]**	**$2.30**

As shown in Table 2.5-5, the CNG price at the pump is less affected by the upstream cost compared to gasoline and diesel, resulting in a final value that is expected to be less than \$3/GGE for some time even if unforeseeable events occur to the natural gas supply. Moreover, the final price could be even lower considering the fact that more than 65 million of U.S houses have available natural gas.

The possibility to refill the car directly at home may be a valuable enabler for promoting the wider adoption of CNG vehicles. In Italy, the main provider of home refueling units is BRC FuelMaker, an Italian company that is considered the worldwide leader in the manufacture and trading of CNG and LNG components and systems [85].The home refueling unit is a small wall or floor mounted unit directly connected to the domestic pipeline. The unit, shown in Figure 2.5-40, compresses and pumps natural gas to the dispensing pressure required for the vehicle.

Figure 2.5-40 Home Refuelling Unit – Phill [85]

This particular unit is more suitable for bi-fuel cars which are not required to provide full range on CNG presenting a tank with smaller capacity with respect to dedicated CNG vehicles.

As with home recharging of electric and hybrid vehicles, CNG home refueling is more likely to occur during the night because the filling time can take 8-9 hours due to dispensing rates between 0.3 and 0.5 gallon gasoline equivalent (GGE) per hour. For example, considering the Fiat 500L 0.9 TwinAir turbo 80cv - CNG:

- CNG tank = 14 kg (1GGE = 2.567 kg of natural gas) = 5.45 GGE
- Filling time = 10 hours considering a dispensing rate of 0.5 GGE/hour

The long filling time may be a disruptive factor for larger cars because the available time during the night would be not enough to refill completely the tank. However, while home refueling may still have some hurdles before being widely accepted, it does offer an alternative solution to the lack of refueling options from CNG stations when no attendant is available (e.g., during night hours).

Another aspect that it is important to consider is the cost. The cost for the unit varies from \$3,000 to \$6,000 plus an installation fee of \$2,000, adding 4+ years for recovering the additional cost [84]. All these costs together with the premium cost of a new car may discourage a consumer. For these reasons, several initiatives in term of tax credit, incentives at federal and states level have been enacted in order to offset these costs. The Home Fueling Appliance Task Force was introduced by The Drive Natural Gas Initiative (DNGI), introduced several targets such as a dispensing rate at least at 1 GGE per hour with an operation lifetime of 6,000 hours. Another target focuses on the cost and the maximum payback period allowed in order to promote adopting the appliance [74]. From a customer point of view, the assessment of the time horizon necessary to cover the additional premium for buying a new CNG car and installing home refueling equipment is crucial. The point is whether to accept an initial higher cost but enjoy reduced fuel consumption and great cost savings in the long term compared to traditional fueled vehicle, or to pay less upfront for a gasoline vehicle and incur greater costs over the lifetime of the vehicle.

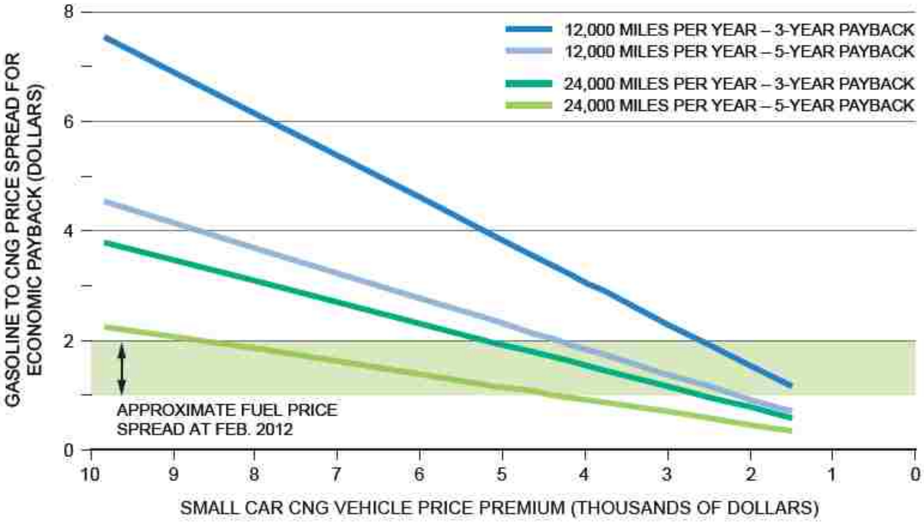


Figure 2.5-41 CNG LDV payback [32]

Actual research and surveys on this subject report that the additional costs for a CNG car must be paid back in less than 3 years in order to sustain the market. As shown in Figure 2.5-41, the main advantage of a CNG car lies in the usage since the higher the annual mileage, the higher the cost saving and the shorter the payback period.

3. METHODOLOGY

3.1. Process definition

This section summarizes the milestones of the process adopted during the project development.

The first step, consisting of an extensive literature review and case definition, identifies the state of the art of the natural gas system in two different geographic domains (United States and Italy/Europe). To this purpose, data related to:

- Proven and unproven reserves of natural gas;
- Production and consumption rates by country;
- National energy mix;
- Import and Export levels of natural gas by country;
- Infrastructure and distribution;
- Adopted and leading technologies;
- Market share of CNG vehicles;
- Future trends

and to other aspects have been collected and summarized. In addition, current natural gas programs in the U.S., Canada and Europe were analyzed so as to determine the local, regional, state, and federal policies that may impact the future shape of NGV sector. Understanding policy uncertainty also assists automotive OEMs considering undertaking or continuing investments in natural gas vehicles or supporting infrastructure development.

The main scope of this project was to assess the current issues and related challenges of the natural gas infrastructure system as well as the environmental and economic costs associated with expanding NGVs in the U.S. Because there are many variables, it is critical to narrow the research investigation to particularly relevant scenarios that can provide useful insights into the challenges and outcomes of increased natural gas and NGV adoption. Assessing the U.S. and Italy without considering the differences within each domain would increase the degree of uncertainty of the results. Therefore, a target or reference model for comparative anlaysis has been defined, which will be Italy.

The European - or specifically the Italian domain - was assessed first. Italy currently has the characteristics that appear to sustain the adoption of natural gas as a leading alternative fuel in the transportation sector. The analysis then considers if the U.S. can assume the same characteristics and thereby success in achieving a natural gas market. However, Italian parameters cannot be applied blindly to the US situation. There are significant differences in land area between the two environments and there are even significant differences between the various US states. To obtain more realistic results, additional analysis is undertaken by selecting significant case studies that comprehensively describe and then compare the different levels of development of the natural gas system in the U.S.

The process of selecting the main case studies requires first a detailed, background analysis of each state. These are summarized in a matrix that reports all the variables assessed for each US state including:

- population density
- active policies
- NGVs registered
- number of refilling stations
- resources available
- local production or import of natural gas
- ratio with gasoline market

and other variables. This matrix helps identify the most influential factors and the major areas of potential improvement for enhancing natural gas adoption.

The case studies assume three different degrees of possible infrastructure development – well developed, intermediate, and none - with respect to natural gas. Again, Italy serves as the reference model. The comparison analysis is developed in two directions, and is organized as follows:

- Case $_i$ vs Reference Case
- Case $_i$ vs Case $_{i+1}$

Table 3.1-1Case studies

	Case Study		Selected U.S. States		Reference model
Level	①	Well-developed CNG infrastructure	……	↔	Italy
	②	Intermediate CNG infrastructure	……	↔	Italy
	③	No CNG infrastructure	……	↔	Italy

this table is used only as example

This approach permits us to understand whether or not the reference model is achievable and if so, what are the economic and environmental tradeoffs. If moving to the reference model (i.e., Italy's level of natural gas implementation) is infeasible in terms of economic and environmental costs, then moving level "i-1" to level "i" may be more achievable. In other words, some U.S. states may represent a more moderate level of natural gas implementation for analysis. In other words, if all of the U.S. cannot be brought up the Italian level of natural gas implementation, then dividing the U.S. into regions and assessing how each region could move up to various intermediate or well-developed levels of natural gas implementation could be a more realistic analysis.

To assess the environmental and economic tradeoffs, the effects will also be quantified using the life-cycle assessment (LCA) and cost analysis approach which provide a decision framework to understand the sustainability implications for each case study, such as what are the GHG emissions and energy usage associated with constructing a wider infrastructure network.

In general, LCA assesses the environmental effects associated to a particular product or process along all the phases of its life from production to end use and disposal. According to Scientific Applications International Corporation (SAIC) definition "LCA is a technique to assess the environmental aspects and potential impacts associated with a product, process, or service, by:

- Compiling an inventory of relevant energy and material inputs and environmental releases;

- Evaluating the potential environmental impacts associated with identified inputs and releases; and
- Interpreting the results to help decision-makers make a more informed decision. [86]

LCA is structured into four interactive stages, as shown in Figure 3.1-1:

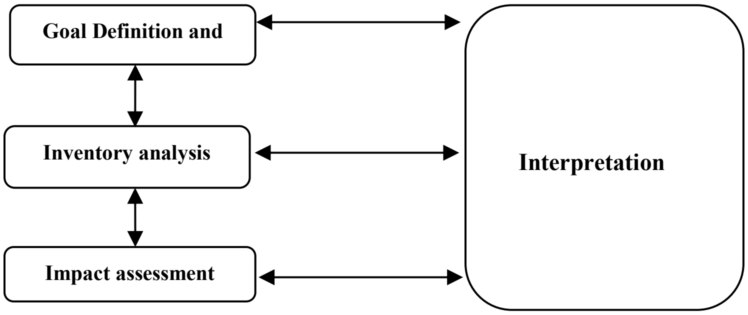


Figure 3.1-1 LCA stages (adapted from [86])

For this research, there are two different LCA protocols or models that can be used:

- A process based approach using the software GaBi.
- Economic Input-Output Life Cycle Analysis (EIO-LCA) (developed at Carnegie Mellon University).

The former is a process model approach based on the standard recommendations of the Society of Environmental Toxicology and Chemistry (SETAC) while the latter uses input-output matrices and industry data to assess the economic and environmental impacts of a product or process on a wider prospective.

In our global environment, each industrial sector interacts with every other sector either directly or indirectly. This is actually the main limitation for GaBi or any other process model approach: the challenge is definable reasonable boundaries around the problem being analyzed. By contrast, in the EIO-LCA approach, the calculation matrices represent all the interactions among the various industrial sectors including both direct and indirect ones.

For example, GaBi focuses on specific product types such as cold-rolled steel or galvanized steel, while EIO-LCA refers to an entire economic sector like the steel sector [87]. Although the literature shows that the results from the two approaches can differ by up to a factor of 10, EIO-LCA obtains relatively reliable and comparable results with less effort during the inventory phase of an LCA [87]. The advantages and disadvantages of each LCA approach are summarized in Table 3.1-2:

Table 3.1-2 Advantages and disadvantages of GaBi and EIO-LCA [88]

<table>
<tr><th></th><th>Process-Based LCA</th><th>EIO-LCA</th></tr>
<tr><td rowspan="6">Advantages</td><td>provide detailed results</td><td>provide economy-wide, comprehensive results</td></tr>
<tr><td>oriented on specific product</td><td>oriented on for systems-level comparisons</td></tr>
<tr><td>identifies areas for process improvements, weak point analysis</td><td>uses publicly available, reproducible results</td></tr>
<tr><td colspan="2">suitable for products in development</td></tr>
<tr><td>databases are continuously update</td><td>provides information on every commodity in the economy</td></tr>
<tr><td></td><td>Less time demanding</td></tr>
</table>

Table 3.1-3 Disadvantages of GaBi and EIO-LCA [88]

<table>
<tr><td rowspan="6">Disadvantages</td><td>requires accurate definition of the boundaries of the analysis</td><td>product assessments contain aggregate data</td></tr>
<tr><td>time demanding and costly</td><td>process assessments difficult</td></tr>
<tr><td>difficult to apply to new process design</td><td>must link monetary values with physical units</td></tr>
<tr><td>use proprietary data</td><td>require more update database</td></tr>
<tr><td colspan="2">uncertainty in data</td></tr>
<tr><td></td><td>availability of data for complete environmental effects</td></tr>
</table>

The tables show that each model has several advantages and disadvantages. However, given the nature of this research, which is to examine broad, nation or state wide effects from natural gas expansion involving multiple industrial activities, EIO-LCA appears more suitable. The use of the EIO-LCA approach will be expanded upon in Chapter 5 after the main case studies have been developed in Chapter 4, and when there is a clearer idea of the variables and issues that need to be assessed.

At this stage, there are three possible outcomes.

1. The results confirm that the full adoption of natural gas vehicles and the supporting infrastructure uniformly throughout the U.S. is realistic and presents acceptable tradeoffs economically and environmentally.
2. There is no realistic scenario in which expanding natural gas adoption can be promoted without undue and unacceptable environmental or economic impacts.
3. An intermediate scenario which expands the adoption of natural gas vehicles and the support infrastructure selectively in the U.S.

4. DATA GATHERING AND CASE STUDIES DEFINITION

This chapter outlines the analysis and defines the main case studies. It pinpoints the most critical gaps of the U.S natural gas system with respect to the reference model and estimates possible growth paths for the future by developing a case scenario matrix with multiple variables, and reporting the actual state of the art of the natural gas system in each U.S. state. A significant challenge was assessing the complexity in collecting and managing data that are not easily available or that refer to different years.

4.1. Definition of the Italian and American models

As mentioned in the Chapter 1, the focus of this thesis was to identify the disruptive factors that thwart, in the United States, the adoption of CNG as a vehicle fuel on a broad scale. To justify the assumptions made in this research development, a target or reference model that presents a well-established CNG market has been defined. This assumes that such a reference model assists in understanding the milestones that have characterized the development of CNG in the reference domain, and helps quantify the gaps and the potentials to achieve a well-established CNG market. In this context, the European or specifically Italian model has been assessed first. However, even though the European wide CNG system is much more developed than in the United States, there are still discrepancies between the European countries. Indeed, only Germany and Italy present a number of CNG stations significantly higher than the European average. However, this similarity between the two countries does not reflect in a comparable number of NGVs. As table 4.1-1 shows, in fact, the number of LDV in Germany fueled by CNG is about 9 times lower than in Italy, with a VRI index in Germany equal to 0.103 or only 103 vehicles per CNG station.

Given these circumstances, the most appropriate reference scenario for the analysis is the Italian one.

Table 4.1-1 Number of CNG stations and NGVs in Europe [89]

Country	Total NGV population (other than ships, trains and aircraft)			CNG stations				
	LD Vehicles	% of total LDV NGVs in the specific country	% of total NGVs in Europe	Total existing	Public	Private	Planned	% of total CNG stations in the area
EU countries								
Austria	7,500	0.15%	0.70%	180	175	5	0	6.1%
Belgium	472	0.01%	0.05%	16	12	4	19	0.5%
Bulgaria	61,000	1.83%	5.58%	106	105	1	7	3.6%
Croatia	66	0.01%	0.01%	2	2	0	1	0.1%
Czech Republic	4,954	0.11%	0.50%	74	47	27	8	2.5%
Denmark	15	0.00%	0.00%	2	2	0	3	0.1%
Estonia	170	0.03%	0.02%	4	4	0	1	0.1%
Finland	1,150	0.03%	0.11%	19	18	1	4	0.6%
France	10,000	0.04%	1.23%	144	35	109	3	4.9%
Germany	94,707	0.20%	8.77%	915	844	71	85	30.8%
Greece	6	0.01%	0.06%	4	0	4	12	0.1%
Hungary	4,000	0.12%	0.37%	18	3	15	8	0.6%
Ireland	3	0.00%	0.00%	0	0	0	9	0.0%
Italy	843,023	2.07%	77.03%	959	912	47	0	32.3%
Latvia	18	0.00%	0.00%	1	1	0	0	0.0%
Lithuania	75	0.01%	0.02%	4	4	0	3	0.1%
Luxembourg	221	0.07%	0.02%	7	6	1	2	0.2%
Netherlands	5,650	0.07%	0.61%	186	119	67	30	6.3%
Poland	3,000	0.02%	0.31%	33	24	9	1	1.1%
Portugal	46	0.01%	0.05%	5	1	4	1	0.2%
Slovakia	900	0.06%	0.12%	14	10	4	0	0.5%
Slovenia	23	0.00%	0.00%	6	1	5	1	0.2%
Spain	859	0.01%	0.34%	66	18	48	12	2.2%
Sweden	41,820	0.92%	4.03%	195	138	57	0	6.6%
United Kingdom	20	0.00%	0.05%	9	1	8	4	0.3%
Total	**1,079,698**	**0.40%**	**100.00%**	**2,969**	**2,482**	**487**	**214**	**100.0%**

However, it is important to outline that the Italian environment differs from the U.S situation in many aspects, including:

- The Italian population is almost equally distributed over its land area while in the United States there are areas with a very low population density.
- The majority of the US states individually present a land area much larger than Italy.

- The customers' needs and trends differ between the two domains. In Italy, customers are more prone to buy small and compact vehicles with a small displacement engine. In the United States a large piece of the market share are trucks and vehicles with high displacement engines.
- In Italy, the penetration of the CNG as a vehicle fuel has been stimulated by a high price difference compared to gasoline. By contrast, in the same period, the price of gasoline in the U.S. was competitive with any other fuels negating the advantages of other alternative fuels.
- The discrepancies within each U.S. state have not been taken into account in this analysis since state government policies and actions affect on the whole state and not a single county or city.

All these aspects represent the key assumptions in the analysis.

4.2. **Creation of the multiple variable matrix**

The multiple variable matrix generates a well-organized chart and map that summarizes all the significant parameters for each state and permits comparing the reference model with each U.S. state.

The first step classified the lower 48 states in six regions rather than in alphabetical order. As a result, it was possible to look not only at states as single entities but also at whole regions and, hence, to identify the most active and developed regions as well as the regions that present low potential. The classification in regions follows:

- **Northeast Region:** Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont, New Jersey, New York, Delaware, District of Columbia, Maryland, Pennsylvania, Virginia and West Virginia.
- **Southeast Region**: Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina and Tennessee.
- **Midwest Region**: Illinois, Indiana, Michigan, Minnesota, Ohio and Wisconsin.
- **Southwest Region**: Arkansas, Louisiana, New Mexico, Oklahoma and Texas.
- **Central Region**: Iowa, Kansas, Missouri and Nebraska. Colorado, Montana, North Dakota, South Dakota, Utah and Wyoming.
- **Western Region:** Arizona, California, Nevada. Idaho, Oregon and Washington.

Figure 4.2-1 Classification of the U.S. states in six regions [90]

After classifying the 48 states in six regions, data about population, land area and population density were collected. These data were gathered from the U.S. Census Bureau and allowed to understand how the population is distributed across the U.S. It is also important to identify the states that have a land size comparable with Italy. Almost all the U.S. states have a population density much lower than the Italian one except for certain states in the Northeast side.

Table 4.2-1 also reports the states that have signed the Memorandum of Understanding, mentioned in the section 2.5.3, and those that have active policies to stimulate the adoption of CNG [74].

Table 4.2-1Population, land area and population density for Italy and the United States [91]

STATE	**Abbr.**	**NGV policies**	**Population**	**Land Area**	**Pop. Density**
MOU				**(Sq Kms)**	**(Sq Kms)**
Italy		incentives	60,920,000	301,230	202
United States			318,900,000	9.827 million	32.45
Central					
Colorado	CO	11	5,029,196	268,628	18.39
Iowa	IA		3,046,355	144,700	20.75
Kansas	KS		2,853,118	211,900	13.22
Missouri	MO		5,988,927	178,414	33.13
Montana	MT		989,415	376,978	2.57
Nebraska	NE		1,826,341	199,098	8.96
North Dakota	ND		672,591	178,647	3.59
South Dakota	SD		814,180	196,541	4.09
Utah	UT	10	2,763,885	212,752	12.86
Wyoming	WY		563,626	251,488	2.12
			Total land area	2,219,146	
Midwest					
Illinois	IL		12,830,632	143,962	89.62
Indiana	IN	18	6,483,802	92,895	68.65
Michigan	MI		9,883,640	147,122	67.99
Minnesota	MN		5,303,925	206,189	25.32
Ohio	OH		11,536,504	106,055	108.30
Wisconsin	WI		5,686,986	140,662	40.01
			Total land area	836,885	
Northeast					
Connecticut	CT		3,574,097	12,548	279.02
Delaware	DE		897,934	5,061	172.52
Maine	ME		1,328,361	79,932	16.47
Maryland	MD		5,773,552	25,315	222.54
Massachusetts	MA		6,547,629	20,306	320.01
New Hampshire	NH		1,316,470	23,227	56.65
New Jersey	NJ		8,791,894	19,210	451.99
New York	NY		19,378,102	122,284	159.39
Pennsylvania	PA		12,702,379	116,076	107.24
Rhode Island	RI		1,052,567	2,707	388.24
Vermont	VT		625,741	23,957	25.93
Virginia	VA		8,001,024	102,548	75.76
West Virginia	WV	16	1,852,994	62,362	29.10
			Total land area	615,531	

STATE	Abbr.	NGV policies	Population	Land Area	Pop. Density
Western					
Arizona	AZ		6,392,017	294,313	22.09
California	CA	27	37,253,956	403,932	91.00
Idaho	ID		1,567,582	214,314	7.11
Nevada	NV		2,700,551	284,448	9.14
Oregon	OR		3,831,074	268,631	14.11
Washington	WA		6,724,540	172,348	38.00
			Total land area	1,637,986	
South West					
Arkansas	AR		2,915,918	134,856	21.17
Louisiana	LA		4,533,372	112,825	39.09
New Mexico	NM		2,059,179	314,311	6.31
Oklahoma	OK	14	3,751,351	177,847	20.48
Texas	TX	15	25,145,561	678,051	35.88
			Total land area	1,417,889	
South East					
Alabama	AL		4,779,736	131,426	35.47
Florida	FL		18,801,310	139,760	131.14
Georgia	GA		9,687,653	149,976	64.58
Kentucky	KY		4,339,367	102,895	41.49
Mississippi	MS		2,967,297	121,489	24.19
North Carolina	NC		9,535,483	126,161	73.10
South Carolina	SC		4,625,364	77,982	57.45
Tennessee	TN		6,346,105	106,752	58.22
			Total land area	956,441	

The second group of data collected describes an overview of the actual status of the NGV market in the two domains. These are shown in Table 4.2-2. In particular, this set of data includes the NGVs fuel consumption measured in million cubic feet (MMcf), the number of CNG vehicles registered in each state, and the corresponding ratio of CNG compared to conventional gasoline fueled vehicles. Interestingly, the total NGVs fuel consumption between the two domains is very similar. However, the reason why those two numbers are very close, even if the number of registered CNG vehicles is completely different, is that the largest portion of natural gas vehicles in the United States is heavy duty vehicles.

Table 4.2-2 NGVs fuel consumption, number of CNG vehicles, and ratio compared to gasoline and diesel vehicles in Italy and in the United States

STATE	**NGVs Fuel consumption** [92]	**Est. Number of CNG vehicles in use** [93]	**Number of automobiles by state** [94]	**% of total vehicles**
MOU	**(MMcf)**	**2009**	**2009**	
Italy	31,770	843,023	39,700,000	2%
Total United States	31,838	112,115	134,028,323	0.08%
Central				
Colorado	295	1,197	640,899	0.19%
Iowa	0	0	1,736,330	0.00%
Kansas	9	243	874,869	0.03%
Missouri	8	88	2,559,639	0.00%
Montana	1	21	370,107	0.01%
Nebraska	37	366	784,194	0.05%
North Dakota	1	12	347,356	0.00%
South Dakota	0	0	401,661	0.00%
Utah	268	2,658	1,217,120	0.22%
Wyoming	20	329	214,199	0.15%
Total regional		4,914	9,146,374	0.05%
Midwest				
Illinois	316	2,766	5,824,074	0.05%
Indiana	41	1,544	3,135,608	0.05%
Michigan	325	645	4,371,772	0.01%
Minnesota	12	97	2,506,177	0.00%
Ohio	138	929	6,318,803	0.01%
Wisconsin	64	782	2,526,673	0.03%
Total regional		6,763	24,686,107	0.03%
Northeast				
Connecticut	40	1,088	1,983,114	0.05%
Delaware	1	16	463,779	0.00%
Maine	1	12	538,469	0.002%
Maryland	237	2,075	2,597,592	0.08%
Massachusetts	838	1,982	3,128,371	0.06%
New Hampshire	35	138	639,635	0.02%
New Jersey	187	3,894	3,705,322	0.11%
New York	4,165	8,627	8,725,551	0.10%
Pennsylvania	332	1,863	5,818,056	0.03%
Rhode Island	97	960	481,905	0.20%
Vermont	2	23	292,317	0.01%
Virginia	217	1,814	3,732,468	0.05%
West Virginia	0	22	700,103	0.00%
Total regional		22,514	32,806,682	0.07%

STATE	**NGVs Fuel consumption** [92]	**Est. Number of CNG vehicles in use** [93]	**Number of automobiles by state** [94]	**% of total vehicles**
Western				
Arizona	2,128	12,080	2,228,172	0.54%
California	15,769	37,517	19,972,837	0.19%
Idaho	106	218	563,021	0.04%
Nevada	829	2,397	706,912	0.34%
Oregon	188	1,675	1,439,985	0.12%
Washington	524	2,036	3,101,571	0.07%
Total regional		55,923	28,012,498	0.2%
South West				
Arkansas	20	183	947,406	0.02%
Louisiana	13	361	1,940,586	0.02%
New Mexico	314	866	698,100	0.12%
Oklahoma	279	2,932	1,670,353	0.18%
Texas	2,566	10,125	8,830,974	0.11%
Total regional		14,467	14,087,419	0.10%
South East				
Alabama	158	358	2,171,584	0.02%
Florida	78	2,846	7,597,789	0.04%
Georgia	1,113	2,847	4,134,274	0.07%
Kentucky	2	126	1,952,420	0.01%
Mississippi	3	225	1,155,792	0.02%
North Carolina	35	548	3,451,087	0.02%
South Carolina	9	248	1,974,494	0.01%
Tennessee	17	336	2,854,803	0.01%
Total regional		7,534	25,292,243	0.03%

It was assumed that the data about the NGVs in use and number of total vehicles have only slightly changed since 2009, so any error arising from considering those values is assumed to be negligible. Based on the data in the table, even though the total number of vehicles in the Unites States is four times higher than Italy, the CNG market does not reflect the same trend. Indeed, while in Italy 843,023 NGVs represent 2% of the total pie, in the U.S. the CNG market share is less than 0.1%. At a regional level, only two regions (Western and South West) show a CNG penetration higher than the national average. In the South West region, the states that display a major stimulus towards the adoption of CNG as a vehicle fuel are Louisiana, New Mexico, Oklahoma and Texas. This is not surprising since those states are characterized by a well-established infrastructure system and also by a high concentration of reserve natural gas, as reported in Chapter 2: natural gas is produced at low cost in this region. In the Western region, only California has more than 37,000 NGVs. This number includes mostly private and municipal government fleets. In fact, California has more than twenty active policies aimed to promote replacing all government and municipal fleets with NG vehicles and also to attract new customers providing incentives aimed to lower the upfront cost of a new NG vehicle.

By contrast, the regions with the lowest CNG penetration are Central and Midwest. Except for Utah that presents a CNG to gasoline vehicle ratio higher than the regional average, all the other states are characterized by a CNG market share lower than the national average. The main reasons are an inadequate infrastructure system and a limited natural gas production activity. Another critical point is that a number of these states have concentrated populations in select areas due to geographic barriers (e.g. mountains or desert areas).

However, the assessment of the actual status of the NG market in the two domains goes hand in hand with the analysis of the CNG refuel site distribution in each state. Moreover, in order to understand the level of development of this fuel in each state as well as how difficult it is to reach a refuel site compared to a gasoline station, two other variables have been calculated: 1) the density of CNG stations in a radius of 75 km; and 2) the density of gasoline stations in the same area. The adoption of 75 km is based on the average driving range for a NGV. Indeed, since the average driving range for a NGV is about 150 km, it is assumed 75 km to take into account a round trip scenario.

$$\frac{\pi(75)^2}{area\ of\ state} \cdot n.stations\ per\ state = n.stations\ in\ a\ radius\ of\ 75\ km \tag{4-1}$$

Table 4.2-3 shows that the natural gas refueling sites in Italy represent 4% of the total traditional sites. This number may appear insignificant but compared to the 1.2% registered sites in the United States, this discrepancy is significant and underlines the differences between the two scenarios, in terms of supporting infrastructure. At the regional level, only Oklahoma, Utah and California present a ratio comparable to Italy, even though the actual density of stations in each U.S. state is significantly lower than in Italy. In fact, even if certain states in the Northeast region show a density of CNG stations much higher than the national average, it is not attributable to a high number of stations in that area but rather to a smaller land area.

Table 4.2-3 Analysis of CNG and gasoline refueling sites by state

STATE	**NG refuel site by state** [81]	**Gasoline stations** [95]	**% of fuel station**	**Density of CNG stations**	**Density of gasoline stations**
MOU	**2013**	**2013**		**(station per 75 km of radius)**	**(station per 75 km of radius)**
Italy	959	24,005	4%	56.25910	1,408.23744
Total United States	1,370	118,154	1.18%	2.47	212
Central					
Colorado	36	1,672	2.15%	2.36823	109.99090
Iowa	4	1,962	0.20%	0.48850	239.60878
Kansas	6	1,309	0.46%	0.50037	109.16448
Missouri	12	2,975	0.40%	1.18857	294.66641
Montana	2	575	0.35%	0.09375	26.95407
Nebraska	9	1,068	0.84%	0.79882	94.79331
North Dakota	1	455	0.22%	0.09892	45.00782
South Dakota	0	651	0.00%	NA	58.53285
Utah	95	851	11.16%	7.89082	70.68518
Wyoming	11	397	2.77%	0.77294	27.89625
Total regional	176	11,915	1.48%		
Midwest					
Illinois	40	4,036	0.99%	4.91004	495.42280
Indiana	21	2,738	0.77%	3.99484	520.85044
Michigan	19	3,925	0.48%	2.28218	471.44972
Minnesota	11	2,417	0.46%	0.94276	207.14939
Ohio	27	4,117	0.66%	4.49889	685.99794
Wisconsin	46	2,682	1.72%	5.77900	336.94081
Total regional	164	19,915	0.82%		
Northeast					
Connecticut	17	1,195	1.42%	23.94031	1,682.86329
Delaware	1	298	0.34%	3.49180	1,040.55743
Maine	1	916	0.11%	0.22108	202.50980
Maryland	9	1,664	0.54%	6.28268	1,161.59753
Massachusetts	23	2,191	1.05%	20.01642	1,906.78126
New Hampshire	3	682	0.44%	2.28245	518.87586
New Jersey	29	2,545	1.14%	26.67745	2,341.17662
New York	111	4,948	2.24%	16.04083	715.04524
Pennsylvania	51	4,153	1.23%	7.76429	632.25718
Rhode Island	6	357	1.68%	39.17502	2,330.91355
Vermont	3	484	0.62%	2.21286	357.00826
Virginia	20	3,659	0.55%	3.44648	630.53276
West Virginia	3	1,114	0.27%	0.85011	315.67445
Total regional	277	24,206	1.14%		

Western					
Arizona	38	1,728	2.20%	2.28163	103.75433
California	301	8,179	3.68%	13.16833	357.81982
Idaho	13	700	1.86%	1.07193	57.71921
Nevada	9	737	1.22%	0.55913	45.78645
Oregon	14	1,061	1.32%	0.92097	69.79616
Washington	25	2,108	1.19%	2.56334	216.14059
Total regional	400	14,513	2.76%		
South West					
Arkansas	8	1,590	0.50%	1.04832	208.35276
Louisiana	21	2,347	0.89%	3.28917	367.60374
New Mexico	11	970	1.13%	0.61845	54.53623
Oklahoma	94	1,843	5.10%	9.34016	183.12680
Texas	72	10,727	0.67%	1.87647	279.56850
Total regional	206	17,477	1.18%		
South East					
Alabama	23	3,190	0.72%	3.09256	428.92425
Florida	33	6,403	0.52%	4.17256	809.60300
Georgia	26	5,245	0.50%	3.06355	618.01150
Kentucky	4	2,258	0.18%	0.68697	387.79469
Mississippi	5	2,063	0.24%	0.72729	300.07942
North Carolina	36	4,859	0.74%	5.04255	680.60398
South Carolina	11	2,627	0.42%	2.49271	595.30343
Tennessee	9	3,483	0.26%	1.48984	576.56958
Total regional	147	30,128	0.49%		

It is possible to calculate the VRI (vehicle to refueling station index) for the reference model and for each U.S. state as follows:

$$VRI = \frac{Number\ of\ CNG\ vehicles}{Number\ of\ CNG\ stations} \tag{4-2}$$

This index represents “a rule” to assess the profitability of a refueling station and the convenience for a customer. As previously discussed, an acceptable value of VRI is 1000 vehicles to 1 refueling station. Such a ratio means that there is an opportunity to invest in a new CNG station and to amortize the capital and variable cost needed to build a new station if it provides service to at least 1000 vehicles. The VRI, as defined, represents the optimal ratio of dedicated CNG vehicles to refueling stations.

Table 4.2-4 shows that the Italian scenario is close to the target whereas the American one is significantly lower than the ideal 1000 vehicles per station. However, for a more accurate analysis it is necessary to look at the ratio in each state.

Table 4.2-4 Analysis of VRI and evaluation of actual opportunity for each U.S state

STATE	**VRI**	**Actual opportunity reach Italian VRI based on existing CNG stations**	**Additional CNG vehicles to reach Italian VRI**	**Actual opportunity to reach Californian VRI based on existing CNG stations**	**Additional CNG vehicles to reach Californian VRI**
MOU					
Italy	879				
Total United States	90	1,204,319	1,092,204	18,322	10,788
Central					
Colorado	33	31,646	30,449	4,487	3,290
Iowa	0	3,516	3,516	499	499
Kansas	41	5,274	5,031	748	505
Missouri	7.33	10,549	10,461	1,496	1,408
Montana	10.50	1,758	1,737	249	228
Nebraska	40.67	7,912	7,546	1,122	756
North Dakota	12.00	879	867	125	113
South Dakota	NA	0	0	0	0
Utah	27.98	83,511	80,853	11,841	9,183
Wyoming	29.91	9,670	9,341	1,371	1,042
Total regional		154,715	149,801	21,937	17,023
Midwest					
Illinois	69	35,163	32,397	4,986	2,220
Indiana	74	18,460	16,916	2,617	1,073
Michigan	33.95	16,702	16,057	2,368	1,723
Minnesota	8.82	9,670	9,573	1,371	1,274
Ohio	34.41	23,735	22,806	3,365	2,436
Wisconsin	17.00	40,437	39,655	5,733	4,951
Total regional		144,167	137,404	20,441	13,678

STATE	VRI	Actual opportunity reach Italian VRI based on existing CNG stations	Additional CNG vehicles to reach Italian VRI	Actual opportunity to reach Californian VRI based on existing CNG stations	Additional CNG vehicles to reach Californian VRI
Northeast					
Connecticut	64	14,944	13,856	2,119	1,031
Delaware	16	879	863	125	109
Maine	12.00	879	867	125	113
Maryland	230.56	7,912	5,837	1,122	(953)
Massachusetts	86.17	20,218	18,236	2,867	885
New Hampshire	46.00	2,637	2,499	374	236
New Jersey	134.28	25,493	21,599	3,615	(279)
New York	77.72	97,576	88,949	13,835	5,208
Pennsylvania	36.53	44,832	42,969	6,357	4,494
Rhode Island	160.00	5,274	4,314	748	(212)
Vermont	7.67	2,637	2,614	374	351
Virginia	90.70	17,581	15,767	2,493	679
West Virginia	7.33	2,637	2,615	374	352
Total regional		243,501	220,987	34,526	12,012
Western					
Arizona	318	33,404	21,324	4,736	(7,344)
California	125	264,598	227,081	37,517	0
Idaho	17	11,428	11,210	1,620	1,402
Nevada	266.33	7,912	5,515	1,122	(1,275)
Oregon	119.64	12,307	10,632	1,745	70
Washington	81.44	21,977	19,941	3,116	1,080
Total regional		351,626	295,703	49,856	0 (6,067)
South West					
Arkansas	23	7,033	6,850	997	814
Louisiana	17	18,460	18,099	2,617	2,256
New Mexico	78.73	9,670	8,804	1,371	505
Oklahoma	31.19	82,632	79,700	11,716	8,784
Texas	140.63	63,293	53,168	8,974	(1,151)
Total regional		181,087	166,620	25,676	11,209
South East					
Alabama	16	20,218	19,860	2,867	2,509
Florida	86	29,009	26,163	4,113	1,267
Georgia	110	22,856	20,009	3,241	394
Kentucky	32	3,516	3,390	499	373
Mississippi	45.00	4,395	4,170	623	398
North Carolina	15.22	31,646	31,098	4,487	3,939
South Carolina	22.55	9,670	9,422	1,371	1,123
Tennessee	37.33	7,912	7,576	1,122	786
Total regional		129,223	121,689	18,322	10,788

The color scale indicates the distribution of the value according to the min(red) and max(green) value reported in each column.

A low VRI may be due to a low number of CNG vehicles or to a high number of CNG stations which do not serve a sustainable number of NGVs. The latter case is more important from a carmaker's point of view since it provides an actual opportunity to introduce vehicles in the market and use the readily available infrastructure. As a result, two additional variables have been created. The first one assesses the actual opportunity for each state to reach the Italian VRI based on the already built CNG stations. These numbers represent the potential for an OEM to fill the gap compared to Italy by introducing new vehicles in the market. The second variable repeats the same analysis assuming California as the target. California has the highest number of CNG vehicles and stations in the U.S. and represents the most active state in this sense. To evaluate the number of vehicles required to reach the target, the following equation has been used:

$$Needed\ NGVs\ to\ reach\ the\ target\ in\ state_i = VRI_{target} * CNG\ stations_i \qquad (4\text{-}3)$$

In table 4.2-4, the additional number of NGVs required to fill the gap with California is much lower than the one required to reach Italy. A certain number of US states have no chance to move directly from the actual level up to the Italian one. For these reasons, it is more worthwhile to look only at those states that present a realistic potential. For instance, Oklahoma and Utah account for respectively, 94 and 95 NG refuel sites, which are two of the highest values in the U.S., but have less than 3000 vehicles each. This means that an extensive number of vehicles is required to balance between the profitability for the refueling station and convenience for the customers. Indeed, based on equation 4-3, for these two states there is an actual opportunity to introduce from about 9000 to 80,000 NG vehicles. This range provides just an indication of the potential of the local market. However, there is realistically no chance for OEMs to introduce 80,000 vehicles in the short term but it might be a stimulus to identify the starting point and stabilize the upper threshold as high as possible.

The next set of data that has been assessed is in regard to the natural gas production activities in each state and the extension of the natural gas transmission network.

Table 4.2-5 NG transmission pipelines mileage and NG processing plants

STATE	**NG pipelines mileage** [64]	**NG pipelines**	**Density pipelines**	**Natural gas processing plant capacity, 2013** [66]
MOU	**(miles)**	**(km)**	**(km pipelines per km^2)**	**MMcf/day**
Italy	19,685	31,680	0.11	0.8300 [2]
Total United States	296,493	477,158`	0.05	64,308
Central				
Colorado	7,803	12,558	0.05	5,450
Iowa	5,421	8,724	0.06	
Kansas	15,383	24,756	0.12	1,818
Missouri	3,944	6,347	0.04	
Montana	3,861	6,214	0.02	161
Nebraska	5,697	9,168	0.05	
North Dakota	1,873	3,014	0.02	660
South Dakota	1,242	1,999	0.01	
Utah	3,175	5,110	0.02	2,078
Wyoming	7,902	12,717	0.05	8,048
Total regional	56,301	90,607		18,215
Midwest				
Illinois	11,911	19,169	0.13	2,100
Indiana	4,704	7,570	0.08	
Michigan	9,722	15,646	0.11	479
Minnesota	4,447	7,157	0.03	
Ohio	7,670	12,344	0.12	10
Wisconsin	3,471	5,586	0.04	
Total regional	41,925	67,472		2,589
Northeast				
Connecticut	628	1,011	0.08	
Delaware	280	451	0.09	
Maine	609	980	0.01	
Maryland	1,022	1,645	0.06	
Massachusetts	972	1,564	0.08	
New Hampshire	291	468	0.02	
New Jersey	1,520	2,446	0.13	
New York	5,018	8,076	0.07	
Pennsylvania	8,680	13,969	0.12	369
Rhode Island	100	161	0.06	
Vermont	71	114	0.00	
Virginia	2,577	4,147	0.04	
West Virginia	3,758	6,048	0.10	1,895
Total regional	25,526	41,080		2,264

STATE	**NG pipelines mileage** [64]	**NG pipelines**	**Density pipelines**	**Natural gas processing plant capacity, 2013** [66]
MOU	**(miles)**	**(km)**	**(km pipelines per km^2)**	**MMcf/day**
Western				
Arizona	5,989	9,638	0.03	
California	11,770	18,942	0.05	926
Idaho	1,567	2,522	0.01	
Nevada	1,469	2,364	0.01	
Oregon	1,823	2,934	0.01	
Washington	2,072	3,335	0.02	
Total regional	24,690	39,735		926
South West				
Arkansas	6,267	10,086	0.07	24
Louisiana	18,900	30,417	0.27	10,737
New Mexico	6,756	10,873	0.03	3,149
Oklahoma	18,539	29,836	0.17	4,976
Texas	58,588	94,288	0.14	18,547
Total regional	109,050	175,499		37,433
South East				
Alabama	4,818	7,754	0.06	1,403
Florida	4,971	8,000	0.06	90
Georgia	3,483	5,605	0.04	
Kentucky	6,892	11,092	0.11	240
Mississippi	9,784	15,746	0.13	1,123
North Carolina	2,484	3,998	0.03	
South Carolina	2,265	3,645	0.05	
Tennessee	4,304	6,927	0.06	25
Total regional	39,001	62,766		2,881

As mentioned in Chapter 2, the United States relies mostly on domestic production and produces 92% of its total annual NG consumption. In particular, the most active processing plants are located, as expected due to the high concentration of reserves, in the Southwest region. Moreover, another important aspect is that there is a direct relationship between the level of development of the natural gas transmission pipeline network and the magnitude of the production activities in the same region. The most productive regions also have the most developed pipeline network.

In the Western region the only production point is California while in the Midwest almost 90% of the regional production comes from Illinois. Other significant processing plants are located in the Central region, namely in Wyoming, Utah and Colorado providing a total capacity of 18 bcf /day (0.5 Gm^3/day).

The individual states play a significant role in natural gas production. States such as Oklahoma, Texas, Louisiana, Utah, have several common factors:

- Agreement with the Memorandum of Understanding;
- Significant amount of natural gas left in the ground;
- A series of active policies aimed to incentivize the adoption of NGVs and the construction of CNG stations;
- A well-developed infrastructure system;
- Number of CNG stations and NGVs in use higher than the national average; and
- CNG cost at the pump lower than in other states.

Even though the total transmission pipeline network is much more extensive in the U.S., only a few states have a pipeline density comparable to the Italian value of 0.11 km per km^2. Interestingly, the only states that present a pipeline density close to the Italian one are those states that have signed the MOU (exception KS, IL, MI, NJ). By contrast, the Western region reports the lowest pipeline density; in fact, except for California, all the other states like Idaho, Oregon, Nevada, Washington are characterized by a pipeline density equal to 0.02 km per km^2.

Finally, the last set of data in the multiple variable matrix reflects the analysis of the natural gas residential distribution points. Table 4.2-6 shows that in Italy more than 70 percent of homes, including single-family and multi-family residences, have a domestic natural gas connection. On the contrary, based on data provided by the America Gas Association, in the U.S. 65 million homes (50% of total) have available natural gas [96]. Potentially, there are 65 million customers that may exploit the natural gas domestic network to refill their own NGV at home.

Table 4.2-6 Analysis of homes with readily aveilable natural gas

STATE MOU	**U.S homes with natural gas** [96]	**Total homes**	**Percentage of homes with natural gas**	**Density of NG homes** **(homes per 75 km of radius)**
Italy	21,000,000 [97]	28,863,604 [98]	73%	1,231,951
Total Unites States	64,848,508	130,581,536	50%	
Central				
Colorado	1,768,209	2,212,898	80%	116,320
Iowa	974,095	1,336,417	73%	118,961
Kansas	938,041	1,233,215	76%	78,228
Missouri	1,490,331	2,712,729	55%	147,614
Montana	288,705	482,825	60%	13,534
Nebraska	483,444	796,793	61%	42,909
North Dakota	139,861	317,498	44%	13,835
South Dakota	190,413	363,438	52%	17,120
Utah	871,400	979,709	89%	72,380
Wyoming	131,998	261,868	50%	9,275
Total regional	7,276,497	**Regional avg**	64%	
Midwest				
Illinois	3,809,008	5,296,715	72%	467,559
Indiana	1,710,651	2,795,541	61%	325,418
Michigan	3,240,000	4,532,233	71%	389,171
Minnesota	1,557,000	2,347,201	66%	133,443
Ohio	1,708,000	5,127,508	33%	284,597
Wisconsin	1,824,337	2,624,358	70%	229,192
Total regional	13,848,996	**Regional avg**	62%	
Northeast				
Connecticut	541,000	1,487,891	36%	761,865
Delaware	162,000	405,885	40%	565,672
Maine	28,000	721,830	4%	6,190
Maryland	996,000	2,378,814	42%	695,283
Massachusetts	1,522,000	2,808,254	54%	1,324,565
New Hampshire	112,000	614,754	18%	85,211
New Jersey	2,772,000	3,553,562	78%	2,549,997
New York	3,936,000	8,108,103	49%	568,799
Pennsylvania	2,633,831	5,567,315	47%	400,977
Rhode Island	246,702	463,388	53%	1,610,759
Vermont	42,363	322,539	13%	31,248
Virginia	1,155,968	3,364,939	34%	199,201
West Virginia	377,278	881,917	43%	106,909
Total regional	14,525,142	**Regional avg**	39%	

STATE	U.S homes with natural gas	Total homes	Percentage of homes with natural gas	Density of NG homes
Western				
Arizona	1,187,511	2,844,526	42%	71,302
California	10,897,190	13,680,081	80%	476,737
Idaho	380,597	667,796	57%	31,383
Nevada	801,717	1,173,814	68%	49,807
Oregon	753,436	1,675,562	45%	49,564
Washington	1,161,280	2,885,677	40%	119,070
Total regional	15,181,731	**Regional avg**	55%	
South West				
Arkansas	626,731	1,316,299	48%	82,126
Louisiana	948,203	1,964,981	48%	148,514
New Mexico	605,965	901,388	67%	34,069
Oklahoma	1,016,086	1,664,378	61%	100,962
Texas	4,562,224	9,977,436	46%	118,901
Total regional	7,759,209	**Regional avg**	54%	
South East				
Alabama	853,074	2,171,853	39%	114,703
Florida	701,619	8,989,580	8%	88,714
Georgia	359,840	4,088,801	9%	42,399
Kentucky	802,318	1,927,164	42%	137,792
Mississippi	488,256	1,274,719	38%	71,021
North Carolina	1,217,027	4,327,528	28%	170,470
South Carolina	622,748	2,137,683	29%	141,121
Tennessee	1,212,051	2,812,133	43%	200,641
Total regional	6,256,933	**Regional avg**	30%	

It is important to underline a major difference in the use of natural gas between the two domains. In the U.S. natural gas is mainly used for residential or commercial heating while in Italy it is used either as a primary energy source for cooking or as source for heating. For these reasons, in the U.S. South East region, where the climate is always temperate, the percentage of homes with natural gas is lower than elsewhere. Indeed, it is expected that the highest concentration of homes with natural gas is located in a highly populated region close to natural gas processing plants. For instance, in Utah or California where more than 80% of homes have available natural gas, home refueling would be a feasible solution in the short term to overcome the lack of infrastructure.

More importantly, a high degree of home refueling would reduce the needs of CNG stations in major urban areas well supplied with gas to their homes already, and to instead concentrate natural gas fueling sites along major transportation corridors.

4.3. **Case studies definition: Expansion of the transmission pipelines network**

The multiple variable matrix, defined in the section 4.2, provides a basis for infrastructure analysis. In particular, based on data collected for each U.S. state and for the reference model, there are three outcome scenarios for the U.S. natural gas transmission network:

- A high CNG infrastructure growth case that represents idealized infrastructure development throughout the entire U.S.;
- A limited CNG infrastructure growth case in which only selected states are assessed; and
- A proportional CNG infrastructure growth case that considers two different target levels for infrastructure growth.

This section estimates natural gas infrastructure needs and capital expenditures for the three outcomes. All cases result in the need for significant and continuous capital expenditures on natural gas infrastructures. Note that all the analysis reported in the following are assumed to have a 20 year evaluation period.

4.3.1. High CNG infrastructure growth

The High CNG infrastructure growth case tests the upper range of possible infrastructure needs for each U.S. state. This study analyzes the pipeline density to evaluate the additional pipeline mileage required in each state to reach the Italian pipeline density. However, this analysis ignores the geological discrepancies within each state. It does not take into account the differences in the population densities. Instead, it considers each state as a unique “box” and so evaluates the kilometers of pipelines required to reach the target.

The first calculation assesses the expected kilometers of pipelines required to reach the Italian pipeline density in each state, assuming the pipelines do not currently exist.

For this purpose the following equation has been used:

$$\text{Expected km of pipeline from zero}_i = \text{land area}_i * \text{Italian pipeline density} \qquad (4\text{-}4)$$

The last column shows the kilometers of additional pipeline needed to reach the target, starting from the actual status. In some cases, the value reported for certain states is zero. In such states, the pipeline density is higher than in Italy and presumably, no additional actions are required.

Table 4.3-1 High CNG network growth case

Case 1: High CNG growth case			
STATE	**Expected Pipelines from 0 to reach Italian density [km]**	**Added pipelines to reach Italian density [km]**	
Central			
Colorado	28,251	15,694	
Iowa	15,218	6,494	
Kansas	22,285	0	
Missouri	18,764	12,416	
Montana	39,646	33,433	
Nebraska	20,939	11,770	
North Dakota	18,788	15,774	
South Dakota	20,670	18,671	
Utah	22,375	17,265	
Wyoming	26,449	13,732	
	Total needed km from 0	233,385	km
	Total needed km in addition	145,249	km
	Expenditure by region from 0	304,191,915,875	$
	Expenditure in addition	189,315,904,581	$
	Annual needed expenditures	9,465,795,229	$

Midwest			
Illinois	15,140	0	
Indiana	9,770	2,199	
Michigan	15,473	0	
Minnesota	21,685	14,528	
Ohio	11,154	0	
Wisconsin	14,793	9,207	
	Total needed km from 0	88,014	km
	Total needed km in addition	25,935	km
	Expenditure by region from 0	124,692,297,104	$
	Expenditure in addition	36,742,186,632	$
	Annual needed expenditures	1,837,109,332	$
Northeast			
Connecticut	1,320	309	
Delaware	532	82	
Maine	8,406	7,426	
Maryland	2,662	1,018	
Massachusetts	2,136	571	
New Hampshire	2,443	1,974	
New Jersey	2,020	0	
New York	12,860	4,785	
Pennsylvania	12,208	0	
Rhode Island	285	124	
Vermont	2,520	2,405	
Virginia	10,785	6,638	
West Virginia	6,559	511	
	Total needed km from 0	64,735	km
	Total needed km in addition	25,842	km
	Expenditure by region from 0	118,307,944,253	$
	Expenditure in addition	47,228,633,644	$
	Annual needed expenditures	2,361,431,682	$
Western			
Arizona	30,953	21,314	
California	42,481	23,539	
Idaho	22,539	20,017	
Nevada	29,915	27,551	
Oregon	28,252	25,318	
Washington	18,126	14,791	
	Total needed km from 0	172,265	km
	Total needed km in addition	132,530	km
	Expenditure by region from 0	248,934,121,236	$
	Expenditure in addition	191,515,057,236	$
	Annual needed expenditures	9,575,752,862	$

South West			
Arkansas	14,183	4,097	
Louisiana	11,866	0	
New Mexico	33,056	22,183	
Oklahoma	18,704	0	
Texas	71,310	0	
	Total needed km from 0	149,118	km
	Total needed km in addition	26,280	km
	Expenditure by region from 0	181,683,223,596	$
	Expenditure in addition	32,019,082,825	$
	Annual needed expenditures	1,600,954,141	$
South East			
Alabama	13,822	6,068	
Florida	14,698	6,698	
Georgia	15,773	10,167	
Kentucky	10,821	0	
Mississippi	12,777	0	
North Carolina	13,268	9,271	
South Carolina	8,201	4,556	
Tennessee	11,227	4,300	
	Total needed km from 0	100,588	km
	Total needed km in addition	41,061	km
	Expenditure by region from 0	166,731,562,839	$
	Expenditure in addition	68,061,702,050	$
	Annual needed expenditures	3,403,085,103	$
Total			
	$ needed **$2009**	564,882,566,968	$
	Annual needed expenditures	28,114,771,715	$
	Total km needed in U.S from 0	808,104	km
	Total km needed now in the U.S	396,897	km
	Cost from 0	1,144,541,064,902	$

However, the previous table shows that 396,897 kilometers of additional natural gas pipelines are required in all the U.S. which is double the existing level of natural gas infrastructure. As expected, the Southwest region is more developed than other US regions since all states within this region have a pipeline density close or higher than the Italian one. By contrast, Utah which is a high potential state in term of resources available and supporting policies, needs to extend the transmission pipeline network by 77%.

This table also presents information concerning the capital expenditures for pipeline construction. The cost of building natural gas pipeline infrastructures is not fixed since it includes several parameters that are likely to change yearly. The cost per inch-mile of a single pipeline is divided between materials, labor, miscellaneous, and the cost of right of way. The first three items have roughly the same weight in the total cost while the cost of right of way represents just 10 % of total construction cost [99]. The material cost is influenced by commodity prices, like the price of steel which makes the total cost unstable while the miscellaneous category refers to engineering, surveying, administration and environmental costs.

To estimate the expected cost for pipeline growth according to the High CNG transmission growth, refer to the Figure 4.3-1 reported by the INGAA foundation. Figure 4.3-1 shows that pipeline costs are expected to rise from 2009 to 2030 at a rate slightly less than the inflation rate [99]. However for the scope of this analysis, these changes were neglected, and hence the average value of $76,000 per inch-mile from 2009 to 2030 has been assumed.

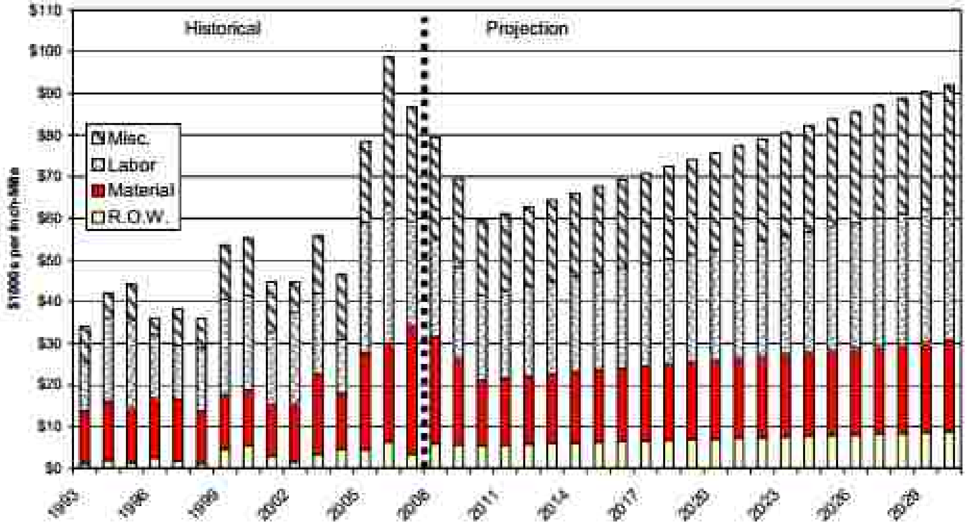


Figure 4.3-1Natural gas pipeline costs ($1000 per inch-mile) [99]

Another aspect considered is the cost of pipeline construction which varies from region to region. The cost of pipeline expansion varies significantly depending on whether the network is already existing or not, the density of neighborhood, and the geology of the land. Costs are typically higher in more densely populated region due to increased costs for permitting, safety, and environmental compliance.

Table 4.3-2 Regional pipeline construction cost comparison [99]

Region	Index
Central	0.92
Midwest	1.00
Northeast	1.29
Southeast	1.17
Southwest	0.86
Western	1.02

An index of 1 refers to the U.S. average

The regional expenditures have been calculated as shown in the following equation:

$$Reg.costs_i = \frac{(pipeline\ diameter * Cost\ per\ inch-mile) * (needed\ km\ pip_i . * regional\ factor_i)}{1.60934} \qquad (4\text{-}5)$$

Where:

- Pipeline diameter [inch] is assumed equal to 30 inches for transmission pipelines
- Cost per inch-mile is assumed equal to $76,000 inch-mile (Average value from 2009-2030)
- 1.60934 is the constant factor to convert miles to km

For each region two estimated values have been reported: one refers to the estimated cost to realize the whole network from scratch while the latter indicates the estimated expenditure to extend the network. These latter numbers provide an indication of the additional resources needed.

For instance, in the Southwest region the estimated expenditures for the additional construction of 26,280 km is $32 billion. This value may appear steep, but this value is only 20% of the expected cost for the whole construction in the same region.

By contrast, the Western region would require $191 billion for additional pipeline construction that corresponds to the 80% of the total cost from scratch.

Moreover, the regions that require the highest investments are Central and Midwest. This result is not surprising given these two regions are the least developed in terms of NG infrastructures.

At a national level, the projected costs to bring the US NG pipeline network up to the Italian density amount to $563 billion which corresponds to an annual investment of about $28 billion on a 20 years.

4.3.2. *Limited CNG infrastructure growth*

The underlying premise in the Limited CNG infrastructure growth case is similar to the previous case. The major difference is that this case estimates the kilometers of additional pipelines and the expected costs necessary to reach the Italian pipeline density *only for those states that present a high potential for CNG penetration on large scale.* The variables assessed to declare the potential of each state are those reported in the multiple variable matrix.

Table 4.3-3 Limited CNG transmission growth case

Case 2: Limited CNG growth case			
STATE	**Expected Pipelines from 0 to reach Italian density [km]**	**Added pipelines to reach Italian density [km]**	
Central			
Colorado	28,251	15,694	
Iowa	15,218	6,494	
Kansas	OK		
Missouri	No Potential		
Montana	Low Pop		
Nebraska	20,939	11,770	
North Dakota	Low Pop		
South Dakota	Low Pop		
Utah	OK		
Wyoming	26,449	13,732	
	Total needed km from 0	90,857	km
	Total needed km in addition	47,689	km
	Expenditure by region from 0	118,421,964,487	$
	Expenditure in addition	62,158,039,687	$
	Annual needed expenditures	3,107,901,984	$
Midwest			
Illinois	OK		
Indiana	9,770	2,199	
Michigan	OK		
Minnesota	Low Potential		
Ohio	OK		
Wisconsin	Low Potential		
	Total needed km from 0	9,770	km
	Total needed km in addition	2,199	km
	Expenditure by region from 0	13,840,978,656	$
	Expenditure in addition	3,115,858,656	$
	Annual needed expenditures	155,792,933	$

Northeast			
Connecticut	1,320	309	
Delaware	NO		
Maine	NO		
Maryland	2,662	1,018	
Massachusetts	2,136	571	
New Hampshire	NO		
New Jersey	NO		
New York	12,860	4,785	
Pennsylvania	ok		
Rhode Island	Low Pop-Low Pot		
Vermont	Low Pop-Low Pot		
Virginia	10,785	6,638	
West Virginia	6,559	511	
	Total needed km from 0	36,321	km
	Total needed km in addition	13,831	km
	Expenditure by region from 0	66,380,145,959	$
	Expenditure in addition	25,276,875,959	$
	Annual needed expenditures	1,263,843,798	$
Western			
Arizona	30,953	21,314	
California	42,481	23,539	
Idaho	Low Potential		
Nevada	Low Potential		
Oregon	Low Potential		
Washington	Low Potential		
	Total needed km from 0	73,434	km
	Total needed km in addition	44,853	km
	Expenditure by region from 0	106,116,315,017	$
	Expenditure in addition	64,815,984,617	$
	Annual needed expenditures	3,240,799,231	$

Southwest			
Arkansas	14,183	4,097	
Louisiana	ok		
New Mexico	33,056	22,183	
Oklahoma	ok		
Texas	ok		
	Total needed km from 0	47,238	km
	Total needed km in addition	26,280	km
	Expenditure by region from 0	57,554,581,225	$
	Expenditure in addition	32,019,082,825	$
	Annual needed expenditures	1,600,954,141	$
South East			
Alabama	NO		
Florida	14,698	6,698	
Georgia	Medium Potential		
Kentucky	Ok		
Mississippi	Ok		
North Carolina	Low Potential		
South Carolina	Low Potential		
Tennessee	NO		
	Total needed km from 0	14,698	km
	Total needed km in addition	6,698	km
	Expenditure by region from 0	24,363,722,665	$
	Expenditure in addition	11,103,083,065	$
	Annual needed expenditures	555,154,153	$
Total			
	$ needed	200,539,811,960	$
	Annual needed expenditures	10,026,990,598	$
	Total km needed in U.S from 0	272,318	km
	Total km needed now in the U.S	141,551	km
	Cost from 0	386,677,708,009	$

The same equations 4-3 and 4-4 have been used to estimate the expected costs and the kilometers of additional pipeline needed to reach the target.

From the table 4.3-2, the selected states are characterized by at least one of the following factors:

- Significant amount of natural gas reserves
- Proximity to an import access
- Reasonable number of NGVs and CNG stations
- Relatively high VRI
- At least modest level of transmission pipelines developments

However, the most important aspect in this case is that the total expected cost for infrastructure growth amounts to \$200 billion dollar which is 65% lower than the previous case. This corresponds to an annual investment of roughly \$10 billion rather than \$28 billion. At a regional level, the Southwest is again the most attractive scenario for CNG while Western, Central and Midwest regions lag behind other markets.

4.3.3. Proportional CNG infrastructure growth

The proportional CNG infrastructure growth case differs from the previous ones since it defines an upper and lower range for infrastructure growth. In other words, instead of assuming as unique target the Italian pipeline density, the proportional CNG infrastructure growth case defines as a lower threshold the Californian pipeline density and as upper range the Italian pipeline density. The reason why California has been assumed, in this case, to be the threshold between the low-medium and medium-high potential states is because it represents the most advanced status in the U.S. either in terms of number of NGVs or as available infrastructure. In other words, if the Italian reference model is not achievable, then California represents the next “best” achievable reference model given its location within the US, number of NGVs, and infrastructure. The primary data for the creation of Table 4.3-4 are:

- Italian pipeline density: 0.105 km/km^2
- Californian pipeline density: 0.05 km/km^2

Based on these hypotheses, the basic premise was to calculate:

- for those states whose pipeline density was lower than the California one, the additional kilometers of pipeline needed to move from the its current status up to the lower threshold (California);
- for those states that were characterized by a pipeline density between the two limits, the additional kilometers of pipeline needed to upgrade to the upper extreme of the range (Italy);

Table 4.3-4 Proportional CNG infrastructure growth

Case 3 Proportional CNG growth case			
STATE	**Added pipelines to reach California if density is < than CA or to reach Italy if density is >CA and <Italy**		
		Target State	
Central			
Colorado	39	**CALIFORNIA**	
Iowa	6,494	**ITALY**	
Kansas	0	**iTALY**	
Missouri	2,019	**CALIFORNIA**	
Montana	11,464	**CALIFORNIA**	
Nebraska	168	**CALIFORNIA**	
North Dakota	5,363	**CALIFORNIA**	
South Dakota	7,218	**CALIFORNIA**	
Utah	4,867	**CALIFORNIA**	
Wyoming	13,732	**ITALY**	
	Total regional km needed	51,364	km
	Expenditure by region	66,947,892,697	$
	Annual needed expenditures	3,347,394,635	$
Midwest			
Illinois	0	**iTALY**	
Indiana	2,199	**iTALY**	
Michigan	0	**iTALY**	
Minnesota	2,512	**CALIFORNIA**	
Ohio	0	**iTALY**	
Wisconsin	1,010	**CALIFORNIA**	
	Total regional km needed	5,722	km
	Expenditure by region	8,106,204,633	$
	Annual needed expenditures	405,310,232	$

Northeast		
Connecticut	309	**ITALY**
Delaware	82	**ITALY**
Maine	2,768	**CALIFORNIA**
Maryland	1,018	**ITALY**
Massachusetts	571	**ITALY**
New Hampshire	621	**CALIFORNIA**
New Jersey	0	**ITALY**
New York	4,785	**ITALY**
Pennsylvania	0	**ITALY**
Rhode Island	124	**ITALY**
Vermont	1,009	**CALIFORNIA**
Virginia	662	**CALIFORNIA**
West Virginia	511	**ITALY**
Total regional km needed	12,458	km
Expenditure by region	22,768,847,883	$
Annual needed expenditures	1,138,442,394	$
Western		
Arizona	4,163	**CALIFORNIA**
California	0	**CALIFORNIA**
Idaho	7,528	**CALIFORNIA**
Nevada	10,975	**CALIFORNIA**
Oregon	9,663	**CALIFORNIA**
Washington	4,748	**CALIFORNIA**
Total regional km needed	37,077	km
Expenditure by region	53,578,520,978	$
Annual needed expenditures	2,678,926,049	$
Southwest		
Arkansas	4,097	**ITALY**
Louisiana	0	**ITALY**
New Mexico	3,867	**CALIFORNIA**
Oklahoma	0	**ITALY**
Texas	0	**ITALY**
Total regional km needed	7,963	km
Expenditure by region	9,702,568,689	$
Annual needed expenditures	485,128,434	$

South East		
Alabama	6,068	**ITALY**
Florida	6,698	**ITALY**
Georgia	1,428	**CALIFORNIA**
Kentucky	0	**ITALY**
Mississippi	0	**ITALY**
North Carolina	1,919	**CALIFORNIA**
South Carolina	12	**CALIFORNIA**
Tennessee	4,300	**ITALY**

Total regional km needed	20,425	km
Expenditure by region	33,855,597,831	$
Annual needed expenditures	1,692,779,892	$

Total		
$ needed in the United States	194,959,632,710	$
Annual needed expenditures	9,747,981,636	$
Total km needed now in the U.S	135,010	km

In this case only the column relative to the needed additional kilometers of transmission pipeline is reported. However, it is important to state that even though the Limited and Proportional Case studies are based on two different set of assumptions and calculations, they both lead to similar results. Indeed, according to the Proportional Case study 135,010 km of pipelines are necessary in all the U.S. requiring an annual expenditure of $9.47 billion. These results differ by only 5% from the previous case.

For the majority of the U.S. states there is more opportunity to move from the actual level to an “intermediate level”, identified as California, instead of aiming for the ideal target, as represented by Italy. This also clarifies the two-way analysis introduced in the methodology. In fact, for all those states which are less prone to CNG adoption, it is likely unfeasible to propose massive natural gas development. By contrast, advocating a gradual transition to a higher level of CNG implementation through an intermediate stage could result in future development, particularly when aided by initiatives such as introducing home refueling appliances and government incentives.

4.3.4. Validation of the results

How realistic are the resulting cost estimates for increased natural gas infrastructure from the previous three growth case studies? The INGAA estimated that U.S. requires up to 61,000 miles (100,000 km) of transmission pipelines by 2030, resulting in a total investment of $110 billion.

Region	**Transmission pipelines [$ billion]**
Southwest	27.6
Central	24.8
Southeast	15.4
Northeast	10.1
Midwest	12.9
Western	8.7
Offshore	6.3
Total	106

Figure 4.3-2 Detail of the INGAA estimation (adapted from [3])

Based on these values, it appears that the High CNG infrastructure growth case exceeds real expectations. Indeed, the total expenditures estimated in that outlook are 3.5 times higher than the INGAA estimation. This is almost obvious since in the U.S. there are regions or individual states that unlikely will achieve the infrastructure as represented in Italy.

However, the Proportional and Limited CNG infrastructure growth cases appear achievable by the INGAA estimation since both the outlooks shows a total result that differs by just 20%. Furthermore, the American Gas Association, reports that from 1972 to 2012 more than $120 billion dollar were spent for transmission pipelines construction [100]. In particular, even if this value is lower than the case studies outcomes, it must be taken into account that from 1972 to present the monetary value is drastically changed due to inflation.

Given these circumstances, the Proportional and Limited growth cases appear to be realistic over a 20 year time line and in keeping in magnitude with costs outlined previously in the literature.

4.4. **Case studies definition: CNG stations developments**

This section evaluates three potential scenarios for CNG stations growth in the United States based on the analysis of the CNG stations density in each country (Italy and the U.S.) and on the ratio CNG to gasoline stations. The underlying premise is similar to the case studies defined to estimate the infrastructure growth. In particular, the theory behind each case is summarized in the following:

- Case 4: Estimates the number of CNG stations required to reach, in each U.S. state, the Italian density of NG refuel sites. This projection assumes that no stations are currently available.
- Case 5: Is almost identic to the Case 4, expect that it assumes as maximum level of CNG station growth in each state to correspond to the current number of gasoline stations. In other words if the required number of stations to reach the Italian density is higher than the actual number of gasoline stations, the *latter value* is assumed as maximum level of growth in that state.
- Case 6: Defines a lower and an upper level of CNG stations development. It assumes the number of CNG stations in California as a threshold between low-medium and medium-high status, while Italy represents the top level. Based on the CNG stations density, this case estimates the additional CNG stations needed to reach either the Californian or the Italian level.

The above analysis is shown in Table 4.4-1. For the cases 5 and 6, the first column reports the total number of stations including those already existing while the last column reports only the additional CNG stations required to improve the actual status. It is important to underline that this analysis does not account for individual difference in CNG stations design, nor does it distinguish between private and public stations.

Table 4.4-1Case studies for CNG stations growth

STATE	Case 4	Case 5			Case 6	
	Number of CNG stations required to reach Italy from 0	Number of CNG station required to reach Italy provided that CNG stations < gasoline stations	Actual CNG stations	Additional CNG stations required to reach Italy provided that CNG stations < gasoline stations	Number of CNG stations required to reach Italy or California	Additional CNG stations required to reach Italy or California
Central						
Colorado	855	855	36	819	200	164
Iowa	461	461	4	457	108	104
Kansas	675	675	6	669	158	152
Missouri	568	568	12	556	133	121
Montana	1,200	575	2	573	281	279
Nebraska	634	634	9	625	148	139
North Dakota	569	455	1	454	133	132
South Dakota	626	626	0	626	626	626
Utah	677	677	95	582	159	64
Wyoming	801	397	11	386	187	176
	Total 7,065	5,922	176	Total 5,746	2,133	Total 1,957
Midwest						
Illinois	458	458	40	418	107	67
Indiana	296	296	21	275	69	48
Michigan	468	468	19	449	110	91
Minnesota	656	656	11	645	154	143
Ohio	338	338	27	311	79	52
Wisconsin	448	448	46	402	105	59
	Total 2,664	2,664	164	Total 2,500	Total 624	Total 460
Northeast						
Connecticut	40	40	17	23	40	23
Delaware	16	16	1	15	4	3
Maine	254	254	1	253	60	59
Maryland	81	81	9	72	19	10
Massachusetts	65	65	23	42	65	42
New Hampshire	74	74	3	71	17	14
New Jersey	61	61	29	32	61	32
New York	389	389	111	278	389	278
Pennsylvania	370	370	51	319	86	35
Rhode Island	9	9	6	3	9	3
Vermont	76	76	3	73	18	15
Virginia	326	326	20	306	76	56
West Virginia	199	199	3	196	46	43
	Total 1,960	1,960	277	Total 1,683	Total 890	Total 613

Western						
Arizona	937	937	38	899	219	181
California	1,286	1,286	301	985	1,286	985
Idaho	682	682	13	669	160	147
Nevada	906	737	9	728	212	203
Oregon	855	855	14	841	200	186
Washington	549	549	25	524	128	103
	Total 5,215	5,046	400	Total 4,646	Total 2,206	Total 1,806
Southwest						
Arkansas	429	429	8	421	100	92
Louisiana	359	359	21	338	84	63
New Mexico	1,001	970	11	959	234	223
Oklahoma	566	566	94	472	133	39
Texas	2,159	2,159	72	2,087	505	433
	Total 4,514	4,483	206	Total 4,277	Total 1,057	Total 851
South East						
Alabama	418	418	23	395	98	75
Florida	445	445	33	412	104	71
Georgia	477	477	26	451	112	86
Kentucky	328	328	4	324	77	73
Mississippi	387	387	5	382	91	86
North Carolina	402	402	36	366	94	58
South Carolina	248	248	11	237	58	47
Tennessee	340	340	9	331	80	71
	Total 3,045	3,045	147	Total 2,898	Total 713	Total 566
Total in the United States						
	24,463	23,121	1,370	21,751	7,622	6,252

Case 4 reports that 24,463 CNG stations are required in all the U.S., or 18 times the current number of natural gas refueling sites. However, a more realistic result is the one obtained by case 5. Indeed, it is expected that the number of natural gas stations will remain lower than the number of gasolinestations in each state. For this reason in states like North Dakota, Nevada, Wyoming and Montana, the number of CNG stations has been limited to the same number of gasoline stations.

At the state level, it is noteworthy to consider those states that are characterized by a high potential for CNG penetration. Focusing at the national level, the actual number of CNG stations would have to increase 20 fold to provide sufficient refuelling stations to compare with the Italian reference model. However, focusing only on certain states like Utah or Oklahoma which have a number of refuelling stations already means the number of additional CNG stations would be much lower. These two states require respectively 582 and 482 additional CNG stations to reach the Italian density, which is just 5 times higher than the current values. This assessment, however, does not presume to provide the exact number of stations to be competitive in all the states but will help to understand when and where to invest first.

These results are further supported by the literature. TIAX LLC assessed the U.S. natural gas vehicle market, supported by the America's Natural Gas Alliance, in which it declares that to reach a healthy level of CNG stations a ratio of CNG to gasoline stations similar to the minimum ratios established for diesel is required. It means that a number ranging between 20,000 and 30,000 CNG stations are necessary [69].

By contrast, Case 6 results in significantly lower number of CNG stations nationally than the other two scenarios. Because all U.S. states currently have a CNG station density lower than California, the outlook estimates the impact to move just from a low level of refuel sites to an intermediate level of refuel sites. This can be considered as a starting goal or an intermediate step before aiming to reach the number of fueling stations currently in Italy.

However the assessment of the CNG stations availability is related to another topic that is gaining more attention: the option for CNG home refueling.

4.5. **Home refueling analysis**

The analyses reported so far show that a number of factors influence the adoption of natural gas vehicles, including the price of the fuel, infrastructure growth, payback period and active incentives. Coincidentally, these are almost the same factors affecting the home refueling adoption rate.

Home refueling represents a potential solution to compensate for the lack of current infrastructure and speed up the penetration of NGVs. In other words, a home refueling appliance (HRA) together with LDV bi-fuel vehicles would feed the natural gas market until infrastructure is built and customers feel more comfortable using NGVs. Home refueling does have its own challenges, including poor reliability and quality issues. However, even with these negative aspects, it presents many more benefits that make it a potential alternative in the transition time.

Indeed, with a total cost of about $1.20 per GGE ($1.00 for natural gas cost and $0.20 for electricity cost) HRA provides significant cost savings compared to gasoline that can reduce the payback period for a new NGV. In addition with more than 65 million homes that have available natural gas, in the U.S., there is a potential opportunity for car makers to market a CNG vehicle up to 65 million customers. Single family house occupants have the option, in this case, of refueling the vehicle using the natural gas coming directly from the domestic network.

A parametric analysis of LDV competitiveness in the U.S., developed by Meghan Peterson and Sandia National Laboratories, reports that annual compressor sales are influenced by compressor cost [101].

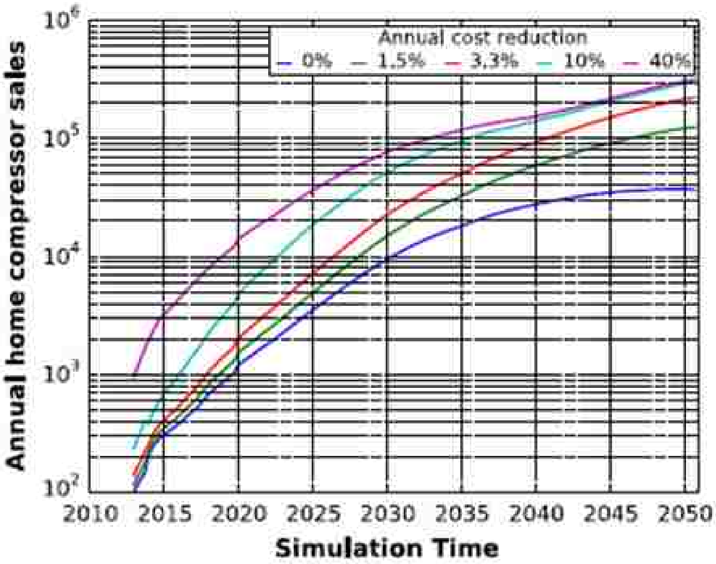


Figure 4.5-1Annual compressor sales as a function of cost reduction [101]

The Figure 4.5-1 shows, that a negligible compressor cost reduction will result in less than 40,000 units annually sold by 2050. By contrast, higher annual cost reductions lead to a range of 100,000 to 300,000 units sold per year. Based on this analysis, reducing the HRA cost to less than $1,000 would encourage potentially a significant adoption of NGVs.

This potential outcome is the cornerstone of a $500 HRA project promoted by General Electric, Whirlpool, Eaton and Chesapeake. The program announced at ACT EXPO 2014 in California, is only at design stage but is intended to solve the main problems experienced with the HRA offered by BRCfuelmaker. In particular, it is aimed to increase the lifecycle time as well as the dispensing rate up to 1 GGE/h. This unit is expected to enter the market by the end of 2015.

Finally, the rate of adoption of home refueling is correlated to the growth of public CNG refueling infrastructure.

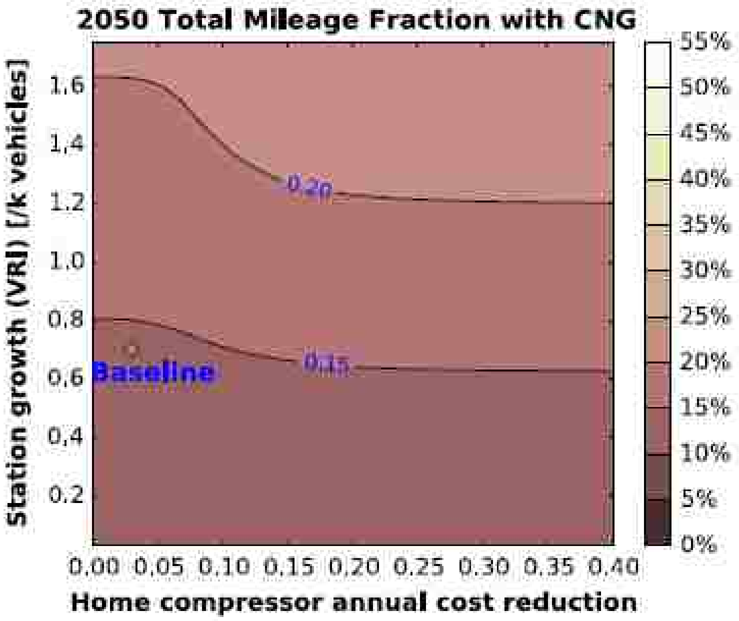


Figure 4.5-2 Influence of VRI and HRA cost on NGVs market share [101]

As shown in the Figure 4.5-2, public infrastructure has a greater influence on NGV sales than home refueling, because a public station provides service to hundreds of vehicles per day. Home refueling results more influential in new or low potential markets since permits limit the imminent need of a massive development of CNG stations and interstate pipelines. As shown in the figure, once the public infrastructure is built which means to reach a VRI equal to 1, the influence of the HRA on the market flattens.

The figure shows a first case scenario (blue line) with no HRA influence on NGV sales and infrastructure growth, and two other case scenarios (green and orange lines) which estimates different influences of HRA on the market.

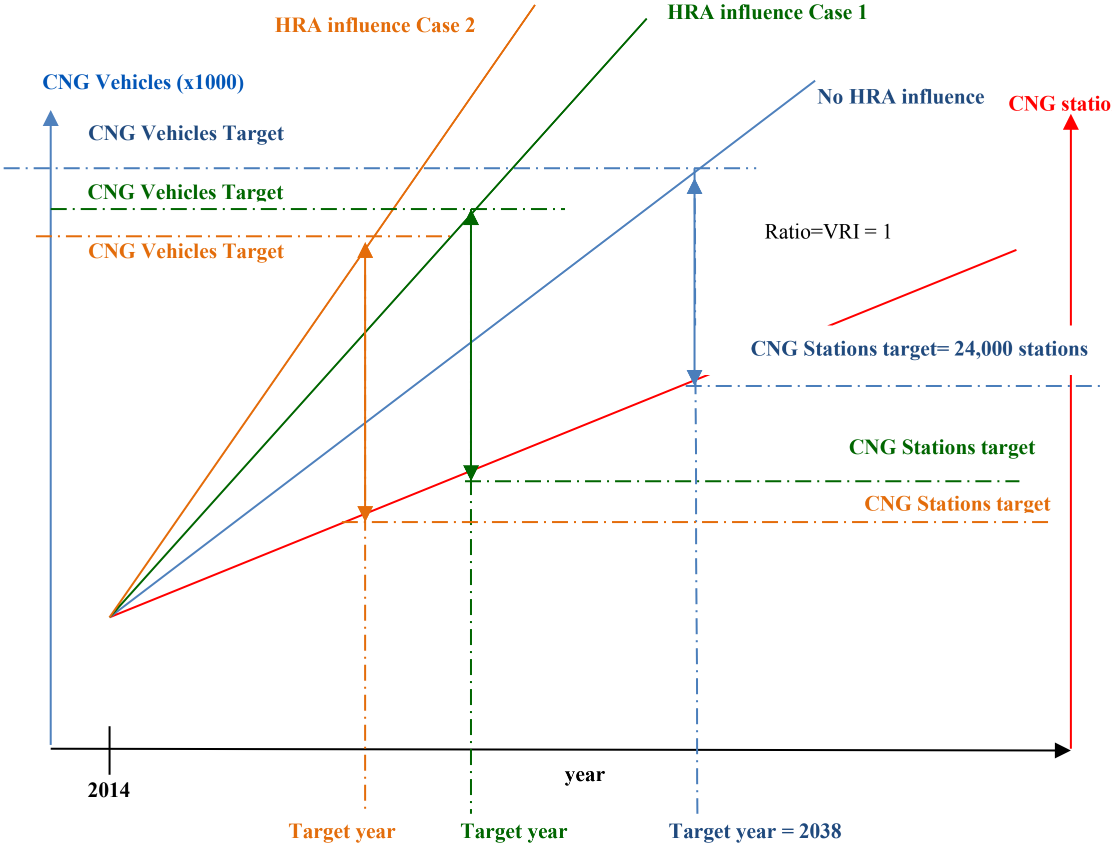


Figure 4.5-3HRA disruptive scenarios for infrastructure growth

The red line indicates the CNG stations growth in the U.S. assuming as a slope the growth rate of Italian CNG stations per year after the introduction of the National gas plan in 2001 (refer to Figure 2.5-35). This slope has been evaluated according to the evaluation of the average annual growth rate:

- CNG stations in Italy in 2002: 325
- CNG stations in Italy in 2011: 900

$$CNG\ stations_{2011} = CNG\ stations_{2002} * (1 + annual\ growth\ rate)^{(2011-2002)} \quad (4\text{-}6)$$

$$annual\ growth\ rate = \left(\frac{CNG\ stations_{2011}}{CNG\ stations_{2002}}\right)^{\left(\frac{1}{2011-2002}\right)} - 1 = \left(\frac{900}{325}\right)^{\left(\frac{1}{9}\right)} - 1 = 0.12 = 12\% \qquad (4\text{-}7)$$

Based on a 12% annual growth, the target of 21,751 stations required to reach the minimum ratio established by diesel stations in the U.S. will be reached in 24 years time according to the following equation:

$$\left(year_{target} - year_{current}\right) = \frac{\ln\left(\frac{Target\ stations}{current\ numb.stations}\right)}{\ln(1+annual\ growth\ rate)} = \frac{\ln\left(\frac{21{,}751}{1{,}370}\right)}{\ln(1+0.12)} = 24\ years \qquad (4\text{-}8)$$

As a result, the U.S. will reach the target number of CNG stations in 2038. Focusing only on significant states the target may be even closer:

- Oklahoma: 15 years to reach 566 stations with no HRA influence;
- California: 12 years to reach 1,286 stations with no HRA influence.

These numbers do not define a specific strategy for automotive manufacturers but provide an indication of the suggested entry time in the market as well as a potential time to begin CNG projects given a typical 24 month period to adapt and certify a new NGV.

With respect to the analysis of the expected time period to reach the target under the influence of HRA, the main assumption is that the higher the impact of the HRA, the steeper is the slope of the green and orange lines since each HRA sold corresponds to at least one vehicle purchased. As a consequence, a higher number of CNG vehicles will result in reaching more quickly the ideal VRI since there will be more vehicles sharing the same station. More importantly, the opportunity to refuel the vehicle at home reduces the need of a public infrastructure rendering the target year even closer. Furthermore, requiring fewer CNG stations should ideally result in less demand for transmission pipelines in the urban areas and hence a significant cost saving. In this case no values are provided since, currently, there are no data available about HRA sales to evaluate the changes in NGVs sales after the introduction of the home refueling option.

5. SIMULATION TOOLS DEVELOPMENT

Because standard life cycle assessment approaches and software (e.g., GaBi) focus on environmental outputs, the *Economic Input-Output LCA* approach was selected instead to allow for both environmental and economic analyses.

5.1. **Brief introduction of Economic Input-Output life cycle assessment**

The Economic Input-Output LCA can be defined as a "top down" approach since it provides comprehensive estimate of economic transactions, environmental effects and resources needed throughout the whole economy to realize a particular output. Conversely, process based life cycle models are usually defined as "bottom up" analyses because the models creation moves up from the data collection to the modeling of flows between unit processes [102]. The EIO-LCA developed by a group of researchers at the Green Design Institute of Carnegie Mellon dates back to the 1930. The economist Wassily Leontief developed a system of equations and an economic input-output model that described the various inputs required to create a unit of output in a specific economic sector in the U.S. economy. [103].

5.2. **Conceptual framework of the Economic Input-Output model**

The primary element of the Economic Input-Output LCA is an Input-Output table that subdivides the entire economy into distinct economic sectors. The word "sector" refers to a group of companies that work on similar products. To date, there are different national and international organizations involved in classifying the sectors. In North America the most adopted classification scheme is the North American Industry Classification Scheme (NAICS) which allocates to each sector a code ranging from 2 to 6 digits. The sector classification starts with the first two digits that broadly classify the sector and becomes more and more detailed with each further digit up to the sixth. For example, the hierarchical classification of the "Oil and Gas Pipelines and related structures construction" sector in the NAICS system is reported in the table 5.2-1 [104]. However, many of the IO sectors do not have a one to one correspondence with the NAICS organization since they represent an aggregation of multiple NAICS codes.

Table 5.2-1NAICS classification sector [104]

Code	Sector
NAICS 23	Construction
NAICS 237	Heavy and Civil engineering construction
NAICS 2371	Utility system construction
NAICS 23712	Oil and gas pipeline and related structures construction
NAICS 237120	Oil and gas pipeline and related structures construction

Further descriptions and specifications of these sectors will be provided at the end of the chapter. A complete analysis and explanation of the NAICS system is at website www.census.gov/eos/www/naics/.

The industry classification system represents the basis for the development of the Input-Output table. By assigning a row and a column to each sector, the I-O table can describe total economic transaction between sectors like total sales from one sector to others, purchase from one sector, or the fraction of purchases from one sector to produce a dollar of output.

The main steps in developing the EIO-LCA are outlined in the following figure:

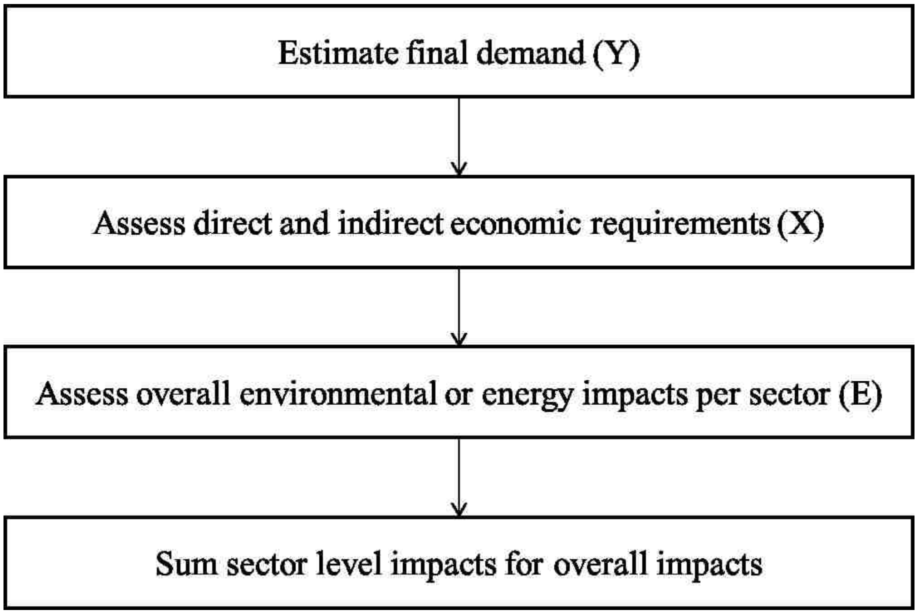


Figure 5.2-1 Flow chart of EIO-LCA approach [102]

To accomplish the first two steps it is necessary to understand the theory behind an IO transaction table. An example is shown in Table 5.2-2.

Table 5.2-2 Example of an Economic Input-Output transaction Table [102]

	Input to sectors				Intermediate output O	Final demand Y	Total output X
Output from sectors	1	2	3	n			
1	X_{11}	X_{12}	X_{13}	X_{1n}	O_1	Y_1	X_1
2	X_{21}	X_{22}	X_{23}	X_{2n}	O_2	Y_2	X_2
3	X_{31}	X_{32}	X_{33}	X_{3n}	O_3	Y_3	X_3
n	X_{n1}	X_{n2}	X_{n3}	X_{nn}	O_n	Y_n	X_n
Intermediate input I	I_1	I_2	I_3	I_n			
Value added V	V_1	V_2	V_3	V_n		GDP	
Total input X	X_1	X_2	X_3	X_n			

The elements X_{ij} in the central matrix represent the input to column sector *j* from row sector *i*. There are also other, important columns:

- *Intermediate Output O:* This column has n elements, each of them representing the sum of the outputs of the sector *i* to all the *n* sectors;
- *Final Demand Y:* Includes the output supplied by the sector *i* to the final customers;
- *Total Output X:* This column has n elements and represents for each row *i* the sum of the intermediate output and final demand.

With respect to the other three rows outside the central matrix*:*

- *Intermediate Input I*: It has n- column, each of them representing the sum of the inputs provided to sector *j* by all the other sectors *i;*
- *Value Added V:* It represents the increment in the value resulting after a particular process [102];

The value added, which includes employee compensation, indirect business taxes and profits, is necessary to ensure correlation between the two X values. Finally, the Gross Domestic Product (GDP) is an economic indicator that may be evaluated either as the sum of the final demand or as the sum of the Value Added.

Because the data gathering activities for the EIO-LCA model are very time and resource consuming, the Economic Input-Output tables are updated approximately every 5 years. It means that the 2002 year, 428-sector model of the U.S was published in 2007, while the table with data gathered in 2007 has not been published yet [103].

However, in order for this table to represent the economic transactions associated to a dollar of output, it is necessary to normalize each element X_{ij} to the total output of that sector X_i. The resulting table **A** represents the requirements from other sector to produce one dollar of output of that sectors and it is named **direct requirement matrix** [102]**.** The strength of this model is that the A matrix may be used to identify the purchases needed to produce the final product as well as all the product along the whole life cycle of that product.

From the algebraic point of view, it means that the required economic purchases needed to realize a desired output Y can be calculated as [103]:

$$X = [I + A + A \times A + A \times A \times A + \ldots]Y = IY + AY + A^2Y + A^3Y + \ldots \qquad (5\text{-}1)$$

Where:

- X is the vector (or list) of required inputs;
- I is the identity matrix;
- A is the direct requirements matrix (with rows representing the required inputs from all other sectors to make a unit of output for that row's sector);
- Y is the vector of desired output.

At this point is it worthwhile to specify three different levels of purchases:

- **The direct purchases:** refer to the first two terms IY and AY (because those are everything related directly to the decisions made by the operators of the final production facility)

- **The indirect purchases:** refer to all the other terms A^2Y, A^3Y, etc.
- **The total purchases:** is the sum of the direct and indirect purchases.

Based on the infinite geometric series approximation the equation (5-1) may be simplified to equation (5-2)

$$X = [I - A]^{-1}Y \tag{5-2}$$

where the matrix $[I-A]^{-1}$ is named **total requirements table (or matrix)**. This method attempts to evaluate the total purchases throughout the all supply chain to produce a specified set of products or services.

The IO-model is less time consuming than a process driven LCA approach. However, this method has limitations and relies on some keys assumptions [102]:

- *Sectors represent average production*: All production facilities in the country that make products and provide services are aggregated in a fixed number of sectors. In the U.S. economy model adopted for the research, all production facilities are classified in 428 sectors.
- *Input-Output model is linear:* All inputs and outputs are assumed to have or can be approximated using a linear relationship. This is also a common assumption adopted also in process-based models.
- *Manufacturing impacts only:* IO models do not include capital expenditures that occur during the use phase and end of life
- *Capital investments excluded:* As with process based models, capital inputs are not considered in most IO tables.
- *Domestic production:* Any IO model for a single economy is limited to estimating effects within that country only, while imported inputs are assumed produced in the same way as in the home country of the model. The basic IO model also considers “circularity”; for example, the use of steel to produce other steel.

The second phase of the EIO-LCA evaluates the **total environmental effects** for each sector. In this case the direct and indirect environmental effects for each sector can be computed by multiplying the output by the environmental impact per dollar of output [103]:

$$E = RX = R[I - A]^{-1}Y \qquad (5\text{-}3)$$

Where:

- E is the vector of environmental impacts such as resource inputs (electricity, natural gas, ores, fuels) and environmental outputs (toxic emissions, global warming potential and conventional air pollution emissions)
- R is a diagonal matrix representing the impact per dollar of output (e.g. kg CO_2/$)
- X is the total output from all sectors.

Using the above, it is possible to estimate all the environmental burdens across the supply chain.

5.3. **Data sets available in the EIO-LCA**

The EIO-LCA is currently available in two different versions:

- A website tool that provides models for the U.S., Germany, Spain, Canada and China.
- A Matlab version that provides only two models of the U.S economy for the benchmark years 1997 and 2002

The two versions of the EIO-LCA share the same datasets which are derived from a variety of public databases and assembled together to develop the **direct requirements matrix (A)** and the **matrix of environmental effects (R)**. The main datasets are [105]:

- **Direct and Total Input-Output tables:** The most updated model is the 428-sector, year 2002 industry by commodity input–output (IO) matrix of the US economy developed by the U.S. Department of Commerce Bureau of Economic Analysis.
- **Energy use**: Estimates of the energy use derive from several different sources. For instance, energy use of manufacturing sectors (roughly 270 of 428) is developed from the Manufacturing Energy Consumption Survey (MECS) while for mining sectors is calculated from the 2002 Economic Census (USCB 1997).

- **Conventional pollutant emissions**: Are from the US Environmental Protection Agency, primarily the National Emissions Inventory (NEI) and onroad/nonroad data sources.
- **Greenhouse gas emissions**: Are calculated by applying emissions factors to fuel use for fossil-based emissions and allocating top-down estimates of agricultural, chemical process, waste management, and other practices that generate non-fossil carbon emissions to economic sectors.
- **Toxic releases and emissions**: Are derived from EPA's 2002 Toxics Release Inventory (TRI).
- **Hazardous waste**: RCRA (Resource Conservation and Recovery Act) Subtitle C hazardous waste generation, management, and shipment were derived from EPA's National Biannual RCRA Hazardous Waste Report.

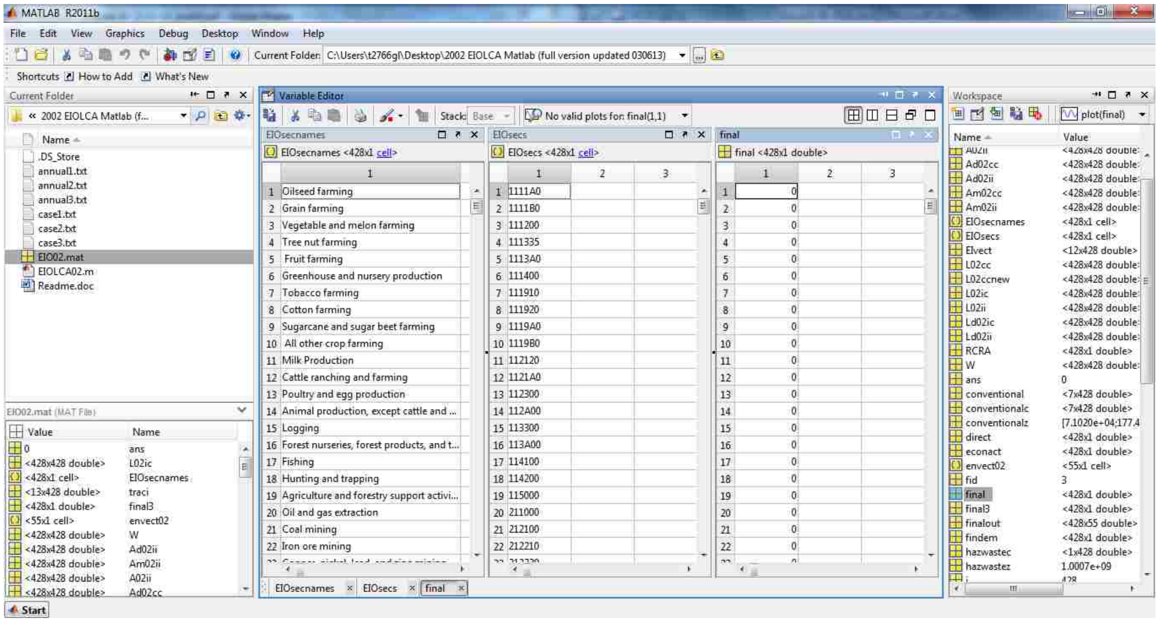
The EIO-LCA website as well as the Matlab model is developed on the same workflow showed in the Figure 5.2-1. The user selects the most representative sector for the object under analysis and modifies the vector of the final demand. The Matlab model is more flexible and consents to easily manage the results. In particular, unlike the web model, the Matlab model allows for modification of the A and E matrix, described before. It provides, thus, the possibility to create custom models. However, in this thesis it is assessed only one sector per simulation, leading in this way to more accurate results.

5.4. **Major steps in using the EIO-LCA tool**

The EIO-LCA method estimates the direct and indirect economic transactions and the environmental effects resulting from activities in the economy. Because of its capability EIO-LCA model will be used to assess the total economy and the major environmental issues resulting from the implement of each case study developed in the previous chapter to estimate transmission pipeline growth. The scope of the analysis is to provide additional understanding as to whether or not the total required economic investments from the various scenarios in Chapter 4 result in undue environmental impacts.

The first step in using the EIO-LCA model is to select the model year and country for the industry data. In this research, the 2002 Matlab version of the model is used because it has more flexibility and options than the currently available online model.

The second step consists of modifying the final demand vector to specify the value in dollars of the output demanded by the sector (e.g. the final demand value for producing 1,000 vehicles is $15 million assuming a unit cost of $15,000). The final demand vector (named "final") includes 428 rows each one corresponding to each sector of the model. The 2002 model classifies the entire economy into 428 sectors "…grouping businesses that produce similar goods or services, or that use similar processes" [105]. Two vectors "EIOsecsname" and "EIOsecs", reporting the name and the code assigned to each sector, are used to find the industry sector that produces the output under analysis. The sector descriptions are based on the corresponding NAICS sectors for industry.



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« 2002 EIOLCA Matlab (f...

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annual2.txt
annual3.txt
case1.txt
case2.txt
case3.txt
EIO02.mat
EIOLCA02.m
Readme.doc

EIO02.mat (MAT File)

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3	Vegetable and melon farming	111200	0
4	Tree nut farming	111335	0
5	Fruit farming	1113A0	0
6	Greenhouse and nursery production	111400	0
7	Tobacco farming	111910	0
8	Cotton farming	111920	0
9	Sugarcane and sugar beet farming	1119A0	0
10	All other crop farming	1119B0	0
11	Milk Production	112120	0
12	Cattle ranching and farming	1121A0	0
13	Poultry and egg production	112300	0
14	Animal production, except cattle and ...	112A00	0
15	Logging	113300	0
16	Forest nurseries, forest products, and t...	113A00	0
17	Fishing	114100	0
18	Hunting and trapping	114200	0
19	Agriculture and forestry support activi...	115000	0
20	Oil and gas extraction	211000	0
21	Coal mining	212100	0
22	Iron ore mining	212210	0

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Figure 5.4-1Example of the final demand vector

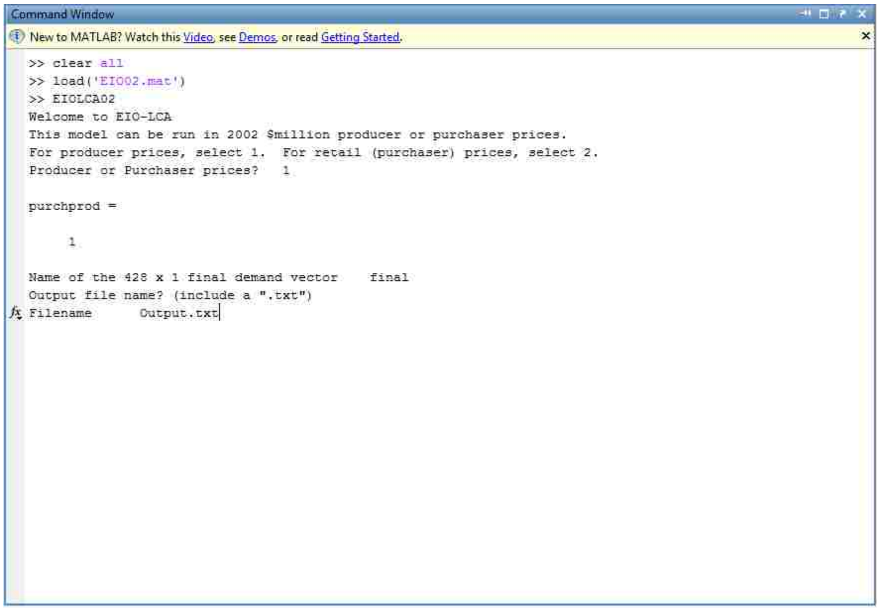
To appropriately asses the total impacts, the unit of the final demand should be a currency-valued input of the same year as that of the model. For example, for the 2002 model the final demand must be expressed in 2002 dollars to account for economic inflation [103]. So to solve this critical point, the economic price index or PPI for a particular sector is used. The following equation shows how to use a price index to convert values from one year to another.

$$\frac{value_1}{value_2} = \frac{Price\ index_1}{Price\ index_2} \tag{5-4}$$

Once the final demand vector is set, the model can be run. After that, several options are submitted:

- Select which model to use: 1 = producer price (industry basis) or 2 = purchaser price (commodity basis). Producer prices are the amount received by a producer from a purchaser, plus any taxes and minus any subsidies. By contrast, purchaser prices are the amount paid by the purchaser and include the cost of delivery (e.g., transportation costs) as well as additional amounts paid to wholesale and retail entities to make it available for sale.
- Enter the name of the final demand vector.
- Enter the name of the output text file.

Finally, after the model runs the results are inserted in an Output text file, as shown in Figure 5.4-2.



```
>> clear all
>> load('EI002.mat')
>> EIOLCA02
Welcome to EIO-LCA
This model can be run in 2002 $million producer or purchaser prices.
For producer prices, select 1.  For retail (purchaser) prices, select 2.
Producer or Purchaser prices?   1

purchprod =

     1

Name of the 428 x 1 final demand vector    final
Output file name? (include a ".txt")
Filename      Output.txt
```

Figure 5.4-2 Input commands

5.5. **Analysis and discussion of simulations results**

5.5.1. EIO-LCA Case study 1 analysis: High CNG infrastructure growth

In this section, the EIO-LCA model is used to examine the total effects on the environment and on the total economy resulting from a significant infrastructure development in the United States to support CNG vehicles. Case Study 1, as described in

Chapter 4, estimated the additional kilometres of natural gas transmission pipelines and the expected costs needed for all the 48 states in the United States to match the current Italian pipeline density.

The critical point in using the EIO-LCA to model the construction of natural gas pipelines in the United States is that the EIO-LCA is based on the "average production" assumption which means that similar production facilities in the country are all assigned to the same production sector. This assumption implies that the analysis could be performed only at national level without considering the regional cost differences in pipeline construction.

However, as mentioned previously, the first step is to select the industry sector most representative of the case under consideration. Among the 428 industry sectors included in the 2002 Model, the one primarily engaged in constructing natural gas pipelines is classified under **"Nonresidential manufacturing structures"** (EIO-LCA code: 230102). This sector does not correspond to a single sector under the NAICS classification but is comprised of one or more NAICS sectors among which is "**237120 Oil and Gas Pipeline and Related Structures Construction**". However, even though the *Nonresidential manufacturing sector* does not comprise only the sector of major interest, it is the most reasonable resolution since there is no method of isolating only data referring to the *Oil and Gas Pipeline and Related structures construction* within the EIO-LCA model.

The NAICS definition of this sector is:

> "*This industry comprises establishments primarily engaged in the construction of oil and gas lines, mains, refineries, and storage tanks. The work performed may include new work, reconstruction, rehabilitation, and repairs. Specialty trade contractors are included in this group if they are engaged in activities primarily related to oil and gas pipeline and related structures construction. All structures (including buildings) that are integral parts of oil and gas networks (e.g. storage tanks, pumping stations, and refineries) are included in this industry.*
>
> Illustrative Examples:
>
> *Distribution line, gas and oil construction, Gas main construction, Gathering line, gas and oil field construction, Natural gas pipeline construction, Natural gas processing plant construction, Oil refinery construction, Petrochemical plant*

> *construction, Pumping station gas and oil transmission construction, Storage tank, natural gas or oil tank farm or field construction."* [104]

Once the sector to analyze has been defined, the following step is to modify the vector of the final demand. As inputs in the final demand vector has been considered the annual expected cost for pipelines construction evaluated in the Case Study 1:

- $ 28,114 million in 2009 dollars

This value is evaluated considering a unit cost of pipeline construction in dollar per inch of diameter per mile [$/inch*mile] equal to $76,000 in 2009 dollars.

However this amount cannot be directly used to estimate the expected costs of construction since the unit of the final demand must be in a currency-valued input of the same year as that of the model. It means that this amount should be converted from $2009 to $2002. In effort to perform this conversion the "Producer Price Indexes" for "Material and Supply Inputs to Construction Industries" have been consulted (see Table 5.5-1 and Figure 5.5-1). These indexes are derived from industry-based, primary product PPIs, and the weights used to develop this model are based on 2002 benchmark input/output relationship data from the Bureau of Economic Analysis (BEA) which is the same reference model of the 2002 EIO-LCA model [106].

For the period 1986 - 2010, activities like oil and gas pipelines and related construction have been classified under the class "material and supply inputs to other heavy construction" [106]. The specification for the series are reported in the following:

- **Series ID:** `NDUBHVY--BHVY—`
- **Industry:** `Material and supply inputs to other heavy construction`
- **Product:** `Material and supply inputs to other heavy construction`
- **Base Date:** June 1986

Table 5.5-1Producer Price Index for material and supply inputs to other heavy construction [107]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2000	137.8	139.0	140.0	139.5	139.3	140.5	140.3	139.8	140.8	140.6	140.4	139.7	139.8
2001	140.1	140.3	139.9	140.5	141.9	141.7	139.7	139.7	140.4	137.9	137.1	136.1	139.6
2002	136.3	136.2	136.7	137.4	137.3	137.5	137.6	137.8	138.1	138.1	137.6	137.4	**137.3**
2003	138.0	138.8	139.2	138.8	138.6	138.9	139.2	139.5	140.3	140.3	140.6	141.0	139.4
2004	143.3	145.3	148.4	151.3	153.8	153.9	155.5	157.9	159.0	161.5	161.2	159.9	154.2
2005	162.3	163.9	166.4	167.4	166.8	167.8	169.8	171.2	174.1	177.1	173.2	174.0	169.5
2006	176.3	175.8	177.8	181.5	184.0	186.4	187.7	188.6	184.4	182.9	182.7	183.5	182.6
2007	182.6	183.9	187.1	190.3	192.6	192.6	194.6	192.3	193.1	193.3	197.4	196.1	191.3
2008	197.9	199.7	205.3	210.1	216.9	222.5	227.3	224.7	225.3	216.0	206.0	198.7	212.5
2009	198.6	195.4	193.7	193.4	195.0	197.3	195.5	198.3	197.4	196.8	198.7	198.6	**196.6**
2010	201.6	200.7	203.9	206.3	207.6	205.9							

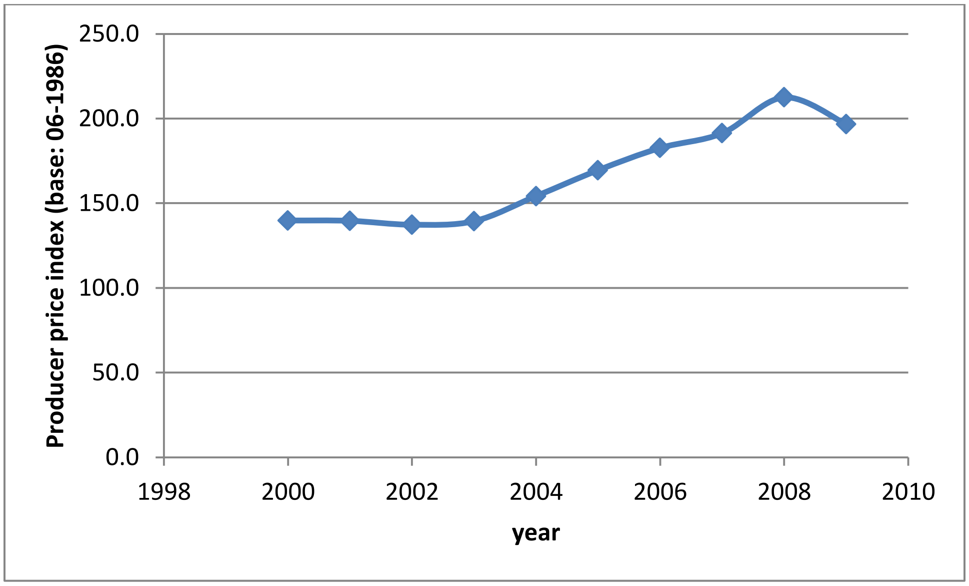


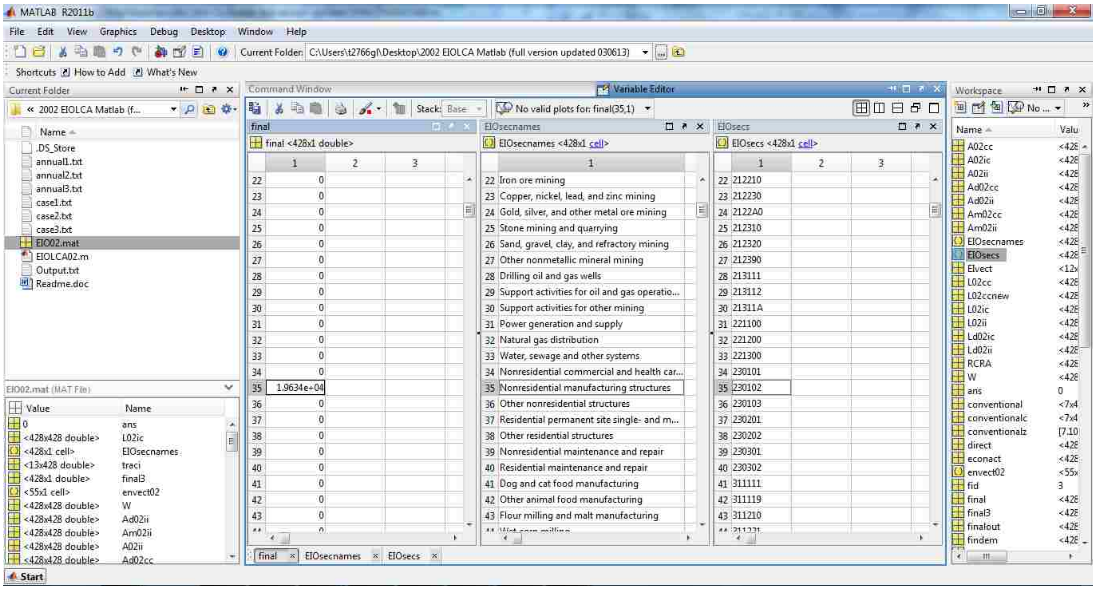
Figure 5.5-1Producer Price Index for material and supply inputs to other heavy construction [107]

Based on these data, the cost of pipeline constructions from currency value in 2009 were converted to that of 2002.

$$\frac{value_1}{value_2} = \frac{Price\ index_1}{Price\ index_2} \tag{5-4}$$

$$\frac{76{,}000}{x} = \frac{196.6}{137.3} \rightarrow x = \$53{,}076\ per\ inch\ mile \tag{5-5}$$

At this point, the adjusted value for 2002 of the annual expected cost of natural gas pipelines construction is $ 19,634.47 million. This value represents the input for the final demand vector that allows one to examine the Case Study 1.



	final <428x1 double>	EIOsecnames <428x1 cell>	EIOsecs <428x1 cell>
22	0	Iron ore mining	212210
23	0	Copper, nickel, lead, and zinc mining	212230
24	0	Gold, silver, and other metal ore mining	2122A0
25	0	Stone mining and quarrying	212310
26	0	Sand, gravel, clay, and refractory mining	212320
27	0	Other nonmetallic mineral mining	212390
28	0	Drilling oil and gas wells	213111
29	0	Support activities for oil and gas operatio...	213112
30	0	Support activities for other mining	21311A
31	0	Power generation and supply	221100
32	0	Natural gas distribution	221200
33	0	Water, sewage and other systems	221300
34	0	Nonresidential commercial and health car...	230101
35	1.9634e+04	Nonresidential manufacturing structures	230102
36	0	Other nonresidential structures	230103
37	0	Residential permanent site single- and m...	230201
38	0	Other residential structures	230202
39	0	Nonresidential maintenance and repair	230301
40	0	Residential maintenance and repair	230302
41	0	Dog and cat food manufacturing	311111
42	0	Other animal food manufacturing	311119
43	0	Flour milling and malt manufacturing	311210

Figure 5.5-2 Final demand vector for construction of $19,634.47 million of transmission pipelines in the U.S.

Once the final demand vector has been defined, the simulation has been run selecting the “Producer price” model. The results, which include both economic and environmental effects, are then imported in an EXCEL sheet for analysis.

5.5.1.1 Economic results

The first part of the analysis interprets the economic effects which are displayed from column C to column I of the EXCEL spreadsheet:

- Total Economic [$mill]
- Total Value Added [$mill]
- Employee compensation [$mill]
- Net Tax Value Added [$mill]
- Profits Value Added [$mill]
- Direct Economy [$mill]
- Direct Economy percentage [%]

The first step in analyzing the result is to sort the table by “Direct Economic” so that sectors are displayed in descending order of direct dollars as shown in Table 5.5-2.

Table 5.5-2 Supply chain economic transaction for construction of $19,634 million of NG pipelines in U.S.,$2002. Top 20 sectors. Results sorted by direct economic output

Code Sector		total econ, $M	Total Value Added	Employee Comp VA	Net Tax VA	Profits VA	direct econ, $M	Direct economy percentage%
	Total, All Sectors	35,256.34	19,500.00	14,600.00	528.00	4,430.00	27,596.25	78%
230102	Nonresidential manufacturing structures	19,634.47	11,675.36	9,911.11	83.42	1,680.83	19,634.47	100%
335120	Lighting fixture manufacturing	1,353.47	565.03	307.20	4.02	253.81	1,335.96	99%
33399A	Fluid power process machinery	897.30	352.88	284.81	3.04	65.03	873.50	97%
420000	Wholesale trade	1,191.07	828.40	449.24	194.06	185.10	679.51	57%
541300	Architectural and engineering services	673.78	419.19	311.38	4.60	103.21	591.17	88%
33299C	Other fabricated metal manufacturing	364.24	161.62	106.46	1.62	53.55	323.16	89%
541100	Legal services	343.97	254.45	145.39	2.13	106.93	250.68	73%
332320	Ornamental and architectural metal products manufacturing	266.54	98.49	79.24	1.61	17.63	237.99	89%
532400	Commercial and industrial machinery and equipment rental and leasing	246.14	136.00	60.98	8.63	66.39	209.95	85%
32712B	Clay and non-clay refractory manufacturing	240.97	83.06	67.56	1.19	14.31	205.24	85%
324110	Petroleum refineries	291.43	23.29	8.34	0.92	14.03	172.12	59%
327320	Ready-mix concrete manufacturing	172.89	57.89	37.81	1.04	19.04	167.50	97%
517000	Telecommunications	310.61	169.34	64.24	23.17	81.94	158.22	51%
531000	Real estate	377.04	297.12	27.73	38.05	231.35	133.65	35%
541200	Accounting and bookkeeping services	188.28	140.38	93.18	1.20	45.99	112.77	60%
332310	Plate work and fabricated structural product manufacturing	118.37	43.75	32.34	0.53	10.88	95.24	80%
333920	Material handling equipment manufacturing	98.78	31.02	27.98	0.29	2.75	89.72	91%
52A000	Monetary authorities and depository credit intermediation	258.78	179.28	72.36	4.07	102.85	88.07	34%
550000	Management of companies and enterprises	598.30	370.36	313.56	9.10	47.70	82.25	14%

The Direct economic effects represent the monetary value purchased by the "Nonresidential manufacturing structures" sector to produce the output required. It is not surprising that sector such as *Fluid power process machinery, Wholesale trade, Architectural and engineering services, Other fabricated metal manufacturing, Monetary authorities and depositary credit intermediation* are in top twenty sectors because they are directly involved in pipeline construction. In addition, the Direct economic effects for the Nonresidential manufacturing structures coincide also with the Total economic effects which means that this sector do not purchase materials within the same sector.

For *Fluid power process machinery*, the Direct Economic effects are $873.5 million, or for every $1 million dollars in pipeline construction, $0.044 million of process machinery are purchased.

For the first row, "Total for all sectors", the Total direct economic effects $27,596.25 include the $19,634.47 million (difference of previous two values) entered in the economy for pipelines construction as well as the $7,961.78 million of purchases made by the sector to produce the required output.

The difference between the output and purchases represents the Value Added to the economy by the sector:

$$Value\ Added_i = Direct\ economic_i - (Total\ Direct\ Economy - Direct\ economic_i) \qquad (5\text{-}6)$$

In this case, the value added by the sector "Nonresidential manufacturing structures" is equal to $11,635.36 million. This value is then split in three different categories as employee compensation, net tax, and profits. By contrast, the total Value Added displayed in the first row includes the VA by the main sector plus the VA by each sector in the economy. This value has an important meaning because allows estimating the total number of employees involved average annually in the sector.

An important consideration is that considering the "Employee compensation" of $9,911.11 million for the "Nonresidential manufacturing structures" sector, and an average annual wage of $35,000 it results that more than 283,000 of workers are involved in the construction of natural gas pipelines.

In order to have a complete picture of the economic effects, it is useful to compare the direct economic effects with the Total Economic Effects. While the direct economic effects includes only the purchases made by the analyzed sector to produce the required output, the total economy adds to this information the estimates of indirect economic effects, or in other words, the complete economic supply chain of purchases needed to produce the desired level of output.

For instance, the Total Economic effects from *Wholesale trade* are $1,191.07 million, while the Direct Economic effects from *Wholesale trade* are $679.51 million. About $511 million of *Wholesale trade* services are required for the purchasing, warehousing, and shipment of the indirect supply chain of goods (e.g., steel from the steel sheet manufacturer to the pipeline manufacturer). The total for all sectors, listed in the first row, is $35,256.34 million. This includes the $19,634.47 million of economic activity entered into the analysis and $15,621.87 million of purchases from all the other sectors in the economy. The overall economic implications appear almost twice the desired output.

Another consideration is that sorting the results by "Total Economic $mill" column, the order of sector changes. In this case, the top twenty includes sectors like *Iron and steel mills, Petroleum refineries* and *Oil and Gas extraction*. Indeed, even if the "Nonresidential manufacturing structures" sector does not make significant use of natural gas or steel, many sectors in the supply chain require steel and energy resources.

To better understand this concept, it is worthwhile to examine the column "Direct Economic Effects by Percentage. This column allows identifying the amount of the economic activity that goes directly to the analyzed sector. For example, in Table 5.5-3, 100% of the economy activity in *Nonresidential manufacturing structures* goes directly to the same sector; 97% of the economy activity in *Fluid process machinery* goes directly to the *Nonresidential manufacturing structures* sector. By contrast, only 2% of the monetary purchases in *Iron and steel mills* are associated to pipeline construction itself. Or in other words 98% of steel mill product is purchased by other sectors in the economy. The same reasoning applies to the *Oil and Gas extraction.* For these reasons, The Direct Economic % is the parameter that distinguishes the proportion of economic impacts that are direct or indirect.

However the strict economic relationship among certain sectors does not reflect strictly in terms of environmental impacts. For example, in effort to reduce the overall life cycle impacts of the *Nonresidential manufacturing structures* sector, it is not certain that changes in the *Fluid process machinery* sector may lead to significant benefits since it may not be the largest generator of emission and wastes in the supply chain.

Table 5.5-3 Supply chain economic transaction for construction of $19,634 million of NG pipelines in U.S.,$2002. Top 20 sectors. Results sorted by total economic output

Code Sector		total econ, $M	Total Value Added	Employee Comp VA	Net Tax VA	Profits VA	direct econ, $M	Direct economy percentage%
	Total, All Sectors	35,256.34	19,500.00	14,600.00	528.00	4,430.00	27,596.25	78%
230102	Nonresidential manufacturing structures	19,634.47	11,675.36	9,911.11	83.42	1,680.83	19,634.47	100%
335120	Lighting fixture manufacturing	1,353.47	565.03	307.20	4.02	253.81	1,335.96	99%
420000	Wholesale trade	1,191.07	828.40	449.24	194.06	185.10	679.51	57%
33399A	Fluid power process machinery	897.30	352.88	284.81	3.04	65.03	873.50	97%
541300	Architectural and engineering services	673.78	419.19	311.38	4.60	103.21	591.17	88%
550000	Management of companies and enterprises	598.30	370.36	313.56	9.10	47.70	82.25	14%
531000	Real estate	377.04	297.12	27.73	38.05	231.35	133.65	35%
33299C	Other fabricated metal manufacturing	364.24	161.62	106.46	1.62	53.55	323.16	89%
541100	Legal services	343.97	254.45	145.39	2.13	106.93	250.68	73%
517000	Telecommunications	310.61	169.34	64.24	23.17	81.94	158.22	51%
324110	Petroleum refineries	291.43	23.29	8.34	0.92	14.03	172.12	59%
211000	Oil and gas extraction	266.65	135.12	17.78	23.81	93.52	12.54	5%
332320	Ornamental and architectural metal products manufacturing	266.54	98.49	79.24	1.61	17.63	237.99	89%
52A000	Monetary authorities and depository credit intermediation	258.78	179.28	72.36	4.07	102.85	88.07	34%
532400	Commercial and industrial machinery and equipment rental and leasing	246.14	136.00	60.98	8.63	66.39	209.95	85%
32712B	Clay and non-clay refractory manufacturing	240.97	83.06	67.56	1.19	14.31	205.24	85%
331110	Iron and steel mills	237.81	64.40	47.20	1.51	15.68	3.88	2%
484000	Truck transportation	212.30	96.46	64.01	3.83	28.61	80.50	38%
221100	Power generation and supply	205.72	140.20	42.76	24.72	72.72	60.68	29%
541200	Accounting and bookkeeping services	188.28	140.38	93.18	1.20	45.99	112.77	60%

5.5.1.2 Environmental results

For environmental impacts, the major categories of interest are the Conventional Air Pollutants, Greenhouse Gases, Energy use and Water Withdrawals.

Conventional Air Pollutants

Conventional air pollutants, regulated under the Clean Air Act, are those pollutants identified by the U.S. Environmental Protection Agency as major health and environmental concerns. The six conventional air pollutants are sulfur dioxide (SO_2), carbon monoxide (CO), nitrous oxides (several pollutants, designated NOx), volatile organic compounds (VOC), lead (Pb), and particulate matter (PM) often identified by their size in micrometers (e.g., PM_{10} or $PM_{2.5}$). The following table 5.4-4 shows the top sectors listed by conventional CO emissions.

Table 5.5-4 Conventional Air Pollutants resulting from the construction of $19,634 million of NG pipelines in U.S.,$2002. Top 10 sectors. Results sorted by CO emissions.

Code Sector		Direct economy percentage %	CO, metric tons	NH3, metric tons	NOX, metric tons	PM10-PRI, metric tons	PM25-PRI, metric tons	SO2, metric tons	VOC, metric tons
	Total, All Sectors	78%	199,135.10	497.62	28,164.70	17,662.22	6,193.20	15,411.13	13,936.58
230102	Nonresidential manufacturing structures	100%	173,590.90	23.52	13,128.88	12,714.16	4,277.96	696.09	8,700.47
532400	Commercial and industrial machinery and equipment rental and leasing	85%	4,236.40	0.26	65.39	13.61	12.03	24.88	344.99
331110	Iron and steel mills	2%	3,343.85	9.53	500.25	139.13	111.36	373.80	113.09
33131A	Alumina refining and primary aluminum production	2%	2,436.72	5.04	105.82	77.52	49.41	775.78	31.65
484000	Truck transportation	38%	1,700.47	4.82	1,794.70	513.04	89.79	36.94	190.79
811400	Household goods repair and maintenance	64%	1,429.16	0.06	20.33	4.37	4.01	1.34	119.35
211000	Oil and gas extraction	5%	1,061.41	0.74	771.29	7.23	6.20	51.91	1,078.16
327310	Cement manufacturing	12%	819.07	2.58	1,196.42	200.10	91.48	879.22	48.79
221200	Natural gas distribution	18%	800.38	0.20	35.48	2.32	2.09	11.46	35.95
33399A	Fluid power process machinery	97%	725.75	4.99	51.44	6.47	4.72	8.31	99.38
420000	Wholesale trade	57%	597.23	1.89	587.66	162.94	30.62	39.95	316.08

The total carbon monoxide emissions from $19,634.47 million of output from the *Nonresidential manufacturing sector* and all the economic transactions across the whole supply chain are 199,135.10 metric tons. Of these carbon monoxide emission, 173,590.9 mt or 87% are emitted by the *Nonresidential manufacturing sector.* Other sectors with high carbon monoxide emissions include *Iron and steel mills* and *Alumina refining and primary aluminum production.* However, only 2% of the outputs from these two sectors are directly purchased by the *Nonresidential manufacturing sector* and so only 2% of those emissions can be attributed to the pipelines construction for its use of steel and aluminum.

The results of the EIO-LCA can be starting points to identify potential changes in the supply chain to reduce environmental effects. For example, if reducing the CO emissions is a primary goal for the analysis, an initial focus may be to scan all the sources of CO emissions in the sector and develop new ways of reducing or removing those emissions.

The same concepts may be applied to assess the other conventional pollutant emissions. In particular, the *Nonresidential manufacturing sector* is the primary source of emission for all the considered pollutants except for NH_3 and sulfur dioxide.

However, another interesting idea is to compare the total emissions for each of the conventional air pollutants regulated by the EPA with the average annual emissions reported in the National Emission Inventory (NEI) [108].

Table 5.5-5Comparison of Air Pollutants Emissions between EIO-LCA and NEI model

	EIO-LCA			**NEI** [108]
	metric tons	***short tons**	**Percentage of NEI**	**short tons**
CO	199,135.10	219,505.18	0.30%	73,433,039.18
NO_x	28,164.70	31,045.75	0.24%	13,119,179.56
PM_{10}	17,662.22	19,468.94	0.09%	20,860,781.30
PM_{25}	6,193.20	6,826.72	0.11%	6,258,732.95
SO_2	15,411.13	16,987.58	0.33%	5,170,010.33
VOC	13,963.58	15,391.95	0.09%	17,743,911.82
NH_3	497.62	548.52	0.01%	4,308,338.13

Conversion: 1 short ton = 0.9072 metric ton

The table 5.4-5 shows that even if the *Nonresidential manufacturing sector* has the greatest impact on the environment in term of conventional pollutants emissions, the estimated overall emissions result almost insignificant compared to the average annual emissions in the United States.

Water use

EIO-LCA estimates that 69% of total water withdrawals come from *Power generation and supply.* However, as mentioned before, only 29% of the 52 billion of Gallons of water can be attributed to the direct use from the *Nonresidential manufacturing sector*. In order to use the same measuring meter, it is beneficial to compare the total water use with the annual U.S. consumption. The USGS water school reported that at the end of 2005 the U.S. accounted for 410 billion gallons/day, or almost 150 trillion gallons/year [109]. Based on these data, the total water use estimated by the EIO-LCA represents only the 0.05 % of the annual water use in the U.S. which may be considered an almost insignificant value.

Energy use and GHG emissions

EIO-LCA estimates total supply chain energy use in pipelines network developments of 122,330 TJ per year. About 50% of that energy use (46,904.2 TJ) comes from energy needed in all the activities related to the *Nonresidential manufacturing* sector and about 20% from *power generation and supply* sector. Most of the coal used in the supply chain is for generating power while the requirements for the *Nonresidential manufacturing* sector is less than 0.001 TJ. By contrast, Table 5.5-6 shows that 21% of total NG use comes from *Nonresidential manufacturing* sector while 15% from power generation.

Also in this case it is worthwhile to assess how the overall process impacts on the average annual energy use. The U.S. Energy Information Administration reported that the total energy use at the end of 2013 was 97.53 quadrillion BTU (about 103 millions TJ) [110]. It means that the total supply energy use is less than 1% of the total U.S. energy and so will be insignificant for a single industrial activity.

For the GHG emissions, even if the *Nonresidential manufacturing sector* has the greatest impact with almost 2.92 million metric tons of $CO_{2eq,}$ the overall emissions prove to be almost insignificant compared to the average annual emissions in the United States. The total GHG emissions from all the sectors of the United States at the end of 2012 totaled 6,526 million metric tons CO_{2eq} [111]. Thus, developing of a 20 years base national plan aimed to promote the development of the natural gas transmission pipelines network presents limited impacts on the environment.

Table 5.5-6 Supply chain energy requirements, GHG emissions and water use from the construction of $19,634 million of NG pipelines in U.S.,$2002. Top 20 sectors. Results sorted by total energy.

Code Sector		Total Energy, TJ	Coal, TJ	Natural gas, Gm^3	Petroleum, TJ	Biomass /Waste, TJ	Nonfossil Electricity , TJ	GHG Emissions, millions of mt CO2e	Water use, kGal
	Total, All Sectors	122,330.28	24,200.68	0.77	52,805.37	3,907.17	11,867.24	8.59	75,936,025.79
230102	Nonresidential manufacturing structures	46,904.20	0.00	0.16	38,201.02	0.00	2,397.68	2.91	1,851,858.42
221100	Power generation and supply	22,367.19	16,289.29	0.12	791.29	0.00	523.01	1.84	52,165,159.72
331110	Iron and steel mills	7,785.62	4,617.49	0.06	75.43	32.33	937.52	0.67	978,154.82
324110	Petroleum refineries	4,997.65	1.63	0.03	3,238.06	245.46	177.93	0.30	195,691.45
484000	Truck transportation	2,777.89	0.00	0.00	2,751.50	0.00	26.39	0.20	10,631.91
327310	Cement manufacturing	2,520.32	1,520.08	0.00	404.94	230.50	233.97	0.44	3,929.60
211000	Oil and gas extraction	2,502.11	0.00	0.05	212.85	0.00	245.33	0.42	17,245.71
32712B	Clay and non-clay refractory manufacturing	1,928.68	313.87	0.03	234.09	27.76	260.28	0.10	70,746.96
325190	Other basic organic chemical manufacturing	1,598.30	199.71	0.02	220.80	481.29	86.19	0.07	482,149.32
322130	Paperboard Mills	1,586.92	144.10	0.01	67.71	939.26	109.45	0.03	1,247,835.22
33131A	Alumina refining and primary aluminum production	1,444.54	0.00	0.01	12.14	36.09	1,011.41	0.09	8,793.65
325211	Plastics material and resin manufacturing	1,131.04	47.41	0.02	245.52	120.22	128.63	0.05	13,767.77
322120	Paper mills	1,119.28	151.02	0.01	73.97	552.73	113.48	0.03	225,133.48
420000	Wholesale trade	1,040.22	4.73	0.01	601.84	0.00	236.72	0.04	83,429.88
335120	Lighting fixture manufacturing	1,016.85	0.00	0.02	24.85	14.60	351.81	0.03	110,344.53
481000	Air transportation	1,013.24	0.00	0.00	1,011.73	0.00	1.51	0.07	554.29
486000	Pipeline transportation	949.95	0.00	0.02	0.00	0.00	227.95	0.08	0.00
325110	Petrochemical manufacturing	736.23	10.07	0.01	282.07	122.57	32.73	0.04	132,329.48
33399A	Fluid power process machinery	718.01	3.96	0.01	6.17	12.02	334.83	0.02	93,600.90
33299C	Other fabricated metal manufacturing	688.29	5.92	0.01	37.07	3.20	201.33	0.03	31,738.43

5.5.2. EIO-LCA Case study 2 analysis: Limited CNG infrastructure growth

Based on the same procedure adopted in the previous section, this analysis assesses the economic and the environmental impacts resulting from the potential implementation of the Case Study 2. As defined in the Chapter 4, this case study estimates the additional kilometres of natural gas transmission pipelines and the expected costs needed to match the Italian level of pipeline density only for those states that have been identified as “high potential markets” for CNG developments.

However, because of the assumption of linearity between inputs and outputs, the outcomes of this analysis result scaled by a constant factor equal to the ratio between the previous and the actual final demand. Indeed, the only input that changes is the required level of economic activities.

Despite this assumption, the annual expected costs expressed in Chapter 4 in 2009 dollars have been converted to 2002 dollars so that they can be inserted as inputs (desired level of output for the sector analyzed) for the final demand vector. By adopting the equations (5-4) and (5-5), the adjusted values for the unit cost of pipeline construction and for the annual expected costs are estimated to be:

- Cost of construction of a transmission pipeline in \$2002 = \$53,076 per inch-mile. To provide clarity, a 24 inch diameter pipeline at a cost of \$100,000 per inch-mile would cost \$2,400,000 per mile.
- Adjusted value in 2002 dollars for the \$10,027 million in 2009 dollars = \$7,002.53 million in 2002 dollars

Computationally, the results are scaled by a factor equal to the ratio between the two levels of final demand.

$$\frac{final\ demand_2}{final\ demand\ _1} = \frac{\$7{,}002.53}{\$19{,}634.47} = 0.35 = 35\% \qquad (5\text{-}7)$$

5.5.2.1 ***Economic results***

First the economic results are considered. From table 5.5-7, a final demand of \$7,002 million requires total economic activity in the supply chain of \$12,573.99 million. This value is 65% lower than the one obtained for the Case 1 (\$35,256.34 million).

It is important to recall that in the total economic output column are the direct and indirect purchases for each sector while the first row reports the sums across all of the sectors to present the total.

Table 5.5-7 Supply chain economic transaction for constructing $7,002 million of NG pipelines in U.S.,$2002. Top 20 sectors. Results sorted by direct economic output

Code Sector		total econ, $M	Total Value Added	Employee Comp VA	Net Tax VA	Profits VA	direct econ, $M	Direct economy percentage %
	Total, All Sectors	12,573.99	6,960.00	5,190.00	188.00	1,580.00	9,842.06	78%
230102	Nonresidential manufacturing structures	7,002.53	4,163.96	3,534.74	29.75	599.46	7,002.53	100%
335120	Lighting fixture manufacturing	482.71	201.52	109.56	1.43	90.52	476.46	99%
33399A	Fluid power process machinery	320.02	125.85	101.57	1.09	23.19	311.53	97%
420000	Wholesale trade	424.79	295.44	160.22	69.21	66.01	242.34	57%
541300	Architectural and engineering services	240.30	149.50	111.05	1.64	36.81	210.84	88%
33299C	Other fabricated metal manufacturing	129.90	57.64	37.97	0.58	19.10	115.25	89%
541100	Legal services	122.68	90.75	51.85	0.76	38.13	89.41	73%
332320	Ornamental and architectural metal products manufacturing	95.06	35.13	28.26	0.58	6.29	84.88	89%
532400	Commercial and industrial machinery and equipment rental and leasing	87.79	48.50	21.75	3.08	23.68	74.88	85%
32712B	Clay and non-clay refractory manufacturing	85.94	29.62	24.09	0.43	5.10	73.20	85%
324110	Petroleum refineries	103.94	8.31	2.97	0.33	5.00	61.39	59%
327320	Ready-mix concrete manufacturing	61.66	20.65	13.48	0.37	6.79	59.74	97%
517000	Telecommunications	110.78	60.40	22.91	8.26	29.22	56.43	51%
531000	Real estate	134.47	105.97	9.89	13.57	82.51	47.67	35%
541200	Accounting and bookkeeping services	67.15	50.06	33.23	0.43	16.40	40.22	60%
332310	Plate work and fabricated structural product manufacturing	42.21	15.60	11.53	0.19	3.88	33.97	80%
333920	Material handling equipment manufacturing	35.23	11.06	9.98	0.10	0.98	32.00	91%
52A000	Monetary authorities and depository credit intermediation	92.29	63.94	25.81	1.45	36.68	31.41	34%
550000	Management of companies and enterprises	213.38	132.09	111.83	3.24	17.01	29.33	14%
484000	Truck transportation	75.71	34.40	22.83	1.37	10.20	28.71	38%

As expected the order of sectors is identical to the table 5.5-2 as well as also the percentage of Direct economic over total economy since the process involved are the same. The only difference is that the monetary values that are scaled down by 65%. The value added by the *Nonresidential manufacturing structures* sector is in this case equal to $4,163 million compared to $11,675 million. The change in GDP as a result of this economic activity would be only $7,002 million, since GDP measures only changes in final output, not of all purchases of intermediate goods (i.e., not $12,573 million). The majority of top 20 sectors have a direct percentage higher than 80%. Sectors with small direct purchase percentage are involved in supplying the indirect supply chain of the *oil and gas pipeline and related structures construction* rather than pipelines construction directly.

5.5.2.2 ***Environmental results***

Finally, this case is less energy intensive and produces less environmental impacts than the case 1 since the results are scaled down by 65%.

Table 5.5-8 Supply chain energy requirements, GHG emissions and water use from the construction of $7,002 million of NG pipelines in U.S.,$2002. Top 10 sectors. Results sorted by total energy.

Code Sector		Direct economy percentage%	Total Energy, TJ	Coal, TJ	Natural gas, Gm^3	Petroleum, TJ	Nonfossil Electricity , TJ	GHG Emissions , millions of mt CO2e	Water use, kGal
	Total, All Sectors	78%	43,628.45	8,631.05	0.28	18,832.76	4,232.39	3.06	27,082,182.44
230102	Nonresidential manufacturing structures	100%	16,728.13	0.00	0.06	13,624.19	855.12	1.04	660,455.52
221100	Power generation and supply	29%	7,977.14	5,809.49	0.04	282.21	186.53	0.65	18,604,428.63
331110	Iron and steel mills	2%	2,776.70	1,646.80	0.02	26.90	334.36	0.24	348,853.75
324110	Petroleum refineries	59%	1,782.39	0.58	0.01	1,154.84	63.46	0.11	69,792.32
484000	Truck transportation	38%	990.72	0.00	0.00	981.31	9.41	0.07	3,791.81
327310	Cement manufacturing	12%	898.86	542.13	0.00	144.42	83.44	0.16	1,401.47
211000	Oil and gas extraction	5%	892.36	0.00	0.02	75.91	87.50	0.15	6,150.59
32712B	Clay and non-clay refractory manufacturing	85%	687.85	111.94	0.01	83.49	92.83	0.04	25,231.53
325190	Other basic organic chemical manufacturing	2%	570.02	71.23	0.01	78.75	30.74	0.02	171,956.01
322130	Paperboard Mills	5%	565.97	51.39	0.00	24.15	39.04	0.01	445,033.84

Table 5.5-9 Conventional Air Pollutants resulting from the construction of $7,002 million of NG pipelines in U.S.,$2002. Top 10 sectors. Results sorted by CO emissions

Code Sector		Direct economy percentage %	CO, metric tons	NH3, metric tons	NOX, metric tons	PM10-PRI, metric tons	PM25-PRI, metric tons	SO2, metric tons	VOC, metric tons
	Total, All Sectors	78%	71,020.48	177.47	10,044.79	6,299.14	2,208.77	5,496.30	4,970.41
230102	Nonresidential manufacturing structures	100%	61,910.28	8.39	4,682.35	4,534.44	1,525.71	248.26	3,102.98
532400	Commercial and industrial machinery and equipment rental and leasing	85%	1,510.89	0.09	23.32	4.85	4.29	8.87	123.04
331110	Iron and steel mills	2%	1,192.57	3.40	178.41	49.62	39.72	133.31	40.33
33131A	Alumina refining and primary aluminum production	2%	869.04	1.80	37.74	27.65	17.62	276.68	11.29
484000	Truck transportation	38%	606.46	1.72	640.07	182.97	32.02	13.17	68.05
811400	Household goods repair and maintenance	64%	509.70	0.02	7.25	1.56	1.43	0.48	42.57
211000	Oil and gas extraction	5%	378.54	0.27	275.07	2.58	2.21	18.51	384.52
327310	Cement manufacturing	12%	292.12	0.92	426.70	71.36	32.63	313.57	17.40
221200	Natural gas distribution	18%	285.45	0.07	12.65	0.83	0.75	4.09	12.82
33399A	Fluid power process machinery	97%	258.84	1.78	18.35	2.31	1.68	2.96	35.44

As in Case Study 1, it is noteworthy to compare the conventional pollutants emissions estimated by the EIO-LCA against the data provided by NEI (refer to Table 5.5-10). As expected, the percentages, that were almost insignificant in the previous case - are even lower in this case, implying that infrastructure network development may occur without significant impact and after effects on the environment. Finally, in tables 5.5-8 and 5.5-9, only top 10 sectors are shown rather than top 20 sectors for brevity. These tables are intended only to confirm that the sectors order is the same of the previous case and that results are scaled by a constant factor.

Table 5.5-10 Comparison of Air Pollutants Emissions between EIO-LCA and NEI model

	EIO-LCA				**NEI** [108]
	Case study 1		**Case study 2**		
	***short tons**	**Percentage**	***short tons**	**Percentage**	**short tons**
CO	219,505.18	0.30%	78,284.83	0.11%	73,433,039.18
NO_x	31,045.75	0.24%	11,071.43	0.08%	13,119,179.56
PM_{10}	19,468.94	0.09%	6,943.50	0.03%	20,860,781.30
PM_{25}	6,826.72	0.11%	2,434.71	0.04%	6,258,732.95
SO_2	16,987.58	0.33%	6,058.53	0.12%	5,170,010.33
VOC	15,391.95	0.09%	5,478.85	0.03%	17,743,911.82
NH_3	548.52	0.01%	195.62	0.00%	4,308,338.13

****Conversion 1 short ton = 0.9072 metric ton. The results of EIO-LCA are in metric tons.***

To comprehensively assess the environmental impacts estimated by the EIO-LCA, more supporting arguments need to be added. First of all, it is worthwhile to compare the GHG emissions estimated by the EIO-LCA with the direct emissions from natural gas infrastructure rather than with the total GHG from all sector in U.S. In 2011, methane emissions from transmission pipelines and distribution network totaled 44 and 27 million metric tons of CO_{2eq} respectively [56]. These numbers show that the 3.06 million metric tons of CO_{2eq} expected from infrastructure growth is only a very small value: natural gas transmission pipeline expansion is not the major cause of greenhouse gas emissions. The majority of all GHG emissions from natural gas infrastructure are due to leaked emissions rather than infrastructure construction. Interestingly, the natural gas used in the transportation sector resulted in 40.1 million metric tons of CO_{2eq}, over a total 1,746 million metric tons of CO_{2eq} emitted by all fuels in transportation sector [56]. At this time, two points should be noted. Because of a similar value of emissions from natural gas transmission pipelines and natural gas used in transportation, greater attention should be paid in technologies and process improvements aimed at reducing methane emissions during the transmission phase. The Federal Natural Gas STAR program has launched initiatives to identify technical and engineering solutions to vented and leaked emissions including improved valves, resistant coatings as well as improved leak detection. Lastly, 3.06 million metric tons of CO_{2eq} may be an acceptable compromise if the infrastructure growth leads to a significant increment in NGVs acceptance and corresponding reduction in vehicle emissions.

Table 5.5-11 represents a "GHG emissions flow" table which reports the estimated total GHG emissions resulting from expanding the NG pipeline network in the U.S. over a 20 year span. To evaluate the expected GHG emissions from the NG transmission and distribution phase by the 2034, a proportional analysis has been used:

Current GHG emissions: Current Km of pipelines= (5-8)

= Exp. Emissions :Estimated km of pipelines.

Based on the equation (5-8) and assuming that the technology for transmission and distribution pipelines will remain the same for the next 20 years, the GHG emissions from 558,709 km of pipelines (447,158 km of current infrastructures plus 141,551 of additional km of pipelines) will amount to 58 and 34 million tons of CO_{2eq} respectively. This corresponds to a 1.3% annual increment on 20 years basis. Furthermore, to estimate the GHG emissions from NG used in the transportation sector by 2034, it has been assumed an annual increment in NGVs sales of 12% which corresponds to more than 1 million vehicles on the U.S. road by 2034 and a total GHG emissions of 387 million tons of $CO_{2eq.}$

Table 5.5-11GHG emissions cash flow

	Current emissions [million metric tons of CO_{2eq}]	**Annual increment %**	**Estimated emissions by 2034 [million metric tons of CO_{2eq}]**
NG transmission	44	1.3*	57.93
NG distribution	27	1.3*	33.74
NG pipeline construction	3.06*	-	61.6
NGVs	40.1	12	387
Total	114.16		539.27

*estimated by EIO-LCA

The 12% annual growth rate in the NGVs sales is based on the same assumption made to calculate the Figure 4.5-3, which is the assumption that NG vehicle growth parallels the

12% annual increase experienced in Italy. From this table, the total GHG emissions resulting from NG pipeline constructions, methane leakages during transmission and distribution phase, and NG used in transportation sector represent only the 30% of the emissions produced by burning gasoline and diesel fuel (1,746 million tons of CO_{2eq}). As a result, even though it is expected that there will be a substantial increment of the overall emissions as a consequence of the NG transmission pipeline expansion, their value is still substantially lower when compared to the environmental impacts from gasoline and diesel usage.

5.5.3. EIO-LCA Case study 3 analysis: Proportional CNG infrastructure growth

This section estimates the total economy transactions and environmental effects resulting from Case Study 3. This latter differs from the previous ones in the way it has been defined. As reported in Chapter 4, this analysis considers two different standards: Italy as the high reference, and California as medium reference. The analysis evaluates the impacts of the additional kilometres of natural gas transmission pipelines needed to reach the level of pipeline density in Italy or California. The decision criterion is the current level of pipeline density in each State. For states with a pipelines density lower than California, the target is assumed to be California, whereas for states with an actual pipeline density between the two extremes the target has been assumed to be Italy.The reason why California has been assumed, in this case, to be the threshold between the low-medium and medium-high potential states is because it represents the most advanced status in the U.S. either as number of NGVs or as available infrastructures.

The procedure followed and the assumptions used during the simulation are the same of the previous two cases. The only difference is the adjusted value in 2009 dollars of the annual expected costs for pipelines construction. By using the producer price indexes reported by the BEA, the corrected value to be inserted into the final demand vector is $6,807.62 million.

This value is just 3% lower than the required final demand for the Case Study 2. So the results of the analysis are almost identical to the previous case. The following tables, 5.5-12 through 5.5-14, report the comprehensive economic and environmental effects for the top 10 sectors.

Table 5.5-12 Supply chain economic transaction for construction of $6,807 million of NG pipelines in U.S.,$2002. Top 10 sectors. Results sorted by direct economic output

Code Sector		total econ, $M	Total Value Added	Employee Comp VA	Net Tax VA	Profits VA	direct econ, $M	Direct economy percentage%
	Total, All Sectors	12,224.00	6,770.00	5,050.00	183.00	1,530.00	9,568.11	78%
230102	Nonresidential manufacturing structures	6,807.62	4,048.06	3,436.36	28.92	582.77	6,807.62	100%
335120	Lighting fixture manufacturing	469.27	195.91	106.51	1.39	88.00	463.20	99%
33399A	Fluid power process machinery	311.11	122.35	98.75	1.06	22.55	302.86	97%
420000	Wholesale trade	412.96	287.22	155.76	67.28	64.18	235.60	57%
541300	Architectural and engineering services	233.61	145.34	107.96	1.59	35.79	204.97	88%
33299C	Other fabricated metal manufacturing	126.29	56.04	36.91	0.56	18.57	112.04	89%
541100	Legal services	119.26	88.22	50.41	0.74	37.07	86.92	73%
332320	Ornamental and architectural metal products manufacturing	92.42	34.15	27.48	0.56	6.11	82.52	89%
532400	Commercial and industrial machinery and equipment rental and leasing	85.34	47.15	21.14	2.99	23.02	72.79	85%
32712B	Clay and non-clay refractory manufacturing	83.55	28.80	23.42	0.41	4.96	71.16	85%

Table 5.5-13 Supply chain energy requirements, GHG emissions and water use from the construction of $6,807 million of NG pipelines in U.S.,$2002. Top 10 sectors. Results sorted by total energy

Code Sector		Direct economy percentage%	Total Energy, TJ	Coal, TJ	Natural gas, Gm^3	Petroleum, TJ	Nonfossil Electricity, TJ	GHG Emissions, millions of mt CO2e	Water use, kGal
	Total, All Sectors	78%	42,414.08	8,390.81	0.27	18,308.56	4,114.58	2.98	26,328,370.86
230102	Nonresidential manufacturing structures	100%	16,262.52	0.00	0.06	13,244.97	831.32	1.01	642,072.25
221100	Power generation and supply	29%	7,755.10	5,647.79	0.04	274.36	181.34	0.64	18,086,588.77
331110	Iron and steel mills	2%	2,699.41	1,600.97	0.02	26.15	325.06	0.23	339,143.68
324110	Petroleum refineries	59%	1,732.77	0.56	0.01	1,122.69	61.69	0.10	67,849.71
484000	Truck transportation	38%	963.14	0.00	0.00	953.99	9.15	0.07	3,686.27
327310	Cement manufacturing	12%	873.84	527.04	0.00	140.40	81.12	0.15	1,362.46
211000	Oil and gas extraction	5%	867.53	0.00	0.02	73.80	85.06	0.14	5,979.39
32712B	Clay and non-clay refractory manufacturing	85%	668.71	108.83	0.01	81.16	90.24	0.04	24,529.23
325190	Other basic organic chemical manufacturing	2%	554.16	69.24	0.01	76.56	29.89	0.02	167,169.74
322130	Paperboard Mills	5%	550.21	49.96	0.00	23.48	37.95	0.01	432,646.67

Table 5.5-14 Conventional Air Pollutants resulting from the construction of $6,807 million of NG pipelines in U.S.,$2002. Top 10 sectors. Results sorted by CO emissions

Code Sector		Direct economy percentage%	CO, metric tons	NH3, metric tons	NOX, metric tons	PM10-PRI, metric tons	PM25-PRI, metric tons	SO2, metric tons	VOC, metric tons
	Total, All Sectors	78%	69,043.68	172.53	9,765.20	6,123.81	2,147.29	5,343.31	4,832.06
230102	Nonresidential manufacturing structures	100%	60,187.05	8.15	4,552.02	4,408.23	1,483.24	241.35	3,016.61
532400	Commercial and industrial machinery and equipment rental and leasing	85%	1,468.83	0.09	22.67	4.72	4.17	8.63	119.62
331110	Iron and steel mills	2%	1,159.37	3.30	173.45	48.24	38.61	129.60	39.21
33131A	Alumina refining and primary aluminum production	2%	844.85	1.75	36.69	26.88	17.13	268.98	10.97
484000	Truck transportation	38%	589.58	1.67	622.25	177.88	31.13	12.81	66.15
811400	Household goods repair and maintenance	64%	495.52	0.02	7.05	1.52	1.39	0.46	41.38
211000	Oil and gas extraction	5%	368.01	0.26	267.42	2.51	2.15	18.00	373.82
327310	Cement manufacturing	12%	283.99	0.90	414.82	69.38	31.72	304.84	16.92
221200	Natural gas distribution	18%	277.51	0.07	12.30	0.80	0.73	3.97	12.46
33399A	Fluid power process machinery	97%	251.63	1.73	17.84	2.24	1.64	2.88	34.46

5.6. ***Synopsis of EIO-LCA application***

The EIO-LCA results estimate that environmental impacts resulting from each of the three case scenarios are significantly below the average annual energy consumption and annual conventional air pollutants emissions in the Unites States. This suggests that the planned natural gas infrastructure growth could proceed without significant impacts on the economy and overall environment.

The main limitation of the EIO-LCA is that models are built upon average values for sectors and environmental issues. Indeed, the development of a wider database that takes into account the differences between states, or even better discrepancies within states, would add significant accuracy to the analysis. However, this limitation is offset by the comprehensiveness of a national, economy wide analysis which includes all the supply chain aspects that would be ignored by a process based or even small scaled model due to the necessity to define modeling boundaries.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Methodology summary

This thesis researched the various infrastructure factors and related conditions necessary to stimulate the growth of CNG as a vehicle fuel and to expand CNG usage in the United States, and estimated the corresponding environmental and economic effects. In order to achieve that goal, two complementary analyses were undertaken.

The first one compared and contrasted defined case study scenarios to create a multiple variable matrix that itemized for each US state a series of significant parameters that summarize the current state of the art of CNG implementation in the United States. This was used as a starting point to assess the gaps with respect to a researched and defined reference model (i.e., Italy) to identify potential case scenarios that would simulate alternative approaches to implementing widespread CNG adoption. However, this approach had several limitations since it did not include an economic analysis of the sectors involved in the growth of CNG as a vehicle fuel, and also did not account for the environmental impacts resulting from these case studies. This analysis did however provide a solid basis for defining the scope and case studies as well as building the arguments for how CNG adoption could be assessed.

The second part of the analysis used the economic input-output life cycle modeling approach. This tool evaluated the resulting overall transactions across the supply chain and their economic and environmental impacts. The EIO-LCA models were developed in Matlab and each case study simulated from the indications obtained from the case study comparison analysis. The scope of this approach was to assess the feasibility of the study from the economic and environmental perspective.

6.2. Compare and contrast analysis summary

The findings from the first analysis are summarized below:

- Natural gas resources are not evenly distributed across the United States but there are States such as Oklahoma, Texas, Utah and California that have superior, proven reserves of NG and already available transmission pipelines.
- Some states have a higher penetration of CNG because of both availability and significant incentives or initiatives by government.

- The home refuelling appliance for CNG vehicles can help stimulate CNG adoption especially in markets or states with currently low CNG adoption.
- The first three case studies assess three different scenarios for the natural gas transmission network. Case Study 1 (High CNG infrastructure growth case) is likely infeasible because it does not account for important discrepancies between states. Case Study 2 (Limited CNG infrastructure growth case) and Case Study 3 (Proportional CNG infrastructure growth case) results in more realistic scenarios since the estimated investment to achieve the infrastructure are supported by estimates within the literature and alternative analyses.
- The lack of CNG stations may be offset by significant development of HRA. However, once the level of available infrastructure becomes consistent, the influence of HRA should lessen.
- Three additional case studies assessed the required number of CNG stations in the United States. In particular, the total number of CNG stations estimated by Case Study 4 (High CNG stations growth case) reflects what would be needed to reach the minimum ratio of current diesel-to-gasoline stations, based on the assumption that the proportionality of diesel infrastructure represents a desirable level of CNG penetration.
- The VRI in certain states shows that there is an opportunity for OEMs since there are readily available CNG stations but a low number of vehicles. For instance, for Oklahoma and Utah to reach the target VRI of 879 (Italian reference model), based on the current infrastructure level, an additional 80,000 CNG vehicles would have to be added. Should there be a social demand or incentive to stimulate such an increase, there could be significant opportunities for OEMs to increase CNG vehicle sales.

6.3. **EIO-LCA findings**

The EIO-LCA analysis supports the findings reached by the first analysis. The EIO-LCA was chosen over a process based life cycle assessment because it provides an overview of the total economy and environmental burdens with less effort in scoping process boundaries. The outcomes from the simulations performed with this model include:

- The strict economic relationship among certain sectors is not reflected strictly in terms of environmental impacts. For instance, *Lighting fixture manufacturing* sector is the second more influent sector in term of direct economy but it is not even among the top ten sectors with respect to the conventional pollutants emissions.
- The *"Nonresidential manufacturing structure*" sector, primarily engaged in pipeline constructions, is the most energy intensive sector and the main source of conventional pollutants emissions and greenhouse gases.
- The three simulations estimate that the conventional pollutants emissions resulting from the implement of each the developed case study range from 0.01 to 0.3% compared to the average annual emission reported in the National Emission Inventory (NEI).
- The estimated annual GHG emissions from all activities associated with natural gas pipeline construction account only for 0.04% or less of the 6,526 million tons $CO2_{eq}$ reported at the end of 2012 in all of the U.S. Instead, the more important comparison uses the annual GHG emissions from the operation of natural gas transmission pipelines and distribution networks in the U.S. They are already currently reported by the EPA to emit 44 and 27 million tons of CO_{2eq} respectively on an annual basis. In other words, the results of the EIO-LCA suggest that the construction from expanding the pipeline network could proceed without significant impacts on the overall environment, and that more environmental effort should be directed towards preventing, controlling, and managing emissions from transmission and distribution.
- More detailed analysis could be accomplished with the EIO-LCA model if there was greater in-depth data at the state level, rather than just the national level.

6.4. **Recommendations**

The expansion of Compressed Natural Gas as main fuel for transportation on the U.S. roads appears to be a tangible reality. Currently, a number of different states have already launched programs to capitalize on CNG opportunities. However, it is unlikely that such opportunities would be similar in all states through the U.S. As with other alternative fuel choices, such as hybrid electric vehicles, the growth it is expected to start from select markets characterized as early adopters or pioneers in areas such as California or New York. These markets will likely play a leading role in pushing this alternative fuel in other states.

The development of cheap and reliable home refueling appliances offered together with a wider range of NGVs may stimulate customers to adopt CNG vehicles. The 65 million houses which have available natural gas represent 65 million potential customers. Assuming the same growth rate experienced in Italy after the introduction of the NG National Plan, it would take 24 years in the U.S. to reach a healthy level of infrastructure without HRA penetration. As with HEVs, the potential to refill the vehicle at home would entice more customers leading to a higher degree of NGV adoption. This process could have a double benefit because the higher the number of HRA units, the lower the number of CNG stations possibly required within cities. This aspect would require further research because the only marketed HRA device had previous quality and reliability issues whereas a new project is at design stage and expected to be available in 2015.

Further analysis is also needed on the discrepancies within each of the states. Each state, for example, differs from the Italian reference model because there are areas with a low population density and thus a corresponding low predisposition to stimulate CNG adoption. If the necessary data sets are available, the simulations could be repeated including only those counties within states that show reasonable capacity for investing into CNG infrastructure and usage. The benefit of this analysis would be that instead of considering each state as a unique element and then estimating the infrastructure needed on the whole state, a more focused approach would allow concentrating the resources only on significant areas, resulting so in less investments and resource needed. An example of this scenario would be California: as a state, it has significant natural gas infrastructure, but this infrastructure is concentrated in the interior rather than on the west coast.

Finally, there are other aspects that could be investigated that would support investments in CNG including: 1) greater understanding of the economic opportunities in North America change in the near future; 2) the growing desire to reduce the annual expenditure of $330 billion for foreign oil; and 3) improving technology to reduce the venting of methane at the point of production, which currently represents the weakest environmental control across the whole supply chain of natural gas.

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APPENDICES

Appendix A: National Gas Plan, 2001

The National gas plan introduced in the 2001 is defined as a program agreement between three main actors: the Ministry of the Environment, Fiat SpA and Union Oil [112].

The premises that have led to this agreement are summarized below:

- 31-07-1996: Fiat Spa & Government signed a program aimed to improve the urban environmental conditions by means of Research activities, production and introduction of vehicles with low environmental impact;
- By the end of 1996: Fiat Spa has invested in the development and industrialization of innovative natural gas vehicles;
- April 1997: ENI-Fiat signed a collaboration agreement for the development of the natural gas filling stations network;
- 1998-2000:
    - preliminary results that showed the high potential of this type of fuel;
    - Fiat Spa introduced CNG bi-fuel vehicles in both in LDV market and public transport sector;
    - ENI stimulated the growth of new CNG stations;
    - Union Oil promoted the development of the natural gas distribution network.

Program Agreement Scope:

- Promote a National Plan that gives a strong impetus to greater use of NG as a transport fuel
- Achieve, in the short term, infrastructural, regulatory, economic results and use these to create the conditions to feed the "virtuous cycle" of the next self-expansion in the country.
- Promote the research of new technologies that increase the customer appeal, driving range and performances of new NGV

Article 4 - Assets and responsibilities of parties

- Fiat SpA is commited to:
  - play a leading role increasing the natural gas vehicles demand on the market and implementing research projects for new engine technologies.
  - establish new agreement with fleets and promote the adoption of new bi-fuel vehicles
- Union Oil is committed to:
  - promote the development and growth of the natural gas transmission and distribution network
- The Minister for the Environment and Territory is committed to:
  - identify and introduce new measures to encourage the purchase of natural gas vehicles
  - provide loans to municipalities for the adoption of CNG as a vehicle fuel and incentivize the construction of natural gas distribution systems, allocating resources primarily in urban areas identified in the National Plan.

Table 7-1Annual incentives for infrastructure growth in Italy from 2002-2005 [112]

	Annual Incentives from 2002-2005	
	Euro Million	**N. station**
Public stations	24.4	236
Fleet stations	6.5	25

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