LNG is the sustainable fuel for Aviation

Research work on liquid bio-methane: the only option available to sustain the aviation industry growth of the 21st Century in a balanced environment and economy

Dr. Antonio Nicotra, General Manager, Gasfin Investment SA and AIR-LNG GmbH

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***Synopsis** - the title of this paper may appear presumptuous, claiming that LNG (fossil & renewable) is the only option available for sustaining the aviation industry growth of the 21st Century in a balanced environment and economy. And its content is even more unexpected, showing that the potential resources of bio-methane available on Earth would be an un-exhaustible source of energy, fulfilling the world's entire energy needs, economically, safely and with a carbon neutral or even negative impact, using the same fuel type & quality for all applications: from stationary heat & power to mobile vehicles, through land, water and air.*

1. Background

Mobility and transportation interlink the global economy. Aviation is the most advanced and preferred mode for connecting distant locations, quickly moving passengers and goods over long distances and showing a constant growth, envisaged to continue at a rate of 3-6% per year, faster particularly in Asia, as shown in Figure 1, here-below, by the International Civil Aviation Organization (ICAO) Environmental Report 2010.

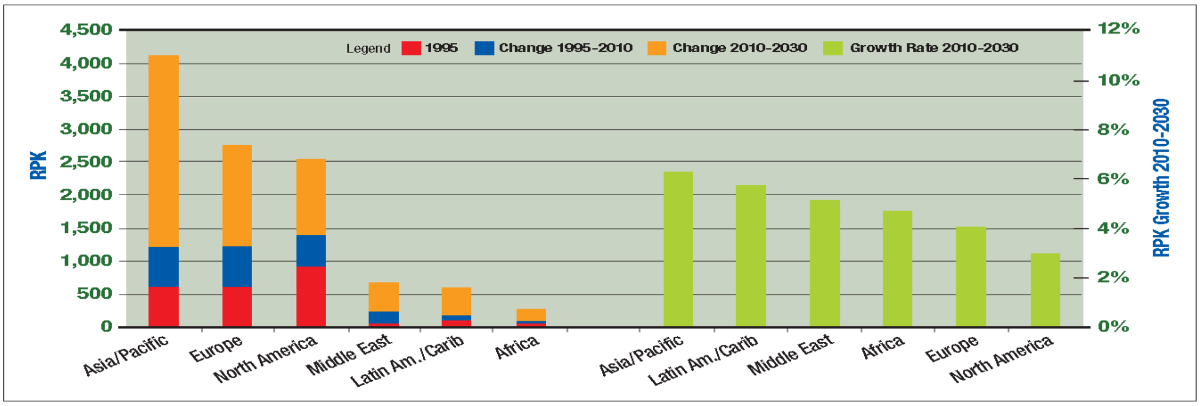


***Figure 1:** ICAO Passenger Traffic Forecasts by ICAO Statistical Region.*

According to the 2011 International Energy Outlook Report by the U.S. Energy Information Administration (EIA), the total energy used by the Transport Sector is expected to grow from about 2.5 billion Tons of Oil Equivalent (TOE) in 2008 to over 3.5 Billion TOE in 2035, consuming over 50% of all liquid fuels (over 60% by 2035) and representing about 20% of all world energy consumption (Figures 2 and 3, by EIA, here below).

Figure 2. World energy consumption by fuel, 1990-2035 (quadrillion Btu)

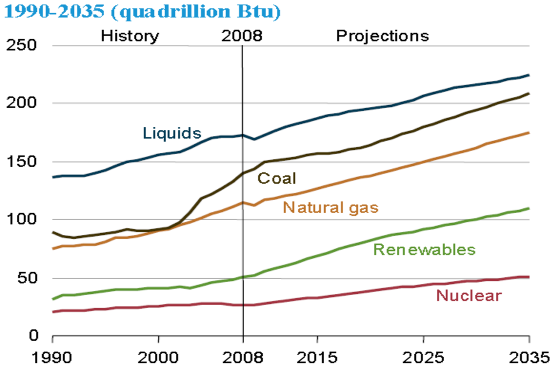
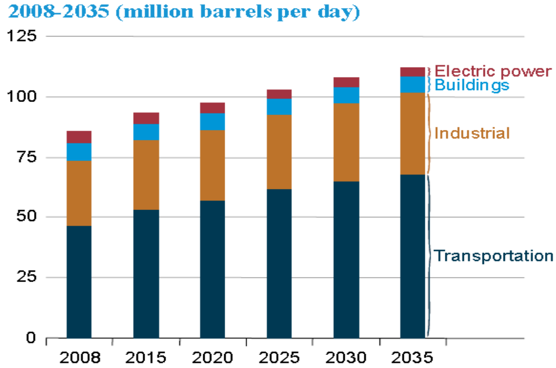


Figure 3. World liquids consumption by sector, 2008-2035 (million barrels per day)



U.S. Energy Information Administration | International Energy Outlook 2011

Aviation consumed about 250 Million TOE of fuel in 2008 and also in 2010; this quantity may double by 2035, depending on some alternative scenarios that combine industry growth with relevant envisaged improved fuel efficiencies & savings (Figure 4, by ICAO, here below).

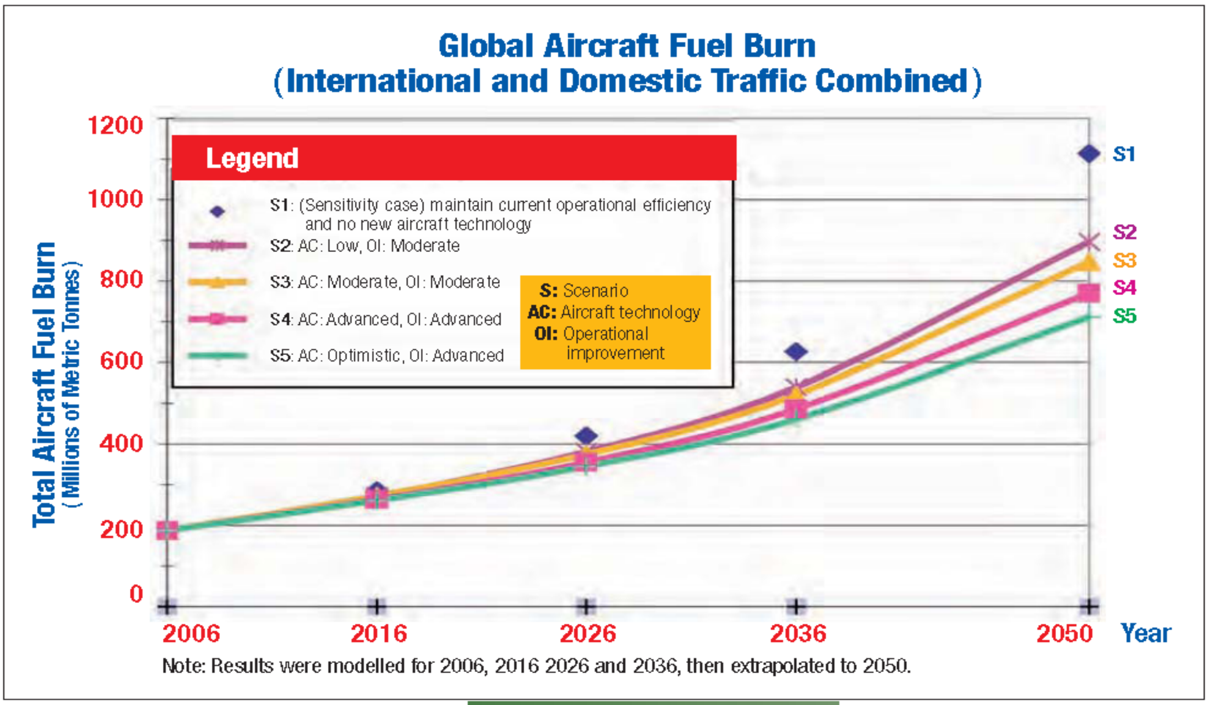
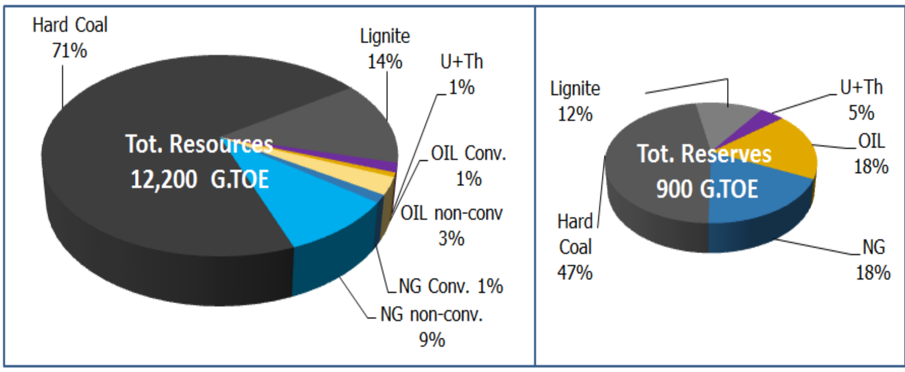


Figure 4: *Total Global Aircraft Fuel Burn 2006 to 2050.* ICAO ENVIRONMENTAL REPORT 2010

In the past century, the transport industry built its backbone infrastructures, carriers and engines on just one main fuel resource: **fossil crude oil**; and aviation has taken the best distillates grades: jet-kerosene and avgas. The reason for this choice was clear: oil, avgas-100LL and jet-A/B/P were the "best picks" satisfying the 5 pre-requisites needed for a preferred transportation/aviation fuel: availability, cleanness, economy, efficiency and safety.

In the last two decades, crude oil and its derivatives lost 3 of the 5 essential pre-requisites, as oil became short in supply, excessively expensive and polluting (Fig. 5 to 7, here below and next page: author elaborations based on referenced information).

1.1 Fuel Resources/Reserves & Availability Compared



FUELS AVAILABILITY		
Fuel	Reserves years	Resources years
OIL	38	97
NG	47	360
COAL	109	2463
U+Th	140	629

Figure 5 Source: Author elaboration based on 2009 statistics of EIA, World Oil, BGR (Germany)

Note: *The limited economic reserves of oil & gas (NG) would only last till the middle of the 21st Century. Still, gas resources are over 3 times more abundant & economical than oil.*

1.2 Fuel Prices Compared (US Gulf + Australian Coal)

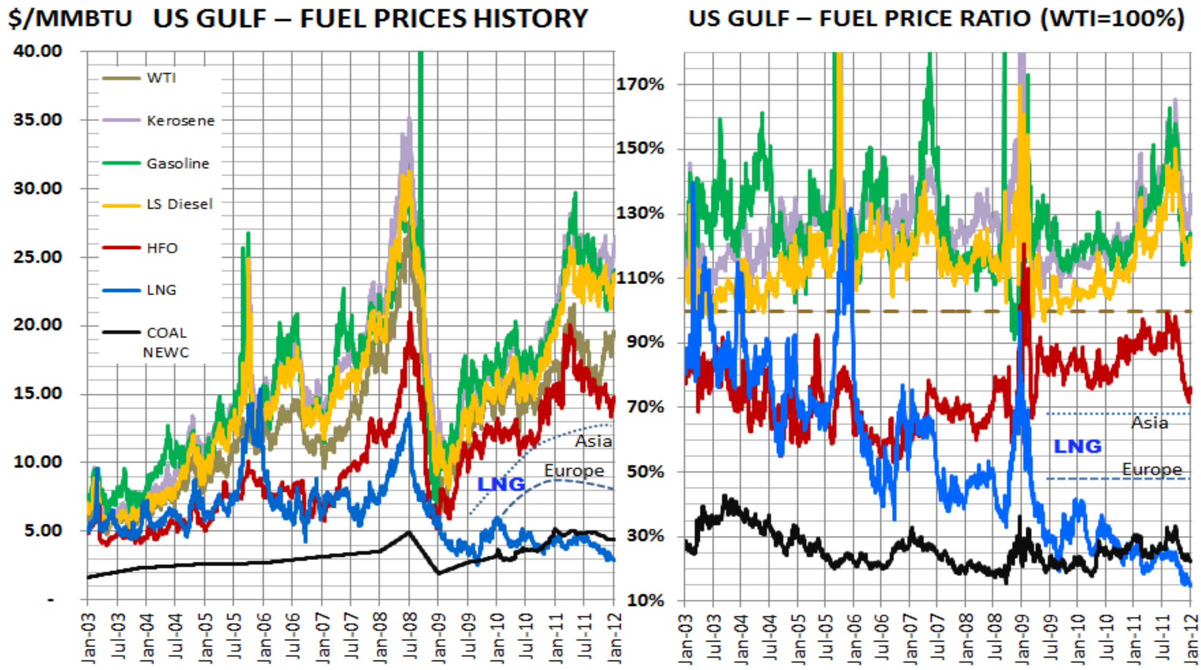


Figure 6 *Source: Author elaboration based on current statistics of EIA, Global Coal, Platts*

Note: *The US Natural Gas Industry, with shale-gas recovery, made it possible to reduce gas prices in the last 10 years from oil-parity to less than 20% of oil, and even below export price of Australian coal. In Europe gas is still 50% of oil-parity and Asian importers pay about 70%.*

1.3 Fuel Emissions from Combustion Compared

Fuel	NG/LNG		MDO	HFO	COAL
Chemistry	CH4 (92-98%)		$-(CH_2)_{12\text{-}20}-$	$-(CH_2)_{25\text{-}50}-$	-C-
S content %	0,0003%		0,50%	1,0%	2,0%
LHV MMBtu/t_{fuel}	49		43	40	26
Power technology	CCGT/EL	DF-DE	DE	DE	clean coal
Assumed efficiency %	52%	42%	42%	42%	42%
CO_2 emissions gr/kWh	-39% 368	-24% 456	601	+7% 646	+91% 1146
SO_2 emissions gr/kWh	-100% 0.001	-100% 0.001	2	+ 115% 4	+562% 12
NO_x emissions gr/kWh	- 98% 0.26	- 87% 1.60	12	12	+25% 15
Particulates emissions gr/kWh	-100% 0.001	-100% 0.001	0.33	+200% 1	+500% 2

Figure 7 *Source: Author elaborations based on industry standards*

Note: *The chemical structure itself explains why the combustion of methane (CH4) releases less CO2 than Mid-Distillate-Oils (-CH2-) or Coal (-C-), while hydrogen or electricity do not release any CO2 at all (locally); but hydrogen or electricity are not primary sources of energy and the "pollution analysis" should not be limited to the power generation phase only, as it should be extended to the entire energy supply chain ("Well-to-Wheel" analysis (W-t-W) – that will be examined in the subsequent paragraph 3 concerning methodology).*

The stationary energy sector has already diversified its fuel needs away from oil to improve competitiveness and reduce greenhouse gases (GHG) emissions, also by means of exhaust fumes abatement systems.

The transport sector, and aviation in particular, only made significant steps in improving performances and reducing fuel-oil consumptions & relevant emissions; now, transports need to sustain their development by ending their current dependency on oil monopoly, and to find alternative substitute fuels able to sustain their long term growth.

Long term availability and economic planning in a balanced environment are the fundamental requirements for the new substitute transport/aviation fuel, coupled with efficiency & safety.

1.4 Aviation Programs towards a "Zero Emission" target

The aviation industry claims that its GHG emissions are only a minimal part of all anthropogenic GHG emissions (2% of all GHG emissions and 13% of all transports, as shown in Figure 8, by the ICAO 2010 report,)

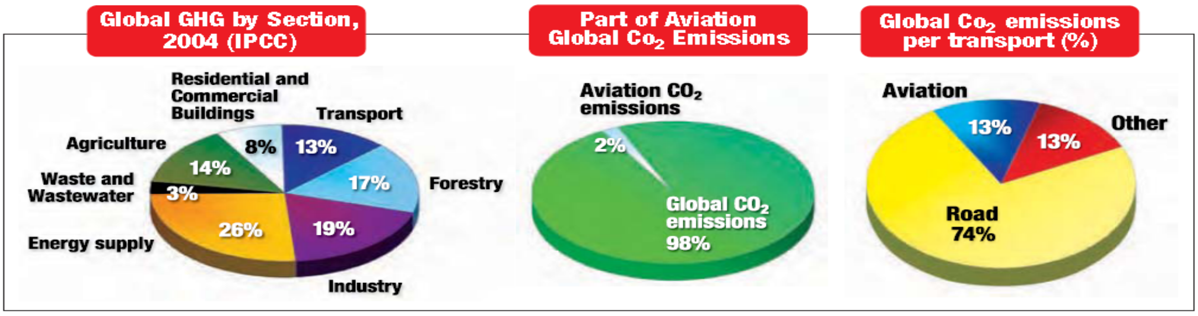


Figure 8 : Aviation's contribution to global CO_2 emissions.
Source: IPCC, 4th Assessment Report, 2007, WGIII, Technical Summary and IPCC Special Report on Aviation and the Global Atmosphere (1999).

Still, aircrafts release GHGs primarily during take-off and landing, nearby critical populated areas, or at high altitude, with limited possibilities of applying mitigation devices.

Consequently, the aviation Industry, through its International Air Transport Association (IATA) and European Advisory Council for Aeronautics Research and Innovation in Europe (ACARE) and European Commission (EC), has set some highly ambitious goals for reducing GHG emissions by 50% by 2050, relative to 2005 levels, in a vision towards a zero-emission target. Some of the programs are hereby summarised in Figure 9.

Figure 9 ***abstracts by referenced reports***

2. Aims

The aim of the transport industry, of aviation, and of this research is to investigate whether the available substitute fuel candidates are able to progressively complement and eventually replace the depleting oil resources, with solutions that need to be:

i. Available for long time,
ii. Environmentally sustainable,
iii. Economically & technically sustainable,
iv. Safe.

On-going studies have already indicated some possible alternative fuels, such as synthetic-oils, liquid hydrogen or methane, alcohols and bio-fuels.

2.1 “Drop-In” Solutions

Boeing, MTU and NASA presented a joint paper at the 2006 International Congress of Aeronautical Sciences (ICAS-2006) on Alternative Fuels and their Potential Impact on Aviation, with conclusion summarised in Figure 10 here below:

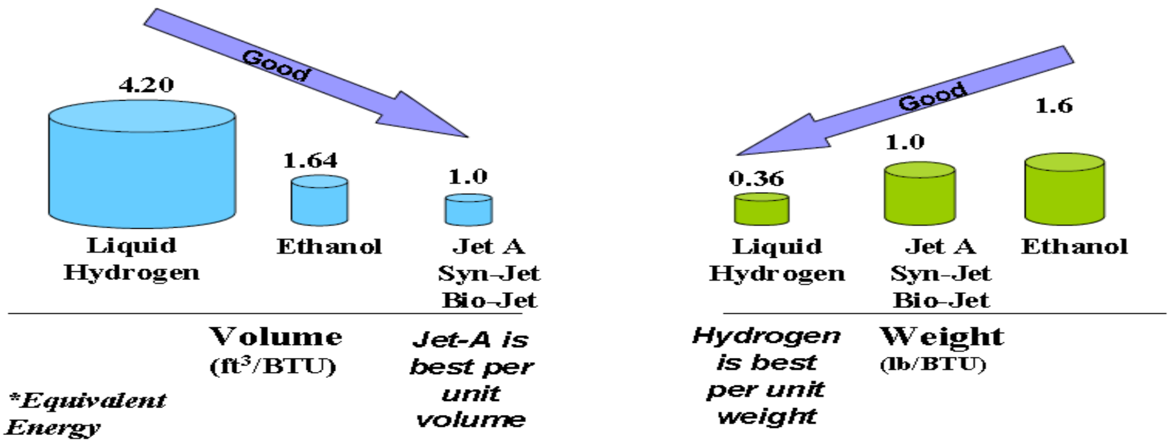


Figure 10 —Aircraft fuels need to have high energy content per unit weight and volume. NASA/TM–2006-214365 – ICAS–2006–5.8.2

Results of the studies were the following:

a) Synthetic kerosene (“Syn-Jet”, via Fischer-Tropsch process) from coal (CTL), gas (GTL), or biomass (“Bio-Jet”, BTL) appeared to be the ideal drop-in solution, having identical or even improved properties of the replaced fuel. *(Author’s note: these solutions would solve the availability issue, but are not environmentally and economically sustainable)*.
b) The hydrogen option, suitable for singular rocket propulsion was dismissed for use in commercial aviation because of excessive complications and performance penalties, not only in aircrafts but also in ground logistics. *(Author’s note: this option may be re-submitted in an unforeseeable future vision of solar-hydrogen and fusion power*).
c) Methane in liquid form (liquid natural gas: LNG) consisting primarily of methane (90-99%), with minor quantities of ethane (1-6%), propane (0-2%) and nitrogen (1-4%), was considered similar to hydrogen for its cryogenic characteristics, and simply dismissed without a more careful examination of its potential.
d) Alcohols (methanol and ethanol) were discarded for use in aviation because of their low energy densities.
e) Bio-fuels, either hydrogenated from vegetable oil or animal fats (HVO) or synthesized (Fischer-Tropsch: BTL) from cellulosic crops, appeared to be a viable option for their mix-ability (drop-in) with current fuels (not requiring modification in aircrafts or ground logistics) and from an environmental point of view. *(Author’s note: bio-fuels availability in large quantities, their conflict with the food industry and economics still remain open issues).*

Based on the initial conclusions, the aviation industry has focused its effort on qualifying "drop-in" options for progressively mixing and possibly replacing jet-kerosene with synthetic-kerosene generated from alternative fossil resources (coal or gas) or renewable resource (biomass). Drop-in options include: Coal-To-Liquid (CTL), Gas-To-Liquid (GTL), Biomass-To-Liquid (BTL) and Hydrogenated-Vegetable-Oil (HVO).

The main developments of "drop-in" solutions currently implemented or in progress by relevant operators are summarized in Figure 11 here below:

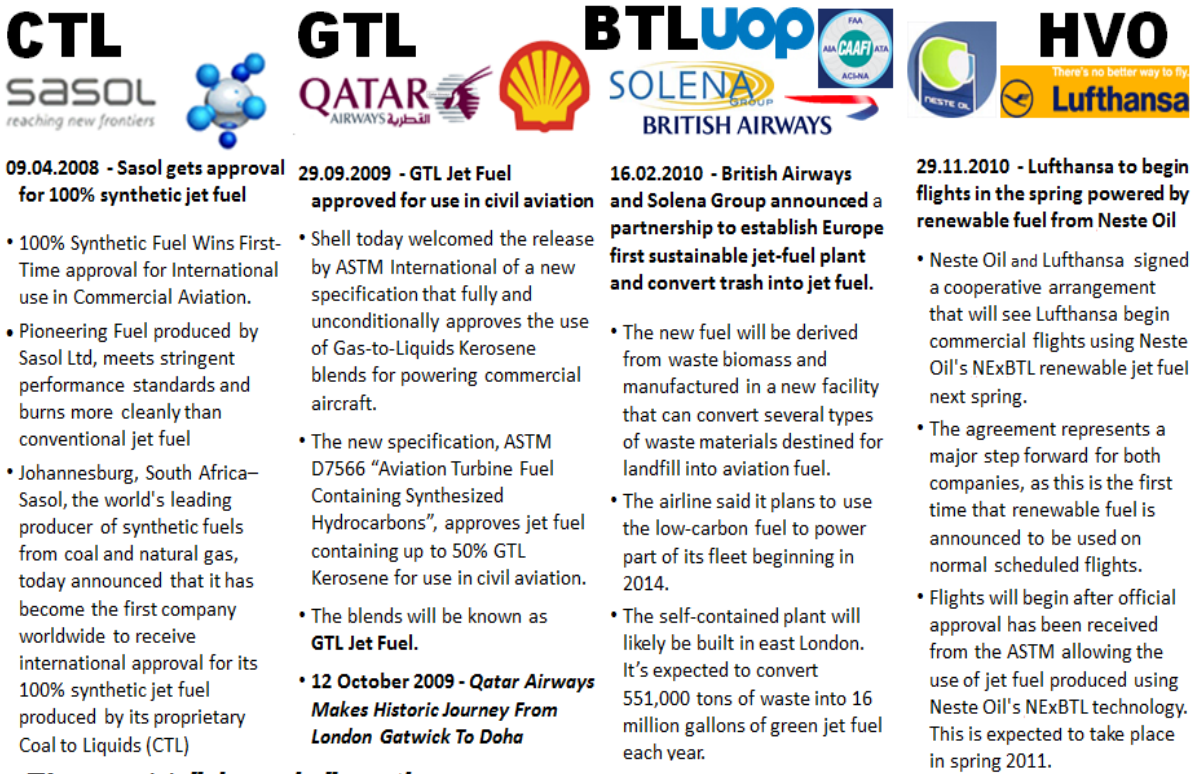


Figure 11 "drop-in" options *abstracts from press releases by relevant operators*

The strength & advantages of the "drop-in" options are the complete miscibility of the new alternative fuels with jet-kerosene, allowing continuing use of the same logistics & equipment used for the oil-based kerosene, giving continuity to the existing infrastructures, tanks & engines of the fuel end-users (**"Down-Stream" Industry Operators**).

The weakness & disadvantages of the "drop-in" options are the high capital & operating costs required for making the new synthetic fuel, with high energy consumption and relevant GHG emissions. This synthetic-kerosene trade at a premium compared to the typical jet-kerosene, shifting the costs and pollution problems from the end-users to the source/fuel manufacturers (**"Up-Stream" Industry Operators**).

"Drop-in" options do not reduce aircrafts' GHG emissions (emissions from synthetic-kerosene – syn-jet/bio-jet - are similar to traditional-kerosene). On the contrary, the "preparation" phases of synthetic-kerosene release more GHG than traditional refinery-kerosene and these emissions are not compensated by the CO2 sinking ability of relevant biomass and energy crops in the case of renewable-kerosene (BTL, HVO).

2.2 <u>“Non-Drop-In” Solutions</u>

Natural Gas (NG) is an efficient and safe fuel, suitable for all types of engines used by mobile vehicles: PISI/DISI, DICI (dual fuel, with pilot) and Gas Turbines, for land, water and air transportation, and gas is also cleaner, more economical and more abundantly available than oil, either from fossil origin or from renewable biomass resources.

NG has already replaced oil in all heat & power stationary applications (CHP units) connected, to the gas-grid-network, and even inside our homes, thanks to its safe and non-toxic characteristics.

The main reason limiting the utilisation of NG for mobile applications has been its lower energy density per unit of volume, as NG, in its gaseous form at atmospheric pressure, occupies a volume about 1,000 times higher than oil derivatives, making it impossible to store it under these conditions in carried-on tanks of vehicles (evidently, storage is not an issue for stationary power engines linked to the gas-grid).

<u>NG energy density is significantly increased by compression and cryogenic liquefaction</u>:
CNG [at 200 bar/ambient temperature] reaches a 5 : 1 volume ratio versus oil.
LNG [at -162°C/1bar or -150°C/10bar] reaches a1.8 :1 volume ratio versus oil.

<u>NG energy density per unit of mass is 15% higher than oil (14 kwh/Kg$_{gas}$,12 kwh/kg$_{oil}$)</u>; and

<u>LNG energy density per unit of volume is about 40% lower (6 kwh/liter$_{LNG}$,9.5 kwh/liter$_{oil}$).</u>

Figure 12 here below shows the energy densities per unit of mass and per unit of volume of most fuels, including batteries needed to operate electric vehicles. The combined graph reveals the small differences existing between LNG and gas-oils, compared to greater differences for hydrogen and alcohols.

ENERGY DENSITY OF FUELS	MJ/Kg	Ratio
Hydrogen, liquid	120.07	2.81
Hydrogen, compressed at 700 bar	120.07	2.81
Methane, liquid	50.00	1.17
Bio-LNG	49.80	1.16
lean-LNG	48.64	1.14
CNG (compressed at 200 bar)	47.60	1.11
LPG	46.40	1.08
Gasoline	43.50	1.02
GTL BTL	43.20	1.01
Jet A aviation fuel/kerosene	42.80	1.00
Diesel/heating oil	42.70	1.00
Bio-diesel oil (from vegetable oil)	37.50	0.88
Bio-butanol	34.36	0.80
Bio-Ethanol	26.95	0.63
Battery, lithium sulfur	1.80	0.04
Battery, fluoride ion	1.70	0.04
Battery, lithium-manganese	0.92	0.02
Battery, zinc-manganese (alkaline),	0.50	0.01
Battery, nickel metal hydride (NiMH),	0.40	0.01
Battery, nickel cadmium (NiCd)	0.14	0.00
Battery, lead acid	0.14	0.00

ENERGY DENSITY OF FUELS	MJ/lt	Ratio
Diesel-heating oil	35.01	1.67
Jet A aviation fuel/kerosene	34.67	1.65
GTL BTL	33.26	1.58
Biodiesel oil (vegetable oil)	33.00	1.57
Gasoline	31.32	1.49
butanol	27.49	1.31
LPG	25.52	1.22
lean LNG	21.89	1.04
bio LNG	21.41	1.02
Ethanol	21.16	1.01
Methane liquid	21.00	1.00
Hydrogen, liquid	8.50	0.40
CNG (NG compressed to 200 bar)	6.97	0.33
Hydrogen, compressed at 700 bar	4.80	0.23
Battery, fluoride ion	2.80	0.13
Battery, lithium-manganese	2.04	0.10
Battery, lithium sulfur	1.80	0.09
Battery, nickel metal hydride (NiMH),	1.55	0.07
Battery, zinc-manganese (alkaline),	1.29	0.06
Battery, nickel cadmium (NiCd)	1.08	0.05
Battery, lead acid	0.36	0.02

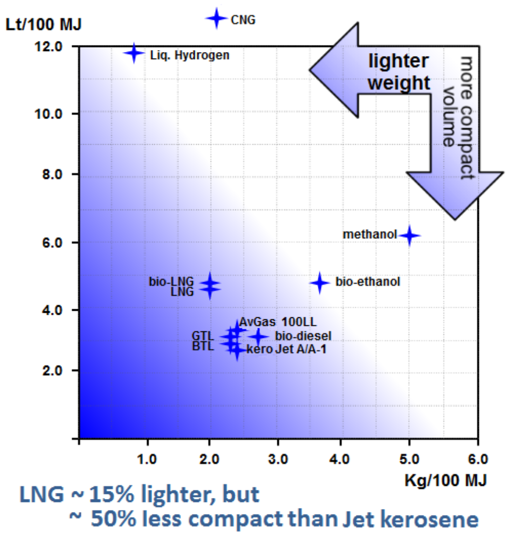


Figure 12 – ENERGY DENSITIES OF FUELS

<u>CNG technology for SHORT RANGE transports (cars & municipal buses)</u>

CNG is already established as a complement or replacement fuel to gasoline in PISI/DISI short range road vehicles (cars, city buses, municipal services LD trucks): low fuel costs, low pollution and good efficiency are the positive aspects, whereby weight and space needed for the HP tanks, short range and longer refuelling times are the negative aspects. Over 3 million vehicles already drive on CNG in Latin America, >1.6 mil in Pakistan, nearly 1 mil in India and Iran, >0.6mil in Italy. World consumption of CNG for mobility is currently about 22 Million tpy (not even 1% of total 2.5 Billion tpy of fuel used by the transport sector). It is envisaged that this amount could increase 10 times by developing the CNG technology in the rest of the world at the same levels as the above mentioned pioneering Countries.

LNG technology for long range transports (for HD vehicles, ships & aircrafts)

LNG is already available and at the early stages of application for ships (particularly in Norway) and HD long range road vehicles (beginning in the USA and EU). Substantial lower emissions of CO2, SO2, NOx and PM from LNG compared to diesel oil coupled with lower prices make LNG very attractive as complement or replacement of diesel in DICI engines; lack of LNG refuelling stations and capillary distribution and lack of common technology standards are currently the main obstacles for a rapid diffusion of this technology worldwide.

Still, the LNG Interstate Clean Transportation Corridor has been in operation in the US since 2004 and is rapidly expanding with over 28 operating refuelling stations and the LNG Blue Corridor Project in Europe is in progress, for serving the main communications EU routes with LNG & CNG from East to West and North to South. (Routes in Figure 13 here below)

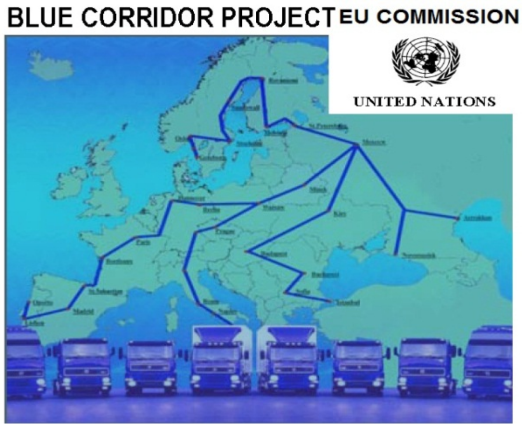


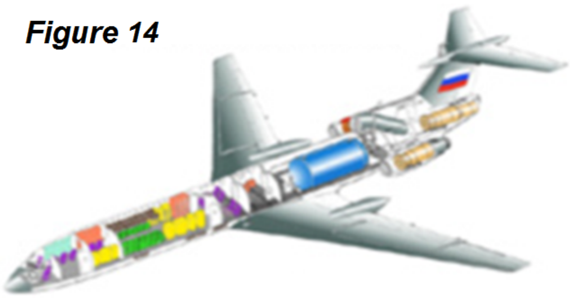
Figure 13 - ICTC LNG Corridor in the US and LNG Blue Corridor project in the EU

Assuming that LNG replaces diesel oil at the same rate CNG is replacing gasoline, LNG consumption for HD transports could increase to 200 Million tpy in the next decade.

Aviation is the fastest growing means of long range transports and its contribution to air pollution is increasing even faster due to the impossibility of treating and decontaminating the exhaust gases. **NASA/Boeing** and **EADS/Airbus** have considered cryogenic hydrogen and methane as fuel for commercial aviation since the 1980s: in the early 2000s hydrogen was dismissed due to excessive complications and costs, and methane was summarily dismissed for its cryogenic similarity to hydrogen.

In the mid-1980s, **Tupolev** built the TU-155 cryogenic aircraft on the basis of serial TU-154B. In order to use liquid H2 or LNG as fuel, airframe and some standard systems were modified, cryogenic fuel charging, storage and feeding systems were installed ensuring fire/explosion safety, plus data acquisition and recording system. Cryogenic fuel resource was kept in 17.5 m^3 capacity fuel tanks installed in a special compartment in the rear portion of the passenger cabin. The aircraft performed its maiden flight using liquid hydrogen on April 15, 1988. Upon flight testing and development, on January 18, 1989, TU-155 a/c performed its first flight on liquefied natural gas. (Figure 14)

Figure 14



Tupolev TU-155 cryogenic aircraft

photo of the TU 155 flying laboratory, courtesy of Mr. E. Pronin

The TU-155 fulfilled a large flight testing program, and over 100 domestic commercial flights and several international flight demonstrations were made including those to Berlin and Hannover (Germany), Nice (France) and Bratislava (Slovakia). Positive results encouraged the development of the new cryogenic model TU-156. However, in the 1990s, the program was terminated due to the reorganization of the FSU and lack of financing.

After 20 years, the world energy scenario has substantially changed and aviation requires cheaper, cleaner and more abundantly available alternative fuels.

2.3 Jet-LNG for Aviation

Based on the consideration that "drop-in" solutions would not be able to adequately support future Aviation requirements, AIR-LNG, a private company based in Bonn and Luxembourg, has revitalized the opportunity of using LNG (from fossil or renewable sources) as most sustainable fuel option for commercial aircrafts.

Jet-LNG is currently being specified as mixture of fossil-grades and renewable-grades liquid methane for specific application as fuel for jet-turbines of commercial aircrafts.

LNG is a "non-drop-in" option, as it can only be mixed with kerosene in the combustion nozzle, (therefore requiring separate storage and supply infrastructure inside the aircrafts and at the airports), yet AIR-LNG research work and solutions aim at proving that LNG is still the most sustainable and profitable option to complement and replace kerosene.

The strength & advantages of the LNG "non-drop-in" option are lower costs and prices, lower GHG emissions and greater abundance of gas compared to oil.

In addition, the energy density of LNG per unit of mass is 15% higher than kerosene (with consequent aircraft lifting advantages).

The weakness & disadvantages of the LNG "non-drop-in" option are the immiscibility of LNG with kerosene, requiring separate storing/supplying infrastructures/equipment in aircrafts and airports. Also, the 40% lower energy density per unit of volume of LNG compared to kerosene requires 60% more storage space in the aircraft for the same energy.

The LNG "non-drop-in" option reduces CO2 aircrafts emissions by about 25% and total GHG/CO2 equivalent emissions by 50%. Furthermore, the "preparation" phases of LNG also release over 50% less GHG that traditional refinery-kerosene and new syn/- or bio-kerosene; and, for renewable-LNG, emissions are entirely compensated by the CO2 sinking ability of relevant biomass waste and energy crops that are converted into bio-gas/LNG.

AIR-LNG Research Work on LNG as sustainable fuel option for Aviation is currently in progress within the **Burn-FAIR project of the LuFo IV-3 program** (2010-2013), sponsored by the German Federal Ministry of Economics & Technology (BMWi) and coordinated by the European Aeronautic Defence & Space company (EADS) with partners including the German national research centre for aeronautics and space (DLR), Airbus, Lufthansa, MTU, Hamburg Airport, TGE & Air-LNG. The aim of this project is to compare performances and sustainability of the HVO option (Hydrogenated Vegetable Oil "drop-in solution" coordinated by Lufthansa) with the LNG option ("non-drop-in solution" coordinated by AIR-LNG).

AIR-LNG research work focuses on LNG as fuel for aviation on the following basis:

I. Methane (CH_4) is a fuel that is chemically & physically more similar to kerosene (-CH_2-) than hydrogen (H_2). Methane and kerosene have similar "flame characteristics" and can be mixed in the combustion chamber. Methane flammability, safety risks and GHG emissions are lower than kerosene. Methane is not toxic! Methane energy density is 1.6, compared to kerosene = 1, and hydrogen = 4, allowing the former to deliver the same thrust with 15% less fuel weight than kerosene.

II. Methane cryogenic conditions (- 162°C) are much easier than hydrogen (- 252°C); cryogenic methane is stored and transported in insulated tanks & tankers (at low pressure) that are very similar to oil tanks & tankers, but made of different materials.
III. Methane and oil are different fluids and not mixable before the combustion nozzle, they require separate storage and distribution equipment, but can be burned into the same combustion engine, with the well-known dual-fuel nozzle technology.
IV. LNG's industrial technology & logistics network and methane for mobile applications is already commercially available and has increased enormously in the last 5 years, hence LNG can be considered as a suitable energy source candidate not only for ships and road/rail transports but also for airports/aircrafts.
V. Renewable bio-gas (upgraded to bio-methane) is the most abundant bio-fuel available on earth; when recovered from waste biomass, bio-methane is not competing with the food industry and could become an inexhaustible source of energy for complete replacement of fossil crude oil; moreover bio-methane technology is already commercially available and mature.
VI. The possibility to install LNG systems as complement to kerosene appears economically and technically feasible even in existing aircrafts. New aircrafts based on LNG as main fuel will enhance the advantages.
VII. The bio-methane solution, as main substitute of kerosene, appears to be the only available option able to meet the IATA 2050 target of -50% GHG emissions and thereafter zero-emission.
VIII. The energy intensity and the economics of a new bio-LNG world mass production infrastructure chain appears to be more advantageous than the corresponding new infrastructure chain based on BTL or HVO bio-kerosene.
IX. Prices of fossil LNG and bio-LNG are about 1/3 of fossil kerosene and bio-kerosene.
X. The setting up of LNG as main complement/alternative fuel to kerosene is feasible in a time frame of one or two decades. In addition, it will wipe out the oil monopoly in transports, it will extend the time of oil availability in the 21st century and possibly facilitate the transition to a future hydrogen age.
XI. The consolidation of bio-methane potential networks (in gaseous and liquid form) at regional levels worldwide would allow most Regions to become energy-independent, facilitating the distribution logistics with one fuel (methane) for all applications (households, industries and transports by land, water and air).
XII. Bio-gas technology, with conversion of residues into syn-gas and bio-hydrogen, and the LNG cryogenic technology represent a strategic intermediate step towards an innovative future based on renewable-hydrogen.

3. Methods

The methodology applied by AIR-LNG for this research work on LNG for Aviation is based on the following four pillars;

Life Cycle Assessment (LCA): of most fuels: currently used and potential alternatives for aviation and all other transports and stationary applications, (because all forms of energy are interconnected and competitive in the entire life cycle assessment from sources to final use).

Potential Availability Assessment & Supply Scenarios: of alternative bio-fuels for transports, aimed at fulfilling energy requirement from crops without competing with food needs.

Economic Assessment: of the LNG "non-drop-in" option versus the GTL, BTL, HVO "drop-in" options.

Jet-LNG Technology: with fuel specification & qualification program and proposed solutions for using Jet-LNG in existing commercial aircrafts (short/ mid-term solutions) and for new aircrafts (long-term solutions).

3.1 Introduction to Life Cycle Assessment (LCA) and Carbon Footprint Matrix

The Transport Industry is committed to sustaining its growth in a preserved environment, aiming towards a “low-carbon” and “carbon-neutral” economy, by eagerly searching for new fuels solutions, as complement or alternative to crude oil derivatives.

Hydrogen based Fuel Cells and Electric Motors appear to be the “cleanest” options as these systems do not release any CO2 locally where the engines operate.

Bio-fuels also appear to be very environmentally friendly based on the concept that all the CO2 released by their combustion is eventually re-absorbed during the growth of the relevant energy crop bio-fuels are derived from (the bio-fuel “carbon neutral” principle).

However, Electricity and Hydrogen are not “primary resources” of energy, and relevant amounts of CO2 and other GHG are released where these forms of energy are generated and distributed (depending on the primary source of the energy being utilized).

Also, the preparation phase of bio-fuels (including crop planting, cultivating, harvesting, transporting & processing into the final product and subsequent distribution to consumers) requires substantially higher amounts of energy compared to the preparation process of the fossil fuel to be replaced, consequently releasing higher amounts of CO2 and other GHG.

Therefore, the “cleanness” of each relevant fuel option cannot be defined only by the amount of emissions released during the work (motion) performed by the final-user-engine operation (this combustion phase is called “tank-to-wheel” (T-t-W)), but it must also include all GHG released during the entire supply chain of the relevant fuel: including extraction from the source, upgrading, transport, refining process and distribution to the tank of relevant vehicle (this supply phase is called “well-to-tank” (W-t-T)) plus the GHG emissions relevant to all additives and by-products eventually utilized through the fuel supply chain.

This entire process is called “Life Cycle Assessment” or “Well-to-Wheel” (W-t-W) or “Cradle to Grave” analysis of the relevant fuel and is aimed at assessing the entire “Carbon Footprint” of the fuel during its entire Life Cycle in order to assess more correctly the overall impact on GHG emissions of the fuel under scrutiny and not only the local effects.

Even the electricity directly generated from solar or wind power has a Carbon Footprint that concerns the GHG emissions related to the production and transportation of all the component and equipment forming the related infrastructure.

Relevant approaches and calculations for LCA are strictly regulated by ISO 14040/14044 standards. Current and best available technologies are considered for the various unit process steps.

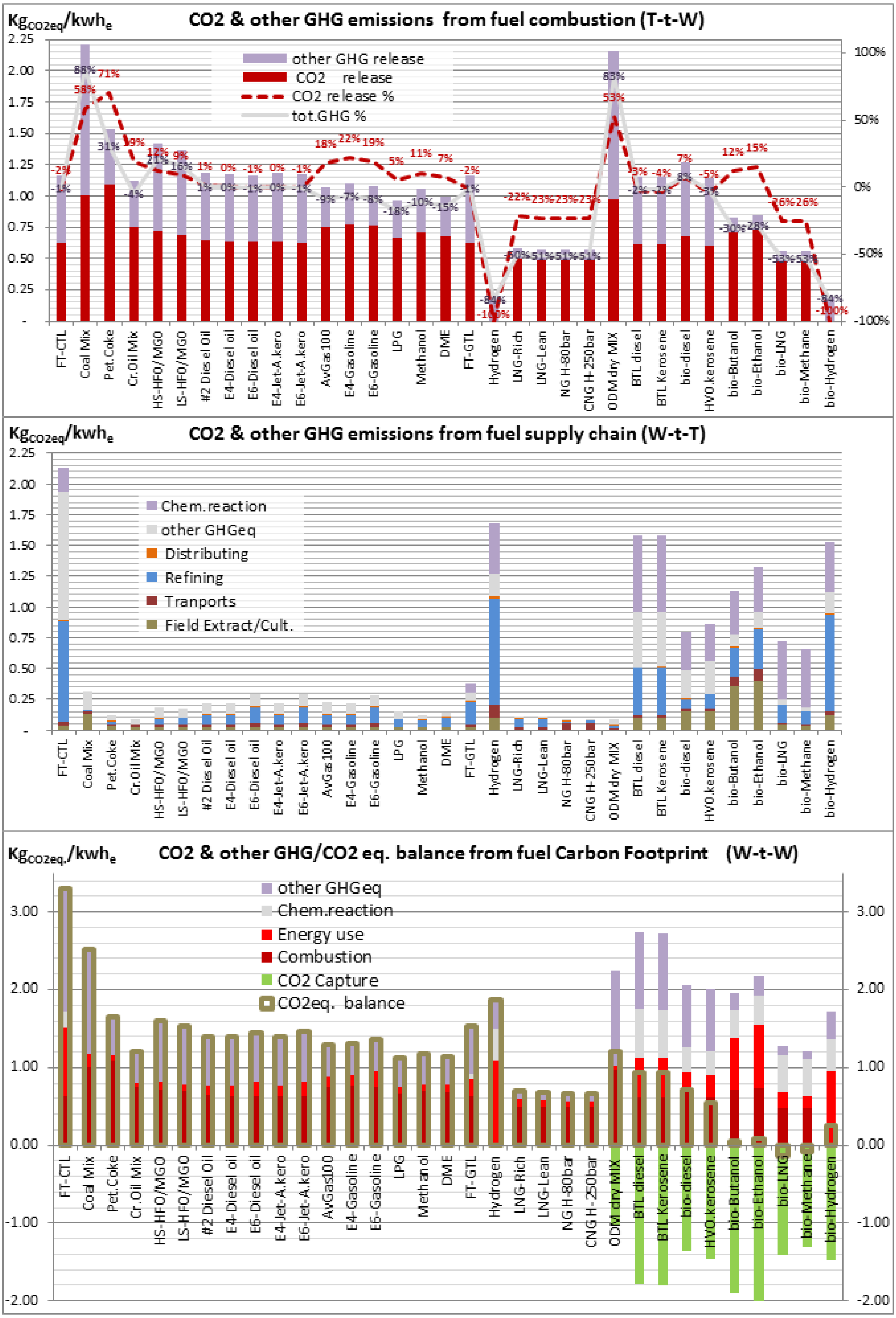
Furthermore, when bio-fuels are investigated, the analysis should not be limited to the Fuel Life Cycle (as regulated by the “carbon neutral” principle of the EU-DIR 2009/28/EC), but should be extended by counting the carbon through the overall Carbon Balance between Atmosphere and Biosphere, as relevant amounts of CO2 may remain suspended in the Atmosphere or sink into the Biosphere, depending on each specific bio-crop cultivation.

A key point of the LCA of the fuel under scrutiny concerns the types of fuels used during its preparation phase: should the sources of the scrutinized-fuel and the preparation-fuels be different, the scrutinized-fuel cannot be considered “sustainable” (because it would be dependent on availability, economics and polluting contributions of a different fuel source); therefore the entire supply chain of the scrutinized-fuel must be self-sustainable and independent from other sources.

Carbon-Footprint-Matrix calculated by Gasfin under ISO14040/044

Gasfin Investment SA, based in Luxemburg, partner of AIR-LNG has calculated LCAs under ISO 14040/044, full-carbon-counting & self-sustained fuel supply chain, and has collected the data in a Carbon Footprint Matrix extended to most fuels used by transports. The comparative results of this Matrix are summarized in Figure 15 on the following page.

Figure 15 - FUEL EMISSIONS - WELL-TO-WHEEL CARBON FOOTPRINT - COMPARED



Source: Author elaboration based on industry best practises

Note to Figure 15 above: *Fuel combustion releases CO2 and other greenhouse gases (GHG: including CO2, CO, CH4x, NOx, SOx, H2O and more) not only from the engine that generates the required final-user power/service (T-t-W), but also during the entire process of extracting, upgrading and delivering the fuel to its final application (W-t-T).*

Other GHG/CO2 equivalent emissions are calculated by converting into CO2 the global warming potential assumed by the International Panel for Climate Changes (IPCC), according to the table in Figure 16 here below.

Figure 16 CO2 EQUIVALENCES OF THE VARIOUS GHGs

Global Warming Potentials of Kyoto Protocol Green House Gases

Chemical formula	Greenhouse gas	Global Warming Potential (1)
CO2	Carbon dioxide	1
CH4	Methane	21
N2O (2)	Nitrous oxide	310
HFCs	Hydro fluorocarbons	140 (C2H4F2) to 11 700 (CHF3)
PFCs	Per fluorocarbons	5 700 (CF4) to 11 900 (C2F6)
SF6	Sulphur hexafluoride	23 900

(1) In a 100-year time horizon. Reading guide: for example one tonne of methane equates to 21 tonnes of CO_2.

Source: Climate Change 1995, the Science of Climate Change: Summary for Policymakers and Technical Summary of the Working Group, UNFCCC

(2) Average assumed for NOx = 90 (N2O + NO + N2O3 + N2O5)

The energy required for the supply chain of the fuel under scrutiny (and the relevant GHG emissions) utilizes the same fuel or a by-product from the same fuel chain or source in order to make each fuel "truly self-sustainable".

Depending on the fuel being investigated, GHG emissions from the final-user-engine (T-t-W phase) may be more or less than the combined release of GHG from all the energy-processes involved in the fuel manufacturing and supply chain (W-t-T phase). Extremes would be for hydrogen-engines with 0% T-t-W and 100% W-t-T and crude-oil pump-jack-engines with a 99% T-t-W and 1% W-t-T. Average may be about 50/50.

Fuel combustion: *Methane generates about 25% less CO2 and 50% less total GHG/CO2 equivalent emissions than oil derivatives; while coal releases 50% more CO2 and 90% more GHG/CO2 equivalent emissions than oil derivatives. The only GHG/CO2 equivalent emissions generated from combustion of hydrogen are related to NOx emissions. Combustion of synthetic "drop-in" alternatives (CTL, GTL, BTL, HVO) releases amounts of GHGs comparable to distillate-oils (gasoline, kerosene, diesel oil) independently from the primary resource (Coal, NG, biomass, vegetable oils).*

Fuels supply chain: *Traditional fossil fuels supply chains are most efficient & least polluting; reforming processes (producing hydrogen) and Fisher-Tropsh synthesis (producing synthetic liquid fuels & chemicals) are highly energy intensive, generating significantly higher emissions; the bio-fuels supply chains release over 3 times more emissions than correspondent fossil fuels.*

Life Cycle Carbon balances: bio-methane, in liquid or gaseous forms, appears to be the only option able to achieve a "negative carbon footprint", where more Carbon sinks into the Bio-sphere (into trunks and roots) than the amount sourced into the Atmosphere by the entire fuel supply chain and combustion.

3.2 Alternative Bio-Fuels Potential-Supply Matrix

The "low carbon footprint" or even the "negative carbon footprint" of a new alternative fuel option is not sufficient to make the fuel qualify as preferred option for sustaining the future growth of the transport industry if it is not accessible and cost competitive.

The "environmentally friendly" alternative fuel must also be abundant in supply, able to cover the growing demand of fuel for all means of transports, and economically viable, with regards to its production & distribution costs and to the technologies & infrastructures required to allow the current transport industry to switch from current fuels to the new alternative/ complementary fuel. Evidently the technologies of the new alternative fuel need to be proven, reliable, efficient and safe, (same or better than current fuels).

Gasfin has elaborated the potential productivity of the alternative bio-fuels considered "mature" by transports as complement (*drop-in*: BTL and HVO) or alternative (*non-drop-in*: Bio-LNG/LBM - Liquid Bio Methane) to the traditional oil derivatives currently in use.

The bio-fuels potential-supply Matrix has been elaborated referring to the energy demand statistics provided by the 2010 EU STATS and US EIA and the 2009 FAO statistics on world agriculture & forestry. Results are shown in the following table (Fig.17a) and graphs (Fig.17b)

FUEL DEMAND (EU & EIA Stats 2010)

LIQUID FUEL CONSUMPTION	(M. = Million)	EU27	WORLD	EU27 %	W %	E27/W%
Total Liquids	tot. M. tn	582	3,465	100.0%	100.0%	16.8%
All Transports	M. tn	377	2,064	64.9%	59.6%	18.3%
Aviation	M. tn	53	262	14.2%	12.7%	20.3%
TOTAL ENERGY	M. TOE	1,158	12,203			9.5%
BIO-FUELS RESOURCES (FAO Stats 2009)						
LAND total	**tot. M. ha**	**433**	**13,459**	**100%**	**100%**	**3.2%**
agriculture	M.ha	185	3,907	42.7%	29.0%	4.7%
pastures	M.ha	65	2,350	15.0%	17.5%	2.8%
forests	M.ha	156	3,640	36.0%	27.0%	4.3%
PEOPLE	**M. Nr**	**500**	**6,775**			**7.4%**
LIVESTOCK	**tot.M. Nr**	**850**	**27,500**	**100%**	**100%**	**3.1%**
Cattle	M. Nr	90	1,300	10.6%	4.7%	6.9%
Hens	M. Nr	500	23,000	58.8%	83.6%	2.2%
Pigs	M. Nr	160	2,000	18.8%	7.3%	8.0%
Sheep	M. Nr	100	1,200	11.8%	4.4%	8.3%
BIO-FUELS RESERVES						
CROP PRODUCTION	**tot. M. tn**	**1,896**	**45,261**			**4.2%**
VEGETABLES RESIDUES	**tot. M. tn**	**3,206**	**68,090**			**4.7%**
LIVESTOCK PRODUCTION	**tot. M. tn**	**187**	**1,154**			**16.2%**
ORGANIC DRY MASS WASTE	**tot. M. tn**	**3,649**	**83,043**			**4.4%**
from Veg-production	M. tn	664	22,630	18.2%	27.3%	2.9%
from Veg-residues	M. tn	328	5,074	9.0%	6.1%	6.5%
from Wood & paper	M. tn	795	28,971	21.8%	34.9%	2.7%
from Meat-production	M. tn	66	577	1.8%	0.7%	11.4%
from Livestock manure	M. tn	1,598	23,080	43.8%	27.8%	6.9%
from Municipal-Solid O.W.	M. tn	125	1,694	3.4%	2.0%	7.4%
from Municipal Sewage	M. tn	75	1,016	2.1%	1.2%	7.4%
Bio-FUELS POTENTIAL						
LAND for ENERGY CROPS	tot. M. ha	25	626	10%	10%	4.0%
Cellulosic Residues	tot. M. tn	1,013	32,354			3.1%
All ODM Waste	tot. M. tn	3,649	83,043			4.4%
HVO potential	**tot. M. tn**	**26.5**	**1,891**	**tn/ha**		**1.4%**
from Energy Crops	M. tn	25.0	1,878	1.0	3.0	1.3%
from oil/fat Waste	M. tn	1.5	13.5			11.4%
BTL potential	**tot. M. tn**	**211**	**5,975**	**tn/ha**		**3.5%**
from Energy Crops	M. tn	80	2,003	3.2	3.2	4.0%
from cellulosic Waste	M. tn	131	3,972			3.3%
Bio-LNG potential	tot. M. tn	866	19,907	tn/ha		4.4%
from Energy Crops	M. tn	88	2,191	3.5	3.5	4.0%
from all ODM Waste	M. tn	779	17,716			4.4%

Figure 17a - ***bio-fuels potentials versus demand based on referenced statistics***

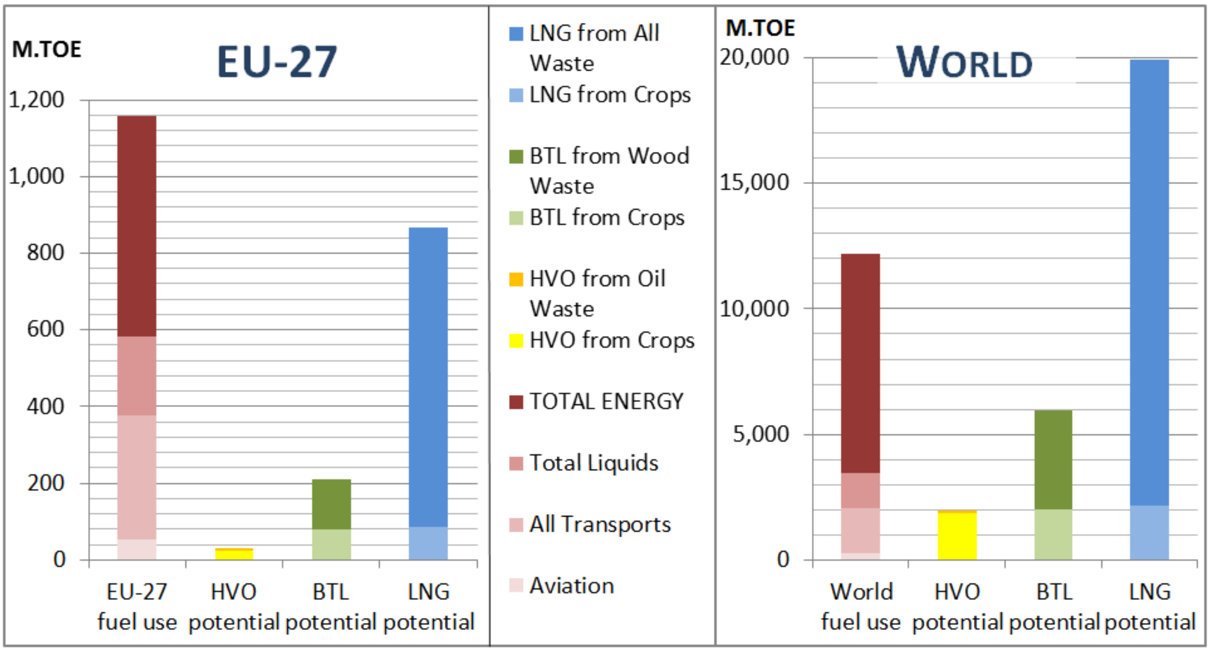


Figure 17b ***biofuels potential versus demand based on referenced statistics***

Results can be summarized as follows:

- ✓ **In EU-27**, the bio-Methane potential productivity reaches 75% of all EU-27 current energy demand (and it is 50% higher than all liquid fuel demand). BTL potential would only reach about 36% of all liquid fuel demand in EU-27. HVO potential would only be able to contribute to about 5% of all liquid fuel demand in EU-27.
- ✓ **Worldwide:** the bio-Methane potential productivity is about 60% higher than all World current energy demand. BTL potential would only reach about 50% of all energy demand. HVO potential would only be able to contribute to about 15% of all energy demand.

The main differences on productivity are related to the different qualities and quantities of substrate-bio-mass wastes from which the 3 different bio-fuels can be produced.

The conclusions of this analysis are somehow astonishing, showing that if humanity learns to recover half of the biomass currently wasted and naturally decaying into CO_2 and methane:

- ✓ It is possible to fulfil all world energy requirements halting the exploitation of fossil and nuclear resources and achieving a “negative” CO_2 balance, because the conversion of methane into useful energy and CO_2 avoids natural emission of methane from decay (with GHG negative effect 21 times worse than CO_2).
- ✓ EU-27, and any other region of the world with poor fossil energy resources, high energy consumption and suffering from abandoned land and urbanization, would significantly reduce their dependency on energy imports and implement their security of energy supply strategies primarily with “local” biomass wastes & residues.
- ✓ Furthermore, the extended recovery of waste biomass and the cultivation of energy-crops non in competition with food agriculture will favour the growth of vegetation, reduce desertification & destabilization of abandoned fields and revitalize agriculture favouring the return to an agrarian life style.

3.3 Alternative Bio-Fuels Economics-Forecast Matrix

The low carbon footprint and abundant availability of a candidate alternative fuel for transports would not be able to sustain industry growth if its economics were not favourable, with regards of fuel production and distribution costs and relevant investments needed to implement the entire supply chain.

"Drop-in" fuels, that can be mixed with the current fuels in use, have the advantage of sharing the same infrastructures, while "non-drop-in" fuels would require more investments for the logistics needed to implement new supply infrastructures parallel to the existing units.

Gasfin has elaborated a Matrix able to indicate the economical sustainability of the alternative bio-fuels considered "mature" by transports as complement (drop-in) or alternative (non-drop-in) to the traditional oil derivatives currently in use.

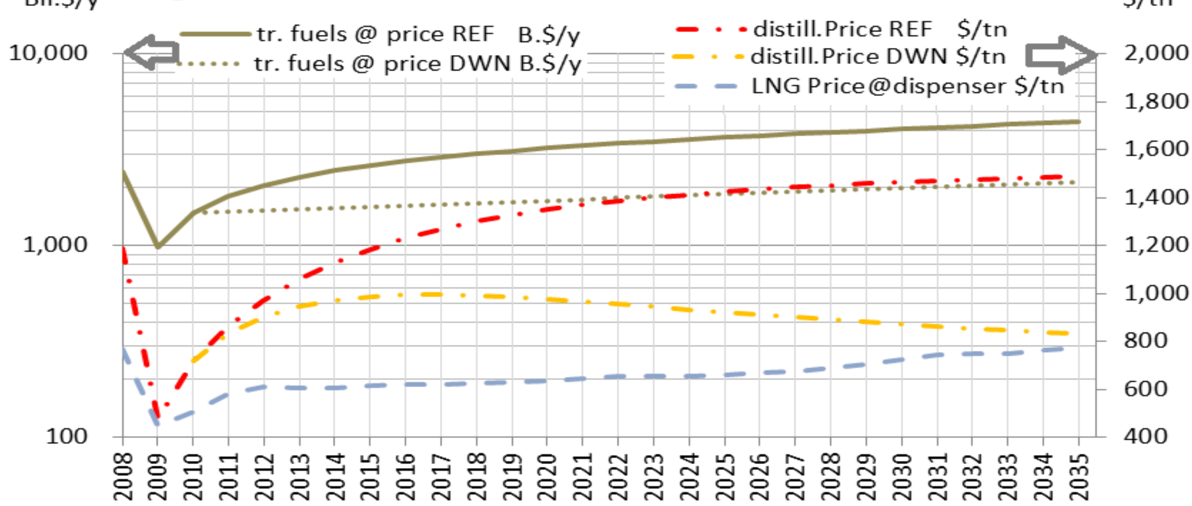
This bio-fuels economic-forecast-Matrix has been elaborated referring to the 2011 energy prices forecast provided by the US EIA and assuming best practice industry standards for CAPEX & OPEX of the various technologies selected for the entire supply chain of the alternative biofuels examined.

Results are shown in the graph in Figure 18 here below and can be summarized as follows:

Transport Fuels TURNOVER and PRICES FORECAST:

- ✓ Mid distillate oil prices have quickly recovered after the 2008 financial crisis and are expected grow to about $1,500/tn_{FOB}$ in the next 25 years in the "reference" EIA 2011 forecast scenario (REF red-line in the graph); oil prices may return to the 2010 level of about $800/tn_{FOB}$ in the event of a new recession or a new fuel being established as main substitute to oil (DWN yellow-line in the graph).
- ✓ "Drop-in" new fuels such as GTL, BTL and HVO trade at a premium over distillate oil derivatives and do not show ability of reversing the prices upwards trend.
- ✓ Natural Gas prices have recently shown ability to decouple from oil prices with more moderate price increases (LNG blue-line in the graph).
- ✓ The establishing of Natural Gas (from both fossil and renewable sources) as a main substitute of oil also for transports would relieve the pressure on oil prices and converge oil and gas prices to an envisaged average of about $800/tn.
- ✓ The Worldwide TURNOVER of transport fuels is expected to grow from about $1.5 Trillion in 2010 to $4.4 Trillion in 2035 assuming the prices of the reference scenario. This Turnover would only grow to about $2,2 Trillion should the price of fuel return to the $800/tn target, **giving Industry Savings in the range of $1 - 2 Trillion per year**.

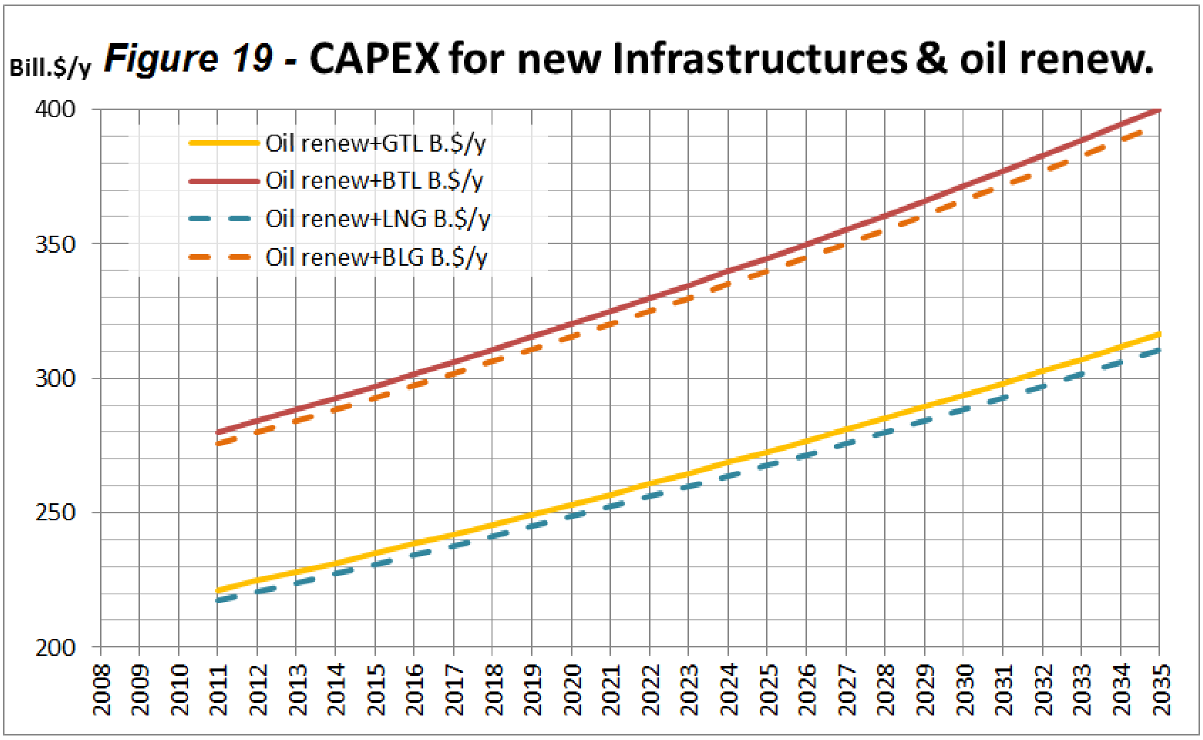
Figure 18 - Transport Fuels TURNOVER & PRICES FORECAST



Alternative CAPEX scenarios for "DROP-IN" and "NON-DROP-IN" INFRASTRUCTURES

Results of the analysis of the CAPEX required for the new alternative fuels infrastructures of "drop-in" fossil-GTL or renewable-BTL and "non-drop-in" fossil-LNG or renewable-LBG, and for oil revamping/upgrading to more stringent environmental requirements, are shown in the graph in Figure 19 here below and can be summarized as follows:

- ✓ The CAPEX required for renewing oil infrastructures and implementing either new GTL refineries and/or new LNG supply chains appear to be in the range of about $220-320 Billion per year for either case.
- ✓ Should BTL and/or LBG programs be implemented in addition to renewing the oil infrastructures, the required CAPEX would range at about $280-400 Billion per year for either case.
- ✓ The basic concept is the consideration that the higher costs required to establish separate/parallel **DOWN-STREAM** infrastructures for the "non-drop-in" LNG/LBG options are compensated by the higher costs needed for establishing the new **UP-STREAM** "drop-in" GTL/BTL infrastructures.
- ✓ The main key point is the consideration that investing in the drop-in alternatives (selling at a premium) does not help lower oil prices and achieve the savings indicated above. On the contrary, investing in LNG and LBG would achieve the indicated savings, from which they could be discounted (as the CAPEX yearly repayment for new infrastructures of $200-400 billion represents about 20-25% of the savings of $1-2 Trillion per year of the fuel prices shown in Figure18).



NOTE: *The author acknowledges that the overall assessments require further investigations to verify, share and revise calculations and results; however, the clear advantages (environmental, availability and economic) shown by adopting natural gas (fossil) and bio-methane (renewable) as main substitutes to oil recommends their relevant programs to be expedited at all levels.*

3.4 LNG Technology for Aviation and Program Time-Schedule

The specification of a new fuel for aviation requires fulfilling a severe test program, regulated by "The Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives" by the American Society for Testing and Materials (code ASTM D4054-09). This practice was developed as a guide by the aviation gas-turbine engine Original Equipment Manufacturers (OEMs) with ASTM International members support, such as the Federal Aviation Administration (FAA) and the European Aviation Safety Agency (EASA).

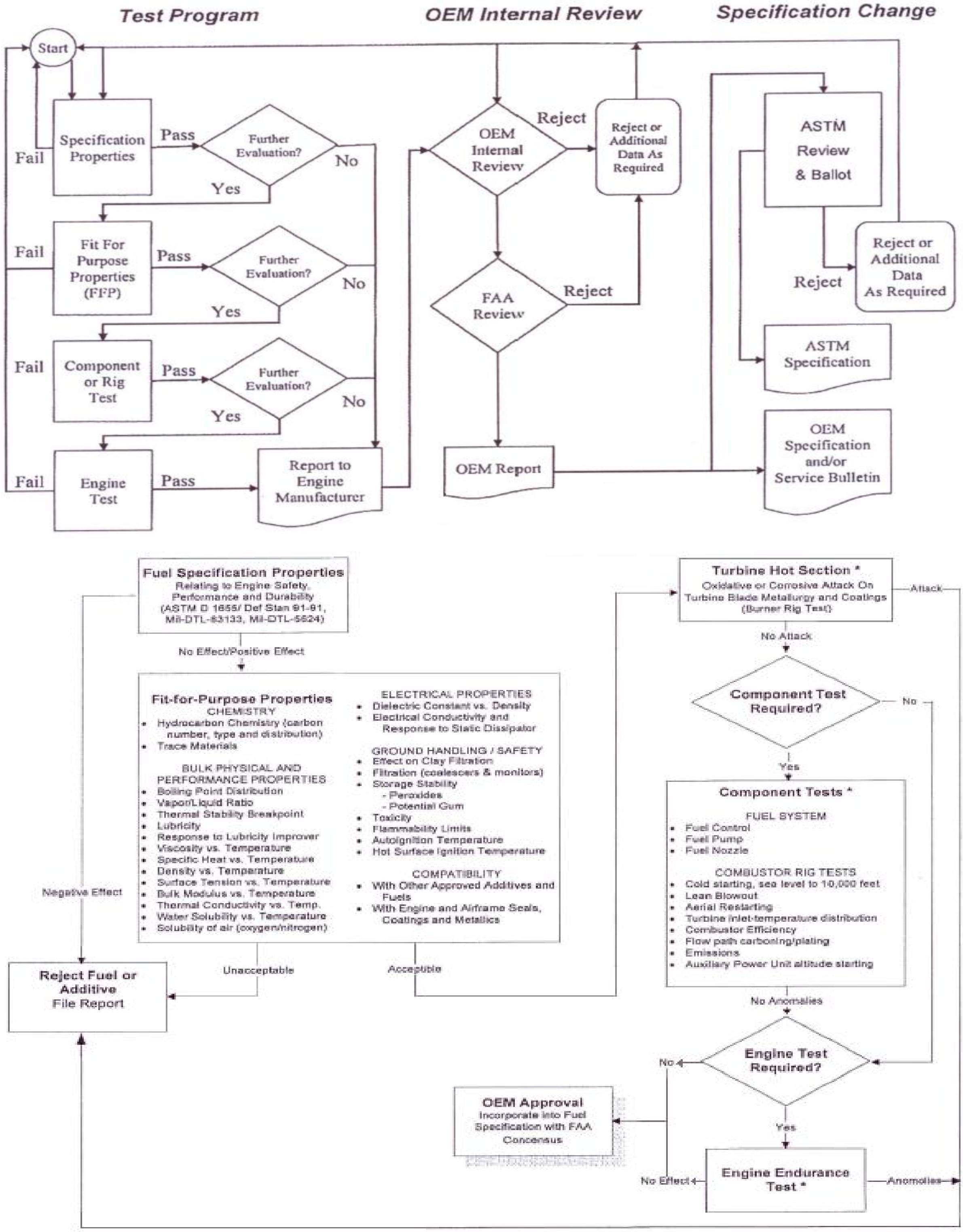


Figure 20a – Flow sheet of aviation fuels specification program according to ASTM D4054-09

Some "drop-in" fuels have already passed this test program and qualified under the revised standard ASTM D7566-11 "Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons" was approved on July 1 2011 and says that "up to 50 percent bio-derived synthetic fuel can be blended with conventional commercial and military jet fuel".

Accordingly, in 2010 AIR-LNG initiated a program for the specification & qualification of LNG as fuel for Aviation and for the development of LNG infrastructures & equipment required for implementing the use of LNG as fuel for propulsion in commercial aircrafts.

LNG infrastructure & equipment include storage and refuelling systems in airports, supply and storage of LNG on board, for use in the Auxiliary Power Units (APU) and in the main propulsion Power Plants (Jet-Turbines, turbo-fan & turbo-propellers).

This program is currently in progress in collaboration with AIR-LNG specialized partner companies and institutions for LNG technologies (Gasfin and TGE Gas Engineering) and for aviation fuels testing (Universities of Aachen, Cottbus, Stuttgart), in cooperation with the relevant international aviation OEMs and Agencies.

The entire program was initiated in 2010, with the initial task of defining the reasons for implementing such challenging task (Environmental, Availability and Economical Assessment defining Strengths, Weaknesses, Opportunities and Treats), then specifying the quality required for the jet-LNG new fuel depending on market availability, and the equipment proposed for using LNG in the existing and new aircraft designs.

The envisaged time schedule of the program is summarized in Figure 20b here below:

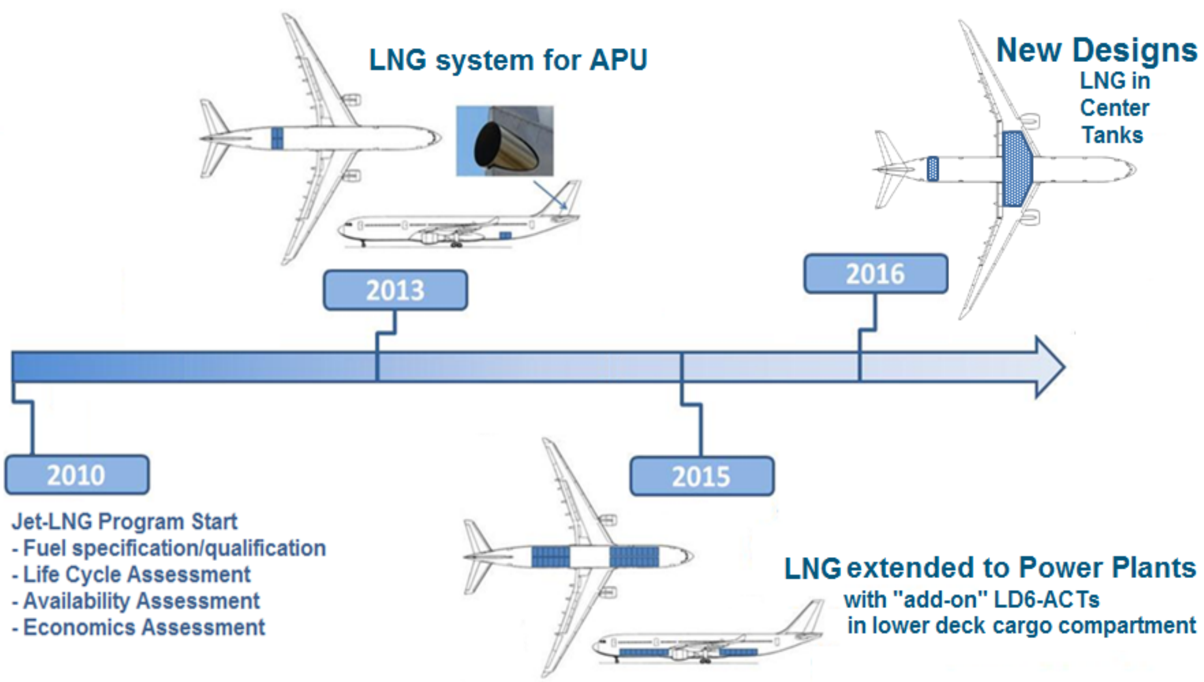


Figure 20b – AIR-LNG Program Time Schedule

4 Results

4.1 Jet-LNG specifications

Jet-LNG specification research work aims at defining the "standard" of LNG to be qualified for use in aviation, in function of the combustion performances of the possible qualities of LNG available in the international market from fossil or renewable sources.

Fossil-LNG would be procured from the existing and future international producers and distributors of LNG worldwide, either directly from the gas-sources, or indirectly from the main existing and future national gas-grids. Also renewable-LNG would be procured either directly from producers or mixed in the gas-grids.

Scope of work is to analyse the combustion performances (flame diffusion, stability & temperatures) of the various possible qualities of LNG in the aircrafts' power engines in order to provide best performances without excessively limiting market sources and upgrading costs (primarily de-propanizer/de-ethanizer techniques).

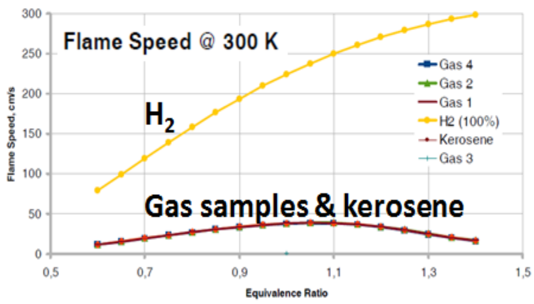
Hence, bench-tests with four grades of LNG (Rich-LNG, Lean-LNG, 70%rich-Mix, pure-Methane/bio-LNG) compared to hydrogen and kerosene were completed in 2011 at the Brandenburg University of Technology (BTU) in Cottbus, Germany.

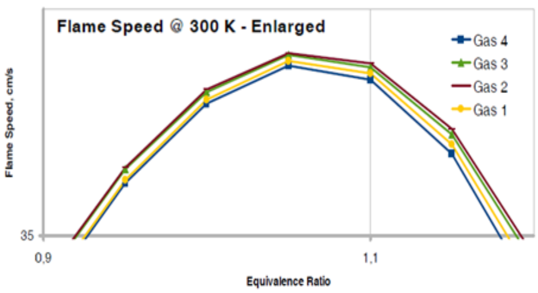
The results are summarized in Figure 21 and show a good proximity of the performances of the four qualities of LNG, similar to kerosene, while quite different to hydrogen.

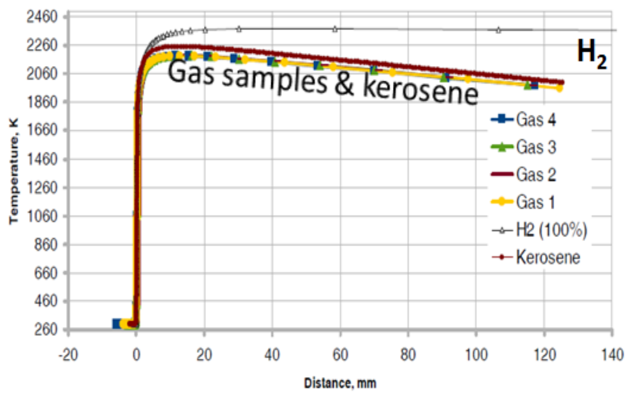
These positive bench results will lead to encouraging follow-up with APU ground testing, planned at the Aachen University of Applied Sciences (FH) in Aachen, and Aircrafts Power-Plants ground testing, planned at BTU and Stuttgart Universities.

Figure 21 - Flame diffusion tests at Cottbus University with 4 grades of LNG compared to hydrogen and kerosene

AIR LNG Name	BioLNG / BioGas		Mischung / 70% Rich		Rich LNG / Qatar, Algerien		Lean LNG / Egypt,Alaska	
BTU Code	Gas 4		Gas 3		Gas 2		Gas 1	
Formula	*Range*	*Real*	*Range*	*Real*	*Range*	*Real*	*Range*	*Real*
CH4	>99,5%	100,00%	93,0-94,0%	93,00%	90,0-91,0%	90,00%	97,0-98,0%	97,50%
C2H6	~0,1%	0,00%	4,0-5,0%	4,00%	5,0-8,0%	6,00%	1,8-2,3%	2,00%
C3H8	~0,1%	0,00%	1,0-2,0%	1,50%	2,0-2,5%	2,00%	0,2-0,3%	0,30%
C4H10	0,00%	0,00%	0,5-1,0%	1,00%	0,5-1,5%	1,00%	0,1-0,2%	0,20%
CO2	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
CO	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
N2	0,0-0,1%	0,00%	0,4-0,5%	0,50%	0,2-1,0%	1,00%	0,0-0,1%	0,00%
H2	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%







4.2 Phase 1 - Short-term approach: APU Conversion to LNG

The first operational step of using LNG for aviation foresees the use of methane in the aircrafts Auxiliary Power Units (APU).

The APU is the engine providing on board aircraft power services and taxing on ground; its low efficiency and high pollution obliges airlines to minimize its use and connect to the (more expensive) electric power provided by airports.

Future APU programs foresee the utilization of more efficient/cleaner Fuel Cell (FC) technologies.

The use of "clean" LNG in the existing APU or in the innovative FC units would permit liberal use of the APU when the aircraft is on ground.

Air-LNG has developed and patented a dual-fuel nozzle fitting into the combustion chambers of existing engines and able to burn both kerosene and vaporized LNG.

The LNG supply system consists of a LNG tank, receiving pipelines, send-out pumps, pipes and vaporizers to the nozzle, the entire LNG system in "parallel" with the existing kerosene system.

The LNG tank design would be a cryogenic multi-lobe-type, fitting into the standard measurements of the typical LD6 cargo container size used by commercial airlines.

LD6 containers are already used as Auxiliary Centre Tanks (ACT) with kerosene to extend commercial aircrafts' flight range.

Figure 22 shows a typical APU and fuel ACT

Figure 22 - APU and ACT

4.3 Phase 2 - Mid-term approach: LNG solutions for existing aircrafts

The second operational step of using LNG for aviation foresees the use of methane in the main power plants of existing aircrafts.

Evidently, the main kerosene-fuel system cannot be touched and therefore it would only be possible to install a separate parallel LNG system (with a relative inevitable weight increase that would be balanced by the envisaged advantages).

The same technology of dual fuel nozzles and LD6-ACT is proposed, with the higher complexity of needs for high pressure pumps and the maximum possible number of LNG LD6-ACTs in order to maximise the use of LNG during the various flight-phases.

LNG tanks shall be installed in the aircrafts' lower-deck reserved for cargo: this space is usually not utilized in passenger flights because of the incompatible logistics of loading cargo within passengers' schedule, but it would represent a loss of cargo-loads for cargo-flights (however, weight and not volume is their main limitation).

Depending on the aircraft types, for short range (A320 and B737 families) mid-range and long range (A330/340/380 and B747/767/777 families), the cargo space available for several LNG-ACTs would allow to cover shorter distances with about 90-95% of LNG replacing kerosene, and long-distances of over 10,000Km with over 50-60% of LNG replacing kerosene, with significant (over 50%) economic and environmental advantages.

Other AIR-LNG programs support the LNG back-bone infrastructures concerning the development of LNG handling & storing logistics in the airports and the upstream logistics of delivering LNG to the airports by road, rails and ships.

4.4 Phase 3 Long-term approach: Changeover to LNG

The third and final operational step of using LNG for aviation foresees the use of methane as main fuel in new specifically designed aircrafts.

The preliminary configuration of the proposed solution has already been defined and foresees the design of the central tank of the aircraft for LNG, while keeping the wing-tanks for syn-kerosene; most of the trip will be flown with LNG for economic and environmental reasons and kerosene is stored in the wings as reserve fuel and for balancing advantages.

5 Summary/Conclusions

AIR-LNG Research Work is currently in progress in the framework of the Burn-FAIR project of the LuFo IV-3 program, sponsored by the German Federal Ministry of Economics and Technology (BMWi) and coordinated by the European Aeronautic Defence and Space company(EADS) with partners including the German national research centre for aeronautics and space (DLR), Airbus, Lufthansa, MTU, Hamburg Airport, TGE and Air-LNG for comparing the HVO solution (drop-in) with the LNG solution (not-drop-in).

The extension of the LNG for Aviation project to the 2^{nd} and 3^{rd} phases will carry the program well into the 2020s.

The initial results are encouraging:

- Technology: LNG is an excellent fuel for aircraft turbo-fans and turbo-propellers, as already proven by Tupolev, and also for Fuel Cells; furthermore this cryogenic technology is a strategic intermediate step forward to a more distant innovative hydrogen technology.
- Economics: LNG (fossil & renewable) is cheaper than kerosene (fossil & renewable) and this gap is expected to increase in the future, unless the oil monopoly in transports is broken.
- Logistics: LNG logistics are rapidly expanding not only for coastal regions (LNG terminals for injection into the grid) but also in-land for transports (Blue corridors for LNG-vehicles); and the capital expenses for developing the relevant new LNG infrastructures are well compensated by the fuel savings.
- Environment: methane releases about 25% less CO2 and 50% less total GHG (CO2 equivalent) than does kerosene, and bio-methane appears to be the only bio-fuel able to achieve a negative carbon footprint (the ultimate IATA target).
- Energy Security of Supply & Simplification: the implementation of an extended bio-gas program for conversion into CNG/LNG and combined gas-grid and CNG/LNG dispensers, with the same methane fuel for all stationary & mobile application, will improve national energy independency and reduce the inefficiencies of multiple/more distant supply fuels logistics.
- Land Preservation & Agrarian Life Style: the extended recovery of waste biomass and the cultivation of energy-crops not in competition with food-agriculture will favour the growth of vegetation, reduce desertification & destabilization of abandoned fields and revitalize agriculture favouring the return to an agrarian life style
- Safety: Methane is a non-toxic and safe fuel (with regulations allowing its use even inside our homes)

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