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EU4Climate

BACKGROUND REPORT

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Glossary of terms

ASPU – Administration of Sea Ports of Ukraine
CMU – Cabinet of Ministers of Ukraine
CRA – centralized refueling of aircraft
DSTU – state standard of Ukraine
ECA – Emission Control Areas
FL – fuel and lubricants
HFO – Heavy Fuel Oil
HGO – Heavy Gas Oil
HSFO – High Sulfur Fuel Oil
HVGO – Heavy Vacuum Gas Oil
GOST – state standard
GHG – greenhouse gases
GSTU – branch standard of Ukraine
IFO – Intermediate Fuel Oil
IATA – International Air Transport Association
ICAO – International Civil Aviation Organization
IMO – International Maritime organization
LGO – Light Gas Oil
MARPOL – International Convention for the Prevention of Pollution from Ships
MDO – Marine Diesel Oil
MGO – Marine Gas Oil
PSPs – policies, standards and procedures
SE – state enterprise
SECA – Sulfur Emission Control Areas
SSSU – State Statistics Service of Ukraine
TR – Technical Regulation
TU – Technical Specifications
UIA – Ukraine International Airlines
UkrNDNC – Ukrainian Research and Training Center for Standardization, Certification and Quality
USLD – Ultra Low Sulfur Diesel
ULSFO – Ultra Low Sulphur Fuel Oil
VGO – Vacuum Gas Oil
VLSFO – Very-Low Sulphur Fuel Oil
bln – billion
hp – horse power
kt – 1000 tons
ktoe – 1000 tons of oil equivalent
M – million
Mt – million tons
mln – million
T – temperature

Introduction

Background Report reflects Ukraine's aviation and waterborne transport sectors fuel use and projections, as well as policy and institutional framework covering the following items:

- general description of the sectors;
- current fuel demand and supply;
- fuel standards and specifications;
- emission of GHG;
- related current legislation;
- current production/supply chain and infrastructure needed to deliver the fuels to vehicles or vessels;
- the costs related to infrastructure and vehicles.

Executive summary

Now, oil is the dominant source of energy for the transport sector in the world and in Ukraine including aviation and waterborne transport, which causes the formation of significant amounts of greenhouse gases. Modern internal combustion engines have been designed to consume liquid fuels made from petroleum. The immediate introduction of alternative fuels for aviation and waterborne transport, which will contribute to the decarbonization of these sectors, requires that such fuels be used in existing engines and supplied as much as possible using the existing infrastructure. At the initial stage, it is important to establish the production of alternative fuels that have fuel characteristics close to the standardized characteristics of traditional petroleum products. In the future, with the development of science and technology, the most modern engines will appear on the market, which will use completely different energy sources, not related to oil refining.

Aviation and waterborne transport are important and promising segments of Ukraine's transport sector, the development of which was affected by the COVID-19 pandemic, and then, in February 2022, **interrupted by Russia's military aggression against Ukraine**.

According to Ukraine's Greenhouse Gas Inventory 1990-2020, GHG emissions from transport in 2020 amounted to 31.81 Mt of $CO_{2\text{-eq}}$, which was about 10% of the total emissions. The emissions from transport decreased by 71.6% as compared to 1990 and by 18.9% as compared to 2019. The reduction in 2020 can be explained by the COVID pandemic. In 2020, the largest contribution to GHG emissions from transport was made by motor transport (73.6%). At that, the emissions from domestic civil aviation and domestic water transport accounted for 0.5% and 0.25% of the total transport GHG emissions, respectively. Despite the current small contribution of aviation and waterborne transport to the total transport GHG emissions, these figures may increase tenfold in the course of further dynamic development of these sectors unless some appropriate measures do not start to be taken right now. One of these measures is switching to **alternative low-carbon fuels**.

Aviation

Civil aviation is an integral part of the transport system of Ukraine, the main activity of which is the implementation of such services as transportation of passengers, luggage, cargo and mail. The legal regulation of the aviation sector is provided by the *Air Code of Ukraine*. State regulation of the aviation sector and the usage of Ukraine's airspace is carried out by the Ministry of Infrastructure of Ukraine and the State Aviation Service.

In the period before the coronavirus infection pandemic, positive dynamics was observed in all areas of operations of the country's airlines: there was a resumption of air traffic after the fall that occurred in 2014-2015 and an increase in cargo and mail transportation by air transport.

Fuel consumption for domestic transportation in Ukraine decreased from 88.3 kt in 2012 to 34.0 kt in 2019 and 19.3 kt in 2020; fuel consumption for international transportation increased from 317 kt in 2012 to 545 kt in 2019 with a subsequent decline to 218 kt in 2020.

For the aviation industry of Ukraine, 2021 was the first year of gradual recovery after a significant decline in production performance in 2020, caused by the negative impact of the Covid-19 pandemic and related restrictions. In 2021, passenger and cargo transportation was carried out by 28 Ukrainian airlines; a total of 74 thousand commercial flights were performed against 45.3

thousand flights in 2020. According to statistics, in 2021, domestic airlines carried 9348.1 thousand passengers, which was almost 95% higher than in the previous year and was 68.2% of the "pre-pandemic" 2019.

A topical problem that affects the efficiency of Ukrainian civil aviation today is the aging of the aircraft fleet. The average age of aircraft exceeds 22 years. The largest Ukrainian carrier, UIA, uses a fleet that is over 12 years old. In addition, the fleet of Ukrainian airlines is not large: only four carriers have more than 10 aircraft; six airlines have a fleet size ranging 3 to 7 aircraft. Ukrainian airlines prefer foreign-made aircraft which makes up 90% of the total number of aircraft.

Most modern aircraft are equipped with gas turbine engines running on jet fuels. Aviation kerosene is the main fuel for jet liners. In Ukraine, the most common were three main brands of this fuel: TC-1, PT and Jet A-1. The first two were traditionally produced in Ukraine; the latter is European fuel, which appeared in Ukraine only about 10 years ago due to some differences in standards for certain quality indicators.

Aviation gasoline (petrol) is used in relatively small airplanes with piston aircraft engines. An example of such gasoline used in Ukraine is AVGAS100 LL.

Until recently, the Kremenchuk refinery remained the only domestic producer of aviation fuel and, in fact, the only operating oil refinery in Ukraine. Unfortunately, in the course of military operations on the territory of Ukraine in 2022, the Kremenchuk refinery's infrastructure was destroyed, the plant stopped working and will not be able to resume it, at least until the end of 2022.

In Ukraine, the requirements for the characteristics of jet fuels TC-1, PT, Jet A-1 and aviation gasoline are set by the Technical regulation on requirements for aviation gasoline and jet fuel approved in 2021 (CMU's Resolution № 523 dated May 26, 2021). Its entry into force was planned for May 29, 2022, but due to the beginning of military operations on the territory of Ukraine, it was decided that "the Resolution will enter into force one year after the cessation or repeal of martial law in Ukraine".

Until the CMU's Resolution that approved the Technical regulation on requirements for aviation gasoline and jet fuel has not entered into force, the quality of aviation fuel is determined by the following normative documents:

Jet A-1: DSTU 4796:2007 Aviation fuel Jet A-1for gas turbine engines. Specifications
PT: GSTU 320.00149943.007-97
TC-1: GSTU 320.001149943.011-99
Aviation gasoline: GOST 1012-72 Aviation gasolines. Specifications. Amended (status: not valid). According to explanations by UkrNDNC, subject to voluntary application of the standard, but in order to have any instructions, rules, etc. that regulate activities in a particular area, a company may apply a not valid GOST, however without referring to it in the relevant field of activity.

One of the main tasks to be solved during the operation of the aircraft is to ensure high quality aviation fuel at all stages of transportation, from the refinery to the aircraft. The main goal of any modern airport is to effectively organize the process of servicing an aircraft on the ground by minimizing the preparation period. In addition, safety is one of the main criteria in the aviation industry.

To perform these tasks, the following documents are valid in Ukraine:

- Instruction on ensuring refueling of aircraft with fuel and lubricants, technical fluids in the enterprises of civil aviation transport of Ukraine (Approved by the Order of the State Aviation Service N 416 of 14.06.2006).

- Instruction on quality control of fuels and lubricants, as well as special fluids in the state aviation of Ukraine (Approved by the Order of the Ministry of Defense of Ukraine N 662 of 08.12.2016).

Aviation fuels that meet technical requirements of DSTU (TU) and have undergone some post-operational preparation are allowed to be used on aircraft. Aviation fuel, lubricants and technical fluids from the moment of their arrival at FL warehouse of a civil aviation enterprise and before refueling of the aircraft are subject to quality control and special technological preparation. It is forbidden to use fuels, oils and technical fluids on civil aircraft without special technological preparation and without passing quality control in accordance with the established rules.

Arrangements and rules for the quality control of aviation fuels must meet the requirements of DSTU 3982-2000 "Aviation fuels, oils, lubricants and technical fluids. Arrangements and rules for quality control. Generalities". The requirements of this standard are mandatory for enterprises and organizations operating in Ukraine.

Refuellers (special vehicles) are used today in the airports of Ukraine, mainly for refueling of aircraft. Usually this type of vehicle is a tank truck equipped with a pump and special equipment for the issuance and accounting of fuel. A feature of refuellers is their maneuverability, autonomy and the ability to deliver fuel directly to the parking lots of aircraft regardless of their location. The use of this type of refueling also has a number of disadvantages: the maintenance of refuellers requires permanent parking spaces for their storage; there exists consumption of fuel and lubricants for refueling the refuellers; additional drivers are required; refueling time is long.

With the development of aviation equipment, as well as in solving the problems of operating costs when refueling aircraft, special systems of centralized refueling of aircraft have appeared to replace refuellers. The system is a set of technical means such as tanks for receiving, storing, dispensing fuel, as well as pumping units, filters, piping systems and refueling units. The main task of the complex is to reduce the time of aircraft parking and ensure their timely arrival at the destination airports. The main advantage of CRA is the continuous supply of fuel to the tanks of the aircraft, which allows to increase the number of aircraft operated simultaneously and significantly reduce the duration of their refueling. In addition, this method of refueling excludes contamination of fuel from the air and is the safest in terms of fire and easy to maintain. CRA system is particularly effective when refueling aircraft that carry passengers and cargo over long distances.

Despite a number of advantages, CRA systems also have some disadvantages: the introduction of these systems is rather a costly process, so when designing them it is necessary to carefully think over and justify the profitability of the complex; refueling by means of CRA systems requires the presence of necessary equipment on the site of the aircraft parking; when using CRA systems it is possible to refuel an aircraft only with one type of fuel. Refuellers do not have these disadvantages.

Complex work on the reconstruction of the refueling system was carried out at Boryspil Airport (Kyiv). In the future, the CRA system will be re-equipped, which will ensure high-quality

maintenance of aircraft. Unfortunately, today, most airports in Ukraine do not have the opportunity to implement CRA system on their territory. The reason for this is the need for large material contributions to the infrastructure.

According to experts, the further development of the aviation industry in Ukraine requires a program for the development and modernization of regional airports and the real implementation of the Common Aviation Area Agreement with the EU. To this end, it is primarily expected to adopt amendments to the State Target Program for the development of airports until 2023 and legislation that should address critical aspects that hinder the development of airports.

Waterborne transport

Ukraine's waterborne transport system includes river and sea transport. The geospatial location of the country makes it the centre of many transport corridors and transit routes, and the combination of a developed system of roads, railways, pipeline transport, sea corridors and ports can make Ukraine a logistics centre of the Eurasian continent.

The central executive body that implements the state policy in the field of maritime transport and inland water transport is the State Service for Maritime and Inland Water Transport and Shipping of Ukraine.

In recent years, some development of inland waterways has taken place in Ukraine, which after the collapse of the USSR were in decline for a long time. In 2014, the volume of cargo traffic and cargo turnover was the lowest since 2000, namely 3 Mt and 1.3 billion t*km, respectively. However, by 2019, the volume of cargo traffic and cargo turnover was restored to 6 Mt and about 3 billion t*km, respectively.

The situation with river transport in 2020, which was a crisis for Ukraine's economy due to Covid-19, did not change significantly in general, but there were some changes in the structure of transportation. There was a positive dynamics of cargo traffic on the Dnieper in the first half of 2021. 60% of inland waterway transport is cabotage, which involves transhipment in seaports of Ukraine with subsequent export of goods.

Experts estimate the potential of Ukraine's inland waterway transport at 80 Mt/yr by 2030, subject to the reorientation of traffic from roads to inland waterway transport, the intensification of international trade, and the attraction of new cargoes to inland waterway transport by the liberalization of transportation, which should be laid down in the Law of Ukraine "On Inland Water Transport".

As of February 24, 2022, Ukraine’s maritime transport system, based on the use of the Azov and Black Seas, included 18 seaports (five of them in the temporarily occupied Autonomous Republic of Crimea). The total capacity of the terminals of the operating thirteen ports is 313.3 Mt, but all these capacities were not fully loaded, half at most.

According to the State Enterprise "Classification Society the Shipping Register of Ukraine", more than 1,000 vessels of inland navigation and mixed navigation are registered in the country, which are suitable for work on inland waterways. Most of this fleet is obsolete as the average age is over 30 years.

Vessel fuel and bunker fuel oils are used by waterborne transport. Vessel fuel is used in marine high- and medium-speed diesel engines, as well as in gas-turbine installations. Bunker fuel oil of F-12 and F-5 brand is used in steam-turbine installations of ships and on vessels of the river and sea fleet.

According to data of the State Statistics Service of Ukraine, the final consumption of petroleum products by the waterborne transport of Ukraine (inland navigation) was 38 ktoe in 2018, 135 ktoe in 2019, and 2 ktoe in 2020.

Since 2020, the International Maritime Organization has strengthened the environmental requirements for marine fuel. Thus, the maximum allowable share of sulphur is reduced from 3.5% to 0.5%, which makes ship operators and shipbuilders think about more environmentally friendly fuels.

Due to the existing fiscal policy, the cost of fuel for bunkering in the ports of Ukraine is more expensive than that in the ports of other countries or outside the territorial waters of the country, which negatively affects the domestic market for bunkering ships. Foreign ships have difficulties with replenishing their fuel reserves when entering the sea trade ports of Ukraine. Today, vessel fuel is purchased in Ukrainian ports, but this fuel is purchased by Ukrainian companies for auxiliary and support vessels operating in ports. First of all, the fuel is purchased by state-owned enterprises (that is sea trade ports) which are obliged to conduct tender procedures for these procurements. Among these state-owned enterprises is the Administration of Sea Ports of Ukraine.

Requirements for the quality of vessel fuel are established by the Technical Regulation on requirements for motor gasoline, diesel, vessel fuel and boiler fuel (2013). In addition to this TR, the Ministry of Economic Development and Trade of Ukraine approved the List of national standards, the voluntary application of which can be considered as proof of compliance with the requirements of the Technical Regulation on requirements for gasoline, diesel, vessel fuel and boiler fuel (Order № 1179 of 01.10.2014, amended). For the vessel fuels, the following standards are specified in this List:

DSTU 4317:2004. Petroleum products. Fuel (class F). Classification. Part 1. Categories of fuels for vessel engines.

DSTU ISO 8216-2:2004. Petroleum products. Fuel (class F). Classification. Part 2. Categories of gas-turbine fuels for the use in industry and vessel engines.

Technical requirements for marine fuel oil F5 and F12 are determined by DSTU 4058-2001 "Petroleum fuel. Oil fuel. Specifications". The Rules for the prevention of pollution from ships (Register of Shipping of Ukraine, 2020) present requirements for the quality of liquid fuel supplied and used on ships.

In international practice, two types of fuel are generally used on ships:

- distillates obtained by distillation that consist of light fractions, which are characterized by low viscosity (2.5-14 mm^2/s) and density (830-860 kg/m^3);

- heavy fuels which are conditionally divided into two groups: intermediate (Intermediate Fuel) and heavy residual ones (Heavy Fuel Oil) with a viscosity range of 180-500 (700) mm^2/s.

On seagoing vessels, the main engines use mainly heavy fuels, and the auxiliary engines of seagoing vessels and all diesels of river and mixed navigation vessels use distillates.

The arrangements and technical support of the fuel supply stages in waterborne transport depends on the characteristics of the required fuel, environmental requirements of the route, refueling volumes, fuel prices, features of the vessel and other factors. The most important stage is the direct refueling of the vessel with fuel and motor oils, which is called bunkering and can be carried out from both shore and floating vehicles.

Compared to fuel oil, low-viscosity vessel fuel is a more environmentally friendly fuel. It is mandatory for use in the Emission Control Areas, but when entering the open ocean, ships switch to fuel oil as a cheaper fuel. According to the MARPOL Convention, maritime shipping should cease the use of heavy fuel oil in the near future, although changes in this area are slow.

Oil ports are used in ports to load or unload oil vessels. Refueling complexes for waterborne transport are a type of oil depot. Oil depots are enterprises consisting of a complex of facilities and installations designed for the reception, storage and issue of petroleum products to consumers. The infrastructure of a port oil depot is a complex of structures and tanks with a system of pipelines, pumps, shut-off equipment, filters, control and measuring devices, fire protection equipment and other elements.

Bunkering (refueling of a vessel with fuel and lubricants in bulk) can take place in a variety of ways: at the berth, on a raid, on the move or drifting in the sea or ocean, from a floating refueling station. Different types of vessels can choose the most acceptable option for bunkering. The fuel supplied to a ship must meet certain requirements and be suitable for use in certain types of engines. Bunkering should be carried out only after the receipts have been checked and the responsible personnel have been convinced that all the standards of the declared key properties such as viscosity, density, heating value, and water content are met.

According to the Law of Ukraine "On Inland Water Transport" (№ 1054-IX of 03.12.2020), replenishment of a vessel with fuel and lubricants in bulk (bunkering) on inland waterways is carried out near berths and in the operational waters of river ports (terminals), and also in places agreed with the central body of executive power, which implements the state policy in the field of inland water transport. Safety rules for bunkering vessels with liquid fuel are established by the Order of Ukraine's State Committee for Industrial Safety, Labor Protection and Mining Supervision "On Approval of Safety Rules for Employees of Port Vessels and Auxiliary Fleet Vessels of Fishery" (№ 13 of 24.01.2007).

The ports of Ukraine have infrastructure for transshipment and storage of petroleum products, which can also be used for bunkering ships. Most of this infrastructure is outdated and therefore needs repair and modernization. At present, at the current cargo turnover, in order to increase the volume of bunkering of fuels in waterborne transport, in particular, sea craft, it is necessary to eliminate legal barriers that have created preconditions for the development of the shadow market of bunkers. Given the requirements of MARPOL and the trend to limit the boundary emissions of pollutants into the atmosphere, maritime transport needs to switch to low-sulfur fuels, which creates new opportunities for the introduction of new types of marine fuels, including biofuels. At the same time, there will be a need for partial modernization of fuel depots and bunkering infrastructure. Thus, the development of the bunkering market and the reorientation to alternative fuels will create economic incentives for the modernization of the fuel supply infrastructure for waterborne transport, which will ensure reducing emissions of pollutants and greenhouse gases.

In 2017, *the Strategy for the implementation of provisions of Directives and Regulations of the European Union in the Field of International Maritime and Inland Water Transport* (the "Roadmap") was approved. The main task of the Strategy is an adaptation of the national legislation to the legislation of the European Union, which will promote liberalization and mutual access to the markets of Ukraine and the European Union and full implementation of Ukraine's commitments in the field of merchant shipping and inland water transport.

1. Overview of aviation and waterborne transport sectors in Ukraine

1.1. General information about the sectors development state

Aviation

Civil aviation is an integral part of the transport system of Ukraine, the main activity of which is the implementation of such services as transportation of passengers, luggage, cargo and mail. In the period before the coronavirus infection pandemic, positive dynamics was observed in all areas of operations of the country's airlines: there was a resumption of air traffic after the fall that occurred in 2014-2015 and an increase in cargo and mail transportation by air transport in Ukraine. During 2016-2018, the volume of passenger traffic increased almost twice compared to 2015 and exceeded the level of "pre-crisis" 2013 by more than one and a half times.

Currently, Ukrainian air transport makes its most significant contribution to passenger turnover: 28.3% and 20.6% of total passenger turnover by all modes of transport in 2019 and 2020, respectively (**Table 1.1**). Air transport has the longest average transportation distance for one passenger (> 2000 km) and for one ton of cargo (> 3500 km) (**Fig. 1.1**).

Table 1.1. Main statistical data for aviation and waterborne transport sectors in Ukraine in 2019-2020 [1, 19, 22].

Indexes	**Aviation**		**Waterborne transport**	
	2019	**2020**	**2019**	**2020**
Final consumption of oil products, ktoe	182 (domestic flights)	89 (domestic flights)	135 (inland navigation)	2 (inland navigation)
share of the total consumption by transport	*2.3%*	*1.3%*	*1.7%*	*0.03%*
Capital investment, mln UAH	1768	856	252	326
share of the sector "transport, warehousing, postal and courier activities"	*4%*	*2.4%*	*0.6%*	*0.9%*
Capital investment index, % to the previous year	109.6%	24.1%	129.7%	67.1%
Transportation of goods by mode of transport, Mt	0.1	0.1	6, including: MT – 2, RT – 4	6, including: MT – 2, RT – 4
share of the whole transport sector	*nearly 0%*	*nearly 0%*	*0.4%*	*0.4%*
Cargo transportation volume index, % to the previous year	93%	95%	109%, in particular: MT – 112%, RT – 107%	92%, in particular: MT – 86%, RT – 95%
Freight turnover, bln t*km	0.3	0.3	3.4, including: MT – 1.8, RT – 1.6	2.9, including: MT – 1.5, RT – 1.4
share of the whole transport sector	*0.1%*	*0.1%*	*1%, including: MT – 0.5%, RT – 0.5%*	*0.9%, including: MT – 0.5%, RT – 0.4%*

Indexes	Aviation		Waterborne transport	
	2019	**2020**	**2019**	**2020**
Transportation of passengers, mln, including:	13.7	4.8	M: 0.079; P: 0.59	M: 0.053; P: 0.257
international flights/voyages	12.5	4.3	RT 0.015	---
domestic* flights/voyages	1.2	0.5	M: 0.079; P: 0.575	M: 0.053; P: 0.257
share of the whole transport sector	*0.3%*	*0.2%*	*nearly 0%*	*0%*
Index of passenger traffic, % to the previous year	109%	35%	101%, in particular: MT – 110%, RT – 100%	46%, in particular: MT – 66%, RT – 43%
Passenger turnover, mln man*km, including:	30242	10107	MT: 1.3; RT: 24.5	MT: 0.7; RT: 3.3
international flights/voyages	29707	9844	MT: 0.1; RT: 16.5	---
domestic* flights/voyages	535	263	MT: 1.2; RT: 8	MT: 0.7; RT: 3.3
share of the whole transport sector	*28.3%*	*20.6%*	*0%*	*0%*
Average distance of transportation of one passenger, km	2206	2107	MT – 17 RT – 41	MT – 13 RT – 13

** Cabotage navigation for marine transport.*
MT – marine transport, RT – river transport.

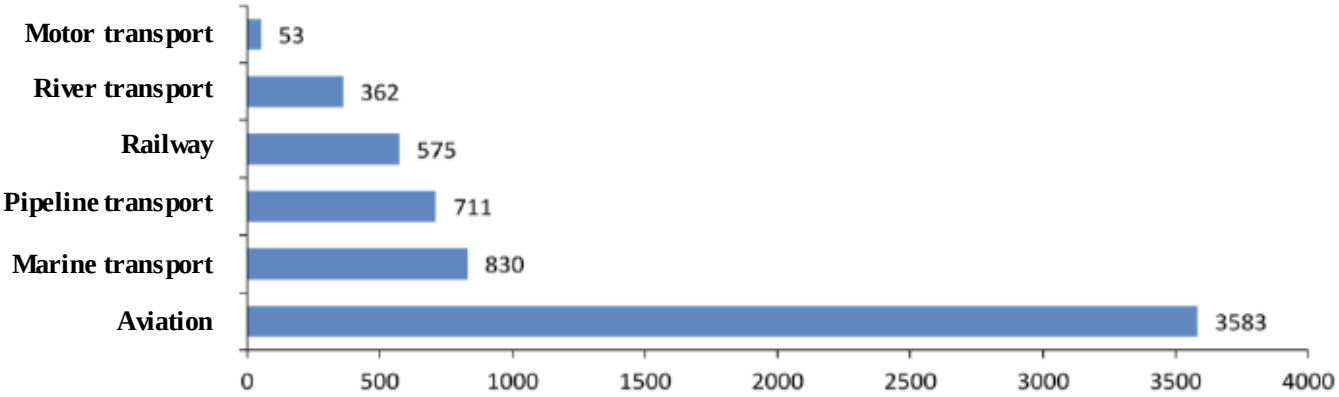


Fig. 1.1. The average distance of transportation of one ton of cargo by certain modes of transport in 2020 [19].

Air traffic in Ukraine decreased during 2013-2016, followed by its growth until 2019 and decline in 2020. For the aviation industry of Ukraine, 2021 was the first year of gradual recovery after a significant decline in production performance in 2020, caused by the negative impact of the Covid-19 pandemic and related restrictions (**Fig. 1.2**). In 2021, passenger and cargo transportation was carried out by 28 Ukrainian airlines; a total of 74 thousand commercial flights were performed (against 45.3 thousand flights in 2020). According to statistics, in 2021, domestic airlines carried 9348.1 thousand passengers, which was almost 95% higher than in the previous year and was 68.2% of the "pre-pandemic" 2019 (**Fig. 1.3**).

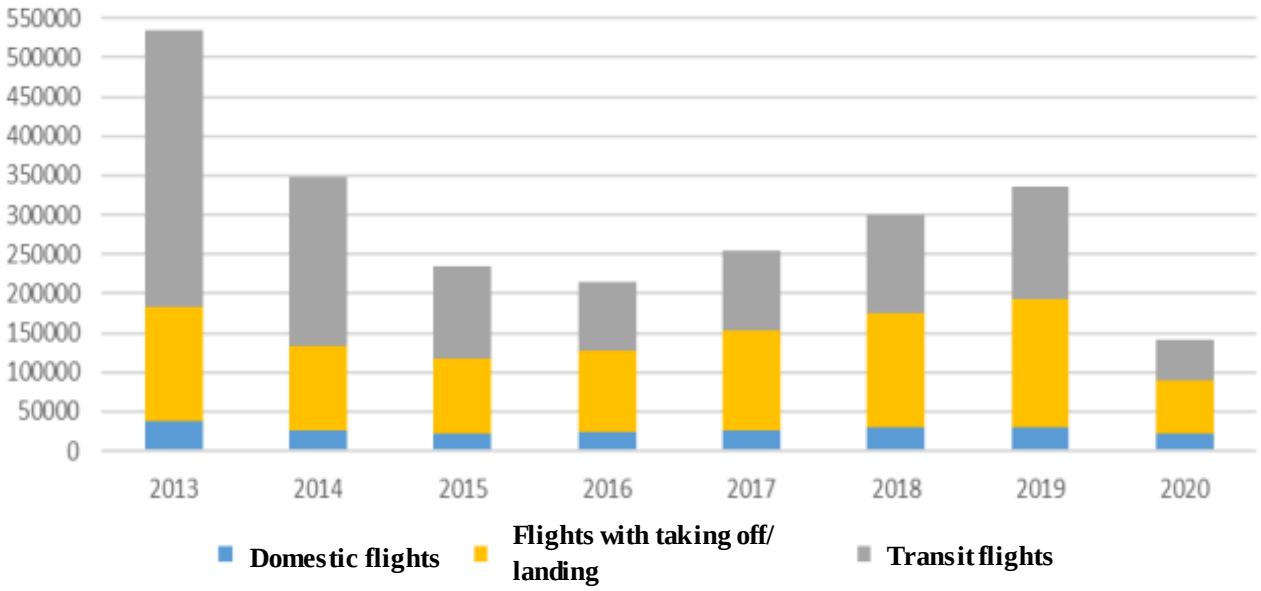


Fig. 1.2. Number of flights in Ukraine [29].

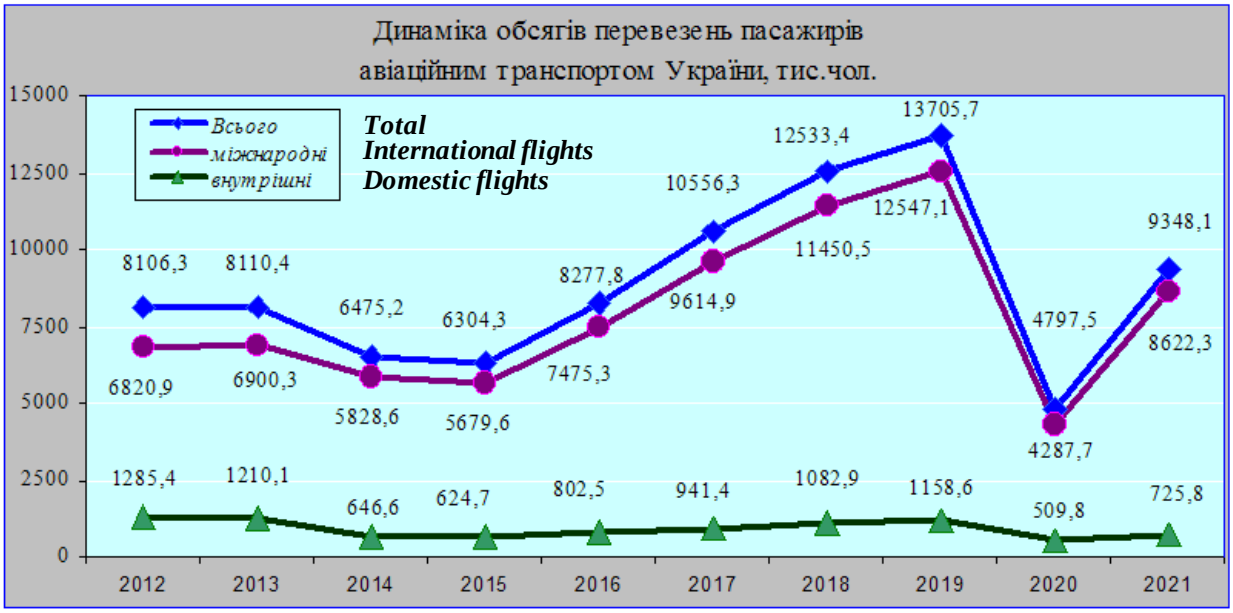


Fig. 1.3. Dynamics of passenger transportation by air transport in Ukraine, **1000 men** [2].

According to the approved schedule, in 2021, regular flights to 42 countries were operated by 9 domestic airlines. The number of passengers who used the services of Ukrainian airlines in 2021 doubled compared to the previous year and reached 2608.9 thousand people. At the same time, 29 foreign airlines from 34 countries, including four new ones, operated regular flights to Ukrainian airports. The volume of traffic of foreign airlines in the international scheduled traffic increased by 83.4% and amounted to 6096.8 thousand passengers, which was 70% of the total volume of scheduled passenger traffic between Ukraine and the world.

Despite the unstable market situation and many restrictions, Ukrainian airlines started operating international scheduled passenger flights on 23 new routes and foreign air carriers on 28 new routes during the year.

Regular passenger traffic within Ukraine was performed by 6 airlines, which provided air services to 12 cities of Ukraine. In 2021, 713.8 thousand passengers were transported by regular domestic flights, which was 41.8% more than a year earlier.

During 2021, commercial flights of Ukrainian and foreign air carriers were served by 19 Ukrainian airports and airfields with the largest share of passenger traffic (58%) at the main airport of the country – Kyiv (Boryspil) (**Fig. 1.4**). According to the results of the year, the number of passengers served at this airport increased by 82.9% as compared with 2020. High growth rates of passenger traffic were also observed at the following airports: Lviv – 2.1 times, Kyiv (Zhuliany) – 2 times, Odesa – by 90.1%, Kharkiv – by 76%.

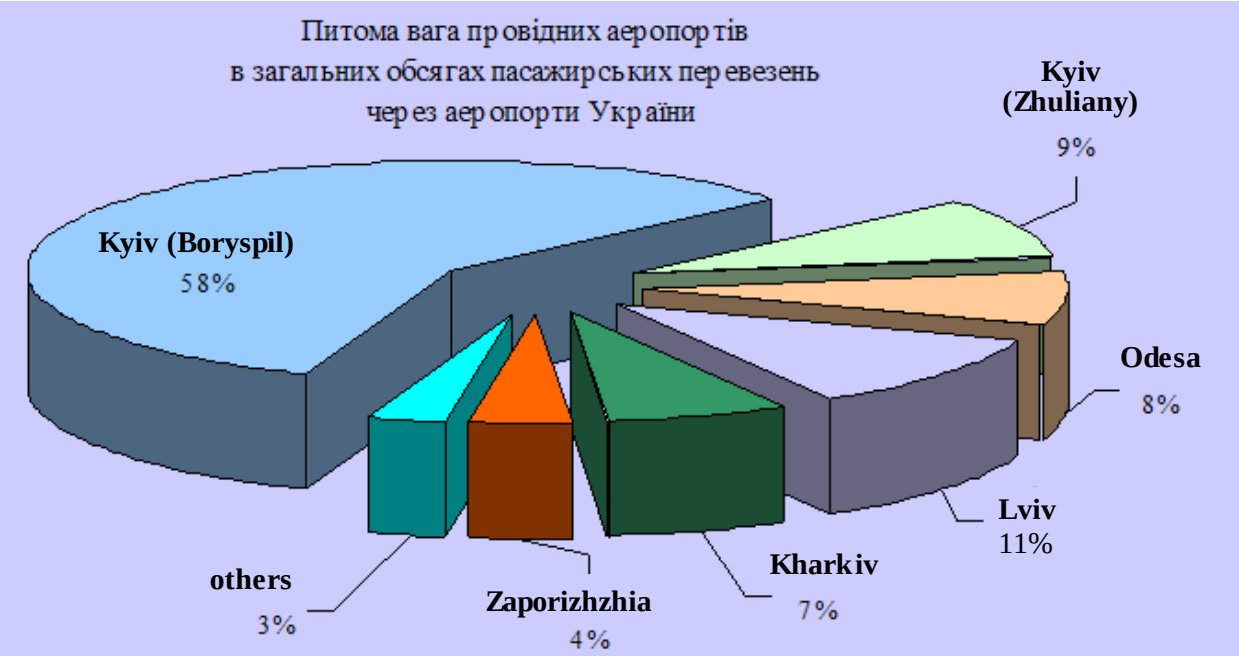


Fig. 1.4. The share of Ukraine's leading airports in the total volume of passenger traffic through the country's airports [2].

Against the background of increasing total passenger traffic, airlines face the question of not only simple but also expanded reproduction of the fleet. However, domestic airlines increasingly decide to order equipment from foreign manufacturers. That does not contribute to the development of the domestic aviation industry, which is directly dependent on these orders. Ukrainian airlines need serious modernization of their fleet. According to the State Register of Civil Aircraft, more than 80% of Ukrainian airlines' aircraft are leased abroad. Only four airlines have their own aircraft.

A topical problem that affects the efficiency of Ukrainian civil aviation today is the aging of the aircraft fleet. The average age of aircraft exceeds 22 years. The largest Ukrainian carrier, UIA, uses a fleet that is over 12 years old. In addition, the fleet of Ukrainian airlines is not large: only four carriers have more than 10 aircraft; six airlines have a fleet size ranging 3 to 7 aircraft. Ukrainian airlines prefer foreign-made aircraft which makes up 90% of the total number of aircraft [21].

With the beginning of Russia's military aggression against Ukraine on February 24, 2022, **Ukraine closed the airspace for civil aircraft** due to high risks in accordance with the requirements of the *Air Code of Ukraine* and the *Regulations on the Use of Ukrainian Airspace*.

Waterborne transport

Waterborne transport is the leader in terms of cargo transportation volumes in the world and provides the lowest prime cost. The potential of Ukraine's waterborne transport, which includes both river shipping routes and marine areas, is difficult to overestimate. The geospatial location of the country makes it the center of many transport corridors and transit routes, and the combination of a developed system of roads, railways, pipeline transport, sea corridors and ports can make Ukraine a logistics center of the Eurasian continent.

Ukraine's waterborne transport system includes river and sea transport. Elements/resources of inland waterways of Ukraine are: inland waterways as such (rivers, lakes, reservoirs, etc.), river fleet, inland waterways infrastructure (berths, anchorages, navigable channels in water areas, shipping locks, fairways, signaling systems, etc.), service infrastructure facilities (river ports, river terminals, and port points), navigation and control system. The river transport system is based on the waterways of the Dnieper, Danube, and Southern Buh. The Pripyat and Desna shipping lanes have been lost in the last decade due to siltation of the bottom. A similar threat exists for other rivers due to insufficient dredging. Inland waterways of Ukrainian rivers in terms of guaranteed depths do not fully meet the requirements for the safety of navigation, only a little more than half of the paths (57%) have guaranteed depths. To restore commercial shipping, it is necessary to carry out dredging works on the Dniprodzerzhynsk shallow waters and the section from Mykolayiv to Voznesensk on the Dnieper River, as well as on the Southern Buh River, where the river depth reaches only 1.6 m with the required minimum of 2.9 m.

There are six consecutive reservoirs on the Dnieper River: Kakhovka, Dnieper, Kamianske, Kremenchuk, Kaniv and Kyiv, and, accordingly, six navigable locks, the operation of which is crucial for river transport across the Dnieper. Due to unsatisfactory technical condition of locks reaching the deadline - 70 years, as well as due to long-term underfunding of maintenance of navigable locks of the Dnieper, which in recent years did not exceed 50% of the required needs, a situation posed a real threat of man-made disaster. According to a study by experts from the engineering corps of the US Army, the need to invest in updating the technical condition of the locks in the priority areas is 8.7-16.2 million US dollars.

Inland waterway infrastructure is a key factor in the functioning of the shipping market. A short length of waterways, including with guaranteed depths, seasonal navigation, unstable operation of locks, low speed of "rotation" of vessels due to underdeveloped port infrastructure mean for potential market operators a small number of voyages, low profitability, and, consequently, low investment attractiveness [14].

Indicators characterizing the state and efficiency of the use of the resource navigable potential of Ukraine's rivers have had negative dynamics for a long time. Since Ukraine's independence, the length of river waterways has almost halved (from 4,000 km to 2,100 km). At the same time, the density of river waterways decreased by 1.75 times, the intensity of cargo traffic by 4.3 times, and passenger traffic by 7.5 times [15].

In recent years, some development of inland waterways has taken place in Ukraine, which after the collapse of the USSR were in decline for a long time. In 2014, the volume of cargo traffic and cargo turnover was the lowest since 2000: 3 Mt (**Fig. 1.5)** and 1.3 billion t*km (**Fig. 1.6**), respectively. However, by 2019, the volume of cargo traffic and cargo turnover was restored to 6 Mt and about 3 billion t*km, respectively (see **Table 1.1**).

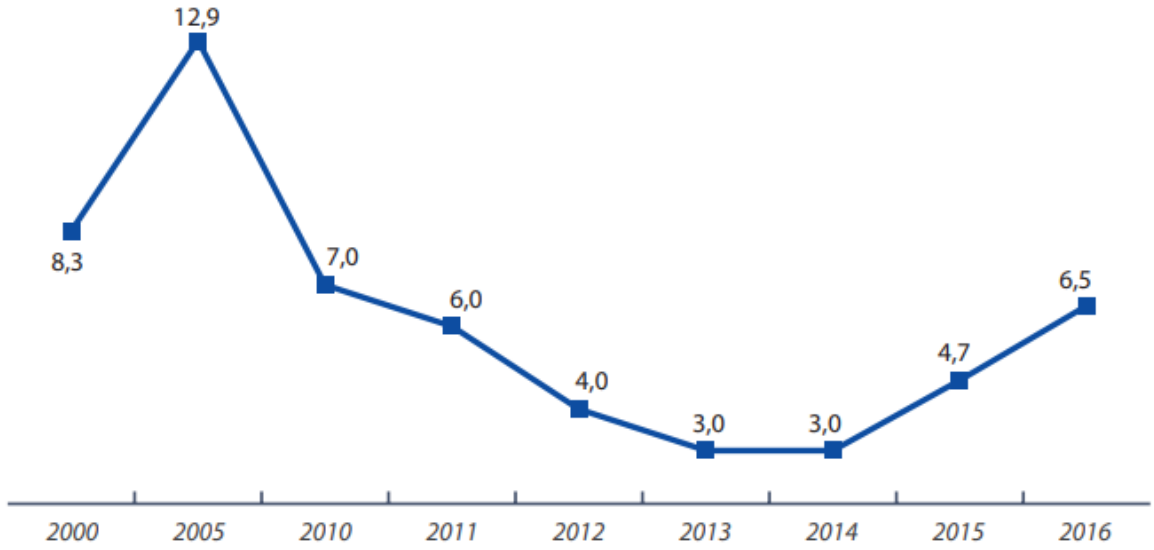


Fig. 1.5. Transportation of goods by inland waterways of Ukraine, **Mt** [14].

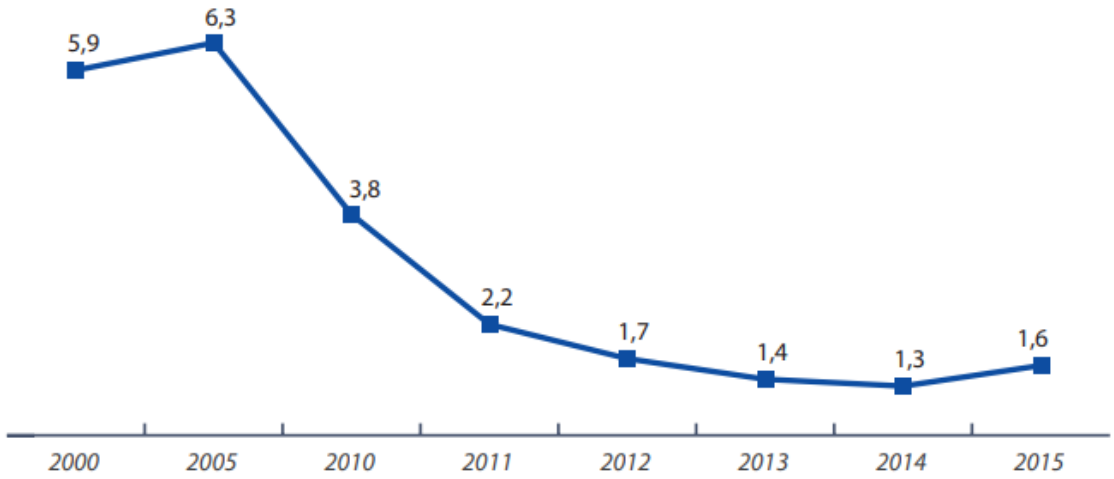


Fig. 1.6. Cargo turnover of inland waterways of Ukraine, **billion t*km** [14].

The situation with river transport in 2020, which was a crisis for Ukraine's economy due to Covid-19, did not change significantly in general, but there were some changes in the structure of transportation. The decrease in grain traffic was a consequence, in particular, of atypical weather conditions and a decline in the amount of grain harvested by farmers in 2020. There was a steady growth in the transportation of petroleum products, metal products, and building materials. There was a positive dynamics of cargo traffic on the Dnieper in the first half of 2021: the figure increased

by 56.4% compared to the same period in 2020. 60% of inland waterway transport is cabotage, which involves transhipment in seaports of Ukraine with subsequent export of goods.

Experts estimate the potential of Ukraine's inland waterway transport at 80 Mt/y by 2030, subject to the reorientation of traffic from roads to inland waterway transport, the intensification of international trade, and the attraction of new cargoes to inland waterway transport by the liberalization of transportation, which should be laid down in the Law of Ukraine "On Inland Water Transport". At the same time, given that Ukraine's economy tends to export, potentially the transportation of goods by the Dnieper, provided the modernization of locks can reach 45 Mt/y (30 Mt of exports, 15 Mt of imports) [16].

Currently, there are 4 operators operating on the inland waterway cargo market under the Ukrainian flag: Ukrrichflot, Nibulon, Ukrainian Danube Shipping Company (state), and Kyiv River Port. Two of them, Ukrrichflot and Nibulon, are vertically integrated companies and at the same time transport operators, cargo owners, river terminal owners, and shipbuilders.

The largest carrier with a market share of about 35% is a private company JSSC "Ukrrichflot". Ukrrichflot's fleet consists of about 100 vessels of various types. Ukrrichflot also owns 5 river terminals on the Dnieper River. Nibulon Agricultural Corporation is an important player with a market share of about 30%. Nibulon's fleet consists of 60 non-self-propelled vessels and 12 tugboats. The company owns grain terminals on the Dnieper and Southern Buh rivers and transports grain through these rivers. The state company Ukrainian Danube Shipping Company with a market share of about 20% carries out transportation exclusively along the Danube. At the same time, a significant part of the fleet is leased from foreign companies that carry out transportation on the international section of the Danube and are not participants in the market of inland waterways of Ukraine. Kyiv River Port closes the top four with 15% share of the market.

Passenger traffic on the Dnieper had a dynamic growth rate in 2016-2018 (the maximum annual figure was 322.3 thousand people), followed by a decrease in the number of users of passenger water transport, in particular due to the Covid-19 pandemic [17].

The unique advantage of the water transport system of Ukraine is a successful combination of existing enterprises. Thus, in Ukraine, there are 30 shipbuilding/ship repair plants (seven of which are located in the temporarily occupied Autonomous Republic of Crimea), which have significant potential for the construction of a variety of ships. At the same time, their work is provided by 11 research and design enterprises and bureaus. And the main thing is the availability of resources for shipbuilding, i.e. large-scale development of the metallurgical industry and a large number of enterprises that manufacture or have the potential to produce components, including engines, even their rare type - gas turbines. However, in 2017-2018, only 28 vessels were built in Ukraine and 371 vessels were overhauled [18].

As of February 24, 2022, Ukraine’s maritime transport system, based on the use of the Azov and Black Seas, included 18 seaports (five of them in the temporarily occupied Autonomous Republic of Crimea). The total capacity of the terminals of the operating thirteen ports is 313.3 million tons, but all these capacities were not fully loaded, at most half [16]. For example, in 2019, the total cargo turnover of ports amounted to only 160 Mt with the highest figures in the ports of Pivdennyi (61.6 Mt), Mykolaiv (30.1 Mt), Chornomorsk (23.8 Mt), Odesa (23.3 Mt) [28]. It is also worth noting the presence in Ukraine of a unique river-sea port in Kherson, which is

equipped with elements of both river and sea logistics. However, its load in 2018 was only 41%, and 51% (2.8 million tons) in 2019.

According to the State Enterprise "Classification Society the Shipping Register of Ukraine", more than 1,000 vessels of inland navigation and mixed navigation are registered in the country, which are suitable for work on inland waterways. Most of this fleet is obsolete as the average age is over 30 years. Technically and morally obsolete vessels with an average service life of 25 to 30 years make up 81.9% of the river transport fleet. The largest share of obsolete vessels is accounted for by cargo and passenger ships (97.1%), bulk carriers (89.5%) and dry cargo vessels (84.4%).

In the structure of the cargo transport fleet of Ukraine, which is registered under the Ukrainian flag, the largest share are ships for general cargo (41.9%), universal ships (34.9%), tankers (15.1%), other ships 8.1%). Detailed data on the number of river and sea vessels by type, as well as the composition and structure of the self-propelled cargo fleet of Ukraine in 2020 are presented in **Annex 1**.

As of June 2022, **Ukraine's seaports are blocked** due to Russia's military aggression against Ukraine, which began on February 24, 2022.

1.2. Consumption of fuels, fuels standards and specifications

Aviation

Fuel consumption by domestic and international aviation of Ukraine in 2007-2019 by aircraft type is presented in **Annex 2**; flight statistics in 2020, including fuel consumption and distances is given in **Annex 3**. These data show that the fuel consumption for domestic transport decreased from **88.3** kt in 2012 to **34.0** kt in 2019 and **19.3** kt in 2020. At that the fuel consumption for international transportation increased from **317** kt in 2012 to **545** kt in 2019, with a subsequent decline to **218** kt in 2020.

Most modern aircraft are equipped with **gas turbine** engines running on jet fuels. **Aviation kerosene** is the main fuel for **jet liners**. In Ukraine, the most common were three main brands of this fuel: **TC-1**, **PT** and **Jet A-1**. The first two were traditionally produced in Ukraine; the latter is European fuel, which appeared in Ukraine only about 10 years ago due to some differences in standards for certain quality indicators. The world leader in the production of jet fuel is the United States; in Europe, the large producers are the Netherlands, the United Kingdom and Germany. Examples of the manufacturers are ExxonMobil, BP p.l.c., Chevron, Valero Energy.

Aviation gasoline (petrol) is used in relatively small airplanes with **piston** aircraft engines. An example of such gasoline used in Ukraine is AVGAS100 LL. This fuel is produced by such companies as Repsol (Spain), ExxonMobil (USA), Puma Energy (Singapore, Switzerland) and others (the location of the head office is indicated in parentheses).

Until 2011, the need for aviation fuel in Ukraine was covered at the expense of domestic petroleum refining, which was done by several Ukrainian refineries. For example, in 2010, of 350 kt consumed by the entire Ukrainian aviation industry, more than 330 kt were produced domestically [3]. In 2011, the situation changed dramatically, and the share of aviation fuel decreased sharply. The fuel production became unprofitable, as prices of Ukrainian kerosene were much higher than prices of similar products at a number of European airports. Accordingly, the share of imports began to grow (**Fig. 1.7**).

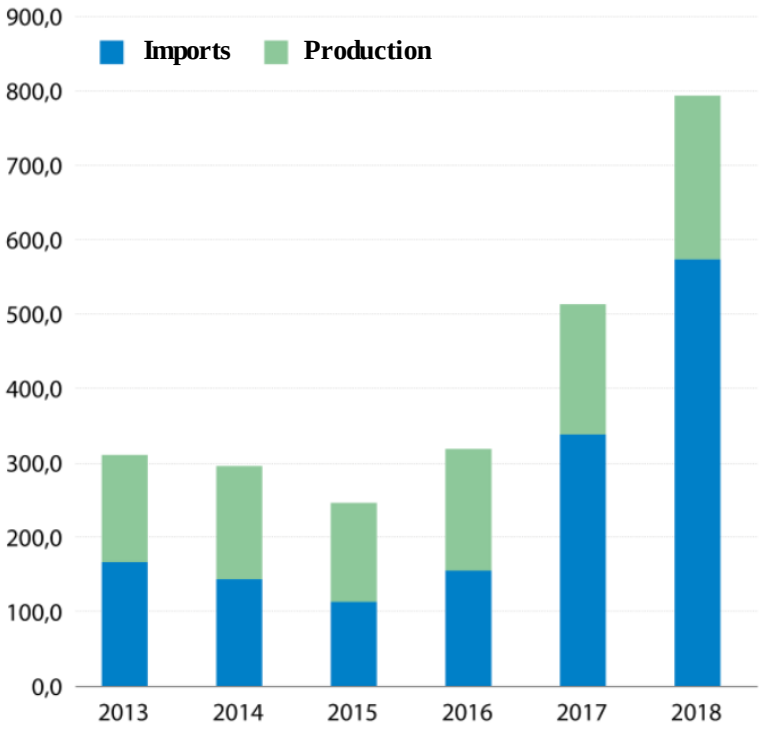


Fig. 1.7. Balance of aviation fuel market in Ukraine, **kt** [4].

It should be noted that not all aviation fuel was consumed for its intended purpose. Thus, according to the estimates of the consulting company UPECO (LLC "Ukrpetrolconsulting"), in 2018, no more than 450 kt were used in aviation; the remaining 350 kt were mixed with diesel fuel and used for road transport.

In 2013, the main exporters of aviation fuel to Ukraine were Belarus and Russia; later the list of exporters expanded considerably. In 2018, Italy became the largest supplier of aviation fuel to Ukraine with the shipment of kerosene being doubled to 208 kt. Fuel was shipped to Ukraine by refineries of Saras, Sasoil, Eni and Kuwait Energy (di Milazzo plant) located in Sicily and Sardinia. Lithuania was the second supplier. The Mazheikiai refinery increased the shipment of the jet fuel by 83% up to 140,000 tons. The Greek refineries of Hellenic Petroleum and Motor Oil supplied 125,000 tons of fuel to Ukraine, which was almost 4.5 times more than in 2017. Since 2016, kerosene import has changed its direction from land to sea. In 2018, the ratio between tanker and railway parties was 61% to 39%.

The main recipient of aviation fuel in 2018 was the Trade Commodity group of companies with 198.3 kt (34.6% of the imports) (**Fig. 1.8**). During several years of its presence, the company turned the Mykolaiv port into the largest kerosene hub: 222.3 kt of the fuel were transhipped through the port in 2018. The second position in the supply was occupied by Alliance Energo Trade (89.6 kt) and BNK-Ukraine delivered 71.7 kt to Ukraine (primarily for OKKO). Amic and Glusco, which performed refuelling airplanes, delivered 43.5 and 39.8 kt, respectively. SOCAR, an active participant of the state tenders, imported 24.5 kt. Other major suppliers include "Luxury Country" (22.1 kt), "Mergen" (18.5 kt), Maddox (17.4 kt) and WOG (16.1 kt).

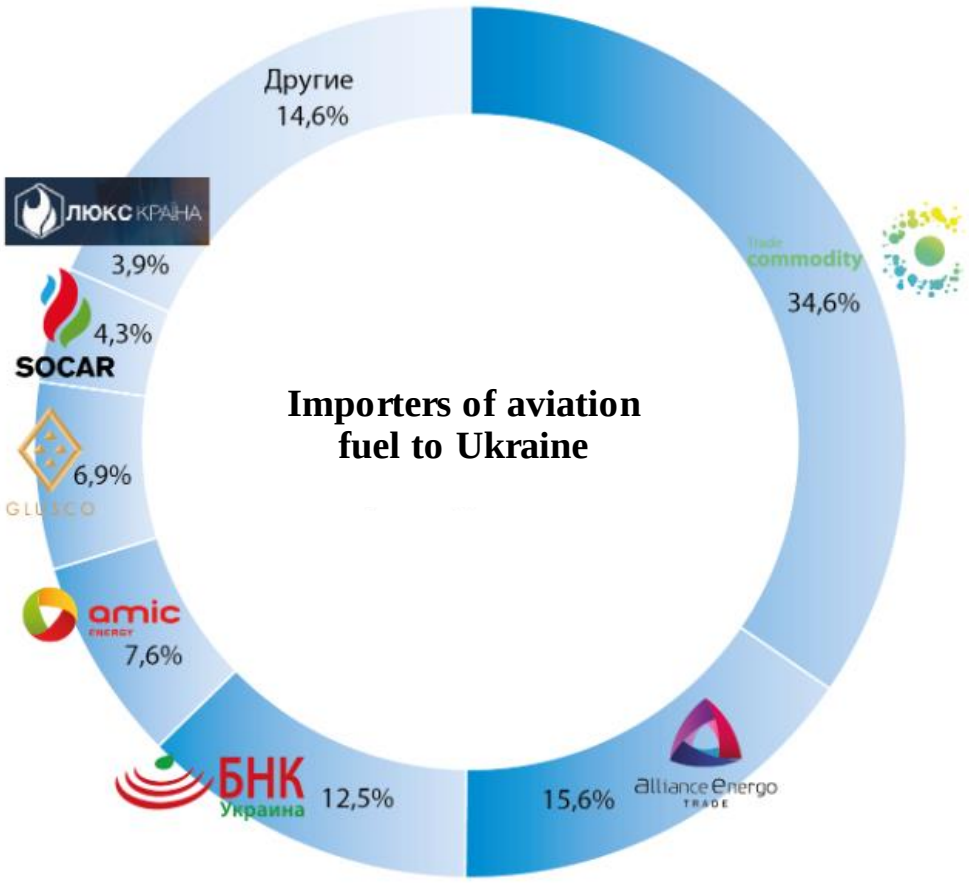


Fig. 1.8. Importers of aviation fuel to Ukraine in 2018 [4].

Until recently, the **Kremenchuk refinery** remained the only domestic producer of aviation fuel and, in fact, the only operating oil refinery in Ukraine. The plant supplied fuel to Boryspil Airport, Kyiv (202 kt by railway in 2018), to the airports of Dnipro (6-7 kt/y of kerosene by road transport), Lviv (2 kt/y), Ivano-Frankivsk (2 kt/y). The "Boryspil" fuelling company performed refuelling at Boryspil International Airport.

Unfortunately, in the course of military operations on the territory of Ukraine in 2022, the Kremenchuk refinery's infrastructure was destroyed, *the plant stopped working and will not be able to resume it, at least until the end of 2022*.

In 2019, the estimated volume of aviation fuel consumption at Ukraine's airports was 220 kt in Boryspil (Kyiv), 50 kt in Zhuliany (Kyiv); the Odessa, Lviv and Kharkiv airports consumed more than 10 kt each, Zaporizhzhia airport – 6.4 kt (railway supply), Gostomel airport (Kyiv region) – about 5 kt (supply by SE "Antonov" vehicles).

In Ukraine, the requirements for the characteristics of ***jet fuels TC-1, PT, Jet A-1*** and ***aviation gasoline*** are set by the **Technical regulation on requirements for aviation gasoline and jet fuel** approved in 2021 (CMU's Resolution № 523 dated May 26, 2021) (**Tables 1.2, 1.3**) [5]. Its entry into force was planned for May 29, 2022, but due to the beginning of military operations on the territory of Ukraine, it was decided that **"the Resolution will enter into force one year after the cessation or repeal of martial law in Ukraine".**

According to this TR:

aviation fuel, namely aviation gasoline and fuel for jet engines, is the fuel for aircraft engines produced from oil or other raw materials;

aviation gasoline is the gasoline for use in aircraft piston internal combustion engines;

jet fuel is the fuel for use in aircraft gas turbine engines;

additive is a substance that is added to aviation fuel to give it special qualities, improve performance, physical and chemical properties.

TR allows adding additives to the composition of fuels for jet engines and aviation gasoline. Additives must have a chemical product safety passport and must not impair other fuel quality indicators. For aviation petrol, this must be confirmed by the test report from an accredited testing laboratory or by a quality passport.

Table 1.2. Fuel performance requirements for Jet A-1, TC-1, PT fuels for jet engines [5].

Indexes	Jet A-1	Jet fuel TC-1	Jet fuel PT
Density, kg/m^3	775…840 at 15°C	not less than 775 at 20°C	not less than 775 at 20°C
Fraction composition:			
10% is distilled at a temperature not exceeding, °C	205	175	175
50% is distilled at a temperature not exceeding, °C	---	225	225
90% is distilled at a temperature not exceeding, °C	---	270	270
98% is distilled at a temperature not exceeding, °C	---	280	280
end boiling point, not above, °C	300	---	---
distillation residue, not more than, %	1.5	---	---
distillation losses, not more than, %	1.5	---	---
Kinematic viscosity, mm^2/sec	not above 8 at minus 20°C	not less 1.25 at 20°C; not above 16 at minus 40°C	not less 1.25 at 20°C; not above 16 at minus 40°C
Lower heating value, not less than, MJ/kg	42.8	43.12	43.1
Flash point in a closed crucible, °C	not below 38	not below 28	not below 30

Indexes	Jet A-1	Jet fuel TC-1	Jet fuel PT
The crystallization onset temperature, °C	not above minus 40	not above minus 55	not above minus 55
Acid number	not more than 0,015 mg KOH per 1 g	not more than 0,7 mg KOH per 100 см^3 of fuel	not more than 0,7 mg KOH per 100 см^3 of fuel
The share of aromatic hydrocarbons	not more than 25% (volume share)	not more than 22% (mass share); no more than 20% (volume share)	not more than 22% (mass share); no more than 20% (volume share)
Concentration of actual resins, mg per 100 cm^3 of fuel	not more than 7	not more than 5	not more than 4
Mass fraction of total sulphur	not more than 0.3%	not more than 0.25%	not more than 0.1%
Methyl esters of fatty acids	not more than 50 mg/kg	---	---

Notes: 1. A dash in the table means that the relevant regulation/standard does not specify this indicator for this type of fuel. 2. Selected indicators are presented for their comparison for different fuels. 3. In the TR, the fuel properties of Jet A-1 are given in a separate table.

Table 1.3. Requirements for the characteristics of aviation gasoline [5].

	Indexes	Unit	Value
1.	The octane number by the motor method is no lower than		99.6
2.	The content of tetraethyl lead is no higher than	g/dm^3	0.27
3.	Factional composition:		
	10 percent is distilled at a temperature not higher than	°C	75
	40 percent is distilled at a temperature not lower than	°C	75
	50 percent is distilled at a temperature not higher than	°C	105
	90 percent is distilled at a temperature not higher than	°C	135
	the end of boiling is not higher than	°C	170
	the sum of temperatures of 10 and 50 percent distillation is no lower than	°C	135
	yield is not less than	%	97
	remainder is not more than	%	1.5
	losses are not more than	%	1.5
4.	Saturated vapour pressure is within	kPa	38-49
5.	The crystallization temperature is not higher than	°C	minus 58
6.	Mass fraction of total sulphur is not more	%	0.05
7.	The content of blue dye is not more than	mg/l	2.7
8.	The content of actual resins is not more	mg/100 см^3	3

9.	Test on a copper plate at a temperature of 100 °C for 2 hours, not more than	points	1
10.	Specific electrical conductivity is not more than	pS/m	450
11.	Heating value	MJ/kg	not less than 43.5

Until the CMU's Resolution that approved the Technical regulation on requirements for aviation gasoline and jet fuel has not entered into force, the quality of ***aviation fuel*** is determined by the following normative documents:

Jet A-1: DSTU 4796:2007 Aviation fuel Jet A-1for gas turbine engines. Specifications (http://online.budstandart.com/ua/catalog/doc-page?id_doc=65323)

PT: GSTU 320.00149943.007-97 (**Table 1.4**)

TC-1: GSTU 320.001149943.011-99

Aviation gasoline: GOST 1012-72 Aviation gasolines. Specifications. Amended (current status: *not valid* http://online.budstandart.com/ua/catalog/doc-page.html?id_doc=54181). According to explanations by UkrNDNC, if a GOST is repealed by the national standardization body, it no longer has the status of a normative document, but is a simple "text". Subject to voluntary application of the standard, but in order to have any instructions, rules, etc. that regulate activities in a particular area, a company may apply a not valid GOST, however without referring to it in the relevant field of activity (http://uas.org.ua/ua/pitannya-vidpovidi/).

Table 1.4. Example of a quality passport for PT jet fuel produced by Public Company «Ukrtatnafta» on 06.01.2018 according to GSTU 320.00149943.007-97 [25].

Indexes	**Value according to the normative document**	**Value according to tests**	**Testing method**
1. Density at 20 °C, kg/m^3, no less than	775	793.0	According to GOST 3900-85
2. Fractional composition: - the beginning of boiling, no lower than, °C - 10% is distilled at T not higher than, °C - 50% is distilled at T not higher than, °C - 90% is distilled at T not higher than, °C - 98% is distilled at T not higher than, °C	 135 175 225 270 280	 152.5 173.0 188.0 210.0 225.5	According to GOST 2177-99
3. Kinematic viscosity at minus 40 °C, mm^2/sec, no more than	16	6.535	According to DSTU GOST 33-2003
4. Lower heating value, kJ/kg, not less than	43100	43194	According to GOST 11065-90 and 7.2 GSTU 320.00149943.007-97
5. Height of non-smoking flame, mm, not less than	25	25.3	According to ASTM D 1322-97
6. Acidity, mg KOH per 100 cm^3 of fuel, not more than	0.7	0.200	According to GOST 5985-79

7. Iodine number, g of iodine per 100 g of fuel, not more than	0.5	0.30	According to GOST 2070-82
8. Flash point in a closed crucible, °C, not lower than	30	45.0	According to DSTU ISO 2719:2006
9. Temperature of the beginning of crystallization, °C, not higher than	minus 55	minus 58	According to ASTM D 2386-06
10. Thermal oxidative stability under static conditions: - amount of sludge, mg per 100 cm³ of fuel, not more than	6	2.8	According to GOST 11802-88
11. Mass fraction of aromatic hydrocarbons, %, not more than	22	18	According to GOST 6994-74
12. Concentration of actual resins, mg per 100 cm³ of fuel, not more than	4	2.0	According to GOST 8489-85
13. Mass fraction of total sulphur, %, not more than	0.1	< 0.0017	According to ASTM D 4294-10
14. Mass fraction of mercaptan sulphur, %, not more than	0.001	0.0003	According to GOST 17323-71
15. Hydrogen sulphide content	absence	absence	According to GOST 17323-71
16. Test on a copper plate at 100 °C for 3 hours	Standing the test	Standing the test	According to ASTM D 130-04 e1
17. Thermal oxidative stability by the dynamic method at (150-180) °C:			According to ASTM D 3241-11a
- pressure drop on the filter during 5 hours, kPa, not higher than	10	0	
- deposits on the heater pipe, points, not more than	2	1	
18. Interaction with water, points, not more than: - condition of interface surfaces	1	1	According to ASTM D1094-00
19. Specific electrical conductivity, pS/m: - at the refuelling temperature of the equipment, not less than - at 20 °C, no more than	50 600	Antistatic additive was not used	According to GOST 25950-83
20. Content of mechanical impurities and water	absence	absence	According to 7.4 GSTU 320.00149943.007-97
21. Content of the sum of water-soluble alkaline compounds	absence	absence	According to 7.7 GSTU 320.00149943.007-97
22. Content of water-soluble acids and alkalis	absence	absence	According to GOST 6307-75
23. Soap content of naphthenic acids	absence	absence	According to GOST 21103-75
24. Mass fraction of naphthalene hydrocarbons, %, not more than	1.5	0.52	According to GOST 17749-72
25. Ash content, %, not more than	0.003	0.0022	According to GOST 1461-75
26. Kinematic viscosity at 20 °C, mm²/sec, not less than	1.25	1.534	According to DSTU GOST 33-2003

Waterborne transport

According to data of SSSU, the final consumption of petroleum products by the waterborne transport of Ukraine (*inland navigation*) was 38 ktoe in 2018, 135 ktoe in 2019, and 2 ktoe in 2020 [1]. According to expert estimations of the authors of the report, the actual bunkering of fuel for inland navigation in 2020 was almost 12 times more than that indicated in the energy balance, its value reaching about 23.7 ktoe. The difference with the SSSU's data can be explained by the fact that in 2020 the main volume of bunkering (replenishment of ship fuel) took place outside the 12-mile zone (i.e. outside the jurisdiction of Ukraine) and therefore was not taken into account by SSSU statistics.

Vessel (ship) fuel and ***bunker (marine/naval) fuel oils*** are used by waterborne transport. Vessel fuel is used in marine high- and medium-speed **diesel** engines, as well as in **gas-turbine installations**. Bunker fuel oil of F-12 and F-5 brand is used in **steam-turbine installations** of ships and on vessels of the river and sea fleet.

Since 2020, the International Maritime Organization has strengthened the environmental requirements for marine fuel (**Table 1.5**). Thus, the maximum allowable **share of sulphur** was reduced from **3.5%** to **0.5%,** which makes ship operators and shipbuilders think about more environmentally friendly fuels.

Table 1.5. Requirements of Annex VI, Regulation 14 of the International Convention for the Prevention of Pollution from Ships (MARPOL) on the sulfur content in fuels [31].

Compliance Date	Sulfur Limit in Fuel (% m/m)
Global	
January 1, 2000	4.5%
July 1, 2012	3.5%
January 1, 2020	0.50%
Emission Control Area	
January 1, 2000	1.5%
July 1, 2012	1.0%
January 1, 2015	0.1%

Ukrainian owners, whose seagoing vessels operate in the waters of EU member states in Emission Control Areas (ECAs), have some difficulties due to the ban on the operation of the fleet using vessel fuel with sulphur content of > 0.1%. Although this problem is not so relevant for the river fleet, the task of reducing the products of incomplete fuel combustion will still have to be solved in the near future.

The first option is to clean the ship's exhaust, but it is unprofitable due to the large size, weight and cost of special equipment. The second option is the use of low-sulphur "pure" (light) fuel MGO. This is almost twice as expensive as the currently used cheapest fuel of IFO 380HS standard. According to experts, the fuel component in the cost of cargo delivery varies in the range of 30-60% depending on the duration of the flight and bunkering ports. This means that with the transition to MGO, tariffs for maritime transport will increase by about 25-40%, and freight flows can objectively be redirected to land transport [10].

Due to the existing fiscal policy, the cost of fuel for bunkering in the ports of Ukraine is

more expensive than that in the ports of other countries or outside the territorial waters of the country, which negatively affects the domestic market for bunkering ships. Foreign ships have difficulties with replenishing their fuel reserves when entering the sea trade ports of Ukraine. Vessel fuel is purchased in Ukrainian ports, but this fuel is purchased by Ukrainian companies for auxiliary and support vessels operating in ports. First of all, the fuel is purchased by state-owned enterprises (that is sea trade ports) which are obliged to conduct tender procedures for these procurements. Among these state-owned enterprises is the Administration of Sea Ports of Ukraine. ASPU planned to purchase almost 7,000 tons of bunker fuel for its fleet for 2020.

The total amount of bunker fuel left in Ukrainian ports does not exceed 40-50 kt. This is mainly diesel fuel while the marine fuel oil, which is most often used by transport vessels, is not available in the ports at all. Fuel oil has been absent in the export bunkering statistics of Ukraine in recent years. According to port expert, bunkering in ports has stopped due to the fiscal policy of the state. Excise duty on the fuel and VAT have made the bunker fuel much more expensive than that in other Black Sea countries or on the grey market outside the 12-mile zone (that is outside Ukraine's jurisdiction). The market could exist only when the fuel for bunkering operations was imported to Ukraine under the customs regime of transit. For many years, there was a struggle around this regime, which the fiscal and law enforcement agencies did not like very much. Somewhere since 2014, they stopped providing the transit regime for the imported bunker, with all the resulting tax consequences. For comparison: in Ukraine in 2005, up to 500 kt of bunker fuel were delivered to ships; the cargo turnover of Ukrainian seaports and terminals was 138.9 Mt [11, 59].

Requirements for the quality of vessel fuel are established by the **Technical Regulation on requirements for motor gasoline, diesel, vessel fuel and boiler fuel** (2013, amended) (**Table 1.6**) [6]. According to this TR, *vessel fuel* is a liquid distillate petroleum fuel used in high- and medium-speed diesel engines of vessels, as well as in gas-turbine installations. It is possible to add to marine fuels additives, additives based on methyl/ethyl esters of fatty acids, which do not impair fuel performance, do not adversely affect the environmental, energy and economic performance of engines as confirmed by test results and approved for use in established order. From January 1, 2017, the use of vessel fuels with a hydrogen sulphide content of more than 0.0002% is prohibited.

Table 1.6. Requirements for the characteristics of vessel fuels [6].

Indexes	Unit	Value
Flash point in a closed crucible	°C	not less than 60
Mass fraction of sulphur	%	not more than 0.5 (from 1 January 2020)* not more than 0.1 (from 1 January 2020)**

** For all types of vessel fuels in states that take the necessary measures to ensure that fuels with a specified mass fraction of sulphur are used in their territorial sea zones, exclusive (marine) economic zones and pollution control zones.*

*** For all types of vessel fuels in states that take the necessary measures to ensure that fuels with a specified mass fraction of sulphur are used in their territorial seas, exclusive (maritime) economic zones and pollution control zones within the SOx emission control zones.*

In addition to this TR, the Ministry of Economic Development and Trade of Ukraine approved the List of national standards, the voluntary application of which can be considered as proof of compliance with the requirements of the Technical Regulation on requirements for gasoline, diesel, vessel fuel and boiler fuel (Order № 1179 of 01.10.2014, amended) [24]. For the ***vessel fuels***, the following standards are specified in this List:

DSTU 4317:2004. Petroleum products. Fuel (class F). Classification. Part 1. Categories of fuels for vessel engines.

DSTU ISO 8216-2:2004. Petroleum products. Fuel (class F). Classification. Part 2. Categories of gas-turbine fuels for the use in industry and vessel engines.

Technical requirements for ***marine fuel oil F5 and F12*** (**Table 1.7**) are determined by **DSTU 4058-2001** "Petroleum fuel. Oil fuel. Specifications".

There are the following brands of fuel oil:

ashy marine fuel oil F5: low-sulphur, sulphurous;
ashy low-sulphur marine fuel oil F12;
fuel oil 40 (low ash, ashy);
fuel oil 100 (low ash, ashy).

Fuel oil of F5 brand is obtained from the products of direct distillation of oil with the addition of up to 22% of kerosene-gas oil fractions of catalytic or thermal cracking. It is allowed to add to fuel oil additives approved for use in the prescribed manner. For the fuel oil with additive, it is necessary to specify "with additive" in its quality certificate.

F5 and F12 fuel oil for the Navy must be produced using technology from raw materials and components used in the manufacture of samples that have been tested with positive results and approved for use in the prescribed manner.

Table 1.7. Requirements for the characteristics of fuel oil [7].

Indexes	**Value for**				**Test method according to**
	F5	**F12**	40	100	
1. Conditional viscosity, conditional degrees, not more: - at 50 °C - at 80 °C	5.0	12.0	8.0	16.0	GOST 6258
2. Viscosity dynamic at a temperature of 0°C, Pa•sec, not more than	0.1-27				GOST 1929 or ASTM D 2983 (1) (Arbitral GOST 1929)
3. Ash content, % mass, not more than for: - low ash fuel oil - ashy fuel oil	0.05	0.10	0.04 0.12	0.05 0.14	GOST 1461 or ASTM D 482 (2) (Arbitral GOST 1461)
4. Mass fraction of mechanical impurities, %, not more than	0.10	0.12	0.50	1.00	GOST 6370

5. Mass fraction of water, %, not more than	0.3	0.3	1.0	1.0	GOST 2477 or ASTM D 95 (3)
6. The content of water-soluble acids and alkalis	absence				GOST 6307
7. Mass fraction of sulphur, %, not more than for: — very low-sulphur fuel oil — low-sulphur fuel oil — sulphurous fuel oil — high-sulphur fuel oil	 1.0 2.0	 0.6	 0.5 1.0 2.0 3.5	 0.5 1.0 2.0 3.5	item 9.4 of this standard or ASTM D 1552 (4) (Arbitral item 9.4 of this standard)
8. Coking, %, not more than	6.0	6.0			GOST 19932 or ASTM D 189 (5) (Arbitral GOST 19932)
9. Hydrogen sulphide content	absent				item 9.3 of this standard
10. Flash point, °C, not less than: — in a closed crucible — in an open crucible	80	90	90	110	GOST 6356 or ASTM D 93 (6) (Arbitral GOST 6356) GOST 4333 or ASTM D 92 (7) (Arbitral GOST 4333)
11. Freezing point, ° C, not higher than for fuel oil from paraffinic and high-paraffinic oil	-5	-8	10 25	25 42	GOST 20287 or ASTM D 97 (8) (Arbitral GOST 20287)
12. Lower heating value recalculated for dry fuel (not discarded), kJ/kg, not less than for: - very low sulphur fuel oil, low sulphur fuel oil and sulphurous fuel oil - high sulphur fuel oil	 41454	 41454	 40740 39900	 40530 39900	GOST 21261 or ASTM D 240 (9), ASTM D 2382 (10) (Arbitral GOST 21261)
13. Density at 20 °C, kg/m^3, not more than	955	960	No norms. Determination is obligatory		GOST 3900 or ASTM D 1298 (11) (Arbitral GOST 3900)

Note 1. In agreement with the consumer, ash content of not more than 0.15% is allowed in F12 fuel oil, indicating the value of the indicator in the supply contract.

Note 2. In the first and fourth quarters of the year, for fuel oil grades 40 and 100 the flash point is allowed in the open crucible not lower than 65 ° C and in the closed crucible not lower than 50 ° C provided the value is stated in an agreement or a contract (or agreed with a consumer in writing, which is an integral part of the contract or agreement). ***Such fuel oils are not intended for vessel power plants.***

Note 3. ***Fuel oils of grades 40 and 100, which are made of high paraffin oil, are not intended for vessel boiler plants.***

Bibliography to the table according to DSTU 4058-2001:
(1) ASTM D 2983-87 Method for determining the dynamic viscosity of liquid automotive oils at low temperatures using a Brookfield viscometer.
(2) ASTM D 482-91 Method for determination of ash content in petroleum products.
(3) ASTM D 95-83 Determination of water in petroleum products and bituminous materials by distillation.
(4) ASTM D 1552-90 Determination of sulphur content in petroleum products (high temperature method).
(5) ASTM D 189-88 Conradson Coke Residue Determination Method.
(6) ASTM D 93-90 Martens-Lensky method of determining the flash point in a closed crucible.
(7) ASTM D 92-90 Methods for determining the flash point and ignition of petroleum products in an open Cleveland crucible.
(8) ASTM D 97-90 Method for determining the pour point of petroleum oils.
(9) ASTM D 240-92 Method for determining heating value in a calorimetric bomb.
(10) ASTM D 2382-83 Method for determining heating value of hydrocarbon fuels in a calorimetric bomb (high-precision method).
(11) ASTM D 1298-85 Determination of density (specific gravity) and weight by API (American Petroleum Institute), crude oil and liquid petroleum products using a hydrometer.

In international practice, two types of fuel are generally used on ships [32]:

- distillates obtained by distillation that consist of light fractions, which are characterized by low viscosity (2.5-14 mm^2/s) and density (830-860 kg/m^3);

- heavy fuels which are conditionally divided into two groups: intermediate (Intermediate Fuel) and heavy residual ones (Heavy Fuel Oil) with a viscosity range of 180-500 (700) mm^2/s.

On seagoing vessels, the main engines use mainly heavy fuels, and the auxiliary engines of seagoing vessels and all diesels of river and mixed navigation vessels use distillates.

International standard ISO 8217: 2017 Petroleum products – Fuels (class F) Specifications of marine fuels applies to fuels for waterborne transport. It describes the requirements for 7 brands of distillate fuels (**Table 1.8**), three of which (DFA, DFZ, DFB) may contain up to 7% methyl esters of fatty acids (FAME); 6 brands of residual fuels (**Table 1.9**), two of which (RMG and RMK) are different by kinematic viscosity. Harmonization of this international standard with an identical degree of compliance in Ukraine was included in the work program of the national standardization for 2018. Therefore, the approval of the DSTU Fuel for ships. Technical conditions based on ISO 8217: 2017 is expected soon.

Table 1.8. Requirements for the characteristics of marine distillate fuels according to the standard ISO 8217:2017 [33].

Parameter	Unit	Limit	DMX	DMA DFA	DMZ DFZ	DMB DFB
Viscosity at 40°C	mm^2/s	max	5.500	6.000	6,000	11,00
		min	1.400	2.000	3,000	2,000
Micro Carbon Residue at 10% Residue	% m/m	max	0.30	0.30	0,30	-
Density at 15°C	kg/m^3	max	-	890.0	890,0	900,0
Micro Carbon Residue	% mas	max	-	-	-	0,30
Sulphur	% m/m	max	1.00	1.00	1,00	1,50
Water	% V/V	max	-	-	-	0,30
Total sediment by hot filtration	% m/m	max	-	-	-	0,10
Ash	% m/m	max	0.010	0.010	0,010	0,010
Flash point	°C	min	43	60	60	60

Parameter	Unit	Limit	DMX	DMA	DFA	DMZ	DFZ	DMB	DFB
Pour point in Winter	°C	max	-	-6		-6		0	
Pour point in Summer	°C	max	-	0		0		6	
Cloud point in Winter	°C	max	-16	Report		Report		-	
Cloud point in Summer	°C	max	-16	-		-		-	
Cold filter plugging point in Winter	°C	max	-	Report		Report		-	
Calculated Cetane Index		min	45	40		40		35	
Acid Number	mg KOH/g	max	0.5	0.5		0,5		0,5	
Oxidation stability	g/m^3	max	25	25		25		25	
Fatty acid methyl ester (FAME)	% V/V	max			7,0		7,0		7,0
Lubricity, corrected wear scar diameter (wsd 1.4) at 60 °C	um	max	520	520		520		520	
Hydrogen sulphide	mg/kg	max	2.00	2.00		2,00		2,00	
Appearance			Clear & Bright					-	

Table 1.9. Requirements for the characteristics of marine residual fuels according to the standard ISO 8217:2017 [33].

Parameter	Unit	Limit	RMA 10	RMB 30	RMD 80	RME 180	RMG 180	RMG 380	RMG 500	RMG 700	RMK 380	RMK 500	RMK 700
Viscosity at 50°C	mm^2/s	max	10	30	80	180	180	380	500	700	380	500	700
Density at 15°C	kg/m^3	max	920	960	975	991	991				1010		
Micro Carbon Residue	% m/m	max	2.5	10	14	15	18				20		
Aluminium + Silicon	mg/kg	max	25	40		50	60						
Sodium	mg/kg	max	50	100		50	100						
Ash	% m/m	max	0.04	0,07			0,10				0,15		
Vanadium	mg/kg	max	50	150			350				450		
Calculated carbon aromaticity index CCAI		max	850	860			870						
Water	% V/V	max	0.3	0.5									
Pour point (upper) in Summer	°C	max	6	30									
Pour point (upper) in Winter	°C	max	0	30									
Flash point	°C	min	60										
Sulphur	% m/m	max	To comply with statutory requirements as defined by purchaser										
Total Sediment, aged	% m/m	max	0.10										
Acid Number	mg KOH/g	max	2.5										
Used lubricating oils (ULO): Calcium and Zinc; or Calcium and Phosphorus (mg/kg)	mg/kg		The fuel shall be free from ULO, and shall be considered to contain ULO when either one of the following conditions is met: Calcium > 30 and zinc > 15; or Calcium > 30 and phosphorus > 15.										
Hydrogen sulphide	mg/kg	max	2.00										

It should be noted that with the introduction of MARPOL 2020, the industry has begun to produce ultra-low sulfur fuels (ULSFO), which are suitable for the use in emission control areas, very low sulfur fuels (VLSFO) and high sulfur fuel oils (HSHFO). Different organizations use different names to denote fuels for waterborne transport (**Table 1.10**).

Table 1.10. Comparison of fuel oil terminology uses by different organization [31]

IMO* (MEPC.320 (74))	**IACS** (UI-SC123)**	**ISO*** (8217:2017)**	**Industry**
DM		DMX, DMA, DMZ, DMB DFA, DFZ, DFB	Distillate Fuel
RM		RMA, RMB, RMD, RME, RMG, RMK	Residual Fuel
ULSFO-DM (≤0.10% S)	LSDMF (≤0.1%S)	DMX, DMA, DMZ, DMB (Sulfur content varies)	MGO (≤0.10% S)/ ECA Fuel
ULSFO-RM (≤0.10% S)	LSRMF (≤0.1% S)	RMA, RMB, RMD, RME, RMG, RMK (Sulfur content as per statutory requirements)	ECA Fuel
VLSFO-DM (≤0.50% S)	DMF (>0.1 % S)	DMX, DMA, DMZ, DMB DFA, DFZ, DFB (Sulfur content varies)	MGO (≤0.50% S)/ Global Fuel
VLSFO-RM (≤0.50% S)	RMF (>0.1% S)	RMA, RMB, RMD, RME, RMG, RMK (Sulfur content as per statutory requirements)	Global Fuel
HSHFO (>0.50% S)		RMA, RMB, RMD, RME, RMG, RMK (Sulfur content as per statutory requirements)	HFO (sulfur content varies)

Note:
* International Maritime Organization (IMO);
** International Association of Classification Societies (IACS);
*** International Organization for Standardization (ISO);
DM – Distillate Marine Fuels;
RM – Residual Marine Fuels;
ULSFO – Ultra-low Sulfur Fuel Oil;
VLSFO – Very Low Sulfur Fuel Oil;
HSHFO – High Sulfur Heavy Fuel Oil;
MGO – (Marine Gas Oil;
LSDMF – Low Sulphur Distillate Marine Fuel;
LSRMF – Low Sulphur Residual Marine Fuel;
DMF – Distillate Marine Fuel;
RMF – Residual Marine Fuel;
HFO – Heavy Fuel Oil;
ECA – Emission Control Area.

When ordering, the buyer of the fuel must determine the maximum sulfur content in the fuel in accordance with legal restrictions. Typical on the market distillate fuels with ultra-low and very low sulfur content are produced from distillate fuels brands DMA, DMX, which have a sulfur content of less than 0.1% for ULSFO-DM and less than 0.5% for VLSFO-DM. ULSFO-RM and

VLSFO-RM fuels containing 0.1% and 0.5% sulfur, respectively, are produced from a mixture of different brands of residual fuels. Marine diesel oil (MDO) usually consists of various mixtures of distillates and a small amount of fuel oil.

The **Rules for the prevention of pollution from ships** (Register of Shipping of Ukraine, 2020) present requirements for the quality of liquid fuel supplied and used on ships [20]. In particular, the Rules state the following:

- liquid fuel must be a mixture of hydrocarbons obtained in the process of oil refining. This does not prevent the addition of small amounts of additives designed to improve some performance characteristic;

- liquid fuel must not contain inorganic acids and any additives or chemical wastes that endanger the safety of the vessel or adversely affect the operation of the mechanisms, or are harmful to personnel, or in general contribute to additional air pollution;

- liquid fuel for combustion purposes obtained by methods other than oil refining *must not:* contain sulphur in the amount exceeding the applicable amount specified in paragraph 3.3; contain sulphur oxides (SO_X) and solids; cause the engine to exceed the applicable NO_X emission limits set out in paragraphs. 3.2.5, 3.2.6, 3.2.7.1.1 and 3.2.9.4; contain inorganic acids; or endanger the safety of the ship or adversely affect the operation of the mechanisms, or be harmful to personnel, or in general contribute to additional air pollution.

The Rules for the prevention of pollution from ships also contain information that is included in the bunker fuel delivery note and the procedure for sampling liquid fuel samples to determine compliance with Annex VI to the International Convention for the Prevention of Pollution from Ships (MARPOL).

1.3. GHG emissions

Greenhouse gas emissions from global aviation and targets for their reduction

The contribution of aviation to **global anthropogenic CO_2 emissions** is currently only about **2%** (915 million tons in 2019), but with further development of the sector it may increase to **22%** (3.1 billion tons) in 2050 if the necessary measures are not taken [60, 61]. Aviation is responsible for **12%** of the total carbon dioxide emissions in the transport sector, with about 80% of "aviation" CO_2 emissions accounted for flights over 1,500 km, for which there are almost no alternative means of transport (**Fig. 1.9**).

Back in 2009, the International Air Transport Association (IATA) set the goal to achieve **carbon-neutral** growth in the sector after 2020 and ensure a reduction in GHG emissions by **50%** by 2050 compared to 2005. [62]. The necessary reduction of CO_2 emissions was planned to be achieved through appropriate technological and economic measures, as well as the use of ***aviation biofuels***, a significant increase in production of which was expected after 2030 (**Fig. 1.10**).

In October 2021, the previous goal was strengthened - to achieve **carbon neutrality** in the aviation sector by **2050**. According to IATA, among all other measures, the contribution of ***sustainable aviation fuels*** to achieve this ambitious goal should be **65%** (**Fig. 1.11**).

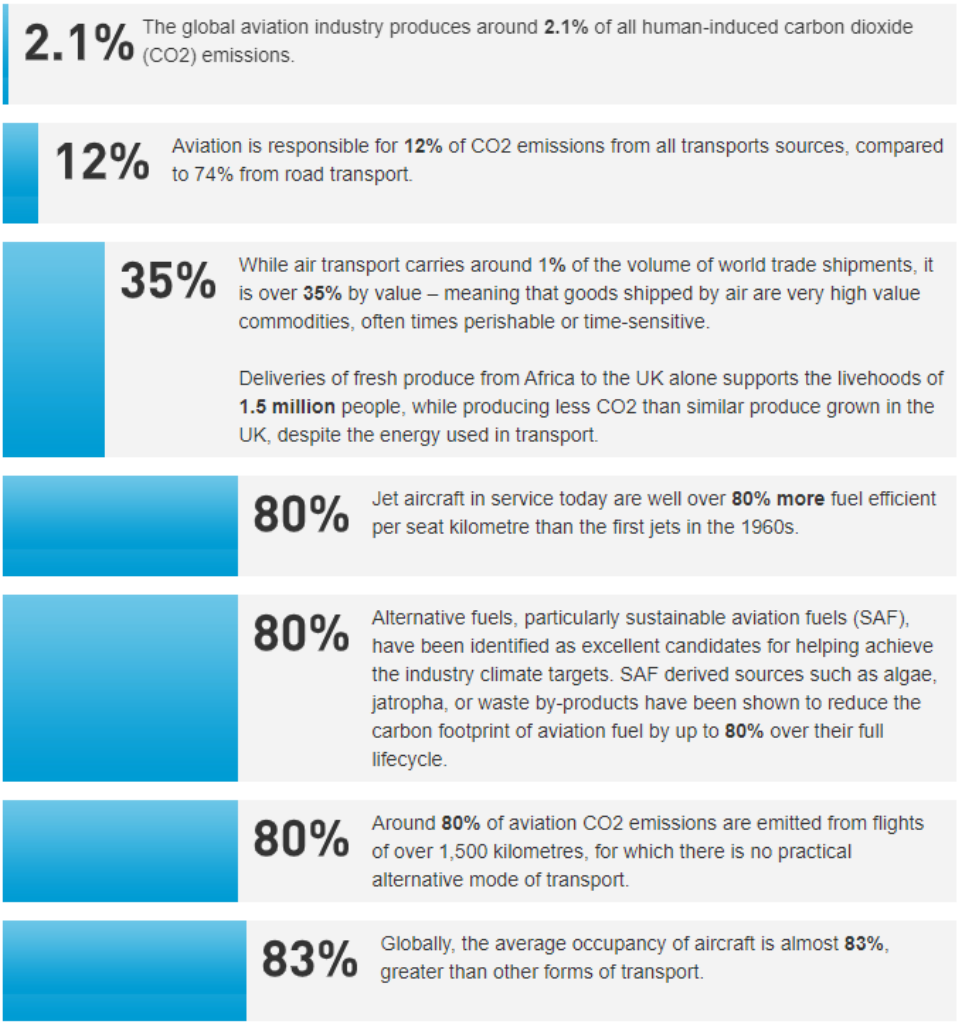


Fig. 1.9. Key indicators of the global aviation sector [60].

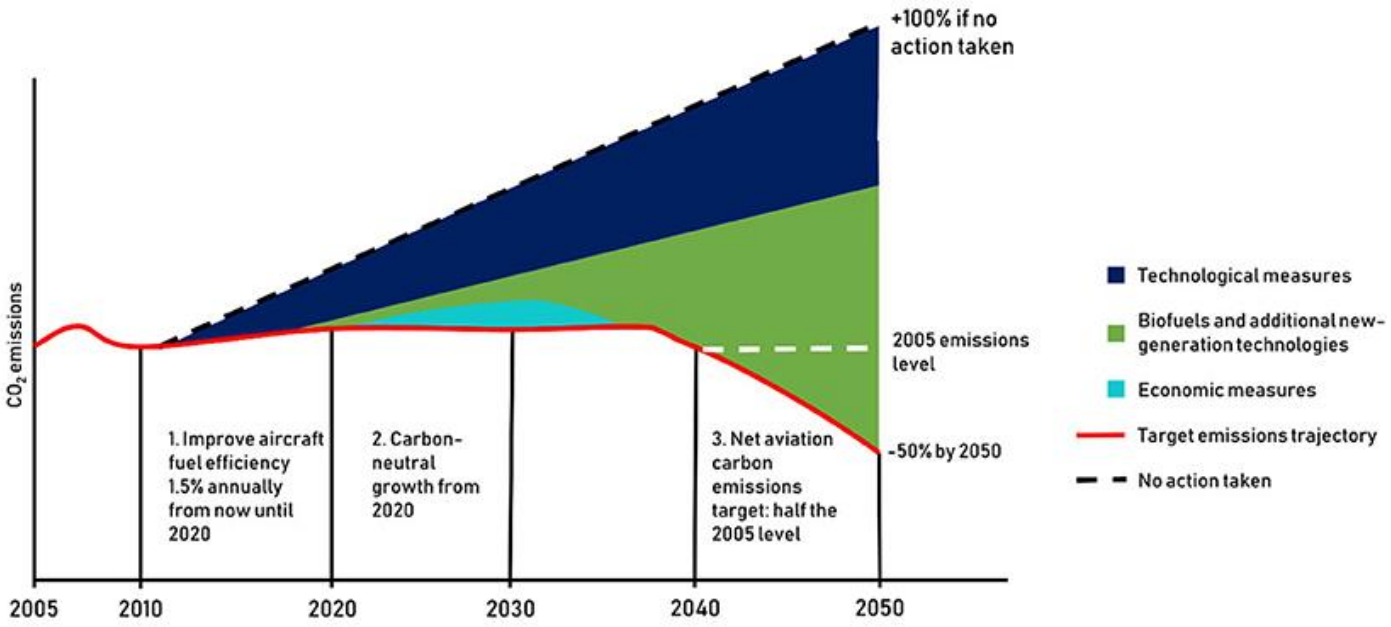


Fig. 1.10. Dynamics of CO_2 emissions in the aviation sector until 2050 under different development scenarios [61].

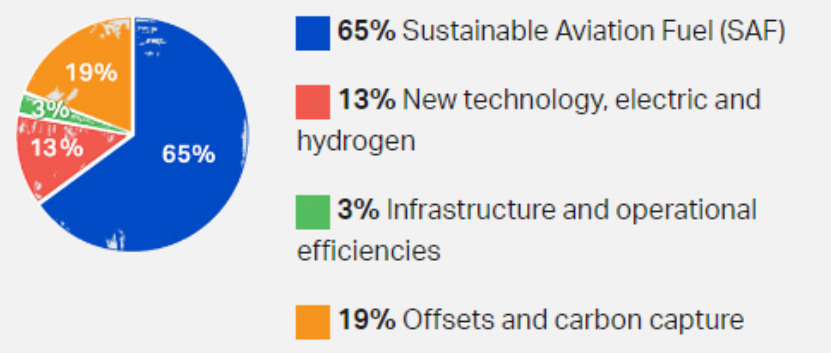


Fig. 1.11. The contribution of various measures to achieve carbon neutrality of the world aviation by 2050. [63].

Greenhouse gas emissions from international shipping and targets for their reduction

The fourth study of the International Maritime Organization (IMO) 2020 on GHG emissions [76] estimated that the total GHG emissions (CO_2, CH_4, N_2O) from shipping in 2018 amounted to 1076 million tons of CO_{2eq}, of which 1056 million tons - CO_2 emissions), which accounted for about **2.9%** of total global anthropogenic GHG emissions this year. According to the method of distribution of emissions based on voyages performed, the contribution of international shipping to this emission amounted to 740 million tons of CO_2 in 2018. According to a number of long-term economic and energy scenarios, without the introduction of additional measures, CO_2 emissions from international shipping could reach **90-130%** of the level of 2008 by 2050 (**Fig. 1.12**). In this regard, the IMO is actively involved in further improving the energy efficiency of ships and developing measures to reduce GHG emissions from ships.

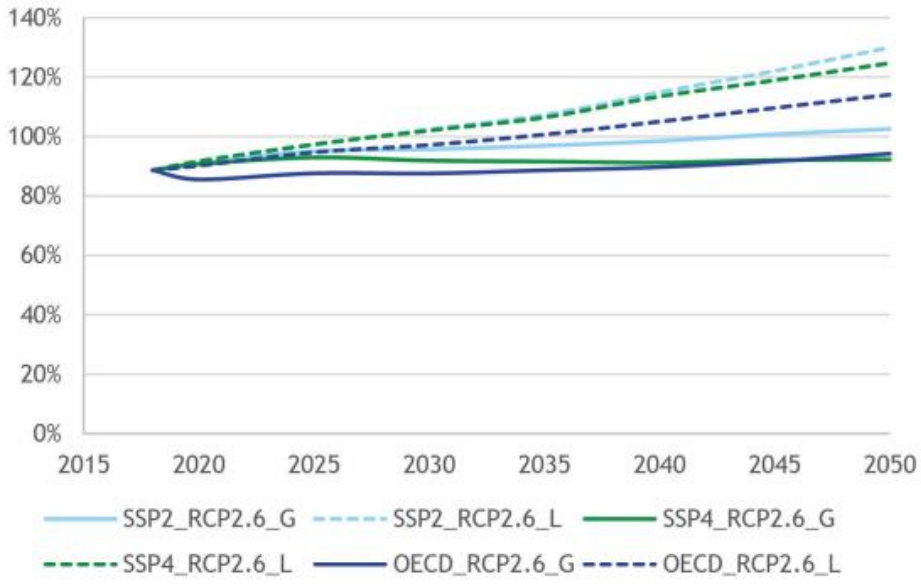


Fig. 1.12. Forecast of growth in CO_2 emissions from international shipping by 2050 compared to the level of emissions in 2008 under different scenarios * [76].

** Scenarios differ in their different objectives to curb global temperature rise (from 1.5 ℃ to 2.8 ℃) and various forecasts of world energy consumption, which depends on the volume and structure of transportation of energy products by international shipping*

During the period 2008-2018, the specific CO_2 emissions from international shipping decreased by 32% per ship (up to 11.67 g CO_2/t cargo/nautical mile) and by 29% per voyage (up to 10.70 g CO_2) /t of cargo/nautical mile) due to the increase in the energy efficiency of ships. Further targets include reducing the specific CO_2 emissions of transport work by at least 40% by 2030 and by 70% by 2050 compared to 2008. At the same time, the goal of reducing overall GHG emissions in international shipping is 50% by 2050 from the emission level in 2008 [77].

Greenhouse gas emissions in the aviation and waterborne transport sectors of Ukraine

According to the **National Inventory** of Anthropogenic Emissions by Sources and Removals by Sinks of Greenhouse Gases in Ukraine for 1990-2020 [8], greenhouse gas emissions from transport in 2020 amounted to **31.81** million tons of $CO_{2\text{-eq}}$ (**Table 1.11**), which was about 10 % of total emissions. Compared to 1990, emissions from transport decreased by 71.6%, compared to the previous 2019 - by 18.9%. The decline in 2020 can be explained by the COVID pandemic.

Table 1.11. GHG emissions from Ukrainian transport, million tons $CO_{2\text{-eq}}$ [8].

Emission category	**1990**	**1995**	**2000**	**2005**	**2010**	**2012**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
1.A.3 Transport total, including:	**111.79**	**49.22**	**34.55**	**39.19**	**40.20**	**39.36**	**35.89**	**31.10**	**32.89**	**34.94**	**34.96**	**37.73**	**31.81**
1.A.3.a Civil aviation (***domestic***)	0.68	0.11	0.07	0.20	0.17	0.20	0.09	0.08	0.13	0.17	0.17	0.18	0.16
1.A.3.b Road transport	61.37	20.73	15.78	22.16	28.89	29.10	26.73	22.81	23.96	24.68	24.72	26.65	23.37
1.A.3.c Railway transport	3.83	1.32	1.39	0.88	0.55	0.38	0.45	0.45	0.47	0.56	0.57	0.59	0.42
1.A.3.d Waterborne transport (***domestic***)	3.27	0.43	0.20	0.20	0.10	0.08	0.06	0.08	0.08	0.08	0.08	0.08	0.08
1.A.3.e Other modes of transport	42.64	26.63	17.12	15.75	10.49	9.60	8.55	7.68	8.24	9.45	9.41	10.23	7.78

In 2020, the largest contribution to GHG emissions from transport was made by road transport 73.6% and other modes of transport 24.5%. At the same time, GHG emissions from **civil aviation** accounted for **0.5%** of total GHG emissions from transport, and GHG emissions from **waterborne transport** accounted for **0.25%**.

GHG emissions from domestic aviation in 2020 amounted to 162.78 thousand $CO_{2\text{-eq}}$, which is 8.6% less than in 2019 and 76.5% less than in 1990. Trends in GHG emissions from domestic and international aviation are presented in **Fig. 1.13**. Greenhouse gas emissions from international aviation in 2020 amounted to 694.36 thousand tons of $CO_{2\text{-eq.}}$, which is 2.5 times less than the same figure in 2019 (1737.46 thousand tons of $CO_{2\text{-eq.}}$) and 3.6 times less than in 1990. The decrease in 2020 can be explained by the COVID pandemic.

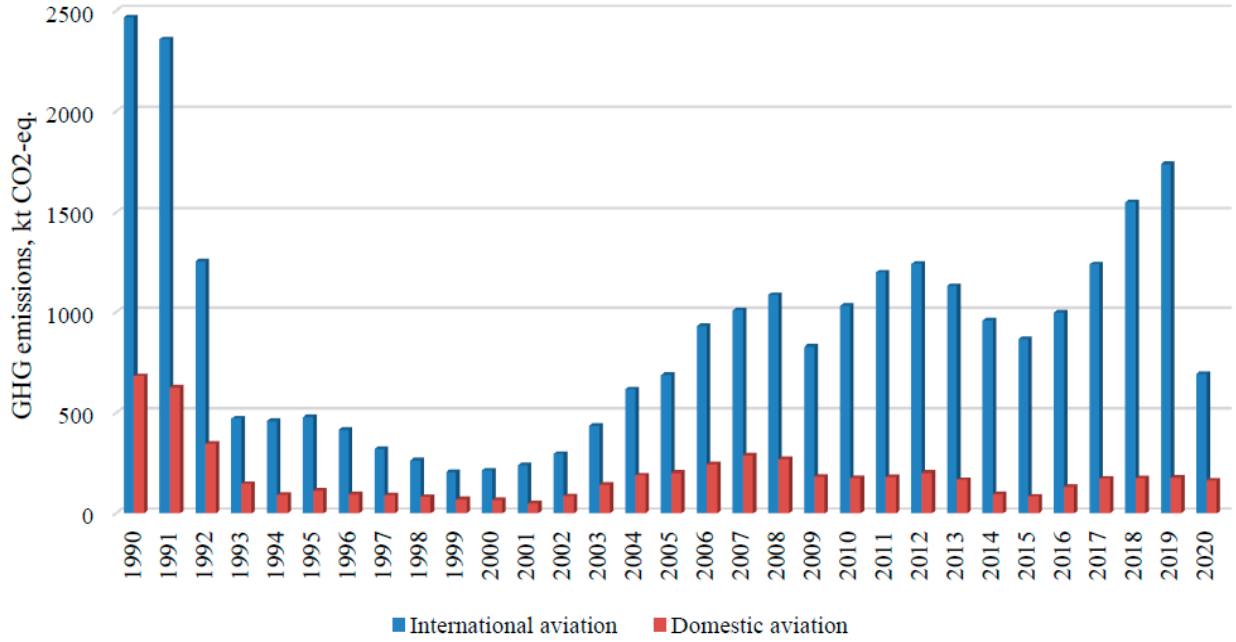


Fig. 1.13. GHG emissions from domestic and international aviation in Ukraine [8].

In 2020, GHG emissions from waterborne transport amounted to 83.19 thousand tons of $CO_{2\text{-eq}}$, having decreased by 1.2% compared to 2019 and by 39.3 times compared to the base year 1990. GHG emissions from domestic and international shipping for 1997–2020 are presented in **Fig. 1.14**. GHG emissions from international waterborne transport in 2020 amounted to 43.48 thousand tons of $CO_{2\text{-eq.}}$, which is 21.7% less than in 2019 and 36.8 times less than in 1990. The reduction in 2020 can be explained by the COVID pandemic.

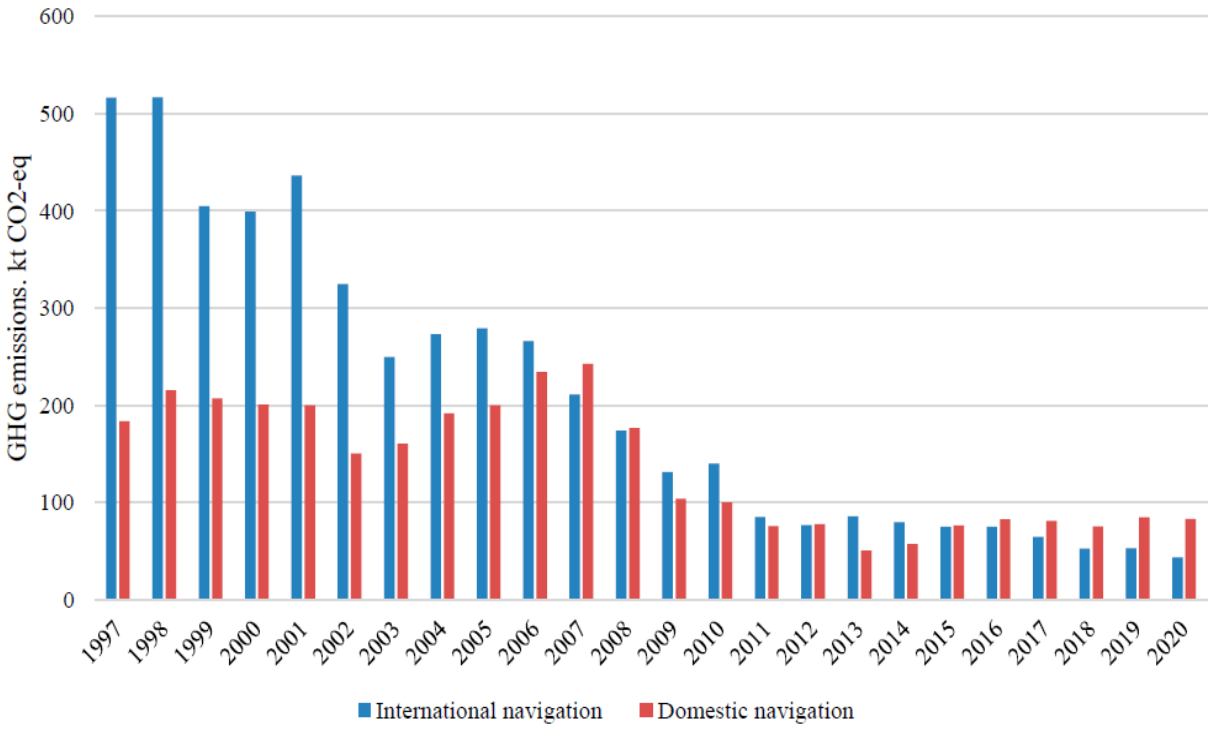


Fig. 1.14. GHG emissions from domestic and international waterborne transport in Ukraine [8].

Ukraine is a member of such international aviation organizations as the European Civil Aviation Conference (ECAC), the European Organisation for the Safety of Air Navigation "Eurocontrol" (EUROCONTROL), and the International Civil Aviation Organization (ICAO). Ukraine also participates voluntarily in the ICAO-implemented Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) international program. To implement CORSIA in accordance with the requirements of the Aviation Rules of Ukraine "Technical requirements and administrative procedures for monitoring emissions from civil aircraft operators" (DASU order of August 2, 2019, № 1001) were collected and approved 9 CO_2 emissions Monitoring Plans, 8 reports on emissions volumes and 8 verification reports.

8 Ukrainian aircraft operators are subject to the Aviation Rules, namely:

- Wind Rose Aviation Company LLC;
- Azur Air Ukraine Aviation Company LLC;
- Ukraine International Airlines PJSC;
- ATD SE "ANTONOV"; ZETAVIA Airline LLC;
- Motor Sich JSC;
- Maximus Airlines LLC;
- SkyUp Airlines LLC.

Based on the obtained data, a generalized report of the country on the total CO_2 emissions for 2020 (a total of 2,339,117 tons of CO_2 from international flights) was prepared and sent to ICAO. The next step in the program is the introduction of a market mechanism to compensate and reduce CO_2 emissions for international civil aviation [29].

At its 220th session in June 2020, the ICAO Council reviewed the analysis of the Committee on Aviation Environmental Protection's (CAEP) of the impact of COVID-19 on the specifics of CORSIA. In this regard, the Council decided that **in the pilot phase, 2019 emissions will be applied for 2020 emissions (i.e. the average baseline CO_2 emissions will be taken on the basis of emission calculations for 2019 only**).

1.4. Review of current legislation and development strategy

Aviation

Transport is one of the most important sectors of social production, and it is designed to meet the needs of the population and social production in transportation.

The basic law that regulates the transport sector is the *Law of Ukraine "On Transport"* [78]. The Law stipulates that aviation, as well as waterborne transport, are parts of the unified transport system of Ukraine.

Public administration in the transport sector is carried out by the central executive body, which ensures the formation and implementation of state policy in the transport sector, tourism and infrastructure (Ministry of Infrastructure of Ukraine), local councils, and other authorized bodies. Public administration in the transport sector is carried out to ensure, inter alia, protection of the environment from the harmful impact of transport and licensing of certain activities in the sector.

According to the Article 32 of the Law of Ukraine "On Transport", **aviation** includes enterprises engaged in passengers, cargoes, and mail transportation, providing aerial photography, as well as airports, airfields, aeroclubs, air traffic control systems, educational institutions, civil aviation repair plants and other enterprises, institutions and organizations, regardless of ownership, that ensure the operation of aviation.

The legal regulation of the aviation sector is provided by the *Air Code of Ukraine* [79]. The Code applies to individuals and legal entities regardless of the form of ownership that carry out activities in the aviation sector and use of the airspace of Ukraine. Ukraine has also acceded to the *Convention on International Civil Aviation* [80], and therefore its provisions are binding for companies that provide activities in the aviation sector.

According to Article 4 of the Air Code of Ukraine, aviation is divided into *civil and state aviation* in Ukraine. Civil aviation meets the needs of the state and citizens in air transportation and private flights and is divided into commercial aviation and general aviation. State aviation uses aircraft to ensure national security and protection of the population. It is entrusted to the Armed Forces of Ukraine, other military formations formed under the laws of Ukraine, the National Police, the specially authorized central executive body for civil protection, protection of the state border of Ukraine, and customs authorities.

State regulation of the aviation sector and the usage of Ukraine's airspace is carried out by the Ministry of Infrastructure of Ukraine and the State Aviation Service [81]. The authorized body in the field of state aviation is the Ministry of Defense of Ukraine.

The State Aviation Service is empowered to adopt and implement the *aviation rules of Ukraine* that regulate all areas of civil aviation and the usage of the airspace of Ukraine [82]. Aviation rules of Ukraine should be developed following the standards and recommended practices of the ICAO, regulations of the IATA, the European Air Navigation Safety Association, the European Aviation Safety Agency, other international aviation organizations, and European Union legislation.

The State Aviation Service is also responsible for 1) certification of subjects and objects of aviation activity, 2) licensing for providing services of passengers and/or cargoes transportation and 3) rights granting to operate air lines to air carriers.

The certificate of compliance with the requirements of the aviation rules of Ukraine must be obtained by enterprises and organizations that perform aircraft maintenance, aircraft operation, ground maintenance, and other activities provided by the aviation legislation. The certificate is issued after the certification procedure, during which the aviation subject's or object's long-term ability to perform the permitted activity safely is checked [83].

The License conditions for conducting activity in the transportation of passengers, dangerous cargoes, and hazardous waste by air transport have been approved by the Cabinet of Ministers of Ukraine [84]. The License conditions establish an exhaustive list of documents to be attached to the application to obtain a license for the right to conduct transportation of passengers, dangerous cargoes, and hazardous waste by air transport, as well as an exhaustive list of requirements to be met during such activities.

Granting of rights to operate airlines to air carriers is provided by the Aviation Rules of Ukraine "Procedure for rights granting and revocation to operate airlines" [85]. These Aviation Rules determine the procedure for granting, revocation, refusing to grant, and limiting the scope of rights to operate airlines to Ukrainian and foreign air carriers. The right to operate an airline (flight route between agreed points) is the right of the air carrier to carry out air transportation to the extent and following with the conditions specified in this document.

Regulations on the usage of the airspace of Ukraine have been approved by the Cabinet of Ministers of Ukraine [86]. It envisages the order of the airspace usage according to the interests of Ukrainian national security and economy. The usage of the airspace of Ukraine is carried out to ensure safe, economical, and regular air traffic as well as any other activity related to the usage of the airspace of Ukraine.

To ensure the implementation of the state policy in the aviation sector, participation of Ukraine in international aviation organizations and other events, the *State Specialized Fund for National Aviation Expenditure and Ukraine's participation in international aviation organizations* has been established. State fees imposed on aviation companies come to the Fund. The procedure for using funds from the Fund has been determined by the Cabinet of Ministers of Ukraine [87].

Security assurance is an important element of civil aviation. According to Article 10 of the Air Code of Ukraine, the security of aviation consists of flight safety, aviation security, environmental security, economic, and information security. In addition, the Law of Ukraine "On the State Program of Civil Aviation Security" has been adopted [88]. Its main task is the establishment of rules for the implementation of the measures to ensure the aviation security of passengers, aviation personnel, aircraft, and property transported by aircraft. In order to coordinate state bodies in the civil aviation protection from acts of illegal interference and the elimination of unjustified obstacles and delays in the air transportation, the *Interdepartmental Commission on Civil Aviation Security* has been established. The Commission is an advisory body to the Cabinet of Ministers of Ukraine [89].

The Ukrainian legislation governing the security of the civil aviation also includes international conventions:

The Convention on Offences and Certain Other Acts Committed on Board Aircraft (Tokyo, September 14, 1963) (Decree of the Presidium of the Verkhovna Rada of the Ukrainian SSR "On the Accession of the Ukrainian Soviet Socialist Republic to the Convention on Offences and Certain Other Acts Committed on Board Aircraft" as of December 21, 1987, No. 5049-XI);

Convention for the Suppression of Unlawful Seizure of Aircraft (The Hague, December 16, 1970) (ratified by the Decree of the Presidium of the Verkhovna Rada of the Ukrainian SSR as of December 27, 1971, No. 352-VIII, entered into force on March 23, 1973);

Convention for the Suppression of Unlawful Acts against the Safety of Civil Aviation (Montreal, September 23, 1971) (ratified by the Decree of the Presidium of the Verkhovna Rada of the Ukrainian SSR as of January 16, 1973, No. 1352-VIII);

Protocol for the Suppression of Unlawful Acts of Violence at Airports Serving International Civil Aviation (Montreal, February 24, 1988), supplementing the Convention for the Suppression of Unlawful Acts against the Safety of Civil Aviation (ratified by Decree of the Presidium of the Verkhovna Rada as of March 14, 1989, No. 7247-XI);

Convention on the Marking of Plastic Explosives for the Purpose of its Detection (Montreal, March 1, 1991) (ratified by the Law of Ukraine "On Ratification of the Convention on the Marking of Plastic Explosives for the Purpose of its Detection").

Ecological security assurance implies obligations on aviation companies to comply with standards for pollutants in exhaust gases and exposure of physical factors and take measures to reduce emissions of pollutants, noise, and radiation (Article 83 of the Air Code of Ukraine). The maximum permissible noise level during aircraft operation, emissions of aircraft engines, and electromagnetic radiation of aviation objects must not exceed the maximum permissible level established by the aviation rules of Ukraine. Market measures to limit or reduce emissions that affect global climate change may be implemented, taking into account the recommendations of the ICAO and under the legislation of Ukraine. In particular, the Aviation Rules of Ukraine "Technical requirements and administrative procedures for operators of civil aircraft to monitor emissions" have been approved by the Order of the State Aviation Service of Ukraine as of August 2, 2019, No. 1001 [90]. The Aviation Rules establish requirements for operators of civil aircraft and State Aviation Service regarding the planning, monitoring, and reporting of the annual emissions of carbon dioxide (CO_2) by aircraft during flights.

Aircraft construction is declared a priority sector of the economy in Ukraine. In particular, the *Law of Ukraine "On the development of the aircraft construction industry"* [91] aims to strengthen the civil and military security of Ukraine, and ensure the competitiveness of domestic aircraft and aircraft equipment. According to the Law, temporary state support measures have been introduced for aircraft construction entities. For the period from January 1, 2013, to January 1, 2025 state financial support for the purchase of domestic aircraft has been introduced as well.

Regarding *aviation fuels*, the following regulations are in force in Ukraine:

1. Aviation rules of Ukraine "Technical requirements and administrative procedures regarding flight operations in civil aviation", approved by the Order of the State Aviation Service as of 05.07.2018, No. 682 [92]. It establishes requirements for the operation of aircraft, in particular, rules on refueling, control, and management of fuel during the flight, etc.
2. Technical Regulation on Requirements for Aviation Gasoline and Jet Fuels, approved by the Resolution of the Cabinet of Ministers of Ukraine as of May 26, 2021, No. 523 [5] (not entered into force), sets requirements for aviation fuels (aviation gasoline and jet fuel) used by air transport, which are put into circulation and provided on the market of Ukraine.

3. Instruction on refueling assurance of aircraft with fuel, lubricants, and technical fluids in the civil aviation of Ukraine, approved by the Order of the State Aviation Service of Ukraine as of 14.06.2006, No. 416 [39], has been developed to ensure the organization of fuel reception and storage as well as procedures for refueling aircraft of civil aviation enterprises with fuels, lubricants, and technical fluids.
4. Instruction on quality control of fuels, lubricants, and special fluids in the state aviation of Ukraine, approved by the Order of the Ministry of Defense as of 08.12.2016, No. 662 [40], establishes a single procedure for organizing and conducting works related to fuel quality control for all types of aircraft engines, lubricants, special fluids and alcohol during their acceptance, storage, transportation, issuance and is mandatory for all subjects of state aviation of Ukraine.
5. Aviation rules of Ukraine "Technical requirements and administrative procedures for certification of aerodromes", approved by the Order of the State Aviation Service as of 06.11.2017, No. 849 [93], provide that the aerodrome operator must inspect organizations involved in the storage and refueling of aircraft, as to the fact that the procedures they use guarantee the refueling of aircraft with uncontaminated fuel of appropriate specifications.

The strategy for the aviation development is formed by *the National Transport Strategy of Ukraine for the period until 2030*, approved by the Order of the Cabinet of Ministers of Ukraine as of May 30, 2018, No. 430-p [94]. It identifies the main directions of the transport industry development for the period until 2030. The objectives of the Strategy envisage assurance of conditions for sustainable development of air transport, liberalization of air transportation, signing, and implementation of the Common Aviation Area Agreement with the EU, organization, and use of Ukraine's airspace in accordance with ICAO standards and recommended practices of other international aviation organizations and EU legislation, etc. The expected results of the Strategy implementation include the development of a mechanism to reduce the cost of air transportation between regions and stimulation of the general aviation development. To implement the National Transport Strategy of Ukraine until 2030, an Action Plan for its implementation has been adopted [95]. It provides specific tasks for the aviation development, responsible bodies for their implementation, deadlines, and necessary funding.

It should be noted that in pursuance of the National Transport Strategy of Ukraine, the Law of Ukraine "On Ratification of the Agreement between Ukraine, on the one part, and the European Union and its Member States, on the other part, on Common Aviation Area" entered into force on May 9, 2022 [96]. The purpose of the Agreement is the gradual establishment of a common aviation area between Ukraine and the European Union and its Member States, based in particular on identical rules in the field of flight safety, aviation security, air traffic management, environmental protection, consumer protection, computer reservation systems, as well as on identical rules regarding social aspects.

In order to create conditions for the implementation of innovative research and development of new competitive aviation technologies, the *State Scientific and Technical Program for the Development of the Aviation Industry for 2021-2030* has been approved [97]. The research and development envisaged by the Program are aimed primarily at increasing the competitiveness

of domestic aircraft as well as reducing the negative impact of air transport on the environment, including emissions and noise reduction.

In order to calculate and forecast CO_2 emissions from air transport and implement appropriate measures to reduce and prevent pollution, State Aviation Service has developed an *Action Plan to reduce CO_2 emissions from aviation* [98]. Measures to reduce and prevent pollution include improving air traffic management and infrastructure use, including the introduction of Performance-based Navigation (PBN), more efficient air traffic management in control areas of terminals and on routes, development of air transport technologies, and reduction of CO_2 emissions in airports.

To meet the needs of Ukraine in ensuring the stable development of the aviation industry, bringing the infrastructure of air transport in line with international standards, *the State Target Program for the development of airports until 2023* has been approved [99]. It provides several ways to achieve the stable development of the aviation industry, including, inter alia, ensuring the construction, reconstruction, and modernization of airports infrastructure, the attraction of private investments in airports development, in particular in aviation fuel supply facilities, etc.

As a result of the Program implementation it is expected to achieve:

increase the total passenger flow to the level of 24.3 million passengers by 2023 (twice more compared to 2015);

doubling airports capacity as well as bringing the level of service provided at airports in line with international standards;

reduction of time for ground maintenance of each aircraft to 35-40 minutes;

increase the share of low-cost airlines to 30 percent of the total air transport market;

creating at least 1,000 jobs.

According to experts, the further development of the aviation industry in Ukraine requires a program for the development and modernization of regional airports and the real implementation of the Common Aviation Area Agreement with the EU. To this end, it is primarily expected to adopt amendments to the State Target Program for the development of airports until 2023 and legislation that should address critical aspects that hinder the development of airports [100].

Waterborne transport

According to the Law of Ukraine "On Transport", the structure of the **maritime transport** includes transport enterprises that carry out the transportation of passengers, cargoes, mail, vessels, shipyards, maritime routes as well as industrial, commercial, construction companies, research, and other organizations that ensure the operation of the waterborne transport.

Inland water transport includes vessels, enterprises, institutions, and organizations that carry out the transportation of passengers, cargoes, and mail mainly by inland waterways as well as provide other services using inland waterway vessels.

The central executive body that implements the state policy in the field of maritime transport and inland water transport is the *State Service for Maritime and Inland Water Transport and Shipping of Ukraine* [101]. Its activities are directed and coordinated by the Cabinet of Ministers of Ukraine through the Minister of Infrastructure.

The main legislative acts governing relations in the field of waterborne transport are the following:

Merchant Shipping Code of Ukraine [102] regulates relations arising in and out of merchant shipping, which means activities connected with the use of vessels for carrying cargoes, passengers, luggage, and mail, for fishing and other sea trades, exploration and extraction of minerals, as well as for other purposes.

The rules of the Code apply to *seagoing vessels* - while they are on their way by sea and inland waterways, unless otherwise specified, and to *inland waterway vessels* - while they are on their way by sea and in cases provided by the Code. However, the rules of this Code do not apply to ships with the Ukrainian naval flag.

Law of Ukraine "On Seaports" [103] defines the legal, economic, and organizational basis of seaports activity in Ukraine. This Law regulates the procedure for construction and closure of seaports in Ukraine, the order for carrying out activities on its territories, and determines the legal regime of port infrastructure.

The Law of Ukraine "On Inland Water Transport" [104] regulates relations in the field of inland water transport, use of vessels, inland waterways, and their coastal strips for navigation, defines the legal regime of river ports, and terminals, inland water transport infrastructure. According to the Law, *the List of Inland Sea Waters and Inland Waterways, classified as navigable* [105] has been approved by the Cabinet of Ministers of Ukraine. At the same time, the Ministry of Infrastructure defines the classification of sea and inland waterways.

According to the Law, economic activity on transportation of passengers, hazardous cargoes, and hazardous waste by inland waterways shall be subject to *licensing*. Terms of obtaining a license and requirements for licensees are established by the License conditions approved by the Cabinet of Ministers of Ukraine [106]. The License conditions establish an exhaustive list of documents to be attached to the application for a license as well as organizational, personnel, and technological requirements obligatory for fulfillment by economic entities that carry out activities on transportation of passengers, dangerous cargoes, and hazardous waste by inland or maritime transport.

In addition, the Law stipulates the obligation to register vessels in the Ship Register or Ship Book (depending on the type of vessel). The procedure for registration of vessels in the State Ship Register of Ukraine and the Ship Book of Ukraine has been approved by the Order of the Ministry of Infrastructure of Ukraine [107].

The Law also establishes the peculiarities of the inland waterway vessel operation on which liquefied natural gas is used as fuel. In particular, captains of such vessels and crew members of vessels involved in the bunkering of these vessels with liquefied natural gas must have a qualification certificate of a specialist in the management of a vessel on which liquefied natural gas is used as fuel.

The Law entered into force on January 1, 2022, but its adoption was preceded by an active discussion between sector representatives. In particular, the Minister of Infrastructure of Ukraine noted that the new Law will increase cargoes flow to 30 million tons per year with an economic impact for the state of 13-16 billion UAH annually and improve competition in the market as well as will increase investments and create new jobs for people. At the same time, the State Regulatory Service of Ukraine believed that the law threatens sustainable economic growth and national security of Ukraine, including shipping under the state flag of Ukraine, shipbuilding in Ukraine,

the bunkering market on inland waterways, and will lead to state budget losses and environmental insecurity [108].

Water Code of Ukraine [109] ensures the conservation, rational use of water for the needs of the population and industries, protection of water from pollution, and improvement of water bodies conditions.

Article 67 of the Water Code of Ukraine defines the peculiarities of the use of water bodies for the needs of maritime and inland water transport. In particular, rivers, lakes, reservoirs, canals, other bodies of water, seaports, as well as inland sea waters and territorial sea are *public waterways*, unless their use for this purpose is prohibited in whole or in part by law.

The Water Code of Ukraine defines the basics of water protection from pollution. In particular, it is prohibited to discharge oil, oil-containing mixtures, harmful liquid substances, cargo, and operational waste, and garbage (except food waste) from vessels in the exclusive (marine) economic zone of Ukraine, territorial sea and other public waterways. Disposal of food waste from ships shall be carried out in compliance with the requirements of the *International Convention for the Prevention of Pollution from Ships, 1973, as amended by the Protocol of 1978* [110]. Discharge of wastewater from vessels is permitted in the territorial sea, inland waters, other public waterways, in seaports without restrictions on the course and during berthing of vessels, provided they are treated and disinfected in ship installations following the requirements of the International Convention on prevention of pollution from ships of 1973, as amended by the Protocol of 1978 thereto, or in accordance with the technical requirements for inland waterway vessels approved by the Ministry of Infrastructure.

The Water Code of Ukraine also establishes the obligation for owners of water vehicles, pipelines, floating, and other objects on water bodies, as well as for other legal entities and individuals to protect water from pollution and clogging due to loss of fuel, chemicals, oil, and other pollutants.

Regarding the usage of *marine fuels*, the following regulations are in force in Ukraine:

1. Technical regulations on requirements for motor gasoline, diesel, marine, and boiler fuels, approved by the Resolution of the Cabinet of Ministers of Ukraine as of August 1, 2013, No. 927 [6]. It establishes requirements for marine fuels that have been put into circulation and sold on the territory of Ukraine to protect humans, animals, and plants, to ensure national security, and environmental protection. It has been developed based on the EU legislation.
2. Order of the Ministry of Economic Development and Trade of Ukraine "On approval of the list of national standards, voluntary application of which can be considered as proof of compliance with the requirements of the Technical Regulation on requirements for gasoline, diesel, marine, and boiler fuels" as of 01.10.2014, No. 1179 [24].

The strategy for the development of maritime and inland water transport in Ukraine is formed by the *National Transport Strategy of Ukraine for the period until 2030*. The objectives of the Strategy include ensuring the development of waterborne transport, namely:

- simplification of formalities for registration of cargoes and vessels in commercial ports;
- Ukraine's institutional and legislative fulfillment of its obligations as a flag state, port state, and coastal state in accordance with international treaties of Ukraine and EU legislation;

- introduction of simplified conditions for registration of vessels under the State Flag of Ukraine, creation of an international register of vessels;
- gradual liberalization of the freight transportation by inland waterways, opening of inland waterways for foreign vessels;
- revision of the policy of formation of tariffs and fees to stimulate the development of inland water transport;
- improving shipping characteristics and increasing the volume of traffic using inland waterways by 5 times and more.

The Strategy for the development of seaports in Ukraine until 2038 is also in force in Ukraine. It has been approved by the Order of the Cabinet of Ministers of Ukraine [111]. The Strategy aims to determine the conceptual basis for the formation of state policy of planning and development of the port industry, aimed at improving service, creating conditions for attracting private investments, and improving the efficiency of existing capacity in the seaports of Ukraine, assurance of environmental security following the international standards, etc. To achieve the aim, the Strategy envisages the implementation of goals in the areas of optimization of the port industry management system, balanced development and efficient use of port capacity, and improvement of service in Ukrainian seaports.

The Strategy envisages priority measures for its implementation in the short-term (five years), medium-term (10 years), and long-term (25 years) perspective for each seaport of Ukraine.

According to the Law of Ukraine "On Inland Water Transport", the Cabinet of Ministers of Ukraine has the authority to approve the *Strategy for the development of Inland Water Transport in Ukraine*. The strategy should include short-term, medium-term, and long-term plans of development. The strategy has to be developed taking into account forecasts of cargo flows, investments, main directions and sources of financing, plans for the development of the national transport system, river ports (terminals), other inland water transport infrastructure facilities, seaports development strategy of Ukraine, as well as shipping security and environmental protection. The strategy must also comply with the general scheme of planning the territory of Ukraine.

The draft Strategy for the Development of Inland Water Transport of Ukraine for the period up to 2031 has been published [112]. The provisions of the draft Strategy are aimed at:

- creation of modernized, technological, efficient, and guaranteed public infrastructure of waterways (in particular, increasing the efficiency of shipping locks);
- creation of an optimal logistics system through the development of logistics centers along navigable rivers;
- creation of a sufficient, modern, ecological and energy-efficient fleet, as well as properly trained and certified personnel to work on it;
- reorganization of the public administration system, which ensures the stable development of inland water transport and waterways, in particular by eliminating duplication of administrative functions of central executive bodies concerning all participants of the waterways, introducing of the quality management system;
- ensuring effective management and a clear administrative structure of inland water transport management, which would be able to respond quickly to changes in the industry and the economy as a whole.

As a result of the implementation of the draft Strategy, effective development of river logistics and improvement of Ukraine's global competitiveness is expected. For the state, the intensification of inland water transport will provide an impetus to strengthen trade and economic international ties, the transfer of cargo flows from highways, will increase budget revenues at all levels in the form of taxes, intensify domestic construction of vessels, will have a positive environmental impact as inland water transport is one of the least harmful modes of transport [112].

In 2017, *the Strategy for the implementation of provisions of Directives and Regulations of the European Union in the Field of International Maritime and Inland Water Transport* (the "Roadmap") was approved [113]. The main task of the Strategy is an adaptation of the national legislation to the legislation of the European Union, which will promote liberalization and mutual access to the markets of Ukraine and the European Union and full implementation of Ukraine's commitments in the field of merchant shipping and inland water transport. Ukraine shall harmonize its legislation, including administrative, technical, and other norms in the field of international maritime transport with the relevant norms adopted by the European Union. The Action plan for the Strategy envisages the list of Directives and Regulations of the European Union in the field of international maritime and inland water transport that shall be implemented in Ukraine.

2. Production and supply chain and infrastructure needed to deliver fuels to the vehicles or vessels

2.1 General features of oil processing into fuels for aviation and waterborne transport

Oil is the dominant source of energy for the transport sector in the world and in Ukraine including aviation and waterborne transport, which causes the formation of significant amounts of greenhouse gases. Modern internal combustion engines have been designed to consume liquid fuels made from petroleum. The immediate introduction of alternative fuels for aviation and waterborne transport, which will contribute to the decarbonisation of these sectors, requires that such fuels be used in existing engines and supplied as much as possible using the existing infrastructure. At the initial stage, it is important to establish the production of alternative fuels that have fuel characteristics close to the standardized characteristics of traditional petroleum products. In the future, with the development of science and technology, the most modern engines will appear on the market, which will use completely different energy sources, not related to oil refining.

In general, liquid petroleum fuels for the main purpose are divided into groups and subgroups in accordance with DSTU 4345 "Liquid fuels. Nomenclature of quality indicators" (**Table 2.1**). During the operation of modern engines, one should use only fuels of brands recommended by engine manufacturers, the quality of which fully meets the requirements of the standards. Thus, for ***the aviation sector***, ***subgroups of fuels B (aviation gasoline) and P (jet gas-turbine fuel)*** are used; ***for waterborne transport, subgroups of fuels G (gas-turbine fuel for ship and stationary power plants), D (diesel fuel for high-speed diesels), C (vessel fuel for medium-speed, low-speed diesels) and F (naval fuel oil)*** are used**.**

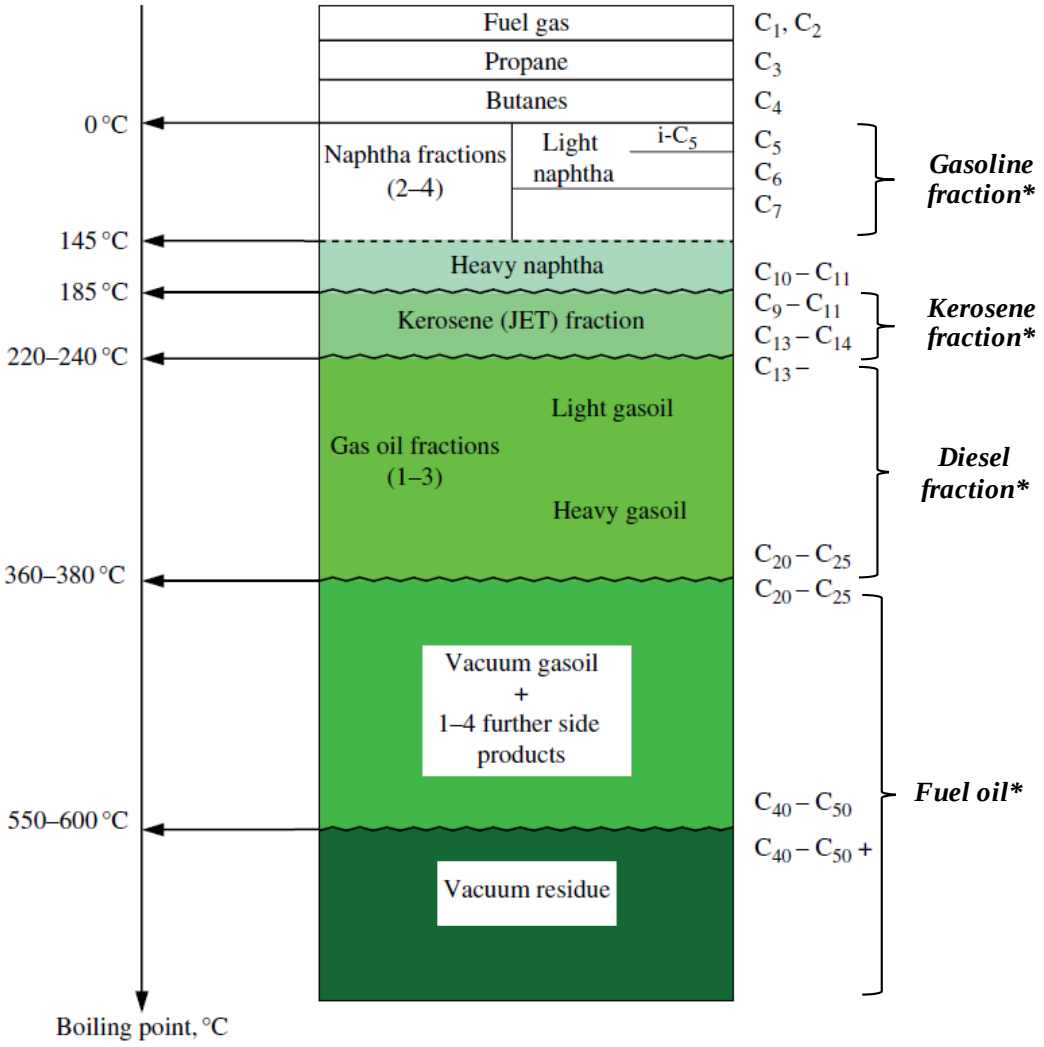
Table 2.1. Classification groups and subgroups according to DSTU 4345 [34].

Fuel groups	Fuel subgroups	Symbol for fuel subgroups
Gasoline	Aviation fuel	B (Б*)
	Motor fuel	A
	Technological fuel	T
Gas-turbine fuel	Jet fuel	R (Р*)
	Fuel for ship and stationary power installations	G (Г*)
Diesel fuel	Fuel for high-speed diesels	D (Д*)
Ship (vessel) fuel	Fuel for medium-speed, low-speed diesels	C
Fuel oil	Naval fuel oil	F (Ф*)
	Fuel oil	M
Domestic fuel	Stove fuel	P (П*)
	Lighting kerosene	GO (ГО*)

** Actual symbols available in the original Ukrainian standard.*

Primary and secondary refining methods are used to convert oil to fuels and other petroleum products. During primary refining, oil is separated into fractions that evaporate at

different temperature ranges (**Fig. 2.1**). At that, the chemical structure of hydrocarbons and hetero-atomic compounds that pass from oil does not change. Secondary oil refining and products recovery are accompanied by changes in the structure of hydrocarbons and hetero-atomic compounds. The process of oil refining can significantly increase the yield of light petroleum products, as well as purposefully change their chemical composition and quality [32].



Note: * alternative name of the fractions

Fig. 2.1. Carbon numbers and boiling points of petroleum products [35].

Direct distillation is the main primary process of oil refining, which consists in its heating under pressure, followed by distillation of steam and liquid phases into fractions. Rectification of the heated oil is carried out at atmospheric pressure and under vacuum. As a result of direct distillation of oil at atmospheric pressure, a number of distillate products are obtained such as gasoline, kerosene, diesel fuel, and fuel oil in the non-evaporated residue (**Fig. 2.2**). Fuel oil is divided into fractions by vacuum distillation to obtain straw distillate (vacuum gas oil), oil distillates, and tar oil in the residue.

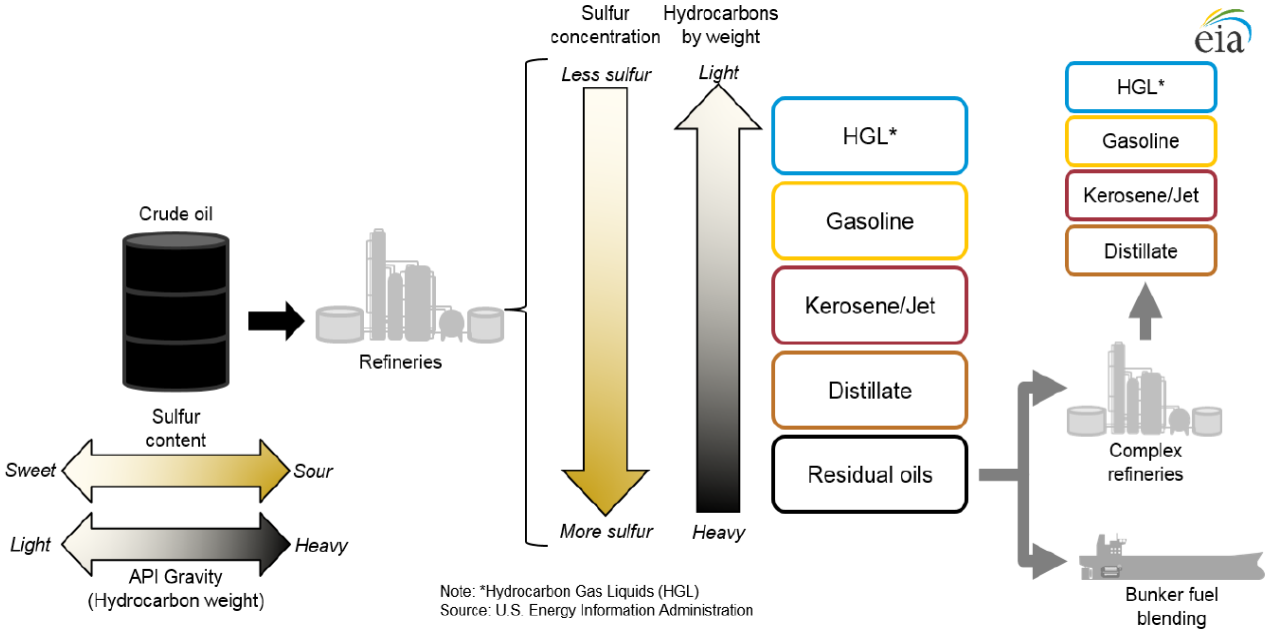


Fig. 2.2. Processing of crude oil and its residues [36].

Vacuum gas oil is usually used as a raw material for catalytic cracking and can also be added to kerosene-gas-oil fractions to obtain diesel fuel of heavy fractional composition. During the secondary oil refining, the main reaction of catalytic and thermal cracking is the splitting of polyatomic hydrocarbon molecules into molecules with fewer carbon atoms. The distribution of sulfur in different oil fractions has a certain pattern: the higher the boiling point of the fraction is, the higher the sulfur content is, the main mass of sulfur being concentrated in the residue. The sulfur content of residual fuels depends on the type of oil (sulfuric or high-sulfur oil) and the technology of fuel production.

Gas-turbine fuels are distillate fuels obtained by the method of slow coking from tar and cracking residues of sulfuric oils. Fuels are characterized by low ash content, low content of mechanical impurities, but high content of sulfur and resinous substances [37].

Two types of distillate fuels are used for the aviation sector, namely aviation gasoline and jet fuels. Two types of distillate fuels (diesel and gas-turbine fuels) and two types of residual fuels (motor fuels for medium- and low-speed diesels and naval fuel oil) are mainly used for waterborne transport. It should be noted that suppliers of fuels for waterborne transport can mix distillate and residual products to obtain fuel with specified characteristics. In addition, gasoline is used for motor boats and boats.

2.2. Fuel supply for aviation

One of the main tasks to be solved during the operation of the aircraft is to ensure high quality aviation fuel at all stages of transportation, from the refinery to the aircraft. The main goal of any modern airport is to effectively organize the process of servicing an aircraft on the ground by minimizing the preparation period. In addition, safety is one of the main criteria in the aviation industry.

In order to reduce the threat of deterioration of aviation fuel and to ensure safe refueling of aircraft fuel tanks, ICAO has developed a guide for the supply of jet fuel in civil aviation [38]. It

provides information on generally accepted international industry practices and covers all the issues on fuel control, operational aspects and staff training in relation to all elements of the supply and distribution chain of aviation fuel. Any commercial enterprise involved in the aviation fuel supply chain is required to establish and adhere to the sectoral and/or their own policies, standards and procedures (PSP) described in this guide, covering the entire field of activity in which they are engaged.

The scheme of the supply and distribution chain of aviation fuel from the refinery to the aircraft is shown in **Fig. 2.3**. Depending on the needs of a particular route, there may be different aviation fuel transport routes, required bulk vehicles and filter systems. From the airport fuel depot, aviation fuel is delivered to an aircraft by hydrant system and by vehicles. The risk of deterioration of aviation fuel due to changes in its properties and contamination may arise in any part of the supply chain on the way from the manufacturer to the final delivery to the aircraft with possible negative consequences for fuel systems and engines.

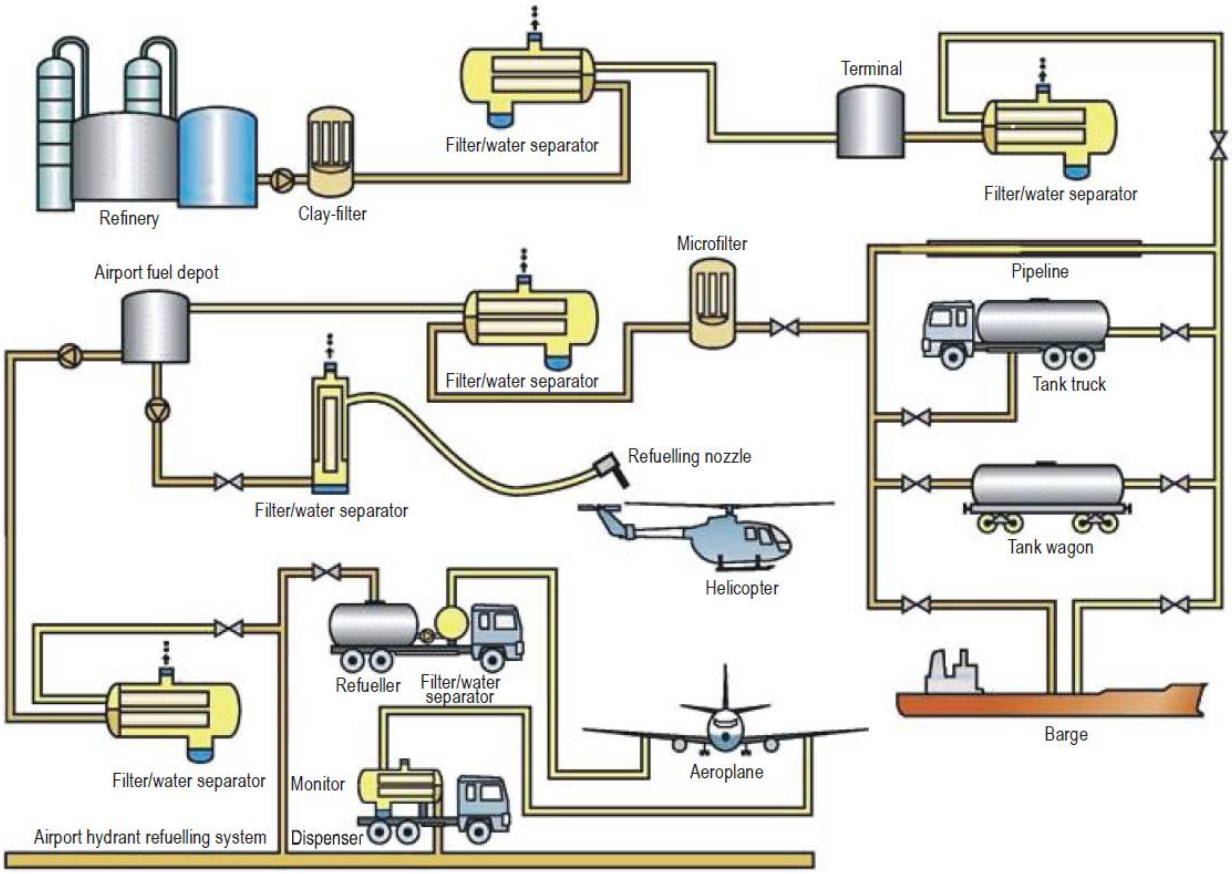


Fig. 2.3. Aviation fuel supply and distribution chain from a refinery to an aircraft [38].

The primary types of contamination are water, particulate and microbiological material. In addition, contamination can occur from other fuel grades and chemicals that may be in multi-product transport systems. The fuel may also be rendered off-specification by either under-dosing/overdosing of approved additives, using an incorrect additive or from product testing issues

not limited to, but including, poor sampling, incorrect test procedures and uncalibrated laboratory equipment. These issues can occur in the various elements of the supply chain.

For the entire supply chain, PSPs have been developed and implemented to ensure the maximum possible guarantees that only conditioned, clean and unpolluted fuel will get to the airport's fuel tanks. These PSPs are provided in industry and company documents covering the production, transportation, storage, transshipment and testing of aviation fuels at refineries, pre-airport terminals and airport warehouses.

To perform these tasks, the following documents are valid in Ukraine:

- *Instruction* on ensuring refueling of aircraft with fuel and lubricants, technical fluids in the enterprises of civil aviation transport of Ukraine (Approved by the Order of the State Aviation Service N 416 of 14.06.2006) [39].

- *Instruction* on quality control of fuels and lubricants, as well as special fluids in the state aviation of Ukraine (Approved by the Order of the Ministry of Defense of Ukraine N 662 of 08.12.2016) [40].

According to the Instruction on ensuring refueling of aircraft [39], the use of a certain brand of aviation fuel in the operation of the aircraft is regulated by flight manuals, aircraft maintenance regulations, industry bulletins, orders of the State Aviation Service.

Aviation fuels that meet technical requirements of DSTU (TU) and have undergone some post-operational preparation are allowed to be used on aircraft.

Aviation fuel, lubricants and technical fluids from the moment of their arrival at FL warehouse of a civil aviation enterprise and before refueling of the aircraft are subject to quality control and special technological preparation. It is FORBIDDEN to use fuels, oils and technical fluids on civil aircraft without special technological preparation and without passing quality control in accordance with the established rules.

Arrangements and rules for quality control of aviation fuels must meet the requirements of DSTU 3982-2000 "Aviation fuels, oils, lubricants and technical fluids. Arrangements and rules for quality control. Generalities". The requirements of this standard are mandatory for enterprises and organizations operating in Ukraine.

Aviation fuels are stable products and can retain their properties for a long time if the rules of acceptance, storage, pumping, transportation, dispensing and refueling are followed. Thus, for TC-1 and PT fuels, the warranty period of storage is 5 years. For other aviation fuels, manufacturers set warranty periods of storage depending on the storage conditions.

The Instruction on ensuring refueling of aircraft contains requirements for the preparation of technical means of aviation fuel supply infrastructure. The means of acceptance, storage, dispensing and refueling of aviation fuels and lubricants, technical fluids include:

- drain overpasses and mobile means of draining;

- receiving and suction tanks of fuel and lubricants warehouses and centralized filling systems, as well as small containers (barrels, cans) for storage;

- means of pumping (pumping stations, pipelines, hoses and filling stations);

- mobile means of refueling (fuel dispensers, oil dispensers, refueling units) and transportation (refuellers) with technological equipment installed on them;

- stationary and mobile cleaning devices (filters and filters-separators).

According to the Instruction on quality control of fuels and lubricants, as well as special fluids [40], if necessary, it is allowed to mix in any proportions in the suction tanks, aviation fuel refueling stations and aircraft tanks fuel for jet engines from among those approved for the use in aviation (PT, TC-1, Jet-A1). At that, the mixture of fuel brands TC-1, PT and Jet-A1, as well as the mixture of fuel with anti-crystallization liquids is taken into account and used by the name of the components of the mixture, for example, PT + Jet-A1 (mixture), PT + 0.1% Nycosol 13 etc. It is allowed to use fuel mixtures for their intended purpose after they are drained from the tanks of the aircraft into the settling tanks of the fuel and lubricants warehouse.

In the case of fuel mixtures used on airplanes, the quality indicators of these mixtures (in the scope of the full test) must correspond to indicators not lower than the "lower" and not higher than the "upper" limit of the relevant standards for components of mixtures. When issuing passports on the mixture, the fuel brand is indicated by the name of the components that are parts of the mixture, for example, PT + Jet-A1 (mixture), PT + 0.1% Nycosol 13, etc.

Mixing of foreign brands of fuel and lubricants with similar brands of fuel and lubricants produced in Ukraine on a mineral basis is allowed both in refueling facilities and directly in aircraft systems and assemblies, if it does not contradict the requirements of the operating documentation.

Mixing of foreign brands on a synthetic basis with fuel and lubricants (foreign and domestic) on a mineral basis is prohibited.

Introduction of anti-crystallization liquid into foreign fuels and lubricants for jet engines and control over its maintenance should be carried out in accordance with the standards for domestic fuels and lubricants.

When refueling aircraft with foreign brands of fuel and lubricants, restrictions are imposed in accordance with the domestic brand of fuel and lubricants for which they are more stringent.

Fuel and lubricants for jet engines with a crystallization onset temperature of minus 38-40 °C, which are approved for usage, may be used in domestic aircraft without restrictions at ambient temperatures of minus 20 ° C and flight duration not exceeding 3 hours.

Fuel and lubricants with a crystallization onset temperature of minus 45-50 °C, which are approved for usage, may be used without restrictions.

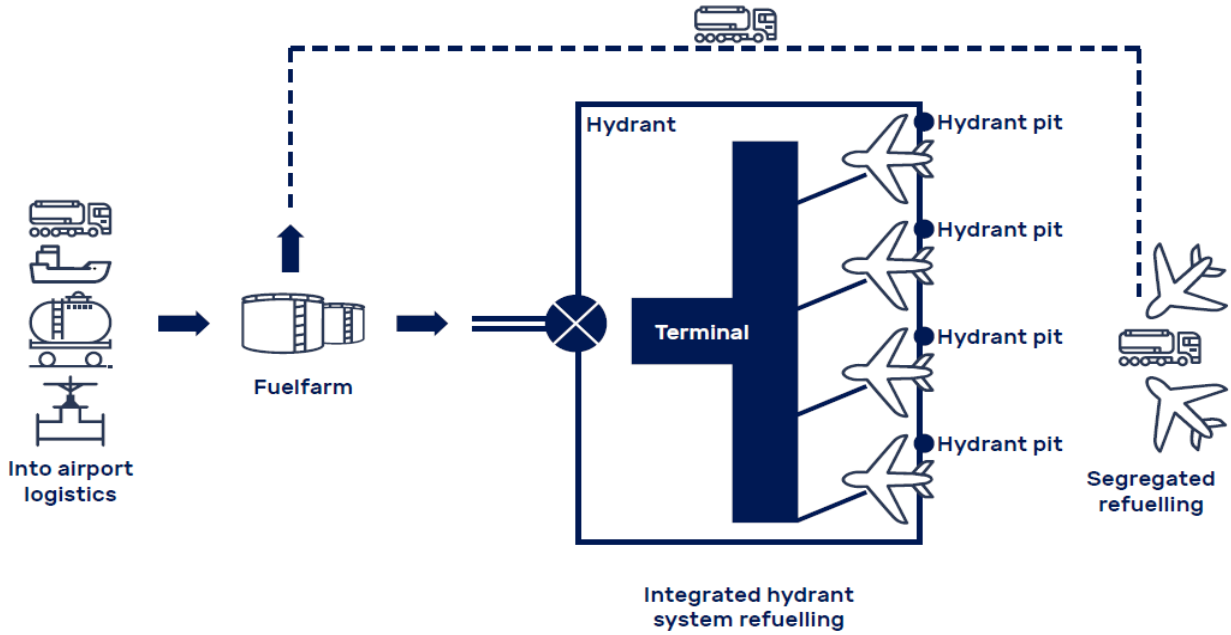
In the case of using foreign brands of fuel and lubricants for aviation equipment, according to the rules of safety, it is necessary to follow the current standards for the treatment of similar domestic brands of fuel and lubricants.

Thus, these instructions do not restrict the use of aviation fuels if they meet the requirements of applicable standards and allow the mixing of fuels under certain conditions. The technological process of aviation fuel supply, transportation, storage, preparation for delivery, delivery to refueling facilities and refueling of aircraft of both Ukrainian and foreign airlines takes place on the regime territory of airports with strict observance not only Ukrainian, but also international requirements and rules.

The technological process of providing aviation with fuel services involves the storage of aviation fuel in tanks with the subsequent filling of refueling facilities, refueling of aircraft on the platform and parking spaces on request. The mode of operation of Ukrainian airports is round-the-clock which requires constant availability of full refuellers on the ramps [41].

A typical scheme of aviation fuel supply at airports is shown in **Fig. 2.4.** In general, there are separate refueling with refuellers on the car chassis, which due to their mobility allows to

supply aviation fuel from the airport fuel depot to any parking place of the aircraft, and the central fuel supply system that uses a system of stationary pipelines and hydrants to refuel aircraft at determined places.



***Note:** * Integrated hydrant system refueling corresponds to the term of aircraft centralized refueling system used in Ukrainian legislation. The system of centralized refueling of aircraft is a complex of constructions and technological equipment for the fuel supply from reservoirs to aircraft tanks by means of stationary pumps through technological pipelines and through refueling units [39].*

Fig. 2.4. Scheme of refuelling at an airport [42].

In Ukraine, aviation fuel is delivered to the fuel depots of airports mainly by rail and road transport. Warehouse of fuels and lubricants is a complex of buildings, structures, equipment and facilities for receiving, storing and dispensing fuel for refueling aircraft and special vehicles. The range and amount of the consumed aviation fuel and lubricants depend on the category of an airport and the annual volume of traffic (**Table 2.2**).

Table 2.2. Approximate data on the volume of fuel and lubricants warehouse depending on the class of an airport [43].

Name	Class of the airport				
	I	II	III	IV	V
Volume of the fuel and lubricants warehouse, m^3, considering delivery type	12700–19700	8000–9700	3500–5300	1000–1325	250–550
Average daily fuel consumption, m^3/day	1000–1500	500–300	200–300	50–100	10–30

According to the functionality, there are **active** and **transshipment** fuel depots of fuel and lubricants. As a rule at each airport, there is one **active warehouse**, which provides the following basic technological operations with aviation fuel: reception of FL; pumping fuel through internal

and external pipelines; fuel filtration before the admission to tanks; fuel storage; sedimentation of aviation fuel and lubricants in tanks and removal of sludge; upper fuel intake from the service tanks; filtration and water separation of aviation fuel before its supply to stationary and mobile refueling facilities; issuance of FL for refueling aircraft (mobile and stationary devices) and for other needs of the airport; addition of special additives to fuel; FL quality control in the process of receipt, storage and issuance; counting the amount of accepted FL, as well as those stored and issued; collection, storage and shipment of waste oil products; environmental protection.

FL transshipment depots are created in the places of FL transshipment from one type of delivery to another. For example, FL transshipment depots are set up at airports where there are no railways. The usable capacity of the transshipment depot should ensure the reception and storage of fuel discharged from the train or tanker.

Reservoirs (**Fig. 2.5**) are the basic elements of the infrastructure for fuel storage at airports. On the territory of the FL storage depot, reservoirs for oil products are placed in groups forming a reservoir park, which is a group (groups) of ground-based tanks designed for storage of oil and petroleum products located in an area bounded by a perimeter embankment or enclosing wall. Reservoir parks are connected with the main technological zones of FL storage by communications and technological storm-water filling and receiving processes (**Fig. 2.6**). Tanks are equipped according to projects.

The specific cost of PBC-2000 m^3 tank starts from 63,000 UAH/t [44]. Thus, a 2000 m^3 tank of 60 tons will cost 3.78 million UAH.

Fig. 2.5. Storage tanks for Jet A-1 [45].

Fig. 2.6. Pumping systems for aviation fuel [46].

Refuellers (special vehicles) are used today in the airports of Ukraine, mainly for refueling of aircraft (**Fig. 2.7**). Usually this type of vehicle is a tank truck equipped with a pump and special equipment for the issuance and accounting of fuel. A feature of refuellers is their maneuverability, autonomy and the ability to deliver fuel directly to the parking lots of aircraft regardless of their location. The use of this type of refueling also has a number of disadvantages: the maintenance of refuellers requires permanent parking spaces for their storage; there exists consumption of fuel and lubricants for refueling the refuellers; additional drivers are required; refueling time is long.

a)

b)

Fig. 2.7. Auto-refuellers: a) АПЗ-22 [47]; b) STOKOTA [48].

At present, Ukraine's airports still use outdated equipment for refueling aircraft: ПЗ-7,5 and ПЗ-22 are quite good machines, but with the development of aviation equipment, the requirements for its maintenance are changing. Virtually every second unit involved in the ground support of flights (including refueling) at domestic airports does not meet modern standards. The solution to this problem may be the purchase of foreign refuellers, which are better suited to work with modern liners [12]. In 2018, SE "Antonov" purchased two new STOKOTA aviation refuellers on the new IVECO chassis at a price of 358,675 EUR/unit[1]; in 2021, the enterprise purchased two aviation refuellers ПЗА-22 for 12196.7 thousand UAH/unit[2].

With the development of aviation equipment, as well as in solving the problems of operating costs when refueling aircraft, special systems of **centralized refueling of aircraft** (CRA) have appeared to replace refuellers (**Fig. 2.8**). The system is a set of technical means such as tanks for receiving, storing, dispensing fuel, pumping units, filters, piping systems and refueling units. The main task of the complex is to reduce the time of aircraft parking and ensure their timely arrival at the destination airports. The main advantage of CRA is the continuous supply of fuel to the tanks of the aircraft, which allows to increase the number of aircraft operated simultaneously and significantly reduce the duration of their refueling. In addition, this method of refueling excludes contamination of fuel from the air and is the safest in terms of fire and easy to maintain. CRA system is particularly effective when refueling aircraft that carry passengers and cargo over long distances, such as Boeing-747, Boeing-777, Airbus A380 and others, whose tanks hold more than 100 tons of aviation fuel. If earlier it took 5-6 hours to refuel a Boeing-777, taking into account the requirements of aerodrome fuel quality control, then now, with the introduction of CRA systems, it takes up to one hour.

a)

[1] https://prozorro.gov.ua/tender/UA-2018-09-20-000366-b
[2] https://prozorro.gov.ua/tender/UA-2021-06-30-004112-c

b)

Fig. 2.8. Refueling the aircraft by means of CRA system using: a) a hydrant on the car chassis; b) a hydrant on the cart.

Sources: a) https://bit.ly/3zvAsTZ, б) https://westmor-ind.com/aviation/hydrant-carts-and-servicers/

Aviation gasoline, which has a high octane number to increase engine power, is used as fuel for light aircraft with piston engines. Mini-gas stations can be used for refueling with aviation gasoline (**Fig. 2.9**). Such stations consist of a filling module, tank, fuel dispenser, pump system, filters, pipelines, control and measuring devices and automation. Mobile refueling systems can be used to refuel aircraft. For example, Gespasa MINI column weighing 22 kg has a 45-50 l/min explosion-proof electric pump and costs UAH 63,000 [49]; MTM-1000 refueling module with a tank of 1000 l costs 90,000 UAH [50].

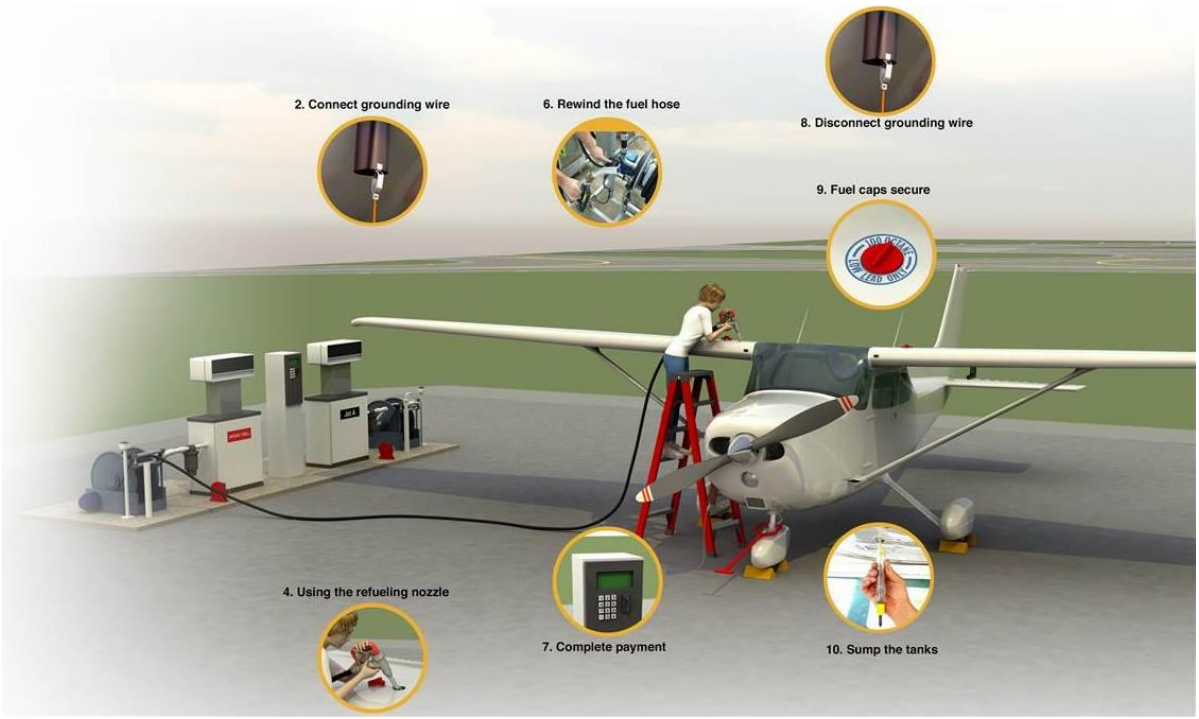


Fig. 2.9. Fuelling station for light aircraft [51].

Despite a number of advantages, CRA systems also have some disadvantages: the introduction of these systems is rather a costly process, so when designing them it is necessary to carefully think over and justify the profitability of the complex; refueling by means of CRA systems requires the presence of necessary equipment on the site of the aircraft parking; when using CRA systems it is possible to refuel an aircraft only with one type of fuel. Refuellers do not have these disadvantages.

Boeing 737-400 aircraft available at domestic airlines consumes fuel in the amount of 20.9 g/passenger-km, A320 consumes 19.1 g/passenger-km, Boeing 767-300 consumes 17.7 g/passenger-km. Given the average flight distance of these aircraft in 2020 (**Annex 3**, **Table A 3.2**) and their passenger capacity, the estimated average refueling volumes will be 6.7 tons of fuel for Boeing 737-400, 4.6 tons for A320 and 21 tons for Boeing 767-300. To refuel such volumes of aviation fuel, it is possible to use auto-refuellers, in particular, АПЗ-22 equipped with a 22,000 l tank and a pump with a fuel supply of up to 1000 l/min.

The fueling complex of Boryspil International Airport, which is designed to receive, store and dispense aviation fuel for refueling aircraft, consists of [52]:

1) Basic FL storage located outside the airport at 11.496 hectares. The total tank capacity is 14,000 m^3, of which 12,000 m^3 are intended for aviation fuel.

2) Warehouses of the central refueling station of 6.6 hectares area, which includes tanks of 7,000 m^3 total capacity and a system of pipelines under the platforms of terminals D and F.

3) Inter-warehouse blocking fuel pipeline, which connects the FL storage and the central refueling station at a distance of 6.9 km, of which 3.3 km are outside the airport.

It should be noted that complex work on the reconstruction of the refueling system was carried out at Boryspil Airport. In the future, the CRA system will be re-equipped, which will ensure high-quality maintenance of aircraft, however this requires significant investment. According to the proposed plan, a private company will have to expand the tank park, purchase dispensers, implement automation systems, build a filter station, provide repair/construction of fuel pipelines under the ramps in 2019-2024. The private partner will have to provide concurrent fuel storage capacity at the level of 14,000 m^3 with the maximum fuel output of 1,200 m^3 per hour. It is also expected that the reservoir park will be almost doubled in 2020-2024 [13]. The planned investment is about 11.9 million EUR (excluding VAT).

Unfortunately, today, most airports in Ukraine do not have the opportunity to implement CRA system on their territory. The reason for this is the need for large material contributions to the infrastructure.

2.3. Fuel supply for waterborne transport

The arrangements and technical support of the fuel supply stages in waterborne transport depends on the characteristics of the required fuel, environmental requirements of the route, refueling volumes, fuel prices, features of the vessel and other factors. The most important stage is the direct refueling of the vessel with fuel and motor oils, which is called bunkering and can be carried out from both shore and floating vehicles. It is a complex technological process, each phase of which is potentially dangerous because it involves the movement of explosive and flammable petroleum products, is carried out on the water, in different weather conditions, often in an

environment of heavy traffic. Spillage of petroleum products during bunkering may cause serious legal and financial consequences [32].

Fuel for water transport goes a difficult way from the oil well to the fuel tank, including raw material extraction, fuel production, transportation, storage, bunkering, and at the end of the life cycle the energy of fuel consumed is transferred to a propeller (**Fig. 2.10**). Pollutants are released into the atmosphere at each stage of this process.

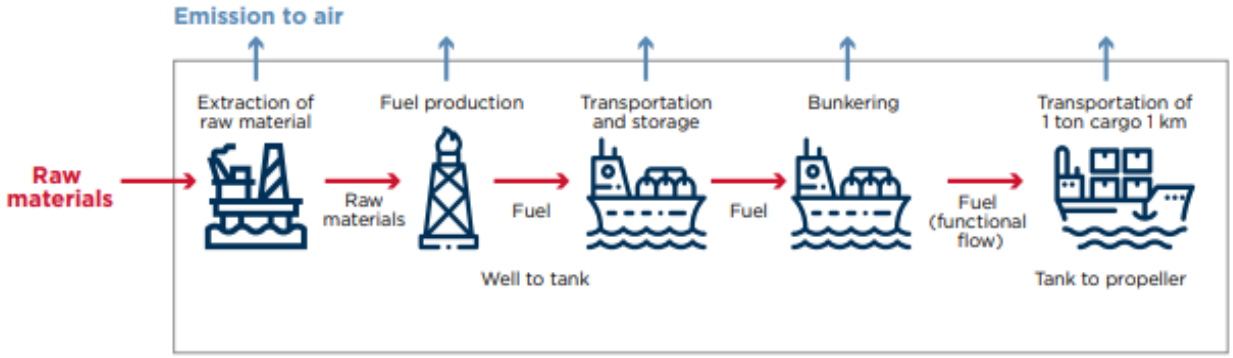


Fig. 2.10. Life cycle of the fuels for waterborne transport "from well to propeller" [53].

Compared to fuel oil, low-viscosity vessel fuel is a more environmentally friendly fuel. It is mandatory for use in the Emission Control Areas, but when entering the open ocean, ships switch to fuel oil as a cheaper fuel. According to the MARPOL Convention, maritime shipping should cease the use of heavy fuel oil in the near future, although changes in this area are slow.

One of the main problems of pollution from shipping is the high sulfur content in vessel fuels. The International Maritime Organization has proposed a strict regulation of sulfur levels in fuels by creating special emission control zones SECA (Sulfur Emission Control Areas) where ships are allowed to use only low-sulfur fuels (0.1%); since 2020 ships sailing in other areas have been allowed to use only fuels with a sulfur content of less than 0.5% (IMO 2020). If low sulfur fuel is not used, exhaust sulfur filtration systems (scrubbers) must be installed to remove SOx emissions. Greenhouse gas (CO_2) emissions will be regulated in a short-term period. Today, low-sulfur fuel used in the marine sector is labeled as VLSFO – Very-Low Sulfur Fuel Oil (0.1%...0.5% sulfur) and ULSFO – Ultra Low Sulfur Fuel Oil (less than 0.1% sulfur). It meets the limitations of SECA zones [54].

VLSFO manufacturers and suppliers use a variety of strategies to stay in line with IMO 2020, while striving to comply with ISO 8217. Globally, the industry uses a wide range of blend components and streams from refinery to create compatible VLSFOs. Depending on the complexity of refinery technology or access of a terminal to the flow of mixtures, the composition of the bunker fuel may be dominated by distillate base or residual base [55].

Processing this fuel on board will be difficult for ship operators as the energy content, density and viscosity of the fuel can vary greatly depending on the flows selected for the fuel production. In addition to these fuel performance issues, inherent stability, bunkering stability, compatibility with other bunker fuels, cold flow characteristics, and overall fuel efficiency can be ongoing issues that need to be managed.

Figure 2.11 provides an overview of fuel oil and vessel fuel production chains with different sulfur contents at refineries. Different refineries may have all or only a few of the

installations shown in the figure. Historically, European refiners have focused on the production of bunker fuel. Refinery production has focused on the use of visbreakers to produce fuel oil with lower viscosity. North American refineries have historically focused on gasoline production, which requires the use of liquid catalytic cracking and coking installations. Some by-product streams from these production facilities were used in the bunkering market, but they accounted for only a small share of bunker fuel supplied on a global basis. Due to the new requirements for low sulfur content, refineries with higher refining complexity have the advantage that they can more easily produce streams of low sulfur mixtures suitable for waterborne transport.

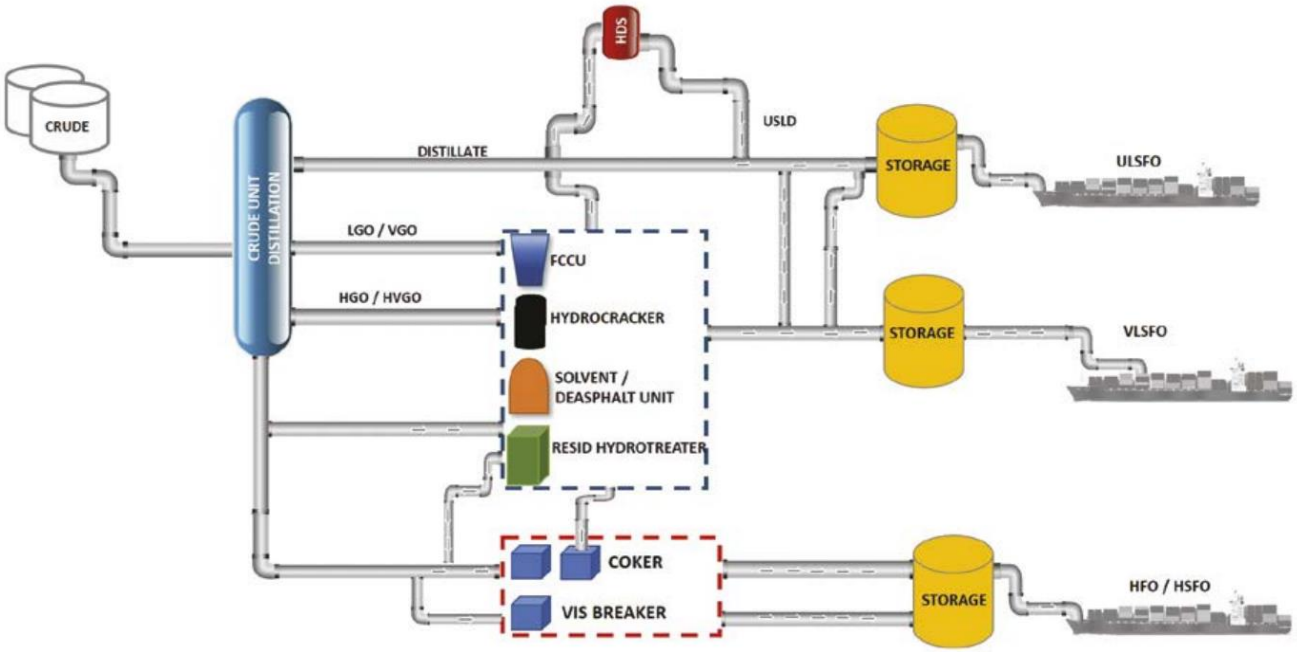


Fig. 2.11. Refinery production chain for different fuels for waterborne transport [55].

Oil ports are used in ports to load or unload oil vessels. Refueling complexes for waterborne transport are a type of oil depot. Oil depots are enterprises consisting of a complex of facilities and installations designed for the reception, storage and issue of petroleum products to consumers. According to the size of the annual turnover, oil depots are divided into five classes [69]:

1) > 500 kt/y;
2) 100 to 500 kt/y inclusive;
3) 50 to 100 kt/y inclusive;
4) 20 to 50 kt/y inclusive;
5) < 20 kt/y.

The territory of an oil depot is generally divided into zones (production, auxiliary, tank park) and areas. The technical equipment of oil depots must meet the following requirements:

a) the tank park must ensure the acceptance, storage and shipment of the specified quantity and range of petroleum products;

b) technological pipelines must allow the simultaneous acceptance and shipment of different brands of petroleum products without their mixing and loss of quality;

c) filling and draining devices, as well as pumping equipment must ensure compliance with time standards for draining and filling oil products.

The infrastructure of a port oil depot is a complex of structures and tanks with a system of pipelines, pumps, shut-off equipment, filters, control and measuring devices, fire protection equipment and other elements (**Fig. 2.12**). It should be noted that due to the their high viscosity, fuel oils are pumped through fuel oil pipelines, which have a larger diameter than the pipelines for distillate fuels, and need heating for transportation. Fuel oil storage tanks can also be equipped with heaters.

Fig. 2.12. General view of bunker fuel storge [57].

Port facilities equipped with sea or river loading arm allow to successfully solve problems related to the pumping of liquids, in particular, fuel between the berth and tankers or river barges (**Fig. 2.13**). These devices are installed at any fixed point on the pier, berth or buoy for loading and unloading ships and river barges [70]. Multi-row hinges provide ease of movement of moving elements of the loading arm during long operation.

Fig. 2.13. Loading arm for filling and draining of oil and oil products [70].

The transport that supplies fuel and lubricants to the ship is called a *fueler*; the ship to which the supplies are directly delivered is called the ship that is bunkered. *Bunkering* can take place in a variety of ways: at the berth, on a raid, on the move or drifting in the sea or ocean, from a floating refueling station [23]:

- from the berth (i.e. from the shore: from a tanker (**Fig. 2.14 a**) or from a pipeline (**Fig. 2.14 b**)) or near the berth (i.e. from a bunker), the bunkering vessel in both cases being moored to the berth;

- from a bunker to a ship on the raid (at anchor) when the ship and the bunker are at anchor (**Fig. 2.14 c**);

- from a bunker to a vessel on the move or in drift; this option is often used by fishing vessels during fishing;

- a floating refueling station is used for bunkering small fleet (yachts and small ships) with gasoline and diesel fuel (**Fig. 2.15**).

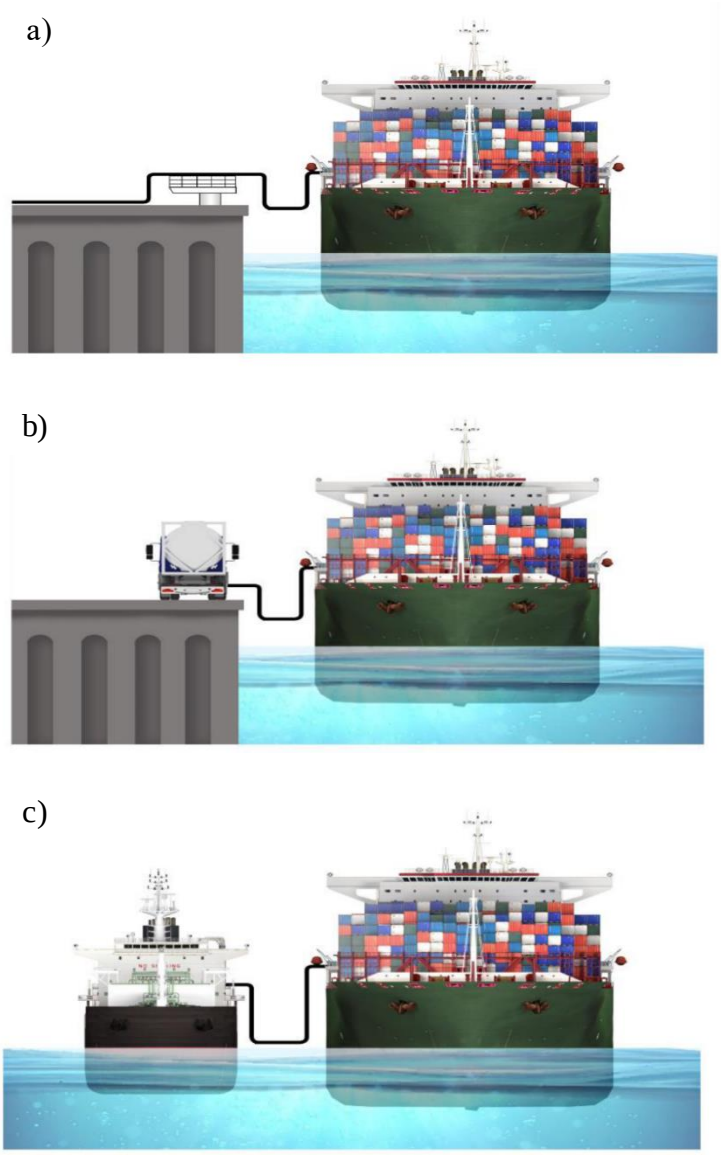


Fig. 2.14. Options for vessel bunkering [66]: a) from a pipeline; b) from an auto-refueller; c) from a vessel-fueler.

Fig. 2.15. Floating refueling station in Croatia [67].

Self-propelled fuelers are usually used in ports with high turnover of vessels. Thanks to the use of fuelers, it is possible to reduce the duration of berthing of ships, which increases the capacity of ports. It should be noted that in order to receive fuel from the bunkering base, the vessel must enter the port even if no other operations are required, but this requires a number of formalities related to non-productive loss of time and payment of port dues. Therefore, bunkering is more often performed from vessels-fuelers.

Different types of vessels can choose the most acceptable option for bunkering. The fuel supplied to a ship must meet certain requirements and be suitable for use in certain types of engines. Bunkering should be carried out only after the receipts have been checked and the responsible personnel have been convinced that all the standards of the declared key properties such as viscosity, density, heating value, and water content are met.

According to the Law of Ukraine "*On Inland Water Transport*"(№ 1054-IX of 03.12.2020) [104], replenishment of a vessel with fuel and lubricants in bulk (bunkering) on inland waterways is carried out near berths and in the operational waters of river ports (terminals), and also in places agreed with the central body of executive power, which implements the state policy in the field of inland water transport. Safety rules for bunkering vessels with liquid fuel are established by the *Order* of Ukraine's State Committee for Industrial Safety, Labor Protection and Mining Supervision "On Approval of Safety Rules for Employees of Port Vessels and Auxiliary Fleet Vessels of Fishery" (№ 13 of 24.01.2007).

Procedures and requirements for fuel bunkering of vessels, including refueling from fuelers, tank trucks and shore pipelines, are defined by the international standard ISO 13739: 2020 Petroleum products – Procedures for the transfer of bunkers to vessels. It applies to inspections and documentation before delivery, during delivery and after delivery.

Bunkering must comply with the rules for the prevention of pollution from ships [20] applicable to seacraft and ships of mixed navigation in accordance with the requirements of MARPOL 73/78/97 and IMO Resolutions.

The ship's fuel system is designed to receive, store, supply to service tanks, move (pump) liquid fuel from one tank to another, as well as to transfer it to other ships. Volumes of fuel for bunkering for the next voyage are defined as the product of the sum of running and parking costs of fuel for a round trip by the dead reserve factor of ≈1.1 and the storm reserve factor of ≈1.15-

1.2. This takes into account the hourly fuel consumption of the main and auxiliary engines as well as of the boiler installation during the movement of the vessel and during its presence in the parking lot. For example, medium-sized vessels use medium-speed marine engines of up to 13 MW with an effective fuel consumption of 205-210 g/kWh. Therefore, with an engine capacity of 500 kW, specific fuel consumption will be more than 102.5 kg/h. Maritime container vessels, depending on their speed and size, consume fuel in the amount 50 t/day to more than 350 t/day [56]. The 2500 TEU [31] container ship have 5 fuel oil tanks of 2,000 m^3 (2 for storage, 1 for settling, and 2 service tanks), 2 tanks for MDO/MGO of 1,300 m^3 total volume(1 for storage and 1 service tank). Large vessels may additionally have separate tanks for low-sulfur fuel oil. The refueling process can take about 9-12 hours for a large vessel, usually 10 hours at 500-700 t/h rate [71].

Thus, the volume of fuel bunkering of seacraft can be estimated as thousands of tons, while that of river vessels is tens and hundreds of tons. At the same time, different types and brands of fuel can be supplied, which still need to be mixed with fuels available in vessel tanks. When mixing compatible fuels, the stability of their mixture is not disturbed and intensive precipitation does not occur. To avoid the consequences of incompatibility, residual fuels with a high content of asphaltenes should not be mixed on board with lighter paraffin-containing grades, as well as fuels should not be mixed with each other if they belong to different bunkers. It is desirable to check the fuels for compatibility before mixing [32].

The general fuel supply chain involves many participants who act in accordance with their functions (**Fig. 2.16**). Refineries produce a wide range of fuels in accordance with current regulations, and fuel is supplied to the market by suppliers. Traders can buy fuel through brokers from different suppliers. The ship's senior mechanic submits an application to the ship's operator for the supply of certain volumes of fuel with certain indicators of quality and compliance with regulatory documents indicating the port of touch and date. The operator of a vessel is looking for a trader who will provide bunkering according to the application at the lowest price. At the bunkering port, the ship's agent organizes the interaction between the bunker and the ship. The described scheme may be different, and include additional intermediaries, which, in particular, may credit the purchase of fuel.

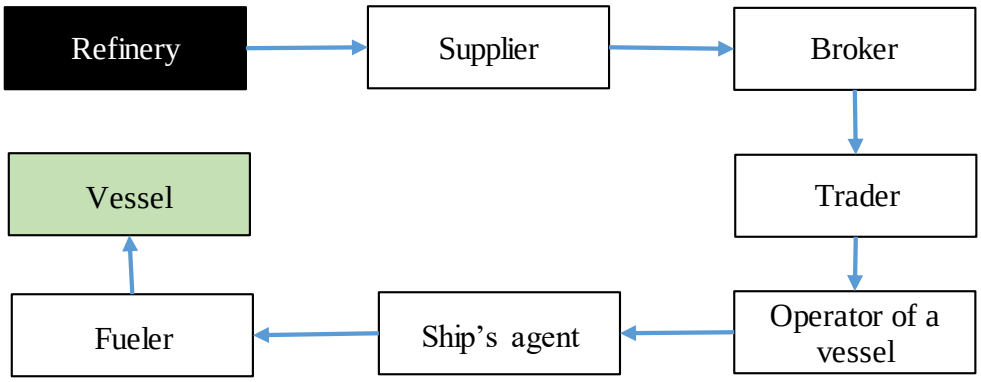


Fig. 2.16. Vessel bunkering scheme from a refinery to a vessel's engine.

Depending on the bunkering conditions, volumes and fuel range, different bunkering vessels can be used, which are a small specialized tanker. (**Fig. 2.17**). The bunkering vessel has a special system of cargo pumps for pumping liquid fuel to the bunkered vessel, as well as devices

for accounting for the amount of fuel transferred. As a rule, these types of vessels have a heating system for heavy fuel oils.

Fig. 2.17. Bunkering with fuel from a bunkering vessel [58].

There are the following types of bunkering vessels: tankers-suppliers with a deadweight of 5-6 thousand tons; raid bunkers with a deadweight of about 3 thousand tons; port bunkers with a deadweight of about 2.0 thousand tons and estuary bunker tankers with shallow drafts with a deadweight of 800 tons to work in estuaries and river ports [68].

In the fuel supply zone outside the country's territorial waters, i.e. beyond the 12-mile zone, OPL Odessa, which supplies vessels from the ports of Odesa, Pivdennyi, Chornomorsk, Mykolayiv and others, has recently become using a Middle Eastern fuel more often, and according to expert estimates, its share in this market is 50-60%. About 6-7 bunkering vessels are more or less constantly here. In particular, the Malburg bunker, owned by PMG Holding, has a deadweight of 5,215 tons and can supply fuel oil at speeds of up to 380 tons per hour [59].

In the waters of the Odessa seaport, including the raid, PJSC "Synthesis Oil" performs bunkering of vessels under the scheme "Board - Board" [64]. In shop №1 of the oil harbor of the state company “USPA” (**Fig. 2.18**) bunkering of vessels is carried out with the help of loading arms at berths №№ 1n, 2n, 4n and 5n. Transshipment and bunkering of vessels by means of a rubber hose is carried out at the berth № 6n. Fuel for bunkering: fuel oil (MGO.MDO) and diesel fuel. The planned turnover of bunkering of vessels from the berths is 350 kt/year of fuel oil and 135 kt/year of diesel fuel.

Fig. 2.18. Oil harbour of SE “ASPU” [64].

At the berths, in the waters (including raids) of seaports of the Odesa region (Odesa, Bilgorod-Dnistrovskyi seaports, seaports "Chornomorsk", "Pivdennyi"), at the berths of LLC "Chornomorsk Fishing Port" activity on bunkering of sea vessels with fuel is carried out by LLC "Paid" "[65]. The distribution of the bunker by ports during each year may be different, but the total amount of fuel used will not exceed 25,000 tons/year of diesel fuel, 25,000 tons/year of fuel oil.

At the disposal of LLC "Paid" are auto-refuellers and bunkering vessel, with the help of which the following technological processes are performed:

– refueling of a bunkering vessel near the seaport berth (15 thousand tons of diesel fuel, 15 thousand tons of fuel oil) according to the scheme "auto-refueller – bunkering vessel";

– bunkering of sea vessels near the berths of the seaport from the auto-refuellers (10 thousand tons of diesel fuel, 10 thousand tons of fuel oil) "auto-refueller – sea vessel";

– bunkering of sea vessels in the water area, including raids, of the seaport (15 thousand tons of diesel fuel, 15 thousand tons of fuel oil) according to the scheme "bunkering vessel – sea vessel".

Bunkering of transport vessels is carried out according to technological schemes:

– auto-refueller (tank – pump with a capacity of 15 m^3/hour) – oil&fuel resistant hose with end flange – ship (receiving branch pipe – fuel line – fuel tanks);

– auto-refueller (tank) – oil&fuel resistant hose with end flange – ship (receiving branch pipe – fuel line – fuel tanks);

– bunkering vessel (tank – pump) – oil&fuel resistant hose – ship (receiving branch pipe – fuel line – fuel tanks).

"Terminal Danube" Ltd. on the territory of the State Enterprise "Reni Commercial Sea Port" is implementing an investment project to create a costly warehouse for petroleum products in the port of Reni to ensure bunkering operations with an investment of 4.5 million USD, of which 1.9 million USD was disbursed. The complex provides services for transshipment and bunkering of vessels on the Danube with light and dark oil products. The capacity of the complex is 60

thousand tons/year. Possibility of concurrent fuel storage of 2 kt [72, 73]. The oil transshipment area holds [74]:

- loading and unloading railway overpass - one-sided for 8 cars;
- pumping stations, one of which is deepened, open, the other - in a room with natural ventilation;
- reservoir park with a total capacity of 2400 m^3, which includes one tank for 2000 m^3 and two for 200 m^3;
- system of technological pipelines and shut-off valves.

Thus, the specific investments in the oil products storage in the port of Reni to ensure bunkering operations amount to 792 USD/m^3 of reservoir park or 950 USD/t of concurrent fuel storage.

The cost of used bunkering vessels is: 445 thousand EUR for a double hull bunkering vessel manufactured in 1969 with a deadweight of 4406 tons, 575 thousand USD for a bunkering vessel manufactured in 1982 with a deadweight of 2959 tons, 295 thousand EUR for a double hull bunkering vessel manufactured in 1981 with a deadweight of 1308 tons, 375 thousand EUR for a double hull bunkering vessel manufactured in 1978 with a deadweight of 1375 tons [75]. For comparison, a new bunkering vessel with a deadweight of 1.5 thousand tons costs from 1.9 million USD.

Conclusions

Aviation and waterborne transport are important and promising segments of Ukraine's transport sector, the development of which was affected by the COVID-19 pandemic, and then, in February 2022, **interrupted by Russia's military aggression against Ukraine**.

In Ukraine, the civil aviation sector uses fuels for jet engines TC-1, PT, Jet A-1 and aviation gasoline. In 2019, domestic aviation consumed 34 kt of fuel and international aviation consumed 545 kt. Waterborne transport uses vessel fuel and naval fuel oils. In 2019, the final consumption of petroleum products by inland navigation amounted to 135 ktoe. In 2020, due to quarantine restrictive measures, there was a decline in traffic in aviation and waterborne transport, which reduced fuel consumption in these sectors.

According to Ukraine's Greenhouse Gas Inventory 1990-2020, GHG emissions from transport in 2020 amounted to 31.81 Mt of $CO_{2\text{-eq}}$, which was about 10% of the total emissions. The emissions from transport decreased by 71.6% compared to 1990 and by 18.9% compared to 2019. The reduction in 2020 can be explained by the COVID pandemic. In 2020, the largest contribution to GHG emissions from transport was made by motor transport (73.6%). At that, the emissions from domestic civil aviation and domestic water transport accounted for 0.5% and 0.25% of the total transport GHG emissions, respectively. Despite the current small contribution of aviation and waterborne transport to the total transport GHG emissions, these figures may increase tenfold in the course of further dynamic development of these sectors unless some appropriate measures do not start to be taken right now. One of these measures is switching to ***alternative low-carbon fuels***.

Regarding aircraft, in general, there are separate refueling with refuellers on the car chassis, which due to their mobility allows to supply aviation fuel from the airport fuel depot to any parking place of the aircraft, and the central fuel supply system that uses a system of stationary pipelines and hydrants to refuel aircraft at determined places. CRA system is considered to be more modern and advanced. Complex work on the reconstruction of the refueling system was carried out at Boryspil Airport. In the future, the CRA system will be re-equipped, which will ensure high-quality maintenance of aircraft. Unfortunately, today, most airports in Ukraine do not have the opportunity to implement CRA system on their territory. The reason for this is the need for large material contributions to the infrastructure.

The ports of Ukraine have infrastructure for transshipment and storage of petroleum products, which can also be used for bunkering ships. Most of this infrastructure is outdated and therefore needs repair and modernization. At present, at the current cargo turnover, in order to increase the volume of bunkering of fuels in waterborne transport, in particular, sea craft, it is necessary to eliminate legal barriers that have created preconditions for the development of the shadow market of bunkers. Given the requirements of MARPOL and the trend to limit the boundary emissions of pollutants into the atmosphere, maritime transport needs to switch to **low-sulfur fuels**, which creates new opportunities for the introduction of new types of marine fuels, including ***biofuels***. At the same time, there will be a need for partial modernization of fuel depots and bunkering infrastructure. Thus, the development of the bunkering market in Ukraine's ports (and not outside the 12-mile zone) as well as the reorientation to alternative fuels will create economic incentives for the modernization of the fuel supply infrastructure for waterborne transport, which will ensure reducing emissions of pollutants and greenhouse gases.

Annex 1. Statistics of river and marine vessels by type

Table A 1.1. River and marine vessels by type, 2015-2017 (at the end of the year, units) [19].

Types of vessels	River vessels			Marine vessels		
	2015	2016	2017	2015	2016	2017
Total	**1321**	**1312**	**1401**	**2485**	**2491**	**3334**
of which: passenger vessels	151	151	166	103	105	131
tankers	-	-	-	11	11	27
dry cargo ships	440	438	455	1118	1123	1280
bulk carriers (non-self-propelled)	-	-	-	41	40	79
special purpose vessels	245	242	257	588	586	847
Technical vessels	93	92	107	183	182	242
service and support vessels	392	389	416	327	327	608
Fishing vessels	-	-	-	114	117	120
of which: industrial vessels	-	-	-	105	111	114
Industrial-processing vessels	-	-	-	9	6	6

Note: Vessels of enterprises of all sectors of economy. Data on the availability of river and sea transport in 2015 - river transport according to the State Inspectorate of Ukraine on Safety on Maritime and River Transport (Ukrmorrichinspektsiya), marine transport - Ukrmorrichinspektsia and the State Agency of Fisheries of Ukraine (State Fisheries Agency); for 2016-2017 - river transport according to the State Service of Ukraine for Transport Safety (Ukrtransbezpeka), marine transport - Ukrtransbezpeka and the State Fisheries Agency.

Table A 1.2. Vessels registered in the State Ship Register of Ukraine, 2018-2020 (by the end of the year, units).

Types of vessels	2018 [27]	2019 [26]	2020 [19]
Marine vessels	678	694	703
River vessels	1222	1284	1313
Vessels of mixed navigation area	158	184	240
Pleasure boats with an engine capacity of 75 hp and more	8964	9594	10188
Pleasure boats with an engine capacity up to 75 hp	> 105.8 thousand	> 109.6 thousand	> 111.8 thousand

Note: Data from the State Maritime and River Transport Service of Ukraine and the Ship Book of Ukraine.

Table A 1.3. The composition and structure of the self-propelled cargo fleet in 2020 [30].

Type	Number of ships	Deadweight, t	Gross capacity, registered/t	Average age, years
Dry cargo ships, including:	*72*	*270429*	*199593*	*38*
Dry cargo (for general cargo)	36	147525	109367	35
Dry cargo (universal)	30	80649	6101	45
Refrigerated	2	571	590	41
Container carriers	2	7018	4919	22
Roll-on/roll-off	1	6437	6327	10
Bulk carrier	1	28215	16859	36
Tankers, including:	*14*	*32052*	*20728*	*38*
Chemical carriers	2	6122	3879	39
Oil tankers	7	20856	13975	37
Tank vessels	5	5074	2874	39
In total, cargo ships	**86**	**302481**	**220321**	**38**

Annex 2. Fuel consumption by domestic and international aviation of Ukraine in 2007-2019 by aircraft type

Table A 2.1. Fuel consumption by domestic aviation of Ukraine by aircraft type, **tons** [9].

Aircraft type	2007	2008	2009	2010	2012	2014	2016	2017	2018	2019
A**310**	10.9	0.0	5.2	5.2	14.2	5.4	5.2	0.0	0.0	
A**318**	0.0	0.0	0.0	0.0	11.9	10.5	7.6	10.7	7.1	
A**319**	323.4	284.7	190.0	175.7	396.8	67.1	17.6	32.3	69.3	40.8
A**320**	2953.4	5446.4	3495.8	3364.9	3369.3	158.3	125.7	112.0	70.4	5.4
A**321**	0.0	0.0	0.0	0.0	725.2	89.3	39.3	76.7	150.0	15.1
A**332**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
A**343**	8.2	24.6	0.0	0.0	7.7	6.4	14.5	7.2	12.6	14.5
AT**43**	0.0	1.4	6.1	5.8	808.2	1.3	0.0	0.0	0.0	
AT**45**	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	
AT**72**	22511.2	10167.6	3392.6	3165.6	10503.1	6591.7	4632.3	5789.7	5666.7	6073.4
B**732**	393.2	3015.6	0.0	0.0	144.7	0.0	0.0	0.0	0.0	
B**733**	3074.6	3325.0	2826.2	2726.2	6713.4	2472.5	2474.9	1215.8	1800.3	50.1
B**734**	4963.8	6554.1	4899.7	4734.3	5991.9	2448.7	16.8	22.4	189.4	65.6
B**735**	3956.0	6522.4	8643.3	8348.8	10666.4	3263.4	4734.1	1890.6	469.5	21.1
B**737**	3.1	2.6	7.1	6.0	0.0	0.0	2.6	8.1	11.4	270.5
B**738**	2.8	11.2	1142.3	1101.5	1674.3	3783.2	6736.2	9081.0	9852.3	13004.8
B**742**	524.1	268.3	308.7	251.5	324.8	825.3	145.0	168.8	302.8	54.6
B**744**	93.6	150.3	29.9	50.1	37.2	82.0	78.4	27.1	30.9	
B**752**	0.0	0.0	4.7	4.7	2.7	0.0	0.0	0.0	0.0	
B**762**	0.0	0.0	0.0	0.0	16.9	0.0	0.0	0.0	0.0	
B**763**	12.7	0.0	17.6	15.1	90.4	0.0	11.6	0.0	34.8	32.0
BA**11**	18211.7	10400.7	4212.2	3955.7	1329.5	639.2	417.7	287.4	760.0	983.2
BE**20**	141.1	122.0	127.8	119.9	74.9	38.8	23.6	20.8	24.4	19.7
C**130**	118.1	139.3	116.2	91.3	65.1	42.1	49.8	28.5	38.9	7.8
C**550**	65.8	170.0	561.2	537.9	1734.0	1130.8	312.1	210.9	161.8	162.4
CRJ**1**	0.0	0.0	11.0	11.0	4.9	0.0	0.0	0.0	0.0	
CRJ**2**	0.0	290.1	656.4	619.2	693.8	270.2	18.1	6.2	11.2	6.1
CRJ**9**	0.0	0.0	3.1	2.4	0.0	0.0	0.0	0.0	0.0	
D**228**	758.9	250.0	146.7	138.9	30.8	5.5	4.5	6.8	6.1	0.4
D**328**	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
DC**87**	52.3	195.0	98.5	90.3	73.2	11.1	0.0	0.0	0.0	
DC**94**	25149.9	22924.0	1615.2	1545.6	106.4	0.0	0.0	0.0	0.0	
DH**8**D	0.0	0.0	0.0	0.0	2.0	2.7	2.1	6.4	1.9	2.1
E**120**	5.3	0.0	1.8	1.8	0.0	0.0	0.0	0.0	0.0	
E**145**	1435.7	7203.4	15504.6	14875.9	7640.7	4187.7	3199.8	5496.5	6018.1	4977.5
E**170**	0.0	0.0	0.0	0.0	0.5	1.7	0.0	2.1	0.0	
E**190**	0.0	0.0	637.9	614.5	1233.9	586.0	3005.8	4431.0	5660.7	7268.5
F**100**	158.2	233.2	1415.5	1329.2	3396.6	235.8	137.5	221.8	196.6	20.8
F**28**	234.4	222.2	209.6	193.6	276.8	154.8	186.2	257.6	261.5	149.5
F**2**TH	1231.7	1732.8	2006.5	1890.6	2297.8	1083.4	398.5	452.9	359.2	671.7
F**50**	0.0	0.0	0.0	0.0	224.4	0.0	0.0	0.0	0.0	
MD**82**	537.5	730.4	1083.4	1035.1	329.3	1.0	0.0	0.0	26.5	50.9
MD**83**	180.1	148.8	689.8	654.1	329.3	87.1	179.6	151.5	82.2	23.6
PAY**3**	8.3	7.3	26.4	23.5	85.7	81.7	31.4	15.4	34.2	13.0
RJ**85**	0.0	0.0	0.0	0.0	172.2	39.9	0.0	0.0	0.0	
SB**20**	0.0	2.1	2.7	2.7	2.0	0.0	0.0	0.0	0.0	
SF**34**	51.0	2151.1	2222.4	2148.7	700.0	674.7	40.1	54.7	49.2	28.0
SW**4**	1.2	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
T**134**	1033.0	412.9	204.6	188.6	246.6	3.7	2.8	3.7	0.0	
T**154**	147.1	10.7	7.5	12.1	7.5	6.0	0.0	0.0	0.0	
STAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.9	
ВСЬОГО:	**88352**	**83123**	**56530**	**54038**	**62558**	**29089**	**27051**	**30097**	**32364**	**34033**

Table A 2.2. Fuel consumption by international aviation of Ukraine by aircraft type, **tons** [9].

Aircraft type	2007	2008	2009	2010	2011	2014	2016	2017	2018	2019
A306	70.8	0.0	17.0	156.2	1049.6	125.1	71.7	137.6	249.7	107.2
A310	926.2	1015.8	49.9	347.4	1011.8	344.1	1471.1	975.5	459.7	631.9
A318	2319.0	1536.3	381.5	1410.3	88.7	377.6	296.8	285.4	356.6	211.0
A319	10478.4	9384.9	3230.3	13071.7	12357.5	16641.8	8992.4	10509.6	9324.3	9871.1
A320	14366.8	25159.0	9636.0	40760.3	52315.6	44137.2	35210.3	41751.7	66850.6	78128.9
A321	2710.0	5946.9	1338.0	7774.1	23680.5	16746.2	16567.0	38211.8	37497.5	37730.0
A332	0.0	117.0	5.2	38.4	108.7	4596.0	2806.2	6450.1	5077.9	4954.2
A333	0.0	0.0	1.4	11.0	0.0	32.0	2381.4	4226.9	5616.2	5850.2
A343	81.5	467.9	18.5	177.0	120.7	1651.2	295.1	411.3	499.9	357.0
A345	0.0	0.0	0.0	0.0	8.1	4058.1	19.4	0.0	0.0	
A346	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	105.1	
AT43	54.3	1233.6	831.9	1296.2	1689.4	17.2	6.2	6.4	2.7	11.2
AT45	1.3	1.3	2.2	5.4	301.4	0.8	0.0	0.0	0.0	
AT72	8569.9	5214.5	851.1	3407.4	3015.6	1320.3	994.9	1241.9	1231.7	3225.6
B190	0.6	2.9	0.0	0.0	5.7	2.9	0.0	0.0	0.0	
B462	18.1	101.3	80.5	374.6	898.1	108.7	6.6	48.7	21.0	
B712	7.3	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
B721	51.2	11.6	4.4	23.0	20.3	0.0	0.0	0.0	0.0	
B722	53.4	25.4	4.0	25.3	0.0	0.0	0.0	0.0	0.0	
B732	1879.1	916.8	2.6	10.6	16.0	6907.8	0.0	0.0	0.0	
B733	26727.4	30041.1	4683.9	20701.1	25530.5	14888.8	16519.1	14413.4	12763.3	5544.9
B734	51788.3	60057.0	7745.5	37449.2	38604.1	6013.6	4509.5	5411.0	12455.4	5615.4
B735	29355.1	37114.1	8979.4	42191.3	48121.9	24765.3	19346.1	13846.3	8795.9	7086.9
B736	915.2	939.9	266.4	1206.6	1549.6	0.0	0.0	0.0	0.0	
B737	1645.8	1868.3	619.8	2622.5	3285.1	0.0	838.8	1212.3	5671.1	15039.6
B738	7694.7	10231.5	5752.1	25413.6	29661.8	78823.0	114768.8	147717.9	172323.7	207682.1
B742	8164.7	8773.8	394.0	6861.4	4925.8	1842.6	1168.7	854.3	1026.0	1956.3
B743	396.7	14.9	9.4	198.7	30.0	73.6	0.0	0.0	0.0	
B744	5170.8	4365.0	237.6	3908.3	3634.8	2111.5	3484.3	5048.1	4983.5	4769.8
B747	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	346.8	
B752	2562.7	3286.1	468.8	2815.2	3099.1	6672.6	1909.7	527.3	493.0	459.4
B753	125.6	139.6	28.6	200.1	111.1	170.3	303.5	364.3	48.7	48.7
B762	202.0	407.9	9.0	71.9	230.0	26.1	0.0	0.0	0.0	
B763	46150.9	50632.7	5463.2	39786.3	50123.7	17556.1	34477.2	39439.7	47890.2	52066.9
B772	0.0	190.3	5.2	66.6	81.0	19.7	145.0	128.2	32969.3	46783.1
B773	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	207.1	141.0
B77W	0.0	0.0	0.0	0.0	0.0	19.1	0.0	65.2	0.0	
BA11	3329.8	1579.6	141.4	567.2	380.2	256.3	226.7	205.3	893.9	567.1
BE20	93.6	91.7	108.5	77.5	82.5	26.0	39.5	45.1	16.8	13.6
C130	6691.0	6485.1	1122.1	5700.7	5441.2	1378.5	772.1	837.8	959.4	500.1
C550	747.3	934.8	1153.2	1167.0	1567.0	1104.8	452.8	404.8	390.7	305.0
CRJ1	393.7	345.6	56.2	140.5	119.1	79.6	68.9	86.6	43.2	

Aircraft type	2007	2008	2009	2010	2011	2014	2016	2017	2018	2019
CRJ2	3887.6	3248.4	1299.8	2744.5	2516.8	1317.7	604.1	585.6	532.0	399.3
CRJ9	1917.0	3185.8	1346.3	3928.3	2278.8	1848.3	2084.9	2821.7	3709.6	1888.3
D228	75.8	18.2	103.6	99.4	52.6	6.2	4.2	2.1	2.7	0.8
D328	11.0	8.1	4.7	10.0	7.0	0.0	2.2	5.9	0.0	
DC85	0.0	0.0	3.5	22.6	76.3	0.0	0.0	0.0	0.0	
DC87	575.0	503.1	44.3	334.8	236.7	50.6	11.0	0.0	0.0	
DC94	16068.3	8413.9	837.5	5088.8	316.9	28.0	29.4	12.1	0.0	
DH8A	0.0	7.4	4.2	11.2	30.0	0.0	0.0	0.0	0.0	
DH8C	0.0	2.0	0.6	2.0	0.0	0.0	0.0	0.0	0.0	
DH8D	650.3	581.5	211.9	871.7	3173.6	2508.9	2151.1	3745.4	4191.3	4501.4
DHC8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.4	
E120	57.7	31.9	40.5	190.2	232.6	450.2	0.0	0.0	0.0	
E145	3717.8	6435.1	6905.7	14517.9	13791.4	5773.5	4884.5	4228.4	4537.0	4417.0
E170	1041.1	1157.0	504.7	1635.5	1943.6	2575.6	3182.0	3952.4	1469.5	1281.1
E175	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2539.5	2810.0
E190	14.9	461.4	1733.5	5944.6	5345.8	15844.9	16846.4	19648.9	20687.3	25163.0
F100	5231.9	6431.2	2696.5	10789.1	13603.7	8133.5	4971.1	2698.0	1717.2	924.4
F27	0.0	0.0	10.3	25.0	0.0	0.0	0.0	0.0	0.0	
F28	570.8	500.0	137.1	475.3	663.6	504.1	409.4	572.2	913.3	708.9
F2TH	6356.1	6245.1	3714.0	5734.2	6358.2	4275.4	3220.8	3210.1	3080.7	3066.9
F50	824.8	570.2	3.6	9.4	6.5	0.0	0.0	0.0	0.0	
JS31	0.6	0.0	1.4	1.2	0.0	0.0	0.0	0.0	0.0	
MD11	0.0	0.0	1.7	19.6	0.0	21.8	0.0	0.0	0.0	
MD82	10434.0	12217.4	1411.5	7395.3	5319.0	158.0	25.7	63.6	3816.2	5308.1
MD83	3541.5	2840.7	187.2	1041.5	2307.8	3050.4	5558.0	11823.7	9980.6	4781.8
PAY3	62.0	49.8	109.4	50.9	51.2	62.4	23.5	20.2	67.3	
RJ85	127.9	24.2	12.7	50.0	1834.1	998.7	1040.4	632.4	0.0	58.5
SB20	604.0	1489.4	395.6	917.8	596.9	0.0	0.0	0.0	0.0	
SF34	289.5	392.2	237.9	347.8	249.3	319.9	297.7	295.6	279.6	284.0
STAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	1.2
SH36	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
SW4	27.2	19.5	21.9	21.5	17.6	0.0	1.6	0.7	3.0	3.5
TBM8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.5
T134	11275.2	2709.5	44.6	228.8	330.9	27.1	0.0	0.0	0.0	
T154	15991.2	15007.4	202.3	1718.4	1679.5	32.7	0.0	0.0	0.0	
TOTAL:	**317096**	**341187**	**75927**	**324262**	**376287**	**300882**	**313498**	**389184**	**487113**	**545257**

Annex 3. Flight statistics of domestic and international aviation of Ukraine in 2020

Table A 3.1. Flight statistics of domestic aviation of Ukraine in 2020 [8].

Aircraft IcaoId (Typical model)	Number of flights	Fuel consumption. kg	Distance. km
ATR72	54	43421	10073
B737-100	13	15508	3053
B737-400	1958	5571862	997011
B747-100-300	11	74558	3398
B767-300	2	11596	1092
BAC111	140	289130	65905
Beech	74	19247	25874
Beech*0.5	2	400	1024
Cassna	892	681301	420177
CRJ145	7	8671	4152
DHC8	3689	6518863	1751094
F100	3999	5666317	1861406
F28	79	161134	37266
A320	96	260957	42526
TOTAL:		**19322965**	

Table A 3.2. Flight statistics of international aviation of Ukraine in 2020 [8].

Aircraft IcaoId (Typical model)	Number of flights	Fuel consumption. kg	Distance. km
A320	453	2329253	525830
A340	19	289382	32286
ATR72	27	189395	47522
B737-100	450	1411274	300259
B737-400	14804	99383975	28306086
B747-100-300	65	3091008	232355
B747-400	175	4993643	397753
B747-400*1.5	6	555652	31281
B757	295	2958410	539165
B767-300	1068	23429684	3771618
B777	75	1102966	102299
BAC111	91	401472	140787
BAe146	15	78354	20979
Beech	78	53158	81532
Beech*0.5	35	10713	26209
Cassna	1978	4357179	2907074
CRJ145	213	616306	317427
DHC8	1250	6076432	2056303
F100	4438	14626642	5908283
F28	132	848785	330650
MD81	55	527643	127963
A310	96	765249	112537
A320	7158	43253048	11580852
A330	491	6710608	859138
TOTAL:		**218060231**	

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