

**USE OF COMPRESSED NATURAL GAS (CNG) AS MOTOR  
FUEL IN UKRAINE, PROSPECTS AND PROBLEMS**

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## **ABSTRACT**

1. Current status of compressed natural gas (CNG) as motor fuel in Ukraine
2. Optimum regional programs for use of CNG as fuel for motor transport and agricultural machinery shall be based on the national program.
  1. Assessment of needs in converting trucks and tractors to CNG and gas diesel engines;
  2. Selection of the optimum scheme of location of CNG stations (CNGS) in regions;
  3. Development of the optimum location scheme for service centers specialized in conversion of cars, certification of gas-cylinders and diagnostics of CNGS equipment.
3. Creation of the specialized center at Ukrtransgas Affiliated Company for coordination of the Program implementation, development of the legal framework, rendering qualified practical assistance to other agencies specialized in optimal location, design, construction and operation of CNGS.

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## 1. History of compressed natural gas stations in Ukraine

Ukraine is one of the world's leaders in using compressed natural gas (hereinafter — CNG) as motor fuel.

The first domestic refueling stations were built, and the first vehicles were converted to use liquefied petroleum gas back in 1936. In 1937, Ukraine's first compressed natural gas refueling station (CNGS) was commissioned to use gas from Priazovskoie field. Its capacity was 180 cubic meters/hour, enough to refuel nearly 76 gas vehicles (lorries).

After the WW2, mass vehicles conversion continued. In 1946, motor race Berlin-Kyiv-Moscow featured virtually all vehicle types ranging from 0.5l midgets to 7.4l hundred-seat buses. The rout of 2,603 km was covered over 14 days (including 11 days of actual races) by 18 vehicles that included 5 using compressed natural gas and 13 — using liquefied petroleum gas.

In 1949-1953, compressed natural gas vehicles (NGVs) were designed and launched into production. A network of nearly 30 CNGSs was set up for these vehicles. The CNGSs used 3- and 4-stage compressors and filled various types of trucks.

## 2. Status of CNGSs in Ukraine

### 2.1. Pre-conditions of CNGSs in Ukraine

Petroleum crisis of the 1970s emphasized the issue of NGVs once again. It became clear that oil reserves were not as large as expected, and that an alternative to liquid fuels was required. On the other hand, large gas reserves were discovered. Thus, the early 1980s gave a start to another era in CNGSs development.

Current stage of conversion of vehicles to use CNG started in 1991, when "CNGSs 500" was designed and constructed by PivdenNII diprogaz. The project underwent long-term modification, and finally it was taken as a basis for 250 stations (in USSR). Until now, it is the core producer in CIS states. Later on, Frunze R&D Company, Sumy, joined the project, and in 1986, they produced the first block and container stations (CNGS-250).

The first standard range of CNGSs was proposed more than 20 years ago: 500, 250, 125 and 75 fillings per day, for lorries only. Domestic and foreign experience demonstrated expediency of the range broadening in order to include "small" stations — from individual CNGSs per one vehicle, and further on, to 10, 20, 40...50 fillings.

CNGS range of 1...500 fillings / day, in its turn, includes the standard range of compressor units having the input pressure range 0,1...0,4; 0,4...0,6; 0,6...1,2; 1,2...3,5(5) MPa and discharge pressure of 25 (32) MPa.

Use of standard capacities would allow formulation of general requirements to any station. At the same time, any further improvements in CNGSs would depend on perfection of each individual sub-system and implementation of new effective decisions.

Marketing studies demonstrate that demand for new stations may be distributed as follows in the feasible future: 70% — CNGSs having capacity of 10...100 fillings; 20% — from 100 to 300 fillings; 10% — more than 300 fillings per day.

### 2.2. Ukraine - the leader in use of CNG as motor fuel

Today Ukraine is the leader in use of CNG as motor fuel due to the well-developed CNGS network of Ukrtransgas Affiliated Company (Fig. 1) and high-professional engineers. For a long time, Ukraine has been ranked first among CNGS networks of CIS states. It enjoys sound positions in international market (Fig 2).

Operation of the Ukrainian CNGS network was highly appreciated by the European Natural Gas Vehicle Association (ENGVA) at the international symposium in Kyiv. The symposium started with the motor race Roma—Kyiv. Participants of the race covered more than 10,000 kilometers, rode through many European states and arrived in Kyiv, Ukraine. 50 vehicles covered the distance from Uzhgorod to Kyiv, using natural gas as motor fuel. Participants of the Roma – Kyiv motor race highly appreciated gas quality and services rendered at the Ukrainian CNGS.

IX<sup>th</sup> meeting of the Section on Compressed Gas Use as Motor Fuel under the International Oil and Gas Council of CIS States took place in Kyiv on June 1 -3, 2004. Then, Ukraine confirmed its status as the leader in compressed gas production and use as motor fuel. According to the *Gas Vehicles Report (June 2005)*, Ukraine is ranked among top ten countries by use of CNG as motor fuel, and holds the 8<sup>th</sup> position (Fig. 2) by the number of NGVs and the 14<sup>th</sup> place — by the number of CNGSs in the world.

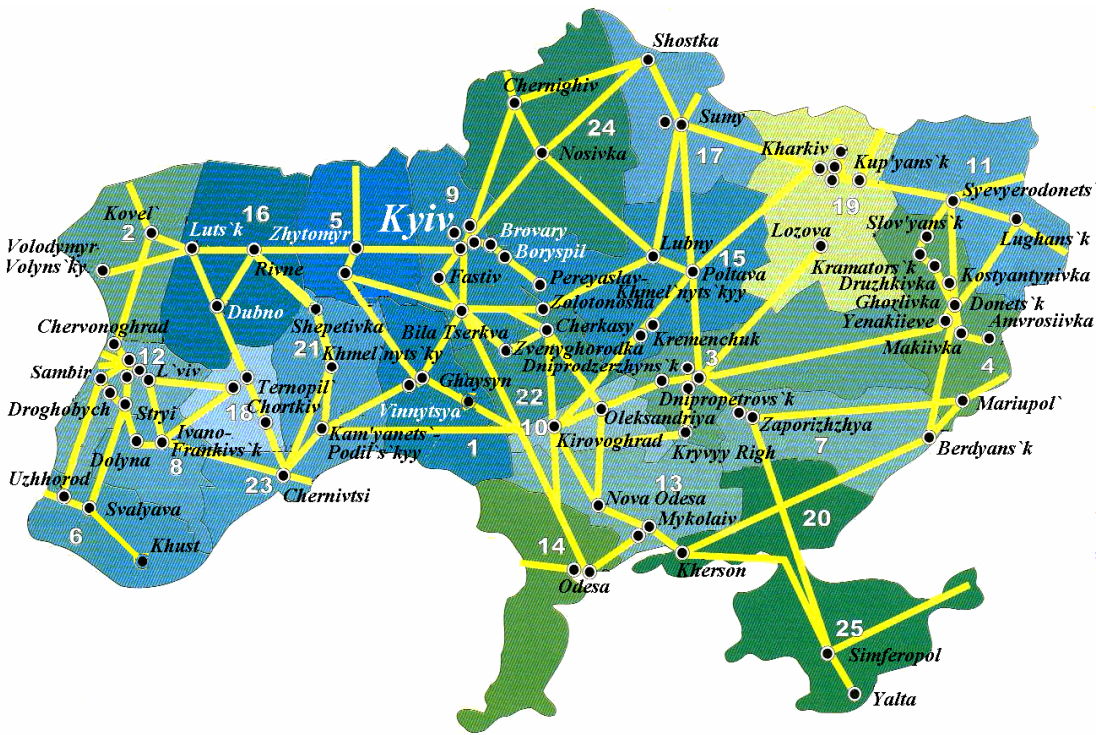
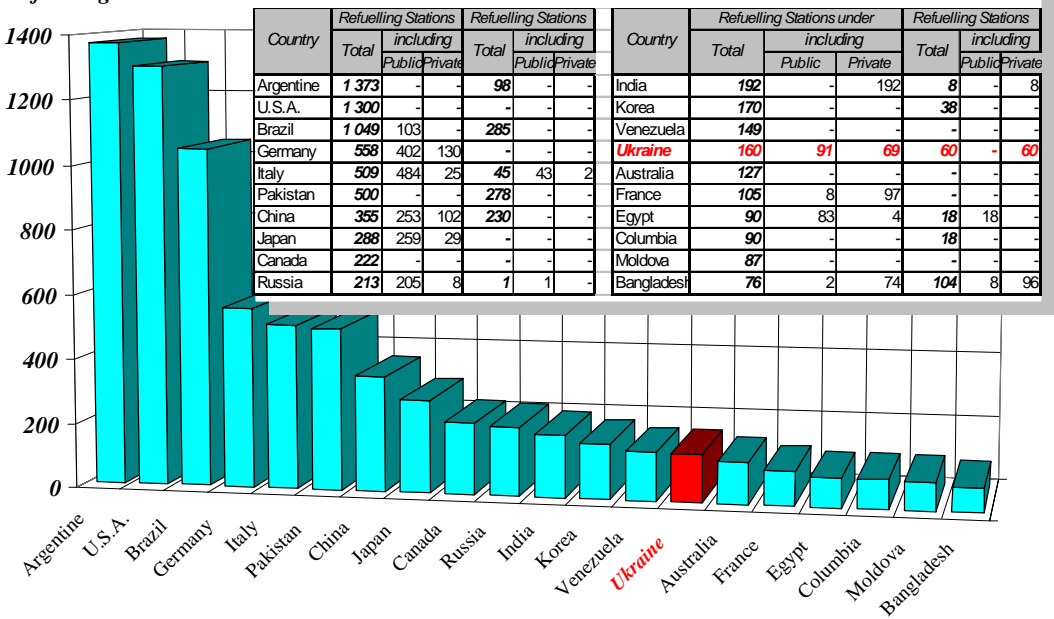


Figure 1 CNGS network of Ukrtransgas and its relations with foreign CNGS networks

Refuelling Stations



## Natural Gas Vehicles

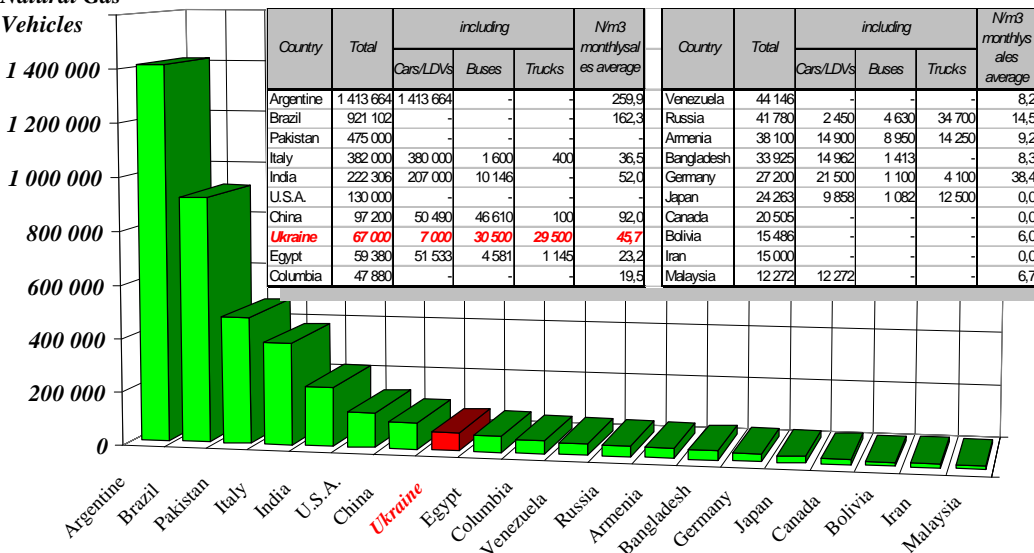


Figure 2 Number of refueling stations and NGVs in different countries

CNGS network of Ukrtransgas (89 CNGSs) can fill up to 100,000 vehicles with CNG instead of 631,000 tons of liquid transportation fuel. Now, up to 70,000 vehicles use CNG as motor fuel in Ukraine.

### 3. General approaches to foundation of CNGSs in Ukraine

#### 3.1. Compressors

All CNGSs manufactured in Ukraine use compressor units of the main producers: Frunze R&D Company, Sumy, and Open Joint Stock Company Uralcompressormash: 4GM2,5, 3GSH1,6 and 6GSH1,6 ("air"-type version 6VSH1,6):

- 4GM2,5 – manufactured by Frunze R&D Company, Sumy, Ukraine; specialized gas four-act, opposed, crosshead compressor, driving force 2.5 tons, the overhaul life — 34,560 hours;
- 3GSH1,6 – manufactured by Frunze R&D Company, Sumy, Ukraine, and Open Joint Stock Company Uralcompressormash, Russia; specialized gas, three-act, W-type, crosshead compressor, driving force 1.6 tons; the overhaul life — 34,560 hours;
- 6GSH1,6 (6VSH1,6) – manufactured by Frunze R&D Company, Sumy, Ukraine, and Open Joint Stock Company Uralcompressormash, Russia; specialized gas (adapted to natural gas) three-act, W-type, crosshead compressor, driving force 1.6 tons; the overhaul life — 13,000 hours.

Compressor units built on their basis demonstrate high effectiveness in terms of specific power consumption and low price levels as compared with foreign analogues. (Figure 3 and Table 1).

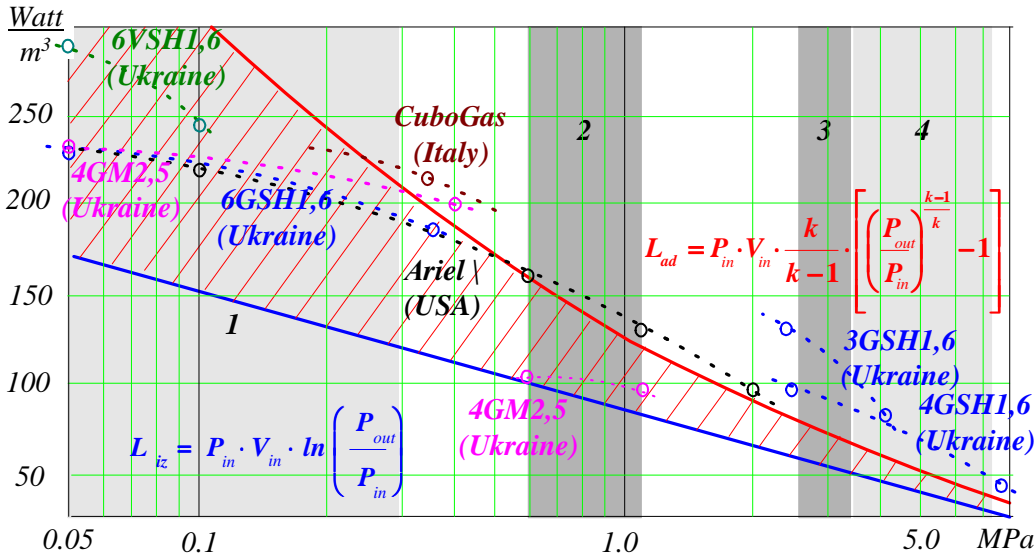


Figure 3 Power consumption for compression of 1 cubic meter of methane per CNGS compressors (up to 200 atmospheres)

One of major characteristics of compressor units' efficiency is the specific power consumption per unit of output – compressed natural gas.

Theoretically, this value should fall within the interval between the line of poly-tropic compression cycle, when all incoming power is used for gas compression (the most effective cycle), and the line of adiabatic compression cycle, when some portion of energy dissipates as heat.

It is impossible to consume less power for consumption, as required for the isothermal cycle, and it is inexpedient to consume more power, when required for the poly-tropic cycle.

Possible working pressures of CNGSs may be divided into four major ranges:

1. – 0,5...3,0 atmospheres (0,05...0,3 MPa) – city natural gas distribution network;
2. – 0,6...12,0 atmospheres (0,06...1,2 MPa) – medium pressure networks;
3. – 25,0...55,0 atmospheres (2,5...5,5 MPa) – gas mains and branch pipeline.
4. up to 75,0 atmospheres (2,5...5,5 and up to 7,5 MPa) – gas mains and branch pipeline.

Operations in the first category are the most profitable ones. Power inputs exceed 150 W/m<sup>3</sup>. In this category, the major specialized gas compressors are “hold together” — from 210...230 W/m<sup>3</sup> at 0,5 atmospheres and to 180...200 W/m<sup>3</sup> at 3,0 atmospheres.

CNGS Manufacturer	Fillings /day	Incoming pressure, atmospheres	Compressor stations, pcs	Compressor unit	Gas dehydration unit (working pressure, sorbent, moisture content g/m3)	Recommended number of stations, pcs	Tentative value of the station, x \$1,000	CNGS cost / production ratio, \$/m <sup>3</sup>
Frunze R&D Company, Sumy	75	0,5-6	2	6GSH1,6	200-250 atmosphere s, silica gel, <0,009	2	190	42,2
	40	0,5-6	1			1	130	54,2
	50	25-75	1	4GSH1,6		1	76	25,3
	250	6-12	2	4GM2,5		5	250	16,7
	200	0,5-3	2			4	250	20,8
	150	1,5-3	2			3	250	27,8
	125	1,5-3	2			2	250	33,3
JSC VEK Sumygasmas, Sumy	45	0,5-2	1	3GSH1,6	200-250 atmosphere s, silica gel, <0,009	1	125	46,3
	60	0,5-2	1			2	130	36,1
	75	0,5-2	1			2	140	31,1
	150	20-80	2			3	-	-

<b>CNGS Manufacturer</b>	<b>Fillings /day</b>	<b>Incoming pressure, atmospheres</b>	<b>Compressor stations, pcs</b>	<b>Compressor unit</b>	<b>Gas dehydration unit (working pressure, sorbent, moisture content g/m<sup>3</sup>)</b>	<b>Recommended number of stations, pcs</b>	<b>Tentative value of the station, x \$1,000</b>	<b>CNGS cost / production ratio, \$/m<sup>3</sup></b>
	200	5-11		6VSH1,6		4	170	14,2
	400	24-42	1			6	165	6,9
	40	1-6	1			1	93	38,8
<b>Gas Institute of the National Academy of Sciences of Ukraine</b>	40	1-6	1	6VSH1,6	200-250 atmospheres, silica gel, <0,009	1	75	31,3
<b>Service Gas Ltd., Yevpatoriya</b>	55	0,1-3	1	6VSH1,6	200-250 atmospheres, filter-separator, ~0.030...0.040	1	77,5	23,5
	90	0,1-3	1			2	118,1	21,9
	110	0,1-3	2			3	125,2	19,0
	180	0,1-3	2			4	208	19,3

Table 1 Basic characteristics of CNGSs, manufactured in Ukraine

### 3.2. Gas dehydration units

Adsorbent-based gas dehydration units of CNGS differ in productivity, pressure of adsorption and type of adsorbent (Table 2).

For block and modular stations having capacity of 40 – 125 fillings per day, there are adsorbent-based technologies for prior- and post-compression gas dehydration. For gas dehydration units installed on compressor units, it is recommended to use zeolite, which gives the lowest drop point of dehydrated natural gas and demonstrates the highest water adsorbitivity. At given pressure levels, silica gel absorbs carbohydrates from natural gas. Absorption of carbohydrates and water decreases water dynamical activity of silica gel by 10...20 %. In addition, power consumption at re-generation of adsorbent increase.

For CNGS, where the lubricant-free compressor shall be used, utilization of the energy-saving technology of gas dehydration with silica gel with further regeneration of adsorbent with undrained heated compressed gas is promising. Such technology is utilized for dehydration of natural gas compressed to 25 MPa on CNGS M 45 (Sumy). Presence of compressor lubricant in incoming gas would decrease dynamic activity of silica gel in water and shorten the service life of adsorbent.

Alumina-based dehydration of natural gas is not so popular method due to rapid decrease in water dynamic activity of this adsorbent in multi-cycle operations.

General accumulated experience of zeolite-based dehydration of natural gas compressed to 25 MPa on CNGS shows that zeolites have high adsorbing capacity in water, can adsorb humidity at high temperature, assure high and stable dehydration level, favorable mechanical features and long service life (Figure 4).

Due to high rate of water absorption by zeolite, adsorption occurrence in the thin working layer, which allows manufacturers to reduce content of adsorbents to the lowest level and produce the space-saving stations.

<b>Method of natural gas dehydration</b>	<b>Facility</b>	<b>Manufacturer</b>
<b>Zeolite-based dehydration of natural gas</b>		
Dehydration of natural gas compressed to 25 MPa with further regeneration of adsorbent using throttled flow of natural gas at temperature of 200-250 °C	Gas dehydration unit for CNGS-500, production	R&D Company Kysenmash, Odesa
<b>Silica gel-based technology of natural gas dehydration</b>		
Dehydration of natural gas compressed to 25 MPa with further regeneration of adsorbent using throttled flow of natural gas at temperature of 40-100 °C with utilization of compressed gas heat.	Gas dehydration unit for CNGS-500	R&D Company Kysenmash, Odesa VNIIGas Ltd.
Dehydration of natural gas compressed to 25 MPa with further regeneration of adsorbent using high pressure undried gas (25 MPa) at temperature of 120-140°C	Gas dehydration unit for CNGS-500	R&D Company Kysenmash, Odesa VNIIGas Ltd.
	Gas filler 3F-1M	Experimental Works of VNIIGas Ltd.



<b>Method of natural gas dehydration</b>	<b>Facility</b>	<b>Manufacturer</b>
	Gas dehydration unit for CNGS M 45	KNPP Ecotranspal, Sumy
Dehydration of natural gas compressed to 25 MPa with further regeneration of adsorbent using throttled flow of dried gas at temperature of 90 °C	Gas dehydration unit for CNGS БКИ-250	I.Frunze R&D Company, Sumy
	Gas dehydration unit for CNGS МБКИ- 125	I.Frunze R&D Company, Sumy

Table 2. Main types of dehydration units for CNGS

Major benefits of silica gel-based dehydration of natural gas compressed to 25 MPa, are low expenditures for re-generation of adsorbent, as compared with zeolite. In addition, using silica gel for absorption of moisture under pressure of 18-25 MPa almost excludes absorption of heavy hydrocarbon from gas; so, moisture is absorbed more effectively. Lower power inputs are required for re-generation of silica gel as compared with zeonite; however, silica gel is less dynamic in water then zeonite, which decreases the adsorption cycle and increases the number of regeneration cycles. Increase in switches from the dehydration cycle to regeneration and vice versa, results in shortening the service live of adsorbent because of pulverization. It should be noted that silica gel demonstrates the best operational qualities if moisture content of incoming gas equals to the equilibrium one, and if there is no condensed moisture and compressor oil in gas.

Practical experience of CNGSs operation demonstrated that of the core requirements should be increased safety and compactness of a station. Thus, when designing city and municipal "garage"-type stations, the challenge of creation of space-saving gas dehydration unit and the station should be solved.

Before, there were no strict regulations as to dimensions of adsorbent-based gas dehydration units at CNGS-500 and CNGS-250. At CNGS-500, dimensions of a dehydration unit were 3 x 2 x 4 m, and at CNGS-250, a dehydration unit was placed into the container having dimensions of 5 x 3 x 3.6 m. Major requirements to design were operational reliability and serviceability.

Prior experience of design of adsorbent-based gas dehydration units proves that unit's dimensions remain almost unchanged at decreasing capacity of a gas dehydration unit. Thus, if capacity of the natural gas dehydration units drops from 4000 m<sup>3</sup>/h to 450 m<sup>3</sup>/h, that is in nine times, the unit's volume decreases in five times, and dimensions — in 1.5 – 2 times only. It is due to the following. The main component of a dehydration unit — adsorber — losses its volume; however, the set of machinery required (separators, filters, electro heaters, heat exchangers) remains the same, and dimensions of such devices decrease by negligible value. In addition, it should be noted that equipment stands for ~ 40 % of the space; the remaining volume falls at pipes and fittings. Gas pipes and locking and regulating fittings take so much volume because of the limited bending radius of steel pipes and bulky electric lines and accessories. Qualified composing and joining of gas lines allows reduction of the unit's dimensions by 10...20 %. Such contraction is achieved due to high professional level of designers, utilization of compact equipment and fittings, and, partly, because of impaired serviceability.

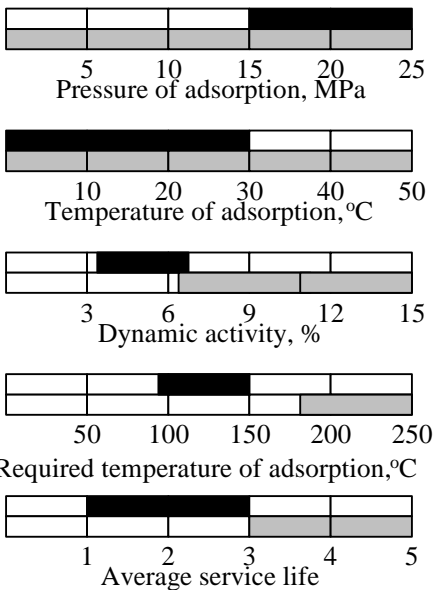


Figure 4. Applicability limits and features of adsorbents, used for gas dehydration at CNGS

■ - silica gel    □ - zeolite

### 3.3. Gas accumulation

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Gas accumulation allows increase in CNGS productivity in rush hours. Pressure in accumulators is within 205...245 atmospheres. Derivative of the pressure differences by geometric volume of an accumulator gives gas active volume — volume to be used for filling vehicles.

Thus, if geometric volume is 1 m<sup>3</sup>, active gas volume shall be about 40 m<sup>3</sup> — it is sufficient for filling 1...2 passenger cars or one taxi bus.

The bigger an accumulator is, the more stable and uniform feeding of the compressor and work of refueling stations shall be.

On the contrary, absence or small volume of gas accumulators shall cause interruptions in work of the compressors — frequent starts and discharges, leading to breakdown thereof.

Especially it deals with CNGSs designed for filling 250-500 vehicles and equipped with 6-8 refueling stations and one compressor. Significant capacity of the compressor (1500...2000 m<sup>3</sup>/h) and insufficient gas extraction from a refueling station — from 360 m<sup>3</sup>/h (for outdated stations (ET-6, КПГ-1, imported ones) having 4...6-mm cross-section of a gas-filling pipe) and 600 m<sup>3</sup>/h (for modern stations (K3M-200) having 10-mm cross-section of a gas-filling pipe) would require simultaneous filling up to 5...80 vehicles, or frequent (once every 1-2 minutes) stopping of the compressor unit.

At CNGSs of Ukrtransgas with output capacity of 500 fillings per day, geometric gas accumulator volume is 18 m<sup>3</sup>, that is active gas volume is less than 720 m<sup>3</sup>, which improves the filling procedures greatly (lack of forced outages of refueling stations in rush hours because of insufficient capacity of a compressor) and increases life time of the compressor.

### 3.4. Automated control system of compressor units and CNGS

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Although technological procedures at CNGSs are rather simple, and “garage”-type CNGSs may do with integrated automatics of the compressor unit, when more than one compressor unit is used within a CNGS, the station automated devices should be installed.

Station automated devices shall not only assure the filling procedures (maintain relevant pressure on refueling stations) and control the operational conditions in the compressor block, but also “distribute” load among compressors for uniform working out and performance of planned maintenance. The latter allows selling compressed natural gas from CNGS on a 24/7/365 basis irrespective of the compressor status, preventive checks and maintenance.

Vibration diagnostic equipment, methods of assessment of technical conditions of the compressor units using vibration and operational characteristics, designed at Ukrtransgas, shall assure the most progressive standards of technical maintenance of CNGSs — based on technical status and control of the parameter levels and the reliability level — if incorporated into the technological control procedures.

In the future, small CNGSs designed for 10, 20, 50 and partly 75 fillings, shall be fully automated touch control units, and starting from 20...40 fillings, they shall operate on a magnetic card with no manual operations involved (except for a cashier's desk). Automated CNGSs should be integrated into multifunction stations or individual fleets.

CNGSs having capacity level of 75 and more fillings per day, may employ the minimum number of permanent workers; although, requirements to the automation level should be respectively decreased then. In current situation, value of one ACS channel should not exceed \$30. And the system value shall be 10...15% of the total value of CNGS at the most.

## 4. Expansion of the motor transport park

Many states have been balancing priorities in CNGS networks development and expansion of the compressed natural gas vehicles park (NGV) for a long time. Lack of NGVs impedes CNGS development and vice versa. At the same time, experience shows that the both processes shall be well balanced and coincident.

<b>Penalties:</b>	Great Britain — fee for entering the downtown of London is collected from all cars except for gas vehicles
<b>Restrictions:</b>	Italy — on certain days, only gas vehicles may go to the downtown of Milan. USA — gas vehicles (with or without passengers) may go by lines reserved for taxi buses (if there are passengers in) and buses
<b>Prohibitions:</b>	Japan, Italy — in some cities, diesel-powered vehicles are prohibited. Pakistan considers possibility of imposing a ban on use of diesel-powered buses in cities.
<b>Laws and regulations:</b>	USA — when purchasing new cars, governmental enterprises and agencies should procure the certain number of gas vehicles.
<b>Budgetary financing:</b>	Japan — the State Budget of Japan for FY 2002 allocated US \$159 million for CNGSs construction and procurement of serial NGV

Table 3. Examples of compulsory measures and incentives used in different countries

Experience shows that the payback period for CNGSs construction and simultaneous conversion to NGV is 4-6 years.

German specialists have calculated the optimum distance between CNGSs for regions with various density of population. In cities, refueling stations shall be located in 10-15 kilometers from each other, and in rural regions — at a distance of 20 – 25 kilometers.

Individual refueling compressor units (GFCU) are gaining popularity. They may be used for slow filling of corporate vehicles at night, or for personal cars in garages.

The International Natural Gas Vehicle Association informs that there are more than 4,000 GFCUs in the world. The most popular stations are those designed for two cars. Until very recently, average value of one GFCU was about USD 5,000. The recent model of FuelMaker GFCU Phil is available at US \$999. A GFCU' service cycle is 4,000 hours. Power consumption is 0.33-0.40 kW x h x /m<sup>3</sup>. Improved consumer features of GFCUs expand economic benefits from use of natural gas as motor fuel for private car owners.

## 5. Final provisions

To increase the use of compressed natural gas as motor fuel in Ukraine, Ukrtransgas shall focus on the following:

1. Conversion of 40,000 vehicles to NGV within the next 1-2 years.
2. Provision of the state regulation of the purchase price for compressed natural gas on the level, allowing CNGSs to preserve the sale price beyond 50 % price for A-76 gasoline, with due regard to the operational cost, like other countries do;
3. Approval of the Governmental Program and individual regional programs, with due regard to specific conditions of regions, for use of natural gas as motor fuel for motor vehicles in Ukraine for the period until 2010, based on experience CNGS network of Ukrtransgas;
4. Development of the regional programs for natural gas use as motor fuel; coordination with and approval by local executive authorities; which programs should entrust entities concerned with relevant tasks.
5. Regional programs should provide for:
  6. analysis of demand of agricultural enterprises of the region (oblast, rayon) in converting lorries, tractors T-150K and K-700, 701 to gas diesel cycle (diesel oil and CNG);
  7. optimum location of CNGSs in regions;
  8. allocation of land plots for construction of CNGSs.
  9. Adoption of the Law On State Policy of Natural Gas Use as Motor Fuel by the Parliament;
  10. Creation of the specialized center at Ukrtransgas for coordination of the Program implementation, development of legal framework, control over construction of CNGSs. The Cabinet of Ministers of Ukraine should approve the Regulations on the Center.

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