

Overview on oil and gas in Croatia

Introduction

Republic of Croatia has a long tradition in production and processing of oil and gas. Despite a small production of hydrocarbons and growing import, obtained know how enables the development of future Oil and Gas strategies after expiration of currently still active oil and gas fields.

To ensure further development of the Oil and Gas industry, it will be necessary to invest into further Research and Development activities especially in the Adriatic Sea. Other regions, such as the Dinarides have perspective too for the reason of being substantially underexplored. There are lots of opportunity to increase existing reserves and production of hydrocarbons in the Pannonian Basin.

Oil and Gas refineries and Gas processing plants play an important role in processing of hydrocarbons and convert them into more valuable products. Active Gas storages provide the basis for equalizing distribution of gas within the country.

This paper is meant to give a short overview about the traditional and present production assets of oil and gas in the Republic of Croatia, as well as about the oil and gas processing and gas storage infrastructure.

Production, refining and distribution of Oil and Gas in Croatia

All exploration activities in Croatia are led by national oil company INA JSC, a medium-sized European oil company with a leading role in Croatian oil business and a strong position in the region. INA Group is comprised of several companies completely or partially owned by INA JSC.

INA was established on January 1, 1964 through the merger of Naftaplin (company for oil and gas exploration and production) with the refineries in Rijeka and Sisak.

Beside production and refining, INA JSC manages a regional network of 495 petrol stations in Croatia and neighboring countries (URL1).

INA (including previous Naftaplin) has carried out systematic hydrocarbon exploration in Croatia since 1952, and up to 2014 resulted in the discovery of 57 onshore oil and gas fields and 17 offshore gas fields, i.e. 1.4 billion boe (barrel of oil equivalents) of hydrocarbon reserves of which 1.2 billion boe was recovered (Cota et al, 2014).

Oil and gas regions in Croatia

In a petroleum geology sense, Republic of Croatia is divided into three regions: 1 Panonian Basin, 2 Dinarides and 3 Adriatic (Figure 1).

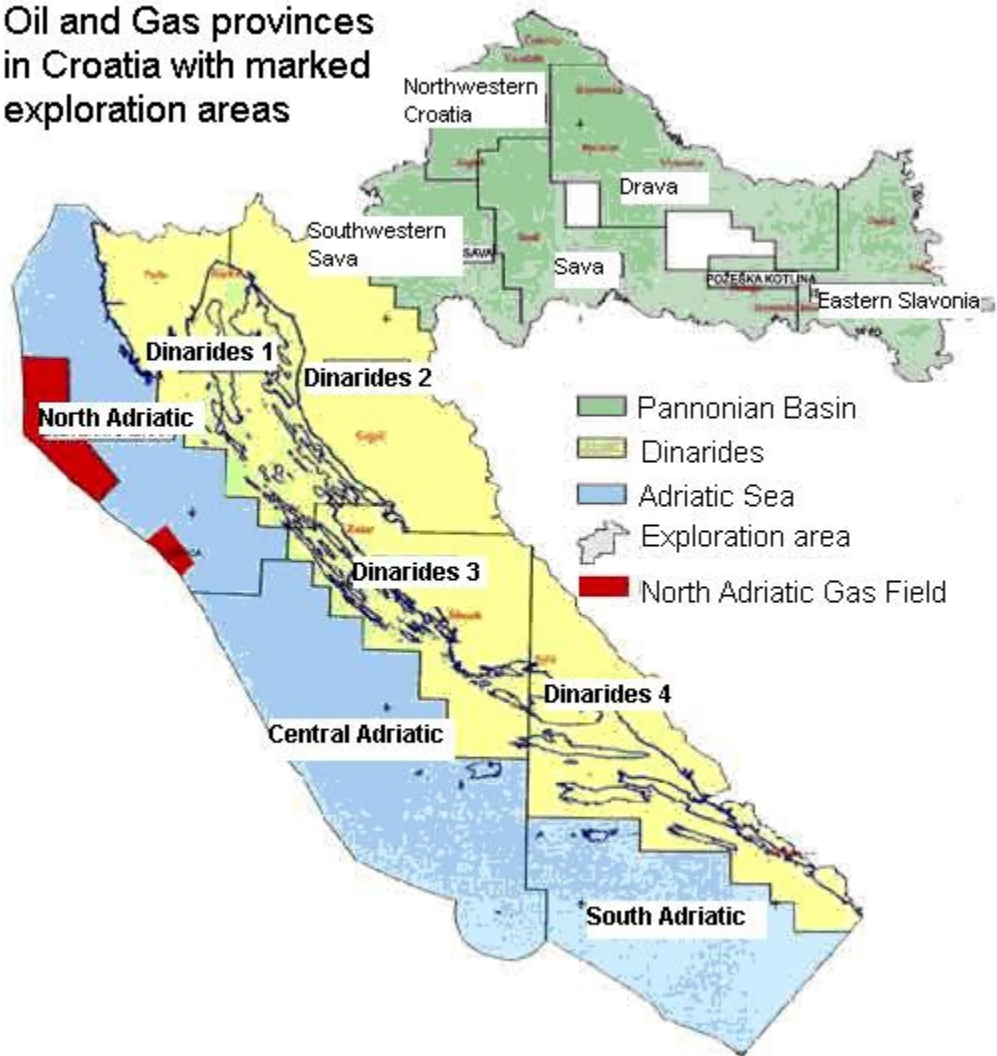


Figure 1 Oil and Gas provinces in Croatia with marked exploration areas (Modified after: URL 2)

The Pannonian Basin

The Pannonian Basin is placed in Central Europe, and covers whole Hungary and parts of Austria, Bosnia and Herzegovina, Croatia, Romania, Serbia, Slovakia, and Slovenia. It is the first region where exploration and exploitation of Oil and Gas in Croatia started in 1844 and lasts until today.

The Croatian part of the Pannonian Basin is divided into four depressions: Drava Depression (Exploration area Drava), Mura Depression (Exploration area Northwestern Croatia), Sava Depression (Exploration areas Sava and Southwestern Sava) and Slavonija - Srijem Depression (Exploration area Eastern Slavonia). Oil and Gas reservoirs along with source rocks are placed in neogene complex, which is divided into formations. Each Depression has its own division (Table 1). Dominated lithology members are sandstones and marls, with oil and gas fields, formed in sandstone reservoirs from Lower Pannonian to Upper Pontian. And some reservoirs are also placed in eroded rocks of pretertiary complex. Reservoirs are screened lithologically, with marls, or tectonically, by faulting.

Table 1 Lithostratigraphic division of the Croatian part of Pannonian Basin (Modified after INA – Naftaplin, 1988, simplified)

Sava Depression	Drava Depression	Mura Depression	Slavonsko – Srijemska Depression	Electro Log Marker	Stratigraphy unit
Lonja Formation	Lonja Formation		Vuka Formation	a'	Upper and Middle Pliocene and Quaternary
Široko Polje Formation	Bilogora Formation		Vera Formation		Upper Pontian
Kloštar – Ivanić Formation	Kloštar – Ivanić Formation	Lendava Formation	Vinkovci Formation	Rj	Lower Pontian
				Δb	
Ivanić – Grad Formation	Ivanić – Grad Formation			z'	Upper Pannonian
Prkos Formation	Križevci Formation	Murska Sobota Formation	Valpovo Formation	Rs5	Lower Pannonian
Prečec Formation	Mosti Formation		Vukovar Formation	Rs7	Pre Badenian, Badenian, Sarmatian
Tg					
Pretertiary rocks, Mesozoic carbonates, Paleozoic magmatite and metamorphic complex					

The first three oil wells were drilled in the region of Međimurje, which belongs to Mura Depression in 1844, and total yield achieved was 20 kg of crude per day in 1850. This oilfield produced until 1918. The second old oil field in Međimurje area was the Selnica field

in the eastern part of the Mura Depression, which produced from 1850 to 1952. Data on total production in a time period from 1844 to 1952 are not known.

The area of the Moslavina (Sava Depression) had a long tradition of oil exploitation too. From 1854 to 1943 oil was exploited nearby the village Mikleuska. Due to long tradition of oil exploitation Moslavina and Medimurje could be considered as the oldest oil exploitation areas of the world.

Intense activities of research and exploitation in Croatia have lasted for the last 70 years, since 1940ies until today on the territory of the Croatian part of the Pannonian Basin. Hydrocarbons have been extracted from 33 oil fields, gas condensates from 9 gas-condensate fields and gas from 17 gas fields (Figure 2).

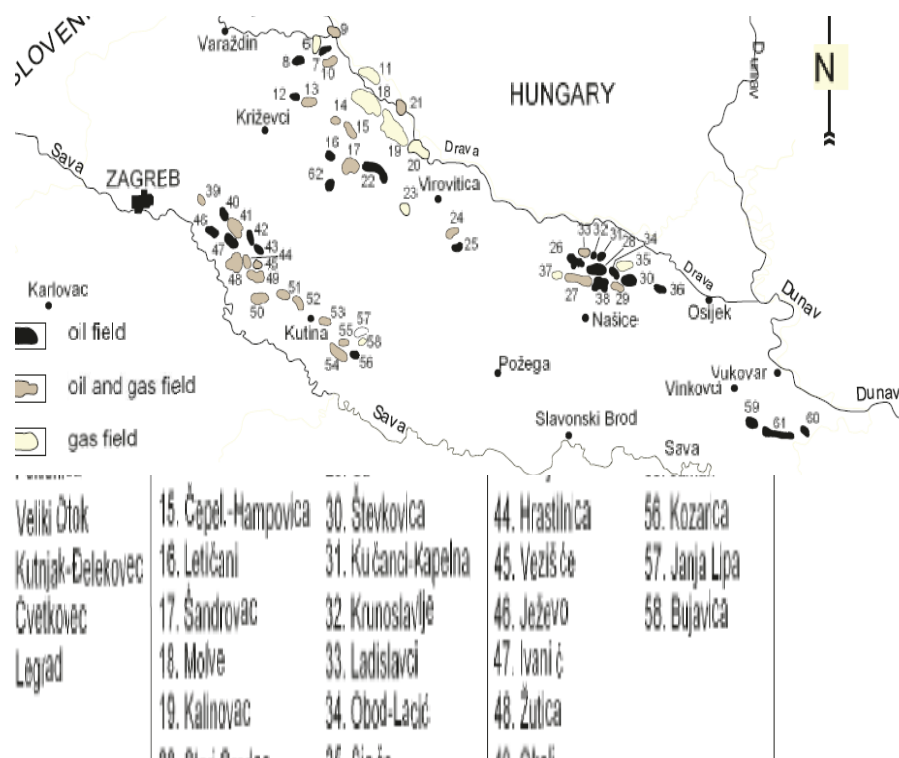


Figure 2 Oil and gas fields in the Croatian part of the Pannonian Basin System (Velić, 2007)

Intensive growth on exploration and production of Oil and Gas in Croatia started in 1952 in the Pannonian basin.

Some of the biggest Oil fields in the Pannonian Basin are: Beničanci, Stružec, Žutica, Šandrovac, Ivanić, Lipovljani, Jamarice, Đeletovci, Jagnjedovac and Bilogora, and some of

the biggest Gas fields in the Pannonian Basin are: Molve, Bokšić, Kalinovac, Stari Gradac and Okoli (Figure 2).

According to the last available data from the Ministry of Economy Republic of Croatia, published in August 2015, at continental part (Pannonian Basin) of the Republic of Croatia there are 54 active oil and gas fields. However, this number is different today since new gas fields were discovered in the north-western part of Croatia: In summer 2016, two new gas fields (Vučkovec, Zebanec) were launched; at the beginning of this year (2017) a third gas field (Vukanovec) was put into production too. According to Croatian national Oil and Gas Company – INA, the commercially recoverable gas reserves amount to roughly 1 billion m³, and expected production life is until 2024.

According to the data base on production, some 92 millions tons of crude, approximately 9 millions tons of condensate and about 60 billion cubic meters of gas were produced on the continental part of the Republic of Croatia (Pannonian Basin) from 1941 to 2015. During this period, more than 3200 boreholes were drilled, where as more than 900 out of them were exploration wells. Peak production of oil was registered in 1981, amounting to 3,140,777 tons. The biggest obtained quantity of gas was 2,176,657,000 cubic meters in 1989. At present days, hydrocarbon production in the Pannonian Basin is about 500,000 tons of crude and condensate, and about 700,000,000 cubic meters of gas per year (Cota et al., 2014).

In order to improve exploitation, secondary methods are implemented. The most common secondary method is water injection, however alternative solutions are explored such as carbon dioxide (CO₂) flooding whereby carbon dioxide is injected into the oil reservoir aiming at an increased output. Tests were conducted in INA's laboratories for fourteen fields (Goričnik & Domitrović, 2003; Novak et al., 2013), It is opportune to mention that some unconventional plays could play their role in the supply of the country (Rusan, 2014). A pilot project of unconventional exploration was undertaken at the end of 2013 continuing into 2014 and beyond (Cota et al., 2014), but results weren't published yet.

However, more investigations and evaluations are mandatory. These plays are relevant in the future reserve planning and acquisition (Velić et al., 2016).

The Dinarides

Dinarides are the mountain chain that elongates from Italy, through Slovenia, Croatia, Bosnia and Herzegovina, Serbia, Montenegro and Albania.

In Croatian part, Dinarides are mostly consists of highly carstified Mesozoic limestones and dolomities.

The Dinarides are still underexplored and considering a number of open professional issues and the demanding terrain, this area is evaluated as being highly risky for further investments. National Oil Company INA considered sharing of exploration risk with potential partners (Cota et al., 2014).

In the Dinarides, just 9 boreholes were drilled to different depths ranging from 700 to 5600 meters in the period from 1959 to 1989. No significant exploration activities haven taken place in the Dinaric part over the last 28 years. There was no proof on existence of hydrocarbons in commercial quantities. Gas was discovered at the Island Brač in 1979 and oil in the Ravni Kotari field in 1966.

The Adriatic Sea

The Adriatic Sea is placed between the Italian and Balkan Peninsula. The Adriatic is the north basin of the Mediterranean and enters deep into the Central European mainland.

Research of the Adriatic offshore has lasted over 40 years, and natural gas extraction has been conducted in North Adriatic Sea since 1999 (Figure 3).

Adriatic Sea represents a most interesting target for further Oil and Gas exploration in Croatia, especially in pre Tertiary carbonates.

The Adriatic Basin is divided in particular depressions of different age. Three depressions are formed in Miocene: Dugi otok, South Adriatic - Albania and Molise. Later, in Pliocene, further subsidence of sea bottom caused the forming of other depressions: Venetto, Po, Marche-Abruzzi, Middle Adriatic, Bradano and Adriatic-Ionian (Prelogović, Kranjec, 1983, Velić, Malvić, 2011) (Figure 3).

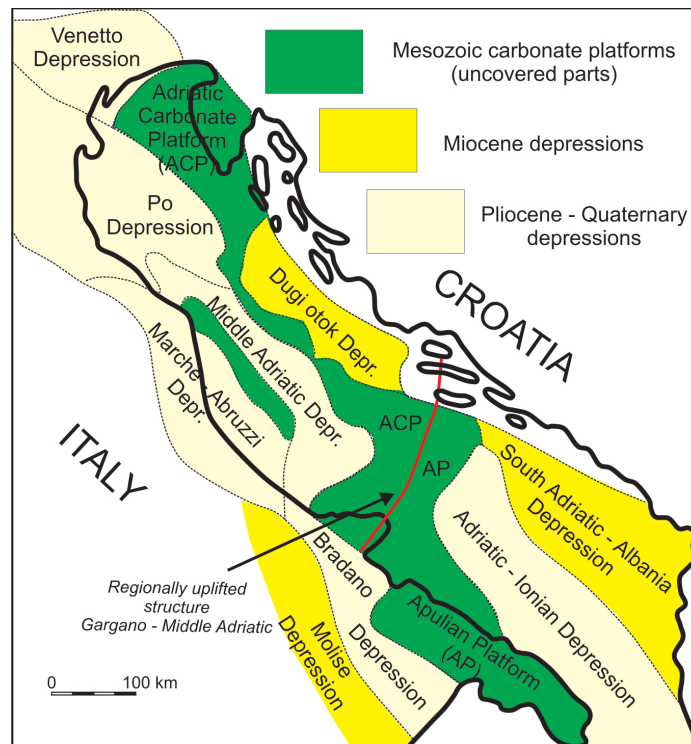


Figure 3 Depression in Adriatic offshore (modified after Prelogović, Kranjec, 1983, from Velić, Malvić, 2011)

The largest depressions are Po and South Adriatic-Albania, but no one has continuous borders and depositional environments through geological past. It is reflected in different sediment thicknesses and areas as well as unconformities among particular lithological units.

Depressions are mostly asymmetrical. Croatian part includes entire the Dugi otok Depression, eastern parts of Po and Middle Adriatic Depressions and northern part of Southern Adriatic-Albania Depression.

The gas in the fields is of biogenic nature, occurring in the shallow Plio Quaternary sands and sandstones of the Po Depression. Production comes from fields Ivana, Ika, Ida, Annamaria, Irina, Ana and Vesna. All these fields are grouped into the ‘North Adriatic’ field group. The gas fields Marica and Katarina are known as ‘Marica’ gas field group (Figure 4).

Croatian nomenclature mostly was based on results obtained with surface exploration of eolian sediments of Susak Island in North Adriatic. This is why Croatian lithostratigraphy includes significantly lower number of lithostratigraphy units. Today valid lithostratigraphy nomenclature of Plio Quaternary sediments in Italian and Croatian parts of Po Depression is given in Table 2.

Since the Cenozoic sediments in the Croatian part of the Po Depression are incorporated in one formation named Susak, this nomenclature is not in use. Since the Italian nomenclature describes Cenozoic sediments more detailed, today is used Italian.

Table 2 Comparison of Croatian and Italian lithostratigraphy nomenclature for rank of formation (After Velić, Malvić, 2011)

Chronostratigraphic units	Lithostratigraphic formations		
	Croatian name	Italian name	
Holocene	Recent sediments		
Pleistocene	Susak	Ravenna	Ravenna
		Carola	Santerno
Pliocene	Susak	Porto Garibaldi	Santerno
		Corsini (In Italian part only)	
		Canopo (In Italian part only)	
		Santerno	

Now, 15 platforms are active in the ‘North Adriatic’ gas field group, 14 of them produce with natural drive, on one compression facilities are being installed. The Gas field ‘Marica’ is being produced from two platforms (**Table 3**). The maximum annual production of gas was achieved between 2007 and 2010 and it reached a total production of about 1.8 billion cubic meters of gas. Another significant production peaked, significantly lower than maximum, was in 2012 and it reached approximately 1.1 billion cubic meters of gas. Since then, it continuously decreases. In a do nothing case, gas field production should last until 2040 (**Figure 5**).



Figure 4 Gas field sites in the Adriatic offshore (Velić, 2007)

Table 3 Gas Rigs on producing field groups North Adriatic and Marica (ECOINA Ltd, 2013)

Number	Name	Purpose	Type	Number of boreholes
Gas exploitation field "North Adriatic"				
1	Ivana K	Compressor	Tetrapod	-
2	Ivana A	Production	Tetrapod	5
3	Ivana B	Production	Tripod	3
4	Ivana C	Production	Monopod	1
5	Ivana D	Production	Monopod	1
6	Ivana E	Production	Tripod	3
7	Ida A	Production	Monopod	1
8	Ida B	Production	Monopod	2
9	Ida C	Production	Monopod	3
10	Ika A	Production	Tetrapod	3
11	Ika B	Production	Monopod	3

12	Annamaria A	Production	Tetrapod	5
13	Irina	Production	Monopod	2
14	Ana	Proizvodna	Monopod	2
15	Vesna	Proizvodna	Monopod	1
Gas exploitation field "Marica"				
16	Marica	Production	Tetrapod	3
17	Katarina	Production	Tetrapod	3

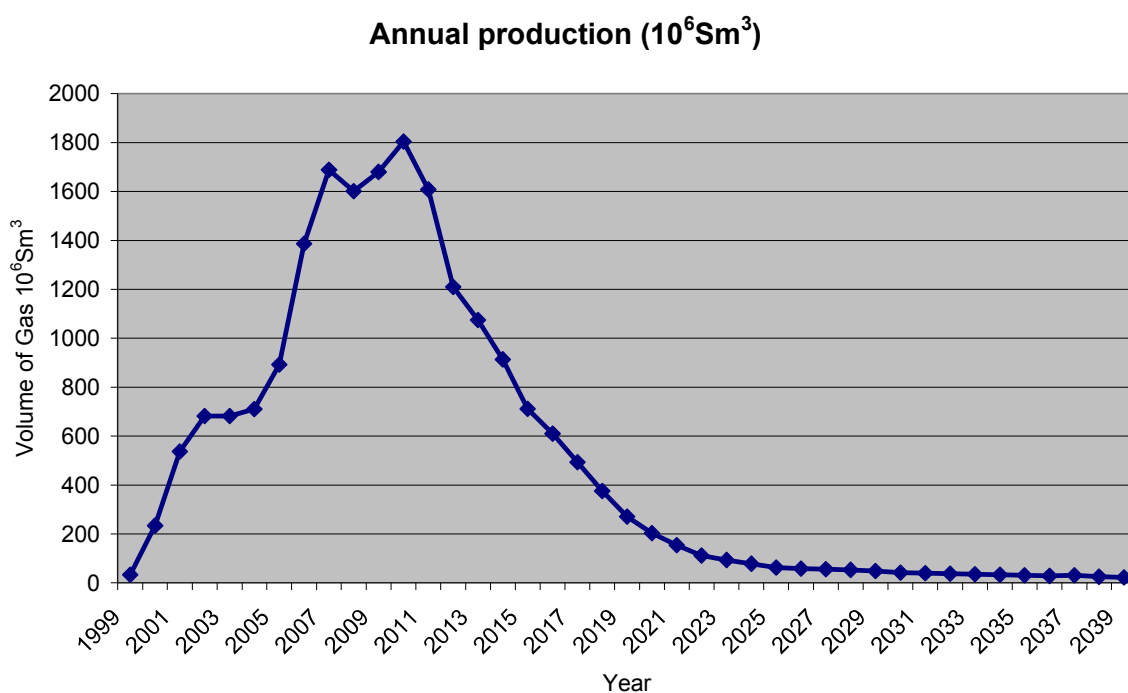


Figure 5 Production forecast of the North Adriatic gas fields, modified after ECOINA, 2009, 2013.

Processing of oil and gas

Processing of crude in Croatia takes place in the Rijeka Oil and Sisak Oil refineries, as well as in the facility of Maziva, Zagreb, and Lube Refinery. Gas is being processed in Molve and Gas Fractionation Ivanic Grad.

The Rijeka oil refinery is a complex refinery with total processing capacity of 5 million tons of crude per year. Current annual performance ranges between 2 – 3 million of tons of crude.

The Sisak oil refinery is a refinery with deep cracking and a total capacity of 4 million tons of crude per year. It annually refines about 650,000 tons of crude.

Consequently, total annual amount of refined crude ranges approximately between 2.5 – 3.5 million of tons of crude. Considering the total production of crude in Croatia, which amounts to approximately 600,000 tons per year, the refineries process about 20% of Croatian oil and 80% of imported oil.

The Lube refinery in Zagreb, with an annual production of up to 16 million tons, produces lubricants by mixing of different oils. The gas processing facilities in Molve annually processes about 800,000,000 cubic meters of gas. The final product is 500,000,000 cubic meters of methane for further distribution, 30,000 tons of condensate, 55,000 tons of C₃₊, further processed at the gas fractionation Ivanic Grad. 120,000,000 tons of CO₂ extracted from gas is transferred toward the existing older oil fields for Enhanced Oil Recovery.

Underground gas storages

Like anywhere else, natural gas is an important energy carrier in the Republic of Croatia, in industry and households. In 2009, domestic production of natural gas covered about 60% of the needs, and another 40% was imported. Total amount of produced natural gas reached $2,892.1 \times 10^6 \text{ Sm}^3$ in 2007. It dropped to $2,013.1 \times 10^6 \text{ Sm}^3$ in 2012. Respectively, import of natural gas amounted to $1,055.1 \times 10^6 \text{ Sm}^3$ in 2007, and in 2012 it raised to $1,357.7 \times 10^6 \text{ Sm}^3$. This demonstrates the ongoing trend of production decrease versus growing import requirement. In order to harmonise the distribution needs, the underground gas storage in Okoli plays a significant role in Croatian Gas Management (ECOINA, 2015).

In 1987, the Underground Gas Storage Okoli was set up in the reservoir rocks of the lower Pontian sandstones within the Kloštar Ivanić Formation, a former gas field. Maximum storage capacity of the Underground Gas Storage Okoli is $553 \times 10^6 \text{ Sm}^3$, at a maximum

capacity of injection / production between 160,000 Sm³/h and 180,000 Sm³/h. During the peak of heating season (December, January), a high production rate was normally applied. Since this caused some danger for the dynamic gas flow within the reservoir, decision was made to open a new one peak load Underground Gas Storage as a backup. Capacity of the peak load storage should be in the range of 50 – 60 x10⁶ m³ in order to enable its filling during several days, but big enough to be support for the main Underground Gas Storage during critical weeks. Expected capacity of injection / production is between 70,000 and 100,000 m³/h (ECOINA 2017).

Underground gas storage in Okoli is led by separate company Underground gas storage Ltd (In Croatian: Podzemno skladište plina d.o.o.), under the Plinacro Group national distributor of natural gas (URL 3).

Conclusion

The Republic of Croatia has a long tradition in production of Oil and Gas. At the moment, the Republic of Croatia produces approximately 20% of oil and 60% of gas and imports the rest. In order to change this ratio, investments into research and development activities are mandatory, as well as further developments in the area of secondary and tertiary methods, such as Enhance Oil Recovery (EOR). Application of EOR has a several advantages, first of all, an elongated lifetime of oil fields. It also develops new knowledges and it has perspective to become a solution for CO₂ emmissions.

The Pannonian Basin is being researched in great detail, but finding of new hydrocarbons and satellite deposits could still be expected.

Due to strong tectonical activities, probability of finding commercial reservoirs of Oil and Gas in Dinarides is low, but this possibility shouldn't be excluded, since this area was not researched in detail.

In the Northern Adriatic offshore area, additional reservoirs could be expected. Besides the main Quaternary play with biogenic gas, new discoveries in older sediments, and in the southern part of the Adriatic Sea can be expected.

Refinery represents important part in Oil and Gas story, regardless of whether there will be new findings or not. Imported crude can be processed into more valuable products, being sold on international markets.

Gas storage can enable constant supply, and it can also prevent risks of high gas prices, by storing gas during warmer seasons, when the price is lower.

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